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A Period Study of the Close Binary V508 Ophiuchi

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Abstract: The short-period ($0^d.34$) close binary V508 Oph was observed in 2005 and four new times of minima were derived. All of the available times of minima, including the new ones, covering 69 years were analyzed. It was shown that the period change of the system is very complex. Two possible period oscillations with periods of 24.73 and 9.91 years and amplitudes of about 0.011 and 0.002 day, respectively, were found to superimpose on upward parabolic change, indicating a secular period increase at a rate of $\mathrm{d}p/\mathrm{d}t = 4.24 \times 10^{-9}$ days yr^{-1}. The mechanisms that could explain the period changes of the system are discussed.

Keywords: stars: binaries: eclipsing — stars: individual: V508 Oph

1 Introduction

V508 Oph ($V_{\max} = 10^m.5$, AN 82.1935, BD +13° 3496, HIP 88028) is a W UMa-type eclipsing binary with an orbital period of $0^d.34$. It was discovered to be a variable star by Hoffmeister (1935) and its eclipsing nature was revealed by Jacchia (1936). Karetnikov (1977) obtained photographic and photovisual light curves. The first BV photoelectric observations were presented by Rovithis & Rovithis-Livaniou (1983). Lu (1986) obtained radial velocity curves of both components of V508 Oph and determined a mass ratio of 0.52. He also estimated the spectral types of the component stars as G0 V + G2 V. Lapasset & Gomez (1990) analyzed the photometric and radial velocity observations of V508 Oph and determined the system's parameters as follows: $M_1 = 1.01\,\mathrm{M}_\odot$, $M_2 = 0.52\,\mathrm{M}_\odot$, $R_1 = 1.06\,\mathrm{R}_\odot$, $R_2 = 0.80\,\mathrm{R}_\odot$, $\log L_1 = 0.087\,\mathrm{L}_\odot$, $\log L_2 = -0.286\,\mathrm{L}_\odot$. The period variation of the system was first announced by Lapasset (1985). Later, Lapasset & Gomez (1990) used a quadratic ephemeris fit to the observed minus calculated (O–C) curve. Their results indicated that the orbital period of the system is increasing. Recently, Kreiner et al. (2001) published only the O–C curve for V508 Oph but their study does not include a period analysis of the system. In order to look for the period change in V508 Oph, we analyzed the O–C variation of this binary with the extended data.

2 New Observations and the O–C Variation

To obtain new times of minima, we observed V508 Oph in the nights of 2005 June 2, 4, 6, and 8 at the Ankara University Observatory. During the observations we used a 30-cm Maksutov telescope equipped with a SSP-5A photometer head which consists of a Hamamatsu R1414 photomultiplier tube. BD +13° 3491 was used as the comparison star. From the observations, four new times of minima (two primary and two secondary) were derived by using the method of Kwee & van Woerden (1956). An extensive list of the former visual, photographic, and photoelectric times of minima was the compilation provided by Karetnikov (1977). We also added times of minima from mainly BBSAG, BAVSM, BAVSR, CoBrn, Orion, and VSOLB[1]. The complete list of times of minima combined with ours is given in the Accessory Materials. Thus, we had a data set of 484 visual, 10 photographic, 52 photoelectric, and six CCD timings covering a period of 69 years from 1936 to 2005.

The behaviour of the deviation of each times of minima from the mean orbital period depends strictly on the mean period used at the calculation. Figure 1 shows the O–C diagram, which is the difference in the values of the primary and secondary minima from the old ephemeris given by Karetnikov (1977)

$$\text{Min I} = \text{HJD}2428416.33242 + 0^d.344791922 \times E \quad (1)$$

Although the visual observations show large scatter, the general trend of the O–C deviations seems to indicate a cyclic variation covering a maximum and a minimum, about 70 000 orbital periods. The cyclic nature of the O–C diagram is seen to be asymmetric, which indicates the light–time effect in the eccentric orbit. Because both the period increase and subsequent decrease during one cycle are not the same, indicating that the O–C curve is rather asymmetrical. Comparing the residuals of the many kinds of fits, we found that the fit of a combination of a long-term period increase and two periods

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[1] BBSAG: 'Bulletin der Bedeckungsveraenderlichen-Beobachter der Schweizerischen Astronomischen Gesellschaft'; BAVSM: 'Berliner Arbeitsgemeinschaft für Veränderliche Sterne – Mitteilungen'; BAVSR: 'Mitteilungsblatt der Berliner Arbeitsgemeinschaft für Veränderliche Sterne'; CoBrn: 'Contributions of the Public Observatory and Planetarium in Brno'; Orion: 'Zeitschrift für Amateur-Astronomie'; VSOLB: 'Variable Star Observers League in Japan – Bulletin'.

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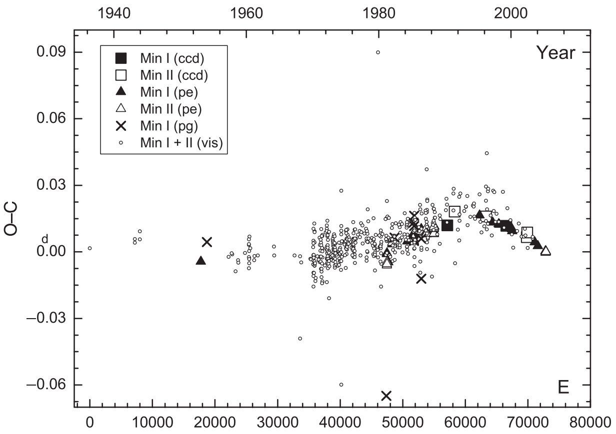

Figure 1 The O–C diagram obtained with the all available times of minima of V508 Oph.

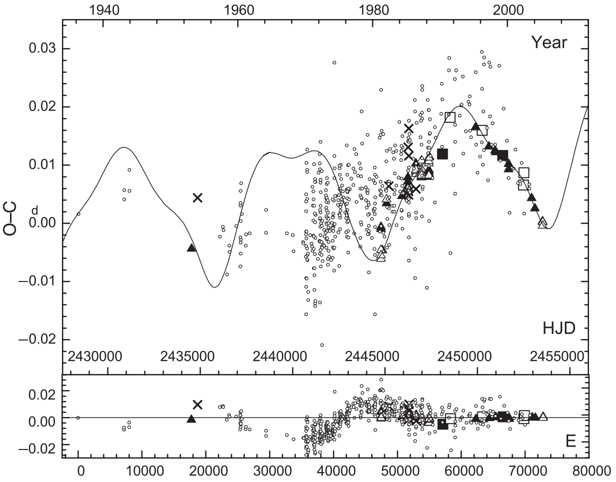

Figure 2 The O–C diagram obtained with visual, photographic, photoelectric, and CCD timings of V508 Oph. The solid line represents two periodical variations superimpose on a continuous increase in its period. At the bottom panel, the O–C residuals are plotted after the subtraction of all the terms in Equation (2). All other items are the same as in Figure 1.

Table 1. The best-fit parameters used in Equation (2)

Parameter	Value	Standard deviation
T_o (*HJD*)	2428416.33242	Fixed
P_{orb} [day]	0.344791922	Fixed
Q	2.0×10^{-12}	6.0×10^{-14}
e	0.43	0.03
ω [°]	286.0	3.0
A_3 [day]	0.011	0.001
P_3 [year]	24.73	0.15
T_3(*HJD*)	2444870	24
A_s [day]	0.0020	0.0003
P_s [year]	9.91	0.12
T_s(*HJD*)	2448531	30

oscillation is one of the best ones. Thus for modelling the O–C diagram we used Equation (2)

$$T_c = T_o + E P_{orb} + Q E^2 + \Delta T + A_s \sin\left(2\pi \frac{E - T_s}{P_s}\right) \qquad (2)$$

In Equation (2), T_o, E, and P_{orb} are the starting epoch, the integer eclipse cycle number, and the orbital period of the eclipsing binary, respectively. Q is the quadratic term. ΔT is the time delay of any observed eclipse due to orbiting around a third-body which can be represent with the following equation given by Irwin (1952)

$$\Delta T = \frac{A_3}{\sqrt{1 - e^2 \cos^2 \omega}} \left(\frac{1 - e^2}{1 + e \cos \nu} \sin(\nu + \omega) + e \sin \omega \right) \qquad (3)$$

where

$$A_3 = \frac{a_{12} \sin i \sqrt{1 - e^2 \cos^2 \omega}}{2.590 \times 10^{10}} \qquad (4)$$

is the semi-amplitude of the light-time effect in days, a_{12}, e, i, and ω are the semi-major axis, eccentricity, inclination, and the longitude of the periastron passage of the orbit of the eclipsing pair around the mass center of the system, respectively, ν is the true anomaly of the position of the eclipsing pairs' mass center on the orbit, and 2.590×10^{10} is the speed of light in km day^{-1}. The epoch T_3 of the periastron passage and the period P_3 of the orbit of the three-body system can be derived from the parameters in Equation (3). In the last term of Equation (2), A_s, P_s, and T_s are the half-amplitude, the period, and a minimum time (in units of E) of the purposed sine curve (second cyclic variation) for the O–C diagram, respectively.

The weights were attributed to be ten for CCD and photoelectric data, five for photographic data, and one for visual observations. However, one can see in Figure 1 that some visual and photographic timings show a large deviation from the general O–C trend formed by other points. Those data (five visual and two photographic) were omitted for the further analysis (marked in italic in the Accessory Material's Table). By applying the weighted last-squares solution with the theoretical function given in Equation (2) we obtained the parameters for the parabolic change, the third-body orbit and the sine-like variation listed in Table 1 with their standard deviations. Corresponding overall fit is displayed, with a superimposed on the observational data, in Figure 2. The O–C residuals from the best fit are displayed at the bottom panel of Figure 2. The value of the sum of the squares of the residuals from Equation (2) for CCD, photoelectric, and photographic data is $\sum (\mathrm{O} - \mathrm{C})^2 = 0.0007$ day^2 while 0.049 day^2 is for all data. This suggested that the theoretical curve can fit the general O–C trend of very well except the visual timings.

3 Conclusions and Final Remarks

The analysis of the O–C diagram of V508 Oph shows that the orbital period of the system is changing in a very complex way and can be explained by the combination of three plausible effects:

(1) A long-term period increase represented by a quadratic term (Q) during the O–C analysis. The corresponding rate of period increase was calculated to be

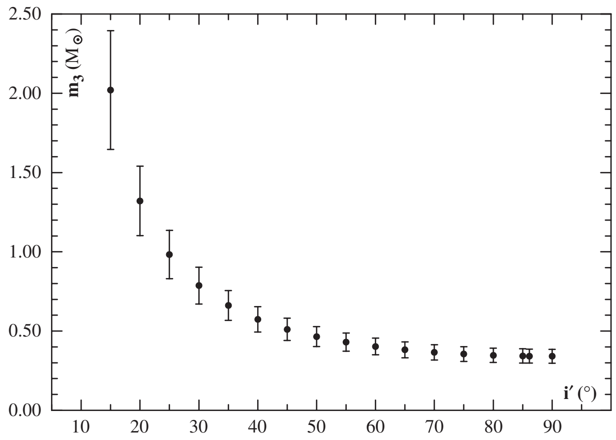

Figure 3 Mass of the invisible (third) component of V508 Oph depending on the orbital inclination of i'.

$\mathrm{d}p/\mathrm{d}t = +4.24(\pm 0.12) \times 10^{-9}\,\mathrm{days\,yr^{-1}}$ which can be attributed to the mass exchange/loss mechanism in the system. If this period increase is originated from the conservative mass transfer phenomenon between the components, then the direction of the mass transfer should be from the less massive to the more massive component a rate of $\Delta M_1 = 4.39 \times 10^{-9}\,\mathrm{M_\odot\,yr^{-1}}$ according to the well known equation based on the formulation by Kruszewski (1966)

$$\frac{\Delta P}{P} = 3\left(\frac{M_1}{M_2} - 1\right)\frac{\Delta M_1}{M_1} \tag{5}$$

where $\Delta P/P$ is the rate of the period change in $\mathrm{yr^{-1}}$ and M_1 and M_2 are the masses of the losing and the gaining components in solar mass, respectively. In case of conservative mass transfer one can also estimate the rate of change of the mass ratio using the formulation given by Yang & Liu (2003) as

$$\frac{\mathrm{d}q}{\mathrm{d}t} = \frac{-q(1+q)}{3p(1-q)}\frac{\mathrm{d}p}{\mathrm{d}t} \tag{6}$$

where q is the mass ratio, p is the orbital period in days, and $\mathrm{d}p/\mathrm{d}t$ is the rate of the period change in days $\mathrm{yr^{-1}}$. We estimated the rate of change (i.e. decrease) of mass ratio for V508 Oph due to the mass transfer in the system as $\mathrm{d}q/\mathrm{d}t = -6.59 \times 10^{-9}\,\mathrm{yr^{-1}}$.

(2) One of the two cyclic structure with the longer period of 24.73 years and higher amplitude of 0.011 day in the O–C diagram might be caused by the light–time effect of a gravitationally bound additional component with an orbital eccentricity of 0.43 in the system. Under this assumption we estimated the projected distance of the mass center of the eclipsing pair to the center of mass of the triple system should be 1.91 ± 0.21 AU. These values lead to a mass function of $f(m_3) = 0.01144 \pm 0.00395\,\mathrm{M_\odot}$ for the hypothetical third-body. The mass of the third-body was computed for different values of the orbital inclination of the three-body system and the derived values are given in Figure 3. In this computation, the masses of the components stars of the eclipsing pair $M_1 = 1.01\,\mathrm{M_\odot}$, $M_2 = 0.52\,\mathrm{M_\odot}$ (Lapasset & Gomez 1990) were applied. If the third body orbit is co-planar with the systemic orbit (i.e. $i' = 86^\circ.13$), its mass would be $0.34 \pm 0.04\,\mathrm{M_\odot}$. Then, Kepler's third law gives the semi-major axis of the orbit to be 8.57 ± 0.05 AU. By adopting the distance of V508 Oph $d = 130.21$ pc given in the Hipparcos catalogue, we get the maximum angular separation of the third-body from the eclipsing pair to be 0.08 ± 0.02 arcsec. Using the mass–luminosity relation for main-sequence stars given by Demircan & Kahraman (1991), we can estimate the bolometric absolute magnitude of the third-body to be about $M_{\mathrm{bol}} \cong 8.89$ mag which is about 4 mag fainter than the binary system. In this case, the supposed third-body is very difficult to detect because its luminosity is extremely small. Since no third light was reported in the photometric study of Lapasset & Gomez (1990) and no any trace in the cross-correlation function profiles of the spectrograms were found by Lu (1986), the orbital inclination of the third-body should not be extremely low, i.e. $i' > 30^\circ$.

(3) Finally, the remaining cyclic structure with the shorter period of 9.91 years and lower amplitude of 0.002 day could be attributed to the magnetic activity cycle effect of the primary component of the system. W UMa type contact binaries are well known to be magnetically very active, e.g. with cool or hot starspots, chromospheric emission, coronal X-ray emission, and generally the primary components of them are dominant in the level of this activity. Applegate (1992) has shown that a cyclic change in the activity level of one component in a close binary system can produce cyclic variation in the orbital period of the system. The basic idea of the magnetic activity cycle effect on the orbital period of a binary system depends on the existance of the spin–orbit coupling. Any change in the rotational regime of a binary star component due to the magnetic activity, will be reflected to the orbit as a consequence of the spin–orbit coupling. We have calculated the activity related parameters by following the Applegate's (1992) formulation as the cycle length $P_{\mathrm{cyc}} = 9.91$ years, the amplitude of the cyclic period variation $\Delta P = 0.103\,\mathrm{s\,cycle^{-1}}$, the angular momentum transfer of $\Delta J = -6.33 \times 10^{46}\,\mathrm{g\,cm^2\,s^{-1}}$ required to produce the observed cyclic effect on the orbital period, required energy $\Delta E = 3.75 \times 10^{40}$ ergs for the ΔJ transfer, the corresponding luminosity change $\Delta L = 3.76 \times 10^{32}\,\mathrm{ergs\,s^{-1}}$ and the brightness variation $\Delta m = 0.06$ mag of the primary component, and finally the subsurface magnetic field strength $B = 14.9$ kG of the primary component. Applegate (1992) also predicts that (a) the long-term light variation and the O–C curve formed by the times of minima should have the same cycle length, (b) extrema in one should coincide with extrema in the other, and (c) the colour of the system should become bluer as the active star brightens. Unfortunately, we do not have enough precise and long-term photometric observations for V508 Oph to check such brightness variations. But there are some evidences in the literature about the variations in the light curve of V508 Oph in certain

orbital phases (see Lapasset & Gomez 1990 and references therein). So, the system deserves to long-term photometric monitoring to clarify its possible magnetic activity cycle characteristics, and also more determinations of eclipsing times over the next decade are very important to settle the O–C diagram of the system.

Accessory Material

A Table listing observed minima times of V508 Oph are available in from the authors or, until December 2010, *Publications of the Astronomical Society of Australia*.

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References

Applegate, J. H. 1992, ApJ, 358, 621
Demircan, O., & Kahraman, G. 1991, Ap&SS, 181, 313
Hoffmeister, C. 1935, AN, 255, 405
Irwin, J. B. 1952, ApJ, 116, 211
Jacchia, L. 1936, AN, 261, 212
Karetnikov, V. G. 1977, PZ Suppl, 3, 247
Kreiner, J. M., Kim, C.-H., & Nha, I.-S. 2001, An Atlas of O–C Diagrams of Eclipsing Binary Stars (Cracow: Wydawnictwo Naukove)
Kruszewski, A. 1966, Adv. Astron. Astrophys., 4, 233
Kwee, K. K., & van Woerden, H. 1956, Bull. Astron. Inst. Neth., 12, 327
Lapasset, E. 1985, IBVS, 2828
Lapasset, E., & Gomez, M. 1990, A&A, 231, 365
Lu, W. 1986, PASP, 98, 577
Rovithis, P., & Rovithis-Livaniou, H. 1983, Ap&SS, 96, 283
Yang, Y., & Liu, Q. 2003, A&A, 401, 631