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UBV photometry and period variations of V 839 Ophiuchi*

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Abstract. A complete period variation analysis and new light curves of V 839 Oph together with new ephemeris data are presented. The period variation was found to be $\mathrm{d}P/\mathrm{d}t = 3.1\ 10^{-7}$ d/yr. The period increment indicates that the conservative mass transfer rate from the less massive component to the more massive one is $6.5\ 10^{-7}\ M_{\odot}$/yr. We fitted parabolic and we discuss the possible detection of sinusoidal curves to the (O − C) diagram and sinusoidal oscillations with period of about 20 yr and semi-amplitude of 0.0065 day.

A simultaneous solution of the B and V light curves was computed using the Wilson-Devinney synthetic light-curve code. The light curve solution indicates that the A-type W UMa-type system is in contact with a filling factor of ∼39%.

Key words: binaries: eclipsing — stars: individual: V 839 Oph

1. Introduction

Light variations in V 839 Oph (BD + 9°3584, HD 166231, $m(V)_{\max} = 8\overset{\mathrm{m}}{.}8$, $m(V)_{\min} = 9\overset{\mathrm{m}}{.}39$) were discovered by Rigollet (1947), who gave 131 visual estimates and classified the star as belonging to the type W Ursae Majoris. The first photometric observations of this system have been made by Binnendijk (1960), who observed it photoelectrically at two wavelengths, 5300 and 4420 Å with the 28-inch reflector of the Flower and Cook Observatory in Pennsylvania in 1958 and 1959, and determined three significant minima. It is a pity that between Rigollet's discovery and Binnendijk's study nobody published about this system.

Only one year after Binnendijk's study, Wilson & O'Toole (1965) observed on one night in 1961 in B and V and published the data of a secondary minimum, that they had discovered using observations of one night in 1961. Again many years (∼13) passed without any observations until Diethelm (1974a) started to visually observe it. The visual data however show a large scatter, although they fill the second big gap between the first group of photometric data and the photometry of Braune et al. (1981).

The first results on its geometrical and physical elements were obtained by Niarchos (1978) using Kopal's frequency-domain technique and Binnendijk (1960)'s data. More photometric observations of the system were obtained in two wavelenghts (B and V) during the years 1982-1983 by Lafta & Grainger (1985) and analysed using Kopal's frequency-domain technique. They also determined the geometrical and physical elements. Although they present all of the observational data, no times of minima have been computed from their observations and in the present work we have calculated three times of minima using their data. After Lafta & Grainger (1985)'s paper, the same frequency-domain technique was applied on V 839 Oph by Niarchos (1989) (using his own data) and by Al-Naimy et al. (1989).

Other photometric times of minima have been given by Niarchos (1988), Hanžl (1990), Paschke (1990), Hanžl (1991), Hanžl (1994), Agerer & Hübscher (1994) and Demircan et al. (1994a).

No spectroscopic observation have been published for the system. We present new observations of V 839 Oph in U, B and V. Using them, we have investigated the period variation of the system and its probable connection with the light curve variations within the context of mass transfer, magnetic activity, and third body in the system. In addition, this paper presents the light curve solution for V 839 Oph using the Wilson-Devinney (WD) code under the radiative envelope and convective envelope assumptions.

2. Observations

V 839 Oph was included in our observing program in 1989 and since then the system was observed for 9 nights in 1989, 8 nights in 1990, 7 nights in 1991, 2 nights in 1992, 2 nights in 1993 and 3 nights in 1994. A journal of the observations is given in Table 1. Differential observations

* Table 2 and Table 5 only available in electronic form: see the Editorial in A&AS 1994, Vol. 103, No. 1.

were obtained with a 30 cm Maksutov telescope of Ankara University Observatory equipped with an SSP − 5A photometer head which is used with a Hamamatsu R1414 photomultiplier tube. Before Sept 29, 1991, the differential observation were made by using an EMI9789QB photomultiplier attached to the Maksutov telescope. The filters used are in close agreement with the standard *UBV* bands.

The same comparison star BD + 9°3578 and check star BD + 8°3590 were chosen as Binnendijk (1960). All differential observations were reduced outside the atmosphere using the extinction coefficients calculated in the usual way, and heliocentric corrections were made for all the observations. The differential measurements in the sense variable minus comparison are listed in Table 2 (available in electronic form). The light curves formed by these observations in different years are shown in Fig. 1 together with the colour curves. No significant reddening in the $B-V$ and $U-B$ colour curves is detectable. Although the seasonal observations were obtained in short time intervals, the scatter in the observations, particularly in the U filter, was found larger than expected. This is due partly to the use of an old photometer (between 1989 and 1991) and to occasional bad weather conditions. The observed differences of the check star relative to the comparison star are given in Table 3. These uncertainties are much smaller in the 1992-1994 observations, which were secured with the new photometer head.

The phases were calculated by using new linear light elements, explained in the following section.

Table 1. Journal of the differential observations of V 839 Oph

Year	HJD 2440000+	Num. of Obs.	Observer[(a)]
1989	7656	24	SD
	7683	4	ZM
	7689	5	ZM
	7701	15	FFO
	7703	35	ZM
	7704	20	GK
	7717	20	HD
	7734	44	FFO
	7736	11	BG
1990	8072	24	FFO
	8073	13	GK
	8084	41	GK
	8087	4	GK
	8089	13	SO
	8090	18	SOS
	8091	21	SO
	8092	24	SOS
1991	8439	32	HD
	8440	21	FFO
	8442	40	SO
	8447	10	SO
	8450	47	FFO
	8456	44	HD
	8467	34	SO
1992	8829	87	ZM
	8835	95	ED
1993	9151	99	BG
	9159	90	FFO
1994	9515	36	AA
	9522	88	HEK
	9536	90	KK

(a) SD: S. Diyep, ZM: Z. Müyesseroğlu, FFO: F.F. Özeren, GK: G. Kahraman, HD: H. Dündar, BG: B. Gürol, SO: S.Özdemir, SOS: S.O. Selam, ED: E. Derman, AA: A. Akalin, HEK: H.E. Kum, KY: K. Yüce.

3. New times of minima

A total of ten primary and ten secondary times of minima were calculated using the well known method of Kwee & Van Woerden (1956) and are listed in Table 4 with their type of minima and number of observations incorporated in the determination of the times of minima. The average times of minima (together with their standard deviation), obtained from the individual estimates of some cycle, but at different passbands, are given in the last column of Table 4. By using our last seven times of minima we determined the following light elements:

$$\begin{aligned}&\mathrm{MinI} = \\ &\mathrm{HJD}\ 2449536.39151 + 0.40900516\,E \\ &\pm 0.00035 \pm 0.00000034\end{aligned} \qquad (1)$$

where the epoch is the improved time of the last of our observed primary minima. Because of the variable period, the new linear elements will be valid only a few years around 1994.

4. Period variation

All times of minima of V 839 Oph available in the literature have been compiled, which altogether contain 71 times of minimum light (24 visual, 3 photographic and 44 photoelectric), cover about 45000 orbital revolutions, and thus provides important new information about the change of the orbital period of the system. There are however 2 big gaps in the data. One, following the discovery by Rigollet (1947), contain ∼4770 cycles, while the other, between the first group of photometric times of minima and the second visual time of minima, contains ∼12000 cycles. The first minimum is visual, as are many around $E=-20000$. However, one can see that the visual estimates in general show a large amount of scatter. Rigollet's minimum is of good quality, because his light curve contains 131 visual estimates.

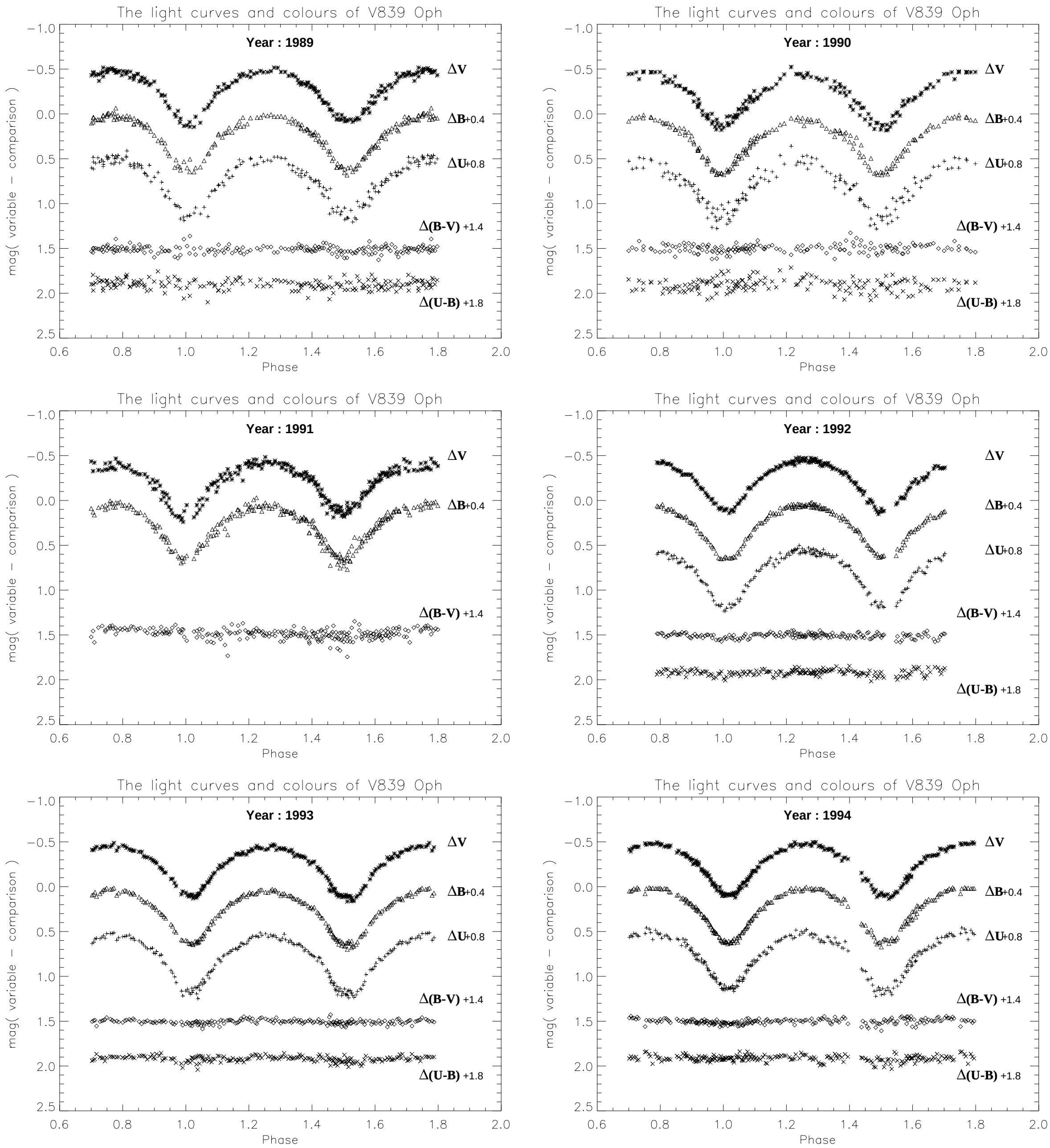

Fig. 1. The light curves and colours of V 839 Oph in between 1989 and 1994

The (O − C) diagram which is calculated using the present work's linear ephemeris are shown in Fig. 2 and are listed as $(\mathrm{O-C})_{\mathrm{lin}}$ in Table 5 (available in electronic form). This form of the (O − C) diagram indicates clearly that the orbital period of V 839 Oph is increasing. Both primary and secondary times of minima follow the same trend on the (O − C) diagram.

We fitted a quadratic function to the distribution of (O − C) variations using all photometric and photographic times of minima together with the first visual time (see Fig. 2). The following quadratic ephemeris was obtained:

$$\begin{aligned} \mathrm{MinI} = \;& \mathrm{HJD}\ 2449536.38555 \\ & + 0.4090041886\,E + 1.7524\ 10^{-10} E^2 \\ & \pm 0.00005 \pm 0.0000000037 \pm 0.0011\ 10^{-10} \end{aligned} \qquad (2)$$

where the coefficient of the square term represent the rate of change of the period ($\mathrm{d}P/\mathrm{d}t\ =\ 3.1\ 10^{-7}\,\mathrm{d/yr}$), which is acceptable. In fact, such a representation of the (O − C) data is statistically much better than the alternative (linear) representation. The $(\mathrm{O-C})'_{\mathrm{q}}$ residuals from the quadratic ephemeris are also listed in Table 5

Table 2. The data for light curves and colours of V 839 Oph between 1989 and 1994. (available in electronic form)

HJD (2400000+)	PHASE	ΔV	ΔB	ΔU	$\Delta(B-V)$	$\Delta(U-B)$
47656.3989	0.503	0.047	0.256	0.250	0.208	−0.006
47656.4057	0.536	0.070	0.215	0.359	0.145	0.144
47656.4175	0.565	−0.015	0.079	0.222	0.094	0.143
47656.4246	0.582	−0.013	0.008	0.131	0.021	0.123
47656.4301	0.596	−0.115	−0.025	0.031	0.089	0.056
47656.4403	0.621	−0.251	−0.141	−0.005	0.109	0.136
47656.4459	0.635	−0.254	−0.182	−0.078	0.073	0.104
47656.4520	0.649	−0.328	−0.201	−0.133	0.127	0.068
47656.4581	0.664	−0.344	−0.255	−0.147	0.089	0.108
47656.4620	0.674	−0.406	−0.210	−0.151	0.196	0.060
47656.4678	0.688	−0.447	−0.294	−0.187	0.153	0.107
47656.4731	0.701	−0.431	−0.297	−0.197	0.134	0.099
47656.4784	0.714	−0.430	−0.333	−0.249	0.098	0.084
47656.4833	0.726	−0.440	−0.333	−0.261	0.107	0.072
47656.4881	0.738	−0.416	−0.331	−0.267	0.086	0.064
47656.4930	0.750	−0.495	−0.373	−0.317	0.123	0.056
47656.5020	0.772	−0.482	−0.337	−0.240	0.145	0.097
47656.5064	0.782	−0.466	−0.341	−0.309	0.125	0.031
47656.5182	0.811	−0.445	−0.340	−0.327	0.105	0.013
47656.5234	0.824	−0.470	−0.338	−0.216	0.132	0.123
47656.5285	0.836	−0.416	−0.289	−0.195	0.127	0.094
47656.5334	0.848	−0.445	−0.325	−0.209	0.121	0.116
47656.5377	0.859	−0.371	−0.279	−0.224	0.092	0.055
47656.5418	0.869	−0.396	−0.247	−0.141	0.149	0.106
47683.3307	0.366	−0.326	−0.234	−0.095	0.092	0.139
47683.3350	0.377	−0.336	−0.213	−0.113	0.123	0.100
....	....	....	....	....	....	....

Table 3. The check star standard deviation list

Check Star Observation Time	n	V	n	B	n	U
1989	18	0.0349	18	0.1706	17	0.0489
1990	19	0.0456	19	0.0302	19	0.1085
1991	27	0.0419	25	0.0389		
1992	39	0.0210	39	0.0233	39	0.0313
1993	36	0.0204	36	0.0176	36	0.0295
1994	55	0.0251	55	0.0202	34	0.0331

and displayed Fig. 3a. We found for the goodness of fit $\chi^2=\Sigma(\mathrm{O}-\mathrm{C})_{\mathrm{q}}'^{\,2}=0.000033$. If the period increase is purely due to the conservative mass transfer from the less massive to the more massive component (from $M_2 = 0.81\ M_\odot$ to $M_1 = 1.19\ M_\odot$ (Al-Naimy et al. 1989)) then with the equation $\Delta P/P = 3(M_2/M_1 - 1)\,\Delta M_2/M_2$, such a transfer rate would be about $\Delta M_2 \simeq 6\ \ 10^{-7}\,M_\odot/\mathrm{yr}$ for the period variation. After fitting the parabolic form, we also applied to the residuals a sinusoidal fit of the form

$$\mathrm{O}-\mathrm{C_s} = A_\mathrm{s}\sin\{[2\pi(E-T_\mathrm{s})/P_\mathrm{s}] - \pi/2\} \quad (3)$$

to all photographic and photoelectric times of minimum light include first Rigollet's visual time. Here A_s, P_s and T_s are the half-amplitude (in days), the period (in days), and a minimum time (in units of E) of the proposed sine curve of the $(\mathrm{O}-\mathrm{C})$ diagram, respectively. We found that the data are best represented by the following sinusoidal ephemeris:

$$\mathrm{MinI} = \mathrm{HJD}\ 2449536.38555 + 0.4090041886\,E + 0.0065\,\sin(0.000358629\,E + 0.769619). \quad (4)$$

The best-fitting parabolic and sinusoidal curves are displayed, superimposed on the observational data, in Fig. 4. The $(\mathrm{O}-\mathrm{C_s})'$ residuals from the best fit, which are listed in Table 5 and displayed in Fig. 3b and the goodness of

Table 4. New times of minima of V 839 Oph from our observations

HJD (2440000+)	Band	Min	n	Mean
7703.4326 ±0.0008	*B*	II	15	7703.4323 ±0.0004
7703.4322 ±0.0005	*V*	II	15	
7717.3402 ±0.0011	*B*	II	14	7717.3387 ±0.0007
7717.3375 ±0.0010	*V*	II	14	
7734.3113 ±0.0039	*B*	I	11	7734.3116 ±0.0016
7734.3117 ±0.0017	*V*	I	11	
7736.3506 ±0.0005	*B*	I	14	7736.3506 ±0.0005
8072.3531 ±0.0007	*B*	II	11	8072.3529 ±0.0006
8072.3524 ±0.0012	*V*	II	10	
8073.3720 ±0.0002	*B*	I	8	8073.3720 ±0.0002
8073.3733 ±0.0017	*V*	I	8	
8089.3265 ±0.0005	*B*	I	10	8089.3263 ±0.0004
8089.3258 ±0.0009	*V*	I	8	
8090.3252 ±0.0007	*B*	II	11	8090.3550 ±0.0006
8090.3544 ±0.0011	*V*	II	10	
8091.3729 ±0.0006	*B*	I	11	8091.3727 ±0.0006
8091.3710 ±0.0018	*V*	I	12	
8092.3949 ±0.0013	*B*	II	11	8092.3961 ±0.0008
8092.3968 ±0.0010	*V*	II	11	
8439.4354 ±0.0006	*B*	I	11	8439.4353 ±0.0005
8439.4348 ±0.0011	*V*	I	10	
8440.4588 ±0.0008	*B*	II	15	8440.4588 ±0.0007
8440.4587 ±0.0006	*V*	II	15	
8456.4059 ±0.0019	*B*	II	13	8456.4087 ±0.0005
8456.4089 ±0.0005	*V*	II	17	
8829.4261 ±0.0012	*U*	II	20	8829.4269 ±0.0004
8829.4271 ±0.0004	*B*	II	20	
8829.4249 ±0.0015	*V*	II	14	
8835.3556 ±0.0008	*U*	I	23	8835.3565 ±0.0002
8835.3566 ±0.0002	*B*	I	23	
8835.3563 ±0.0004	*V*	I	23	
9151.3131 ±0.0006	*U*	II	22	9151.3130 ±0.0003
9151.3128 ±0.0003	*B*	II	15	
9151.3152 ±0.0011	*V*	II	17	
9151.5177 ±0.0005	*U*	I	17	9151.5186 ±0.0002
9151.5191 ±0.0003	*B*	I	17	
9151.5175 ±0.0009	*V*	I	17	
9515.3246 ±0.0005	*U*	II	26	9515.3267 ±0.0003
9515.3270 ±0.0005	*B*	II	25	
9515.3286 ±0.0005	*V*	II	26	
9522.4854 ±0.0005	*U*	I	24	9522.4856 ±0.0003
9522.4864 ±0.0014	*B*	I	25	
9522.4856 ±0.0004	*V*	I	18	
9536.3906 ±0.0004	*U*	I	25	9536.3913 ±0.0003
9536.3921 ±0.0005	*B*	I	22	
9536.3920 ±0.0007	*V*	I	22	

fit of the representation, $\chi^2 = \Sigma(\mathrm{O}-\mathrm{C_s})'^2 = 0.000014$ is much better than that of the previous quadratic one. The period of the cyclic variation is 19.62 yrs.

5. Light curve variation

In addition to our own light curves, we compiled all other published light curves from the literature, and plotted them on the same scale by using different symbols for different night's observations.

All observations cover the interval between 1958 and 1994. A list and short information is given in Table 6 about the available light curves of V 839 Oph. To examine long-term light variation on these curves, we read the light levels at maximum and minimum to form the magnitude

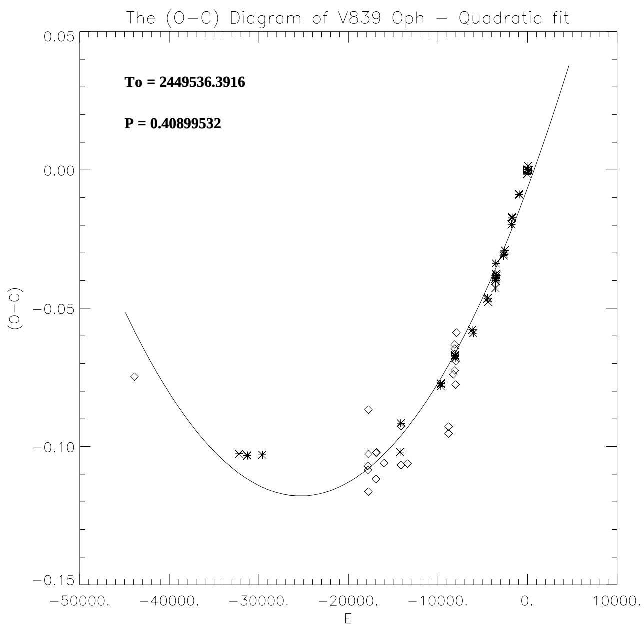

Fig. 2. The (O − C) diagram of V 839 Oph is shown is a quadratic fit through the data points. Photometric data (asteriscs), photographic data (squares) and visual data (diamonds) are shown

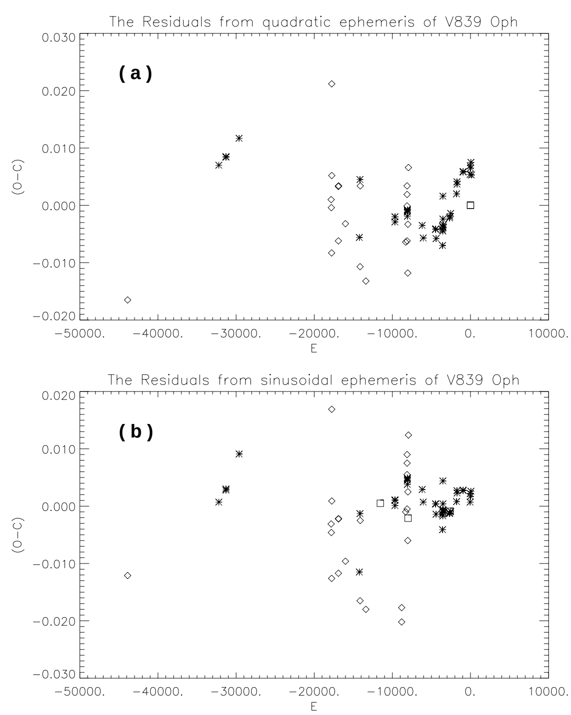

Fig. 3. The calculated residuals from **a)** the quadratic ephemeris, **b)** the best sinusoidal fit

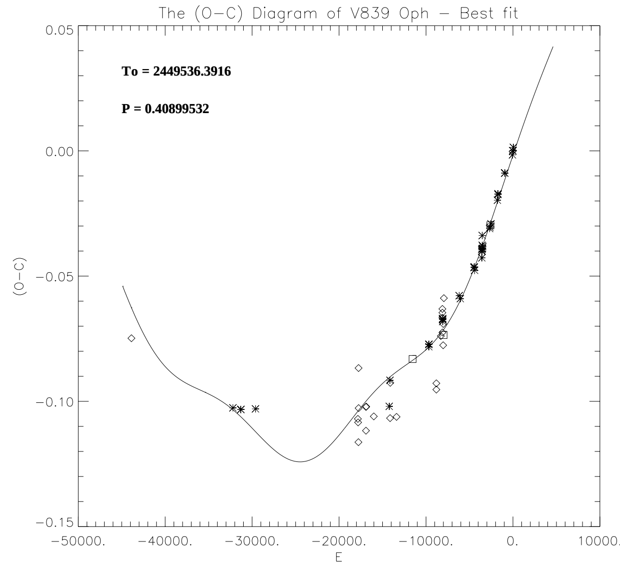

Fig. 4. The best sinusoidal fitting curve superimposed on the (O − C) diagram

differences $\Delta_{\rm max}$, $\Delta_{\rm min}$, and the depths of the minimum $D_{1,2}$ for every light curve, where

$$\Delta_{\rm max} = m_{\rm max1} - m_{\rm max2} \quad (5)$$

$$\Delta_{\rm min} = m_{\rm min1} - m_{\rm min2} \quad (6)$$

and

$$D_{1,2} = m_{{\rm min}_{1,2}} - m_{{\rm max}_{1,2}}. \quad (7)$$

The values for these four parameters in the *V* filter are listed in Table 6 and displayed in Fig. 5. The full amplitude of the irregular variations of the four quantities is always less than $0\overset{\rm m}{.}1$ showing that no significant long term variations are detected in these four quantities. Due to insufficient and very unevenly distributed data points in Fig. 5 no conclusion can be drawn yet about the long-term light variations. Only systematic and continuous observations may help to decide on the existence of general trends in the variations of light levels and depths of the minima.

6. Photometric solution

The *B* and *V*-band light curves of V 839 Oph of 1992, 1993 and 1994 have been used simultaneously for the determination of the geometric and photometric elements using the Wilson-Devinney (WD) code of the light variations of eclipsing variables. First, the observed points ordered in phase were combined into 50 normalised binned points in each colour so that each bin equals 0.02 of an orbital period with weights equal to the number of original points. The solutions were computed on the personal computers

Table 5. Epochs of minimum light of V 839 Oph, $(\mathrm{O}-\mathrm{C})'_{\mathrm{q}}$ residuals from the quadratic ephemeris and $(\mathrm{O}-\mathrm{C_s})'$ residuals from the best fit (also available in electronic form)

HJD Min (2400000+)	Type	Method	E	(O − C)	$(\mathrm{O}-\mathrm{C})'_{\mathrm{q}}$	$(\mathrm{O}-\mathrm{C_s})'$	Source
31587.7617	2	v	−43884.5	−0.07478	−0.01649	−0.01353	1
36361.7317	1	pe	−32212.0	−0.10265	0.00704	0.00116	2
36734.7347	1	pe	−31300.0	−0.10335	0.00837	0.00266	2
36735.7574	2	pe	−31297.5	−0.10319	0.00854	0.00283	2
37424.9147	2	peB	−29612.5	−0.10302	0.01170	0.00780	3
42241.4440	1	v	−17836.0	−0.10707	0.00103	−0.00068	4
42251.4630	2	v	−17811.5	−0.10846	−0.00042	−0.00218	4
42267.4060	2	v	−17772.5	−0.11628	−0.00834	−0.01018	5
42272.5480	1	v	−17760.0	−0.08672	0.02119	0.01932	5
42275.3950	1	v	−17753.0	−0.10268	0.00520	0.00332	5
42620.3830	2	v	−16909.5	−0.10224	0.00331	−0.00013	6
42621.3960	1	v	−16907.0	−0.11172	−0.00619	−0.00963	6
42633.4710	2	v	−16877.5	−0.10209	0.00336	−0.00013	6
42990.5200	2	v	−16004.5	−0.10600	−0.00324	−0.00801	7
43717.5060	1	pe	−14227.0	−0.10918	−0.00557	−0.01147	8
43749.4180	1	pe	−14149.0	−0.09882	0.00453	−0.00137	8
43756.3630	1	v	−14132.0	−0.10674	−0.01065	−0.01655	9
43765.3750	1	v	−14110.0	−0.09263	0.00337	−0.00253	9
44059.4290	1	v	−13391.0	−0.10627	−0.01316	−0.01881	10
44815.4800	2	pg	−11542.5	−0.08312	0.00174	−0.00171	11
45579.2837	1	peB,V	−9675.0	−0.07822	−0.00290	−0.00270	12
45580.3070	2	peB,V	−9672.5	−0.07735	−0.00204	−0.00183	12
45581.3296	1	peB,V	−9670.0	−0.07727	−0.00197	−0.00176	12
45925.4350	2	v	−8828.5	−0.14142	−0.07082	−0.06889	13
45932.4340	2	v	−8811.5	−0.09534	−0.02483	−0.02287	13
45933.4590	1	v	−8809.0	−0.09283	−0.02234	−0.02037	13
46143.4970	2	v	−8295.5	−0.07392	−0.00642	−0.00349	14
46216.5100	1	v	−8117.0	−0.06659	−0.00015	0.00311	13
46216.5120	1	v	−8117.0	−0.06459	0.00185	0.00511	13
46217.5360	2	v	−8114.5	−0.06308	0.00335	0.00661	13
46218.5490	1	v	−8112.0	−0.07256	−0.00615	−0.00289	13
46228.5745	2	peB,V	−8087.5	−0.06745	−0.00118	0.00212	15
46229.3929	2	peB,V	−8085.5	−0.06704	−0.00079	0.00252	15
46230.4152	1	peB,V	−8083.0	−0.06723	−0.00099	0.00232	15
46231.4379	2	peB,V	−8080.5	−0.06702	−0.00079	0.00252	15
46233.4818	2	peB,V	−8075.5	−0.06809	−0.00190	0.00142	15
46253.5130	2	v	−8026.5	−0.07766	−0.01176	−0.00836	13
46259.4520	1	v	−8012.0	−0.06910	−0.00328	0.00015	16
46270.4904	1	pg	−7985.0	−0.07357	−0.00792	−0.00444	17
46286.4560	1	v	−7946.0	−0.05879	0.00663	0.01017	13
47006.4933	2	peB,V	−6185.5	−0.05780	−0.00354	0.00209	18
47062.3199	2	peV	−6049.0	−0.05901	−0.00566	0.00005	18
47703.4324	2	peB,V	−4481.5	−0.04666	−0.00422	0.00142	19
47717.3386	2	peB,V	−4447.5	−0.04634	−0.00414	0.00148	19
47734.3105	1	peB,V	−4406.0	−0.04773	−0.00584	−0.00024	19
48067.4454	2	peB,V,U	−3591.5	−0.03947	−0.00361	0.00123	20
48072.3528	2	peB,V	−3579.5	−0.04009	−0.00431	0.00051	19
48073.3726	1	peB,V	−3577.0	−0.04273	−0.00697	−0.00215	19
48089.3261	1	peB,V	−3538.0	−0.04001	−0.00455	0.00022	19
48090.3548	2	peB,V	−3535.5	−0.03381	0.00164	0.00641	19
48091.3719	1	peB,V	−3533.0	−0.03918	−0.00376	0.00101	19
48092.3958	2	peB,V	−3530.5	−0.03777	−0.00236	0.00240	19
48108.5500	1	pe	−3491.0	−0.03894	−0.00383	0.00088	21
48120.4115	1	peB,V,U	−3462.0	−0.03827	−0.00338	0.00130	20
48439.4351	1	peB,V	−2682.0	−0.03103	−0.00216	0.00136	19
48456.4089	2	pe V	−2640.5	−0.03051	−0.00197	0.00148	19
48474.4055	2	pg	−2596.5	−0.02975	−0.00156	0.00182	22
48500.3773	1	peB,V	−2533.0	−0.02910	−0.00141	0.00186	23
48805.4973	1	peB,V	−1787.0	−0.01971	0.00199	0.00386	23

Table 5. continued

HJD Min (2400000+)	Type	Method	E	(O − C)	$(\mathrm{O-C})'_{\mathrm{q}}$	$(\mathrm{O-C_s})'$	Source
48829.4260	2	peB,V,U	−1728.5	−0.01715	0.00407	0.00583	19
48835.3562	1	peB,V,U	−1714.0	−0.01745	0.00365	0.00538	19
49151.3137	2	peB,V,U	−941.5	−0.00879	0.00588	0.00603	19
49151.5181	1	peB,V,U	−941.0	−0.00888	0.00578	0.00593	19
49515.3267	2	peB,V,U	−51.5	−0.00164	0.00536	0.00368	19
49522.4858	1	peB,V,U	−34.0	0.00004	0.00689	0.00518	19
49536.3916	1	peB,V,U	0.0	−0.00002	0.00653	0.00474	19
49556.4335	2	peV	49.0	0.00113	0.00723	0.00535	24
49556.4340	2	peB	49.0	0.00163	0.00773	0.00585	24
49590.3788	1	peB,V	132.0	−0.00013	0.00526	0.00321	25
49596.3117	2	peB,V	146.5	0.00229	0.00755	0.00547	25
49598.3573	2	peB,V	151.5	0.00291	0.00813	0.00604	25

Sources:
1) Rigollet 1947; 2) Binnendijk 1960; 3) Wilson & O'Toole 1965; 4) Diethelm 1974a; 5) Diethelm 1974b; 6) Diethelm 1975; 7) Diethelm 1976; 8) Braune et al. 1981 9) Diethelm 1978; 10) Diethelm 1979; 11) Diethelm 1981; 12) This paper (from Lafta & Grainger's observations); 13) Kreiner 1988; 14) Ferrand 1985; 15) Niarchos 1988; 16) Kohl 1985; 17) Diethelm 1985; 18) Hanzl 1990; 19) this paper 20) Hanzl 1991; 21) Paschke 1990; 22) Blattler 1991; 23) Hanzl 1994; 24) Agerer & Hübscher 1994 25) Demircan 1994a.

Table 6. The light curves and corresponding asymmetry measures (see text)

Year	Phase Covar.	λ	$\Delta_{\max}$	$\Delta_{\min}$	D_1	D_2	$Ref.^a$
1959	97%	V	0.02	0.01	0.54	0.55	1
1983	100%	V	0.00	0.06	0.62	0.57	2
1985	100%	V	−0.04	0.01	0.55	0.50	3
1989	99%	V	−0.01	0.04	0.56	0.52	4
1990	98%	V	0.03	−0.01	0.55	0.59	4
1991	99%	V	−0.02	0.06	0.59	0.51	4
1992	91%	V	−0.03	−0.01	0.55	0.53	4
1993	99%	V	−0.01	−0.02	0.54	0.55	4
1994	99%	V	−0.03	0.00	0.56	0.53	4

(a):(1) Binnendijk 1960 (2) Lafta & Grainger 1985 (3) Niarchos 1989 (4) Present work

of Ankara University Observatory using WD code's PC version that was implemented by Müyesseroğlu (1994). Based on the General Catalogue of Variable Stars's spectral classification of the primary component, F8 V, the temperature was adopted to be T_1= 6250 K. The other adopted parameters are the gravity-darkening coefficients $g_1 = g_2$, the albedoes $A_1 = A_2$ and the linear limb-darkening coefficients, which were determined from tables by Al-Naimy (1978) for both x_1 and x_2. Model 3 of the WD-differential correction program was used to adjust the following parameters: the orbital inclination i, the mass-ratio $q = M_2/M_1$, the temperature of secondary component T_2, the potential function Ω_1 (or Ω_2) and the luminosities of the two components L_1, L_2. These adjustable parameters were varied until the solution converged.

The subcategories of the W UMa systems, called A-type and W-type by Binnendijk (1970), divided into two spectral groups A9-F8 and F7-M5. There is no certain limit between the two subclasses. Eaton (1983) suggested that the two types of W UMa systems are distinguished by the presence (W-type) or absence (A-type) of magnetic spots. V 839 Oph was classified as an A-type of W UMa systems (Binnendijk 1970). Because of its late spectral type, F8 V, the WD-differential correction program was applied under both the radiative envelope and the convective envelope assumptions, seperately. Both assumptions give similar quality fits, which means that we

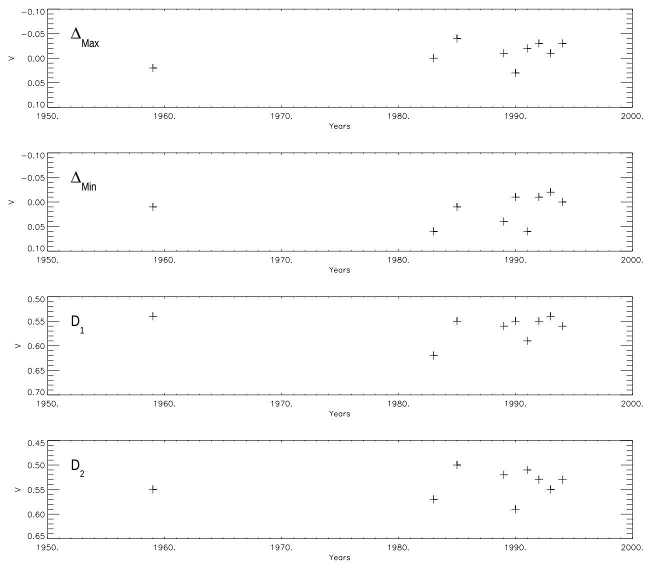

Fig. 5. The change of the $\Delta_{\min}$, $\Delta_{\max}$, D_1 and D_2 describing the long-term behaviour of the light levels of V 839 Oph (see text)

cannot determine easily in this way what kind of envelope is present here. In the theory of Anderson et al. (1983) the radiative photosphere of stars with spectral type later than F5 develop convective "continents", and these "continents" grow for later types until the entire star is enveloped in convection. They were the first to suggest the convective "continents" idea for AW UMa, an A-type W UMa system with a late spectral type (F0-F2V). For V 839 Oph, the light curves show asymmetric structure, usually caused by surface brightness anomalies. For that reason, we have the suspicion that it has convective "continents" on the common envelope of the system. In this case, the gravity-darkening coefficients and the albedoes should be different from the case of a completely radiative assumption. To distinguish between the two cases, we reanalysed the light curve of V 839 Oph for several values of the gravity-darkening coefficients (g) in the range $0.32 - 1.00$ and albedoes (A) in the range $0.50 - 1.00$. For each set of parameters (A, g) we present the sum of the squared residuals of the simultaneous fit to the light curves in B and V ($\chi^2 = \Sigma(\mathrm{res})^2$) in Table 7. There is one minimum of χ^2 at $A = 0.80$ and $g = 0.40$. The final solution is given in Table 8, and the computed light curves based on these elements are shown in Fig. 6. The geometrical representation of V 839 Oph at phase $0^{\mathrm{p}}.75$ is displayed in Fig. 7. The Roche lobe surface was produced by the PC version of Binary Maker (Bradstreet 1990). The fits confirm that the convective "continents" on the envelope of V 839 Oph exist, and that they are thin enough to create surface brightness anomalies, spots, and are able to generate the magnetohydrodynamic energy needed to heat a chromosphere and corona. V 839 Oph is not the only late A-type W UMa system for which these more realistic assumptions produce better fits. The same is the case for some systems presented in Twigg (1979).

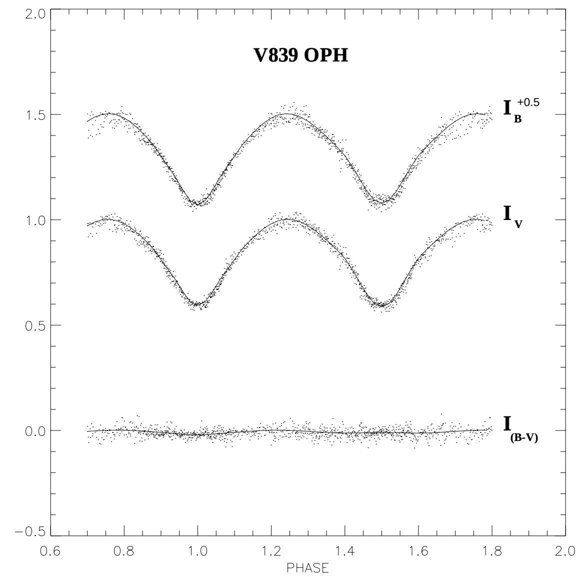

Fig. 6. B and V intensity light curves and $B-V$ colour curve as defined by the individual observations and theoretical light curves for V 839 Oph

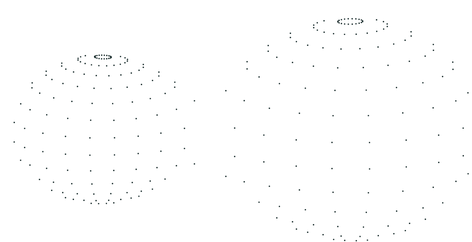

Fig. 7. Geometrical representation of V 839 Oph at phase $0^{\mathrm{p}}.75$

There is one more piece of evidence for convective structure in V 839 Oph. Although our own observations were not taken on subsequent days, we could investigate the short time light variations from the compilation of all other published light curves.

The night-to-night variations in the light curves could be defined at phases of each quadrature, especially between the phases of 0.17 and 0.25 and between the phases of 0.75 and 0.83. Niarchos (1989) reported that the magnitude difference of the outer and the inner envelopes of $\max_I$ have a width of $0^{\mathrm{m}}.049$ in yellow and $0^{\mathrm{m}}.052$ mag in blue. Until we have some spectra to better understand the short-time light variations, we suggest that they could be explained by the active convective "continents", and/or

Table 7. $\chi^2 = \Sigma(\mathrm{res})^2$ of the simultaneous fit to the light curves in B and V for V 839 Oph

A	g	$\chi^2(V) = \Sigma(\mathrm{res})^2$	$\chi^2(B) = \Sigma(\mathrm{res})^2$
0.50	0.32	0.0075223	0.0104486
0.50	0.40	0.0075682	0.0108482
0.50	0.50	0.0073665	0.0102710
0.50	0.70	0.0083371	0.0110518
0.50	1.00	0.0098089	0.0100897
0.70	0.32	0.0090161	0.0132735
0.70	0.40	0.0085283	0.0121798
0.70	0.50	0.0083241	0.0114845
0.70	0.70	0.0087596	0.0122712
0.70	1.00	0.0110986	0.0126784
0.80	0.32	0.0082005	0.0121450
0.80	0.40	0.0065233	0.0095031
0.80	0.50	0.0075505	0.0108820
0.80	0.70	0.0080520	0.0104879
0.80	1.00	0.0136256	0.0158817
1.00	0.32	0.0085341	0.0124114
1.00	0.40	0.0082158	0.0117043
1.00	0.50	0.0076007	0.0110721
1.00	0.70	0.0082611	0.0115917
1.00	1.00	0.0090303	0.0110089

Table 8. Synthetic light curve parameters for V 839 Oph

Parameter	Value
λ_B (Å)	4300
λ_V (Å)	5500
$x_{1B} = x_{2B}$	0.766
$x_{1V} = x_{2V}$	0.612
$g_1 = g_2$	0.40
$A_1 = A_2$	0.80
i	77.034 ±0.244
T_1 (K)	6250
T_2 (K)	5391 ±275
$\Omega_1 = \Omega_2$	2.5841 ±0.0070
q	0.400 ±0.004
$L_1/(L_1+L_2)B$	0.631 ±0.004
$L_1/(L_1+L_2)V$	0.627 ±0.004
l_3	0.00
r_1 , r_2 (pole)	0.4506 ±0.0021 , 0.3017 ±0.0021
r_1 , r_2 (side)	0.4857 ±0.0029 , 0.3176 ±0.0026
r_1 , r_2 (back)	0.5200 ±0.0044 , 0.3667 ±0.0058
fill out	38.8%

by the mass transfer through the connecting neck of their Roche lobes, which will change the surface brightness in short periods.

There are many result in literature about the chromospheric and coronal activities on W UMa systems which explain observational results taken by the HEAO 1, IUE, HEAO 2 (Einstein) and ROSAT satellities (for example, Dupree et al. 1980; Carroll et al. 1980; Eaton 1983; Cruddace & Dupree 1984; Vilhu & Heise 1986; Mcgale et al. 1996). V 839 Oph was placed in only some of X-ray observation lists, and the last X-ray detection of the system has been undertaken with the ROSAT satellite. Mcgale et al. (1996) showed that the ROSAT X-ray fluxes showed that the system was ∼70 per cent brighter in soft X-rays at the ROSAT epoch with constant light curve than in the epoch of the 1979-1981 Einstein survey done by Cruddace & Dupree (1984). Another A-type W UMa systems, AK Her (F2+F6V), also was shown to have a constant light curve in soft X-rays as V 839 Oph in the X-ray spectral survey.

7. Conclusions

The study of V 839 Oph shows that it is an A-type W UMa eclipsing system and that the common envelope of the system has a structure with convective "continents" on a radiative envelope. Examination of our solutions for the period variations and the light curve leads to the following conclusions.

1. Our solution for the period variation of V 839 Oph indicates that the mass transfer rate from the less massive component to the more massive component is higher than expected for an A-type (Cruddace & Dupree 1984). For this system we find ∼6.4 $10^{-7}\,M_{\odot}$/yr.
2. If the sinusoidal (O − C) variations are due to conservative mass transfer in the system, the mass should have flown from the primary to the secondary between 1978-1988, and from the secondary to the primary between 1988-1998. It seems that such a frequent shift (every ∼10 yr) in the direction of mass transfer is not possible dynamically.
3. One other possible mechanism for the sinusoidal (O − C) variations is a third body in the system. For a hypothetical third body, the period ($P_{\mathrm{s}} \simeq 20$ yr) and semi-amplitude (0.0065 d) of the sinusoidal (O − C) variations in Fig. 4 lead to a small mass function of $f(M_3) = 0.00376\ M_{\odot}$. We obtain $M_3 = 0.077\,M_{\odot}$ with the assumption of circular and co-planar orbits of the third body. The semi-major axis a_3 of third body orbit around the center of mass of the triple system is about 31 AU. The bolometric absolute magnitude of the third body was found to be $M_{\mathrm{b}} = 13\overset{\mathrm{m}}{.}12$ using the mass-luminosity function; $M_{\mathrm{b}} = 5.84 - 6.54 \log M$ for $M < 0.7\,M_{\odot}$ (Demircan & Kahraman 1991). The third body, if it exists, should revolve much beyond the

outer Lagrangian points of V 839 Oph, if it were to be stable.

4. Another possible mechanism to explain the sinusoidal period variation of V 839 Oph is a period modulation mechanism described by Applegate (1992) due to magnetically induced deformations in the outer layers of one of the two components. This mechanism can however not be tested at present, since not enough data is available about the level of the minima and maxima of the light curves, to compare with detailed models. Assuming that the primary component is the active component, we estimate, by using Applegate's (1992) formula, that an angular momentum transfer of $\Delta J = 1.9\ 10^{47}\,\mathrm{g\,cm^2\,s^{-1}}$ is needed to produce the observed orbital period change in the 19.62 yr cycle that is $\Delta P = 0.20$ s. The subsurface mean magnetic field of the primary then should be about 8.21 kG. According to the discussion in photometric solution section, if the presence of magnetic spots could create a long-term light variation which is strongly possible but, unfortunately now, we cannot discuss the possible relation between the long-term light curve variation and their probable connection with the sinusoidal period variation cause of absence enough light curves on published. We should admit that in last few years, however the period modulation mechanism seems to be the main cause of such periodicities, the insufficient light curves on literature cannot give permit to reach final conclude in many of W UMa systems, for example, V 839 Oph (the present work), BX And (Demircan et al. 1993), AB And (Demircan et al. 1994b, Kalimeris et al. 1994), DK Cyg (Awadalla 1994) while except well observed systems, for example, SW Lac (Glownia 1986), VW Cep (Karimie 1983) and TZ Boo (Awadalla 1989).

In this paper, we have found that the current period of V 839 Oph increases in time. On top of this, it seems likely that the period also oscillates sinusoidally with a period of ∼20 years. At the moment we cannot give a unique explanation for these oscillations but we have made several suggestions. It is clear that only systematic and continuous photometric and spectroscopic observations help to understand the connection between light curve and the period variation.

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