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Evidence for a hot spot in the contact binary VW Cephei

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Abstract. We study the nature of asymmetry and the intrinsic variability in the light curves of VW Cep. We analyze our own B,V light curves as well as other data from published sources. In view of the presence of significant intrinsic brightness variations at a level of $0^{\rm m}.01$–$0^{\rm m}.03$ on time scales comparable to the orbital period we deal only with *individual* light curves sampled in one-two consecutive orbital cycles. The manifold evidence for the presence of a small hot spot region close to the neck connecting both components is summarized: a) displacements of the brightness maxima from the predicted epochs of elongations suggestive of an additional energy input presumably of hot chromospheric origin, b) the overall pattern of asymmetry in brightness maxima and minima, c) systematic colour changes with the orbital phase, d) the presence of significant cosine odd harmonics in truncated series of the observed light curves. We find that a hot spot with a characteristic size of $R \sim 0.7$–$1.2 \cdot 10^{10}\, cm$ and the temperature contrast $\Delta T/T = 1.3$–1.4 located on the surface of the more massive star can explain the afore-mentioned peculiarities and model light curves based on our model give a rather good fit to the observed data studied so far. The possible physical nature of the hot spot in the light of our results compared with the spectroscopic data (specifically Mg II resonance doublet) and flare activity signatures are briefly discussed.

Key words: stars: binaries: close – stars: binaries: eclipsing – stars: individual: VW Cep

1. Introduction

The contact binary VW Cephei (*HD 197433 = BD* $+75^{\rm o}752, 20^{\rm h}38^{\rm m}03^{\rm s} + 75^{\rm o}25'.0(1950), G5, P = 6^{\rm h}41^{\rm m}$) from the moment of its discovery in 1924 till now remains a target of intensive astrophysical research. The presence of the third, visual component Hershey (1975) even more enhances a keen interest in this object. Since VW Cep is a nearby system with a trigonometric parallax of 0.041 arc sec it is also an ideal target for a very thorough investigation of its surface features. New observational data have been accumulating suggestive of a variable chromospheric and coronal activity, both regular and of a flaring nature (see, for instance, Bradstreet & Guinan 1990; Pustylnik 1995; Choi & Dotani 1998). In particular Choi & Dotani found a significant dip in X-ray flare curve, also detected earlier by Vilhu et al. (1988), during eclipses which can be interpreted as a direct evidence for high temperature flare structures located close to the neck connecting the components of VW Cep. This circumstance even more underscores the importance of studying VW Cep with the aid of a new generation of telescopes having milliarcsecond angular resolution. In recent works the wave-like distortions of the light curves superimposed upon the regular brightness variations caused by mutual eclipses and tidal distortions of both components nearly filling in their respective Roche lobes have received considerable attention.

There is now consensus among the investigators of close binary systems that the AB component of VW Cephei consists of two low mass main sequence stars ($m_1 \simeq 0.9 m_\odot, m_2 \simeq 0.25 m_\odot, R_1 = 0.93 R_\odot, R_2 = 0.5 R_\odot, T_{1\rm eff} \simeq 5000^{\rm o}K, T_{2\rm eff} \simeq 5200^{\rm o}K$) (see Hill 1989).

The light curve synthesis combined with the spectroscopic data suggest that occultation of less massive (but more luminous) component occurs in the primary eclipse. Judging from spectroscopic observations in H_α mass transfer from the less massive component through the first Lagrangian point L_1 is currently underway. This data is in good agreement with the observed shortening of the orbital period and the numerous peculiarities of the light curves. All the above-mentioned in its turn favourably agrees with the theoretical picture (for details, see Robertson & Eggleton 1977; Lucy & Wilson 1979) according to which the VW Cep system “oscillates” between the contact and semi-detached configuration. In its present state mass transfer caused by magnetic wind from the low mass component should result in a gradual merging of the components. And yet despite the variety of the observational data the nature of the wave-like distortions of the light curves and their possible connection with the short term orbital period variations remain obscure. To interpret the different brightness maxima heights (O’Connell effect) the idea of dark spots or of circumstellar (circumbinary) matter have been exploited (for more details see Karimie 1983; Hendry et al. 1992; Pustylnik & Sorgsepp 1975 and more recently in a paper by Kaszas et al. 1998). In the articles just quoted above the long term periodicities in light curves of VW Cep have been investigated. In contrast we concentrate here on

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Send offprint requests to: I.B. Pustylnik studying short term intrinsic variability. For this purpose we have selected only *individual* light curves obtained during good quality observing nights covering full orbital cycles. We analyze specifically the phase behaviour of the light maxima and the quasi-periodic colour changes. The paper is organized in the following way. In Sect. 2 we discuss our results of analysis of the epochs maxima indicating the presence of small but significant displacements with respect to predicted moments of elongation. In Sect. 3 we estimate the amount of additional energy input in terms of the hot spot region which conform both with the pattern of quasi-periodical colour changes (from brightness maximum to minimum) and the observed pattern of asymmetry of the light curves. In the last Sect. 4 we discuss briefly the possible nature of rapid colour variations and indicate that the most probable mechanism to cause these small variations should be flare acitivity superimposed on the quiescent state continuum of chromospheric origin.

2. Epochs of maxima, displacement in respect to elongation

In a separate paper (Pustylnik & Kreiner 1997) we reported for the first time about the discovery of small but significant phase displacements of light maxima in VW Cep from the predicted epochs of elongation. Recently we have extended the data base including observations by Linnell (1982) and Niarchos et al. (1998) in our analysis.

One of the specific features of VW Cep is practically equal durations of both minima and the out-of-eclipse portion of the light curve (the orbital inclination angle is $i \sim 65^{\rm o}$ and both components are very close to their respective critical Roche lobes). Therefore it is appropriate to divide the light curve into four, more or less equal segments (two maxima and two minima). For each of the segment the light changes have been normalized to the brightness at maximum and they have been approximated by the polynomial $l(T) = \sum_{j=0}^{n} a_j\, T_i^j$ where $T_{\rm i}$ is the Julian date for the observation considered and normally $n = 6$ was adopted. The observed moments of brightness maxima have been determined iteratively with the aid of Newton's method solving equation $dl/dt = 0$. In all cases studied so far 25 iterations were sufficient to ensure the formal accuracy of determining the position of the brightness maximum from the smooth curve no greater than $0.^{\rm d}0002$–$0.^{\rm d}0003$. Also iterations were stopped when the difference between the results for two consecutive iterations became smaller than $5 \cdot 10^{-6}$ days, in all cases the sum $\Sigma(O - C)^2$ was monotonically declining with each subsequent iteration step. In this way a number of epochs for the primary and of the secondary maxima have been determined and summarized in Table 1.

In all these cases we have found small but significant displacements of the brightness maxima in respect to the predicted moments of elongation. The displacement amounts to $0.^{\rm d}005$–$0.^{\rm d}008$, i.e $0.03P_{\rm orb}$.When processing observations made after 1990 we used the value of the orbital period $P = 0.^{\rm d}278306$ according to Niarchos et al. (1998) whereas for earlier observations the value $P = 0.^{\rm d}278314$ was used. The real accuracy of measuring the moment of brightness maxima is dictated by the observational errors (in the first place by the effect of asymmetry of the light curves) and should no greater than $0.^{\rm d}001$. In some cases (at $J.D.2439918$, $J.D.2444477$) the asymmetry is so pronounced that brightness in B colour long after the maximum (at phase $\phi = 0.30$–$0.33P$) is still higher than at the moment of the following maximum. We regard these determined displacements of the brightness maxima as real, since in no cases studied so far have we found displacements of the moments of brightness at the bottom of primary minimum from predicted epochs exceeding $0.^{\rm d}001$. In many cases they are easily discernible even from the visual inspection of the plots of the observed light curves.

Table 1. Epochs of primary and secondary maxima and (O - C)

primary	$(O-C)$	secondary	$(O-C)$
2439467.3288	0.006	2439467.4622	-0.003
2439467.6074	0.004	2439521.4620	0.005
2439521.3184	0.001	2439918.3260	-0.007
2439748.4222	0.004	2439918.6089	-0.004
2439935.4510	0.002	2439935.5836	-0.004
2439964.3967	0.003	2439964.5304	-0.003
2444477.8083	0.002	2444477.6674	-0.001
2448531.4173	0.005	2448152.2112	0.002
2449278.3863	0.005	2449276.4298	-0.004

As we see from the data of Table 1, a higher maximum (following the primary minimum) is observed at a later epoch than is expected from the value of the orbital period whereas the lower maximum (preceding the primary minimum) preferentially comes at an earlier epoch. This can be interpreted as evidence for an asymmetric (in respect to the line of centres) brightness distribution over the hemisphere of a primary component facing its low mass companion. It is obvious that this subtle effect will be smoothed out if one deals with the average light curves in view of the intrinsic light variations. Although in our subsequent analysis we operate with the data from 7 individual observing nights the total number of observing nights at our disposal (mostly covering at least one half of orbital cycle) was more than 20 embracing the interval of Julian dates between JD 2438860 and JD 2449604. In all these cases, with one exception only, the higher maximum was observed invariably following the primary minimum.

To analyse in more detail brightness changes during maxima we have approximated full light curves with the aid of truncated series

$$L(\phi) = \sum_{j=0}^{n} (A_j\, \cos j\phi + B_j\, \sin j\phi), \qquad (1)$$

and determined the coefficients A_j, B_j for 6 nights for which observational points covered the whole light curve. The results are indicated in Table 2. In addition in the last rows of the table we are attaching the coefficients of even harmonics of the cosine truncated series tabulated by Rucinski (1995) which model the light curves of W U Ma type binaries for different angles of orbit inclination i, mass ratios q and fill-out parameter f. The

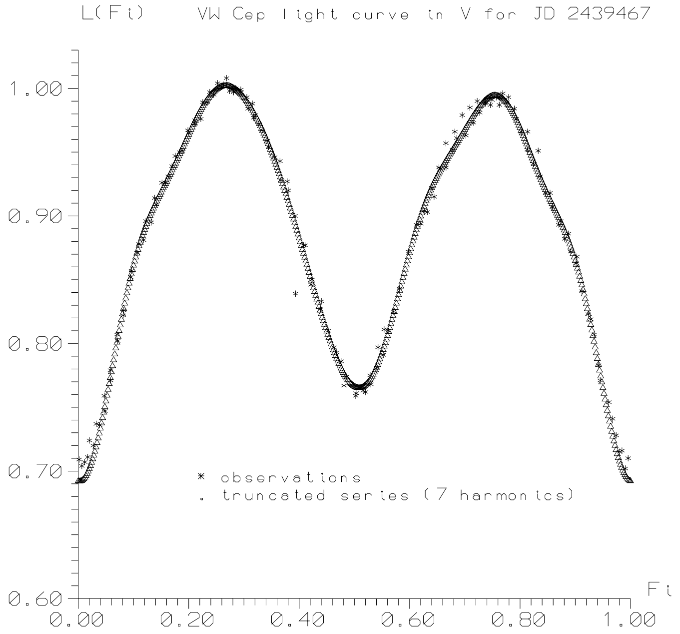

Fig. 1. Observed V light curve of VW Cep for $J.D.2439467$ and approximation by truncated series (see formula (1) in text).

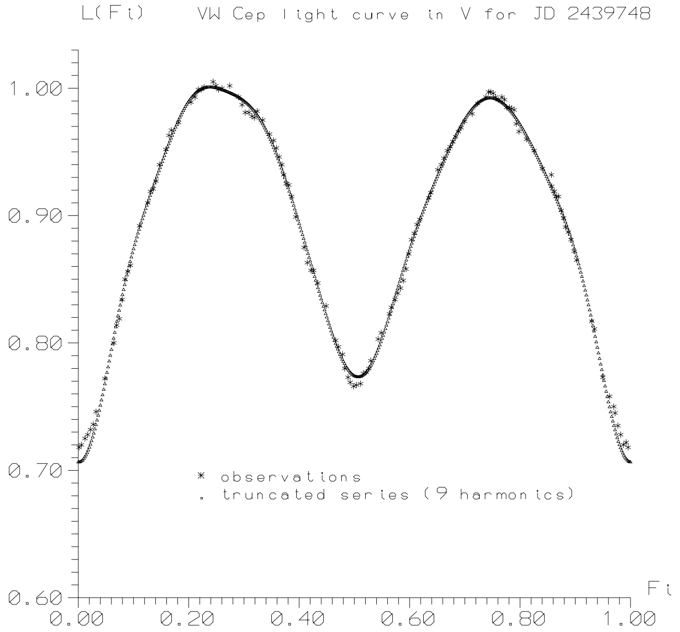

Fig. 2. Observed V light curve of VW Cep for $J.D.2439748$ and approximation by truncated series.

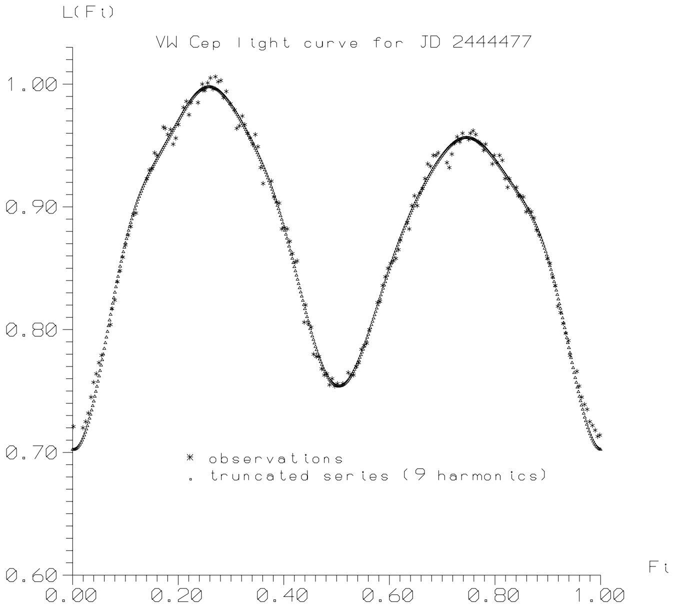

Fig. 3. Observed V light curve of VW Cep for $J.D.2444477$ and approximation by truncated series.

Table 2. Coefficients $-A_j \cdot 10^3$of the truncated series JD2400000+...

39467	A_1	A_2	A_3	A_4	A_5	A_6	C_1
B	22	133	6	24	9	12	37
V	22	124	7	21	9	11	38
39747							
B	22	132	12	27	10	16	44
V	25	121	9	26	8	13	42
39748							
B	22	132	11	26	10	11	43
V	20	123	12	25	8	11	40
39918							
B	29	131	0	19	1	8	30
V	42	131	2	23	8	16	52
44472							
B	14	129	2	17	4	8	20
V	15	120	13	19	6	8	34
R	27	128	17	32	19	20	63
I	2	101	4	11	10	12	16
44477	A_1	A_2	A_3	A_4	A_5	A_6	C_1
B	12	128	11	26	11	14	34
V	15	118	9	26	9	13	33
R	12	108	7	26	8	13	27
I	13	109	9	24	7	13	29
$f = 0.0$	–	103	–	21	–	8	–
$f = 0.5$	–	128	–	13	–	5	–

Figs. 1–3 illustrate typical results for JD2439467, 2439748 and JD2444477.

Similar results are obtained for other 4 nights. As our experience shows, addition of harmonics higher than $n = 6$ practically will not influence the amplitudes of harmonics $n \leq 6$ nor does it improve the agreement with the observed light curves.

As one can see from the plots there is in general a good agreement between the observations and the approximation by truncated series except for the phase interval $\phi = 0.95$–$1.05P$, i.e. the bottom of the primary minimum. The accuracy of approximation by truncated series gradually increases with the growing number of harmonics taken into account. Because of a low inclination angle of orbit of VW Cep light changes due

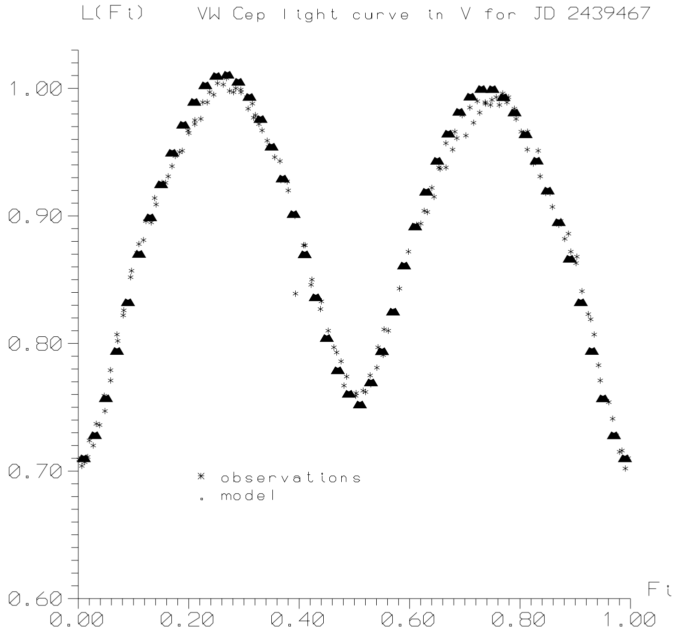

Fig. 4. The observed for $J.D.2439467$ **(*)** and the model light curves for VW Cep in V colour.

to tidal distortions dominate almost during the entire orbital cycle. Only near the bottom of minimum light changes due to reciprocal eclipses become more important but generally their approximation by cosine series is not fully satisfactory. The coefficients of even harmonics A_2, A_4, A_6 are in good agreement with the values found from Rucinski's paper. But in addition to even harmonics considerable odd harmonics are present. Their sums $C_1 = A_1 + A_3 + A_5$ (implying maximum contribution to the total luminosity of the binary at phase angle $\phi = \pi$) are tabulated in the last column of Table 2. Therefore we interpret it as the contribution from the "hot spot" which would have been best visible at the phase angle value $\phi = 0.5P$,if it had not been hidden (at least partially) because of the transit eclipse of a more massive component. Please, note that the value of C_1 is very close to the amplitude of the colour curves and the differences in brightness minima depths (see the light curves in Figs. 4–8 and the colour curves in Figs. 9,10). We found that the value of C_1 is rather insensitive to the number of harmonics taken into account (varying within the margin of 10–20% for the number of harmonics ranging between 6 and 12).

3. Estimate of the parameters of the hot spot

Displacement of the positions of maxima from elongations along with the pronounced overall asymmetry of the light curves can be interpreted as an evidence of an additional energy input which affects the regular light variations caused by the tidal distortions of both components nearly filling in their Roche lobes. Whatever is the nature of the mechanism responsible for the observed asymmetry, to cause the displacement in phase of maximum by $\Delta\phi$ an additional energy input is needed $L \geq C\,\frac{dl}{d\phi}\,\Delta\phi$ where the value $dl/d\phi$ can be estimated with the aid of the theoretical light curve and the constant C should be of order $C \simeq$ 1–10. Making use of the data for the effective temperatures and the radii of the components from Hill (1989) we have found $L_{\rm add} = 2 \cdot 10^{29}\, ergs\, s^{-1}$ and $L_{\rm add} = 2 \cdot 10^{30}\, ergs\, s^{-1}$ for $C = 1$ and $C = 10$ respectively. Another estimate can be

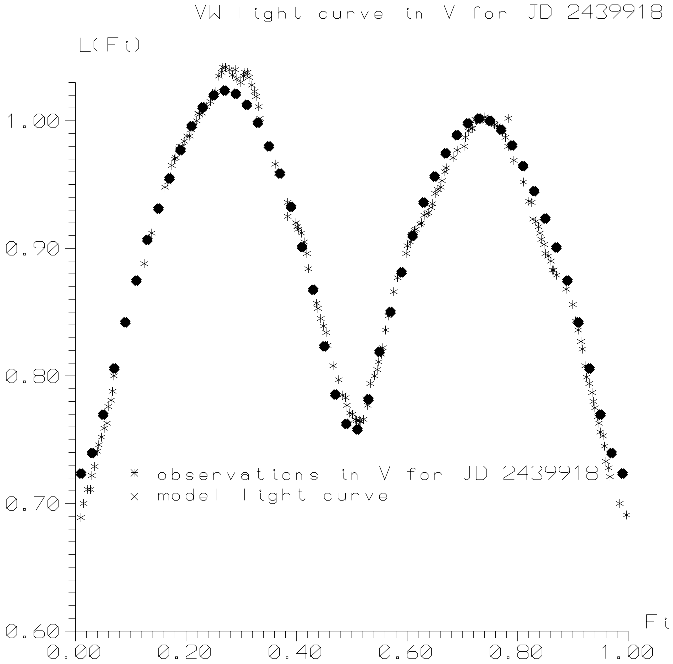

Fig. 5. The observed for $J.D.2439918$ **(*)** and the model **(x)** light curves for VW Cep in V colour. The best fit with the observed light curve has been found for the following parameters of the hot spot: $R_{\rm sp} = 9°, \Delta T/T = 1.45, \chi = 81°, l = 358°$.

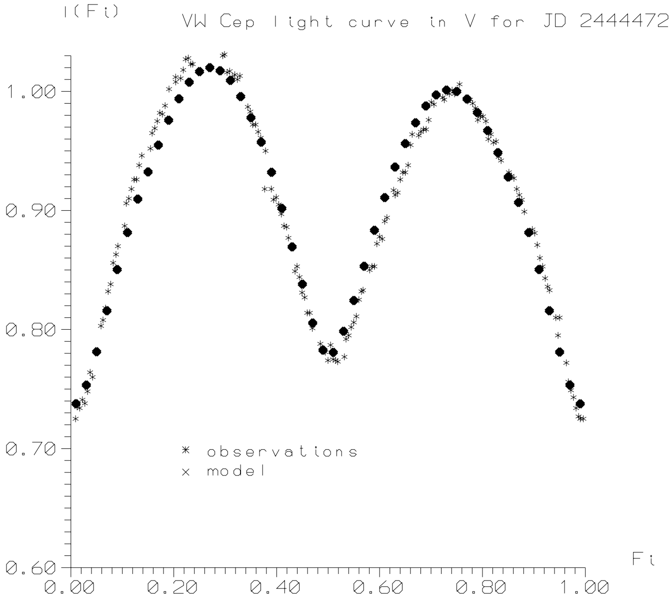

Fig. 6. The observed for $J.D.2444472$ **(*)** and the model $(\mathbf{x})$ light curves for VW Cep in V colour. The best fit with the observed light curve has been found for the following parameters of the hot spot: $R_{\rm sp} = 7°, \Delta T/T = 1.4, \chi = 78°, l = 357°$.

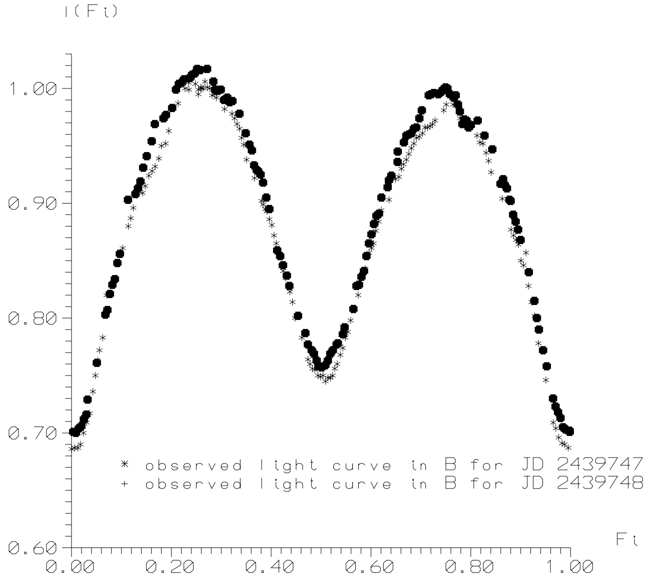

Fig. 7. Comparison between the B light curves of VW Cep taken during two consecutive nights at $J.D.2439747$ and $J.D.2439748$. Note the presence of systematic differences due to intrinsic variability, apparently caused by flare activity.

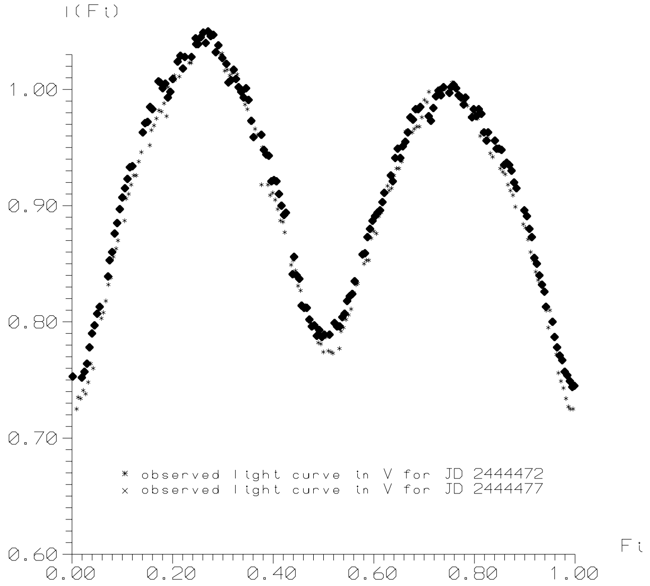

Fig. 8. Comparison between the V light curves of VW Cep taken at $J.D.2444472$ and $J.D.2444477$. The systematic difference between two curves is in evidence.

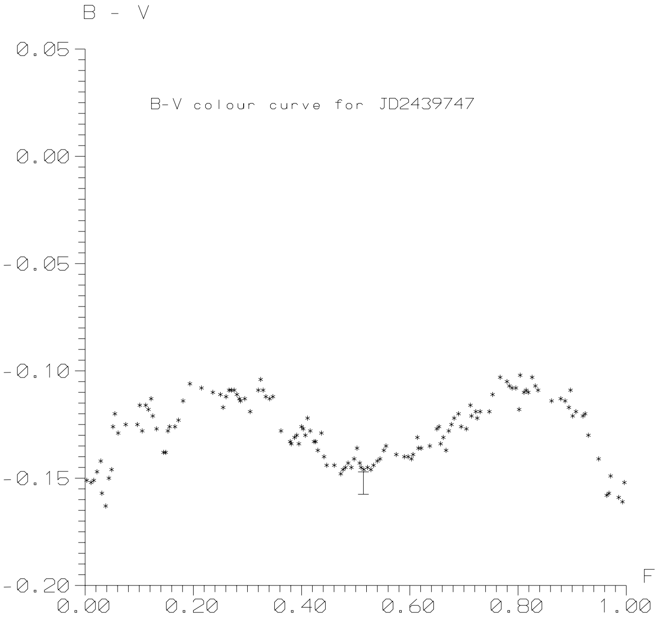

Fig. 9. The quasi-periodical colour changes $\Delta(B-V)$ in VW Cep for $J.D.2439747$. Notice displacement of the minimum from the calculated position ($\phi = 0.5P$) of the secondary brightness minimum. The displacement can be explained by the presence of the small hot spot whose center does not coincide with the center of the visible disc of the primary component(the latter being partially eclipsed) and the location of the “photocenter”is wave-length dependent.

found taking an average value of the difference between the heights of the adjacent maxima. Assuming $T_{\rm eff} = 5200^{\rm o}K$ and the above-given values of the radii of the components we find from the observed light curves the following estimates of $L_{\rm add}$ in different colours in units of total brightness of the binary: 0.005–$0.075(B), 0.005$–$0.045(V), \leq 0.02(R, I)$. These figures must be quite reliable average values for B and V colours but our estimates in R and I are based only upon the data from Linnell (1982) for 2 observing nights. Thus, in absolute measure $L_{\rm add} = 1.3 \cdot 10^{30} - 2 \cdot 10^{31}\, erg\, s^{-1}$ (in B) and $L_{\rm add} = 1.4 \cdot 10^{30} - 1.25 \cdot 10^{31}\, erg\, s^{-1}$(in V). Next assuming that mutual eclipses and tidal distortions fully determine the shape of the light curve for a standard limb darkening law we shall attempt now to estimate the size and the temperature of the putative spot. In doing that we neglect small differences in temperature between the component stars (according to various authors $\Delta T \sim 150^\circ K$) and the gravity darkening effect. Since in U, B, V colours and even in R and I we can safely use Wien’s approximation a simple expression holds for the total luminosity of the binary in wave-length λ_j for the phase angle ϕ in orbit

$$L_{\lambda\,j}(\phi) = \frac{c_1}{\lambda_j^5}\exp\left(-\frac{c_2}{\lambda_j\,T_{\rm st}}\right)[S_{\rm 1st}(\phi) + S_{\rm 2st}(\phi)] + \frac{c_1}{\lambda_j^5}\exp\left(-\frac{c_2}{\lambda_j\,T_{\rm sp}}\right)S_{\rm sp}(\phi), \qquad (2)$$

where $T_{\rm st}$ and $T_{\rm sp}$ are respectively the effective temperatures of the components and the spot whereas $S_{\rm 1st}, S_{\rm 2st}, S_{\rm sp}$ are projected areas upon the plane of the sky of the components and the spot. Now introducing the temperature contrast $\delta T_{\rm sp} = (T_{\rm st} - T_{\rm sp})/T_{\rm st}$ and relative area $\delta_{\rm sp}(\phi)$ in units of the total area of a binary visible at a given phase angle ϕ in orbit we can easily find that

$$\delta_{\rm sp}(\phi) = 0.921034\,\left[\Delta m_{\lambda\,j(\phi,0)} - 2.5\,\lg\left(L_{\lambda\,j}(0)/L_{\lambda\,j}(\phi)\right)\right] \times \exp\left(-\frac{c_2\,\delta T_{\rm sp}}{\lambda\,j\,T_{\rm sp}}\right) \qquad (3)$$

Table 3. Relative size of the hot spot

T_{sp}	U	B	V	R	I
6000	0.063	0.053	0.041	0.038	0.020
7000	0.021	0.024	0.023	0.023	0.016
8000	0.012	0.014	0.014	0.017	0.012

Table 4. Full amplitudes of colour changes

T_{sp}	$B-V$	$U-B$	$V-R$	$V-I$
6000	0.020	0.031	0.016	0.10
7000	0.038	0.070	0.029	0.049
8000	0.057	0.117	0.040	0.064
Δ_{obs}	0.040	0.072	0.030	0.044

where $\Delta\, m_{\lambda\, j} = m_{\lambda\, j}(\phi) - m_{\lambda\, j}(0)$ is the observed difference in stellar magnitudes of VW Cep for phase angles 0 and ϕ. Taking the data for the full amplitude of the light curves in U,B,V,R,I from the paper of Linnell (1982) the orbital elements from the paper of Hill (1989) and calculating from the model light curves $L_{\lambda\, j}(0)/L_{\lambda\, j}(\phi)$ we arrive at the values for $\delta_{\rm sp}(\phi) = \pi/2$,(see data in Table 3) for different assumed values of the temperature of the hot spot.

Applying (3) to the luminosity of VW Cep, for instance, in B and V colors we have the following relation between the relative size of the hot spot $\delta_{\rm sp}(\phi)$ and the colour change $\Delta(B-V)$ between maximum and primary minimum

$$\Delta(B-V) \;=\; 1.086\delta_{\rm sp}\left[\exp\left(-\frac{c_2\,\delta T_{\rm sp}}{\lambda_b\,T_{\rm sp}}\right)\right.$$
$$\left. -\exp\left(-\frac{c_2\,\delta T_{\rm sp}}{\lambda_v\,T_{\rm sp}}\right)\right]. \tag{4}$$

Because of the crude nature of the estimate we have neglected possible differences in the size of the spot in different colors when deriving relation (4). Applying it to different colors we find the amplitudes of color changes for different values of $T_{\rm sp}$. The results are summarized below in Table 4. In the last row the average observed values are indicated for VW Cep. As we see there is a good agreement between the observed and model color indices, if one assumes that $T_{\rm sp} = 7000^{\circ}K$.

The derived parameters of the hot spot depend on the adopted orbital elements, notably on the value of fill-out parameter f. The above-given values of δ were obtained assuming $f = 0.05$. However, the results are not specially sensitive to the assumed value of f. For instance if one takes $f = 0.4$, one finds δ smaller by about 20 per cent than those given-above. As mentioned above, we fully neglected the gravitational darkening and the reflection effect because the latter neither produce any color phase changes (practically equal effective temperatures of the components) nor can one explain with its aid the different level of the adjacent brigthness maxima.

To verify how the hot spot with the above-given parameters can be helpful in interpreting the observed light curves of VW Cep we used the commercially available computer package *BINARY MAKER* (Bradstreet 1993) and modelled with its aid the light curves of VW Cep assuming the orbital and physical parameters from Hill (1989) and changing only the inclination angle $i \simeq 65^{\circ} - 67^{\circ}$.

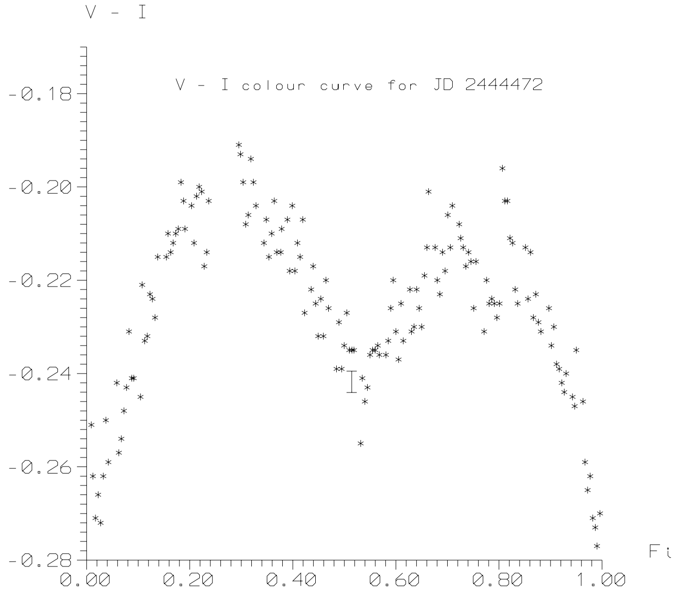

Fig. 10. The quasi-periodical colour changes $\Delta(V-I)$ for $J.D.2444472$. According to the proposed model systematic colour changes between minimum and maximum are caused by the variable contribution from the hot spot region located close to the neck connecting two components, whereas superimposed random fluctuations of colour variations are due to flare activity.

Again we assumed the standard linear limb darkening law. We tried to match the observed light curves, especially the difference in the levels of maxima, their phase displacement by changing the coordinates, the relative radius δ and the temperature contrast $\delta T/T$. We have found the best fit for the following ranges of the hot spot parameters: $R_{\rm sp} = 9^{\circ} \pm 2^{\circ}, \delta T/T \simeq 1.30$–$1.45, L_3 = 0.0$–$0.03$ (the third light),$f = 0.05, l = 80^{\circ} \pm 2^{\circ}, \chi = 357^{\circ} \pm 2^{\circ}$ (l being the latitude and χ the longitude of the centre of the hot spot upon the surface of more massive component). l is the angle from 0 to 180° measured from the upper to the lower pole, the upper pole coinciding with the positive end of the angular momentum of the binary system, χ is the angle from 0 to 360° measured clockwise from the meridian along the line connecting the mass centres as seen from the upper pole.

Figs. 4–6 illustrate results for typical light curves taken at $J.D.2439467, 2439918$ and 2444472. In broad terms the asymmetry is more pronounced in B than in V and decreases even more with the increasing wavelength. The asymmetry of the model light curve is specially sensitive to the values of $R_{\rm sp}$ and $\delta T/T$ and thus systematically slightly higher values of the temperature contrast of the spot and lower values of the size of the spot in B colour in comparison with V are needed to achieve equally good fit with the observed light curves.

Although the agreement between the observed and model light curves is not fully satisfactory we see that the model light curves reproduce the observed phase displacements of maxima and produce the overall observed pattern of asymmetry. Namely, roughly between the phases $0.25P - 0.30P$ the hot spot competes with the decline in brightness due to tidal distortion of the components, thereby the descending branch (after elongation) is more flat than the ascending one (prior to elongation). The maximum following primary minimum is higher than the neighboring one because only a very small portion of the hot spot is visible during the maximum preceding primary minimum. Finally, after phase angle $0.37P - 0.38P$ the hot spot becomes largely obscured and small dips are often visible at this phase angle.

To make a better judgement of an achieved fit between the model light curves and the observed ones, we reproduce in Fig. 7 and Fig. 8 respectively observed light curves in B colours for JD 2439747 and JD 2439748 as well as for V colour for JD 2444472 and JD 2444477. All these nights are of a good quality and yet the presence of small but systematic differences between the individual nights is obvious. In all evidence the presence of rapid intrinsic variability in VW Cep (on time scale comparable to and shorter than orbital period) make at this stage attempts to achieve an ideal fit between the model and observed light curves premature. As we see from Figs. 4–6, the systematic differences between the observed and model light curves are comparable to what we observe in Figs. 7, 8 for the light curves taken at close epochs. Several independent factors combine to make rather complicated the confrontation between observed and model light curves: i) there is no simple straightforward procedure permitting to normalize the observed light curves with due account of both the hot spot and the contribution from the third component, ii) the variation of brightness of the hot spot with phase must be taken into account, iii) the detailed physical mechanism behind intrinsic variability and the relevant time scales remain largely unknown.

Figs. 9 and 10 illustrate peculiar behaviour of $\Delta(B-V)$ and $\Delta(V-I)$ colour curves close to the secondary minimum: displacement of the moment of minima for colour curves is clearly in evidence (no similar effect has been recorded for the primary minimum when the putative hot spot region is averted from the observer being on the far side of a primary component!). The displacement can be interpreted assuming that the hot spot is shifted from the center of the visible disc projected upon the plane of the sky of the primary component and the shift is wave-length dependent.

4. The short-time intrinsic variability

We turn now to the short time intrinsic variability observed in VW Cep. We assume that the hot spot region can be interpreted as the photospheric burn and also the preferential site of the flare activity, its size being comparable (but still appreciably less) than the characteristic volume occupied by the plasma during the decay of the flare (which agrees well with the observed dips seen during X-ray flare ascribed to eclipses, see Choi & Dotani 1998). In what follows we offer only rough estimates, a more rigorous approach is deferred till more observational data in favour of the hot spot will become available inviting application of more sophisticated models.

For optically thin free-free emission the frequency dependence of the intensity is given by

$$I(\nu) \sim \ln(5 \cdot 10^7 \cdot T^{3/2}/\nu) \, \exp -(h\nu/kT). \tag{5}$$

(Lang 1974) where the logarithmic factor is an approximation to the Gaunt factor if $\nu \leq 5 \cdot 10^7 T^{3/2}$. For $\nu \leq kT/h$ the spectrum is rather flat with intensity slowly increasing towards lower frequences. The requirement of the optically thin plasma is fulfilled if $\nu \geq \nu_1$ where $\nu_1 = 0.53\, T^{-0.675} N\, r^{1/2}$, N-being the number density and r the characteristic size of a flaring region. Using the data from the paper of Choi and Dotani $r \simeq 5 \cdot 10^{10}\, cm$ and $N \simeq 5 \cdot 10^{10}\, cm^{-3}$ we find that at least close to the peak of the flare the frequency domain for which the spectrum of decaying flare is flat comprises not only UBV region but stretches even to far infrared.

Thus, for a slowly decaying flare we may expect comparable figures for the amplitude of the effect of asymmetry in optical region and the contribution from the flare. Moreover, the X-ray fluxes and that in UV are recorded also during the quiescent state at a level lower by a factor of only 3–4 compared with the peak luminosity. We use this fact to make a quantitative estimate based upon a naive model assuming the volume and emission measure remain constant during the flare (see Doyle et al. 1989). Despite the crude nature of this model it should be applicable for an estimate to our case because the energy released during the flare in question exceeds only by a factor of 4 the flux in far UV during the quiescent state. Thus, from the conservation of energy condition we have

$$\frac{d}{dt}\left(\frac{3}{2}pV\right) = -F \tag{6}$$

where $p = 2n_{\mathrm{e}}kT$ is electron pressure and F is the free-free radiative loss integrated over all frequences

$$1.4 \cdot 10^{-27}\, T^{1/2}\, N_{\mathrm{e}}^2\, V g_{ff}(T)\, erg\, s^{-1} \tag{7}$$

$g_{ff}(T)$ being the averaged Gaunt factor. Thus we find from (6) that the variation of the temperature with phase is given by

$$T(t) = [T_0^{1/2} - C\,(t - t_0)]^2. \tag{8}$$

The constant C can be found from combinations of (5) and (6) and is equal to $C = 2 \cdot 10^{-12} N_{\mathrm{e}}$. Now applying this simplified model we estimate the parameters of the flare in extreme UV (see data published by Rucinski 1998) setting $T_0 = 1.5 \cdot 10^5\,{}^{\mathrm{o}}K$ and the minimum temperature equal to that of the hot spot $T_{\mathrm{sp}} = 7000^{\mathrm{o}}K$. We find $N_{\mathrm{e}} \simeq 1.75 \cdot 10^{11}\, cm^{-3}$ for $\Delta t_{\mathrm{fl}} \simeq 860\, sec$.

With these figures in hand we have calculated for the case of optically thin plasma (both free-free and bound-free processes were taken into account) the expected changes in colours $\Delta(U-B), \Delta(B-V), \Delta(V-R)$ between two measurements: one taken close to the peak of the flare with the just quoted parameters T_0, N_{e},and another right after the flare.

We have found for the wavelength integrated luminosity of the flare $L_{\mathrm{fl}} \simeq 2.85 \cdot 10^{31}\,ergs$ whereas $L_{\mathrm{bol}} = 2.4 \cdot 10^{33}\,ergss^{-1}$ (Hill 1989). Combining these data we find readily: $\delta[\Delta(U-B)] = -0.015, \delta[\Delta(B-V)] = 0.007, \delta[\Delta(V-R)] = 0.004$ (where δ stands for the variation of respective index between the two points - one at the peak of the flare, another one right after it. Thus, we see that for realistic parameters of the flare the observed intrinsic colour changes of order $0^{\mathrm{m}}.01$ from one observational night to another (or within the same orbital cycle) can be easily reproduced. We shall look now how these estimates agree with other available data for VW Cep. According to van't Veer (1999) a good estimate of the corotating distance (Alfven radius) can be found from relation

$$R_{\mathrm{A}}^2 = \frac{1}{2\,\pi}\,J_0\,P\left(\frac{1}{m_1} - \frac{1}{3m}\right) \tag{9}$$

where J_0 is the orbital angular momentum of binary, m_1 and m are respectively the mass of a primary component and the total mass of binary. Relationship (8) has been derived for the specific case of net mass loss with no accompanying changes of the orbital period. Inserting the values of orbital elements and physical parameters of VW Cep we find $R_{\mathrm{A}} = 1.49R_{\odot}$. Assuming the velocity of gas is equal to the sonic velocity $v_{\mathrm{s}} = 1.5 \cdot 10^6\,cm\,s^{-1}(T \simeq 10^4\,{}^{\mathrm{o}}K)$ and taking into account that the radius of the primary component equals to $R_1 = 0.93R_{\odot}$ we estimate the characteristic time of propagation of the flare $t_{\mathrm{fl}} = (R_{\mathrm{A}} - R_1)/v_{\mathrm{s}}$ equal to 7.5 hours which is in excellent agreement with the observed X ray flare duration (Choi & Dotani 1998). Since the values of characteristic size of the emitting region and of the radius of the secondary component are quite close to each other $(\sim 0.5R_{\odot})$ it is clear that partial eclipses of flaring structures by the low mass companion are expected depending on exact circumstances of the flares and this is in agreement with the observed dips in X ray flux reported earlier by both Vilhu et al. (1988) and Choi & Dotani (1998).

The coronal densities in VW Cep $n_{\mathrm{e}} \sim 5 \cdot 10^{10}\,cm^{-3}$ are by a factor of 30–50 higher than those in solar corona. Thus taking a solar value as a rather conservative estimate for chromospheric density $10^{12}cm^{-3}$ in combination with the emitting volume associated with the hot spot $V \simeq 5 \cdot 10^{29}\,cm^3$ (which is based upon above given estimates of the size of hot spot from the light curve analysis and radial extension $\Delta r \simeq 10^9\,cm$ as the product of sound velocity and the time scale of both spectral changes in UV (see Pustylnik 1995) and just quoted duration of flare in extreme UV, both of order 6–8 $\cdot\, 10^2\,sec$) we find the following figure for wavelength integrated luminosity from recombining plasma $L_{\mathrm{rcmb}} \sim 7 \cdot 10^{31}\,erg\,s^{-1}$ or $L_{\mathrm{rcmb}}/L_{\mathrm{bol}} \sim 0.03$. It is worth noticing also that the total luminosity of VW Cep both in $MgII2795, 2802\dot{A}$ resonance feature and in L_{α} are of order $10^{-4} \cdot L_{\mathrm{bol}}$ (for details, see Rucinski 1995; Pustylnik 1995) which favourably agrees with our estimate for L_{rcmb}.

Thus, again we find that the observed intrinsic colour changes of order $0^{\mathrm{m}}.01$–$0^{\mathrm{m}}.02$ from one observing night to another can be easily reproduced.

As we mentioned the individual light curves being at our disposal invariably showed the higher brightness maximum following the primary minimum (over the time interval of nearly 30 years). There are, however, exceptions (see, for instance, discussion by Bradstreet & Guinan (1990) where to the contrary, the brightness of the maximum preceding the primary minimum was higher and even the amplitude of the secondary minimum was higher than that of the primary one. Although, in our view, the evidence for that is scarce and may be partially due to intrinsic variability causing inevitable uncertainties in the procedure of normalizing the averaged light curves, it would be interesting to look for a possible interpretation of these rare events. Let us assume that our basic proposed idea of the small hot spot region close to the neck connecting two components is correct and the flaring region is associated with it. Then for the above-quoted coordinates of the hot spot and typical durations of the flare statistically we should see preferentially the type of the asymmetry of the light curves which is actually observed. Let us assume now that occasionally rather powerful flare with a duration $\Delta t \leq 0.25P$ occurs right at the phase when the flaring region is averted from observer. In this relatively rare case we would observe occasional alternation of the heights of adjacent brightness maxima.

We find especially encouraging that the derived value of the temperature of the hot spot is practically coincident with the temperature needed to generate $MgII\lambda 2795, 2802\dot{A}$ strong resonance doublet feature, whereas both the flux in this feature and the phase of its maximum are in good accord with the above given estimate of the luminosity of the hot spot and its location (for details see Pustylnik (1995) and the graphical data in Bradstreet & Guinan (1990) for $MgII\lambda 2795, 2802\dot{A}$ and H_{α} line composite profile). To summarize, we find the proposed hot spot is an essential cohesive element of the model for VW Cep because it solves an old enigma of the color changes on one hand and gives natural explanation to small differences in depths of minima for practically equal effective temperatures of the components on the other. With its application the discrepancies between the photometric and spectroscopic data find a natural explanation.

For a detailed verification of the proposed idea new rapid multicolour photometric data in UBVRI are badly needed.

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