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V456 Ophiuchi and V490 Cygni:
Systems with the shortest apsidal-motion periods
(Research Note)

P. Zasche and M. Wolf

Astronomical Institute, Faculty of Mathematics and Physics, Charles University Prague, 180 00 Praha 8, V Holešovičkách 2, Czech Republic
e-mail: zasche@sirrah.troja.mff.cuni.cz

ABSTRACT

Our main aim is the first detailed analysis of the two eclipsing binaries V456 Oph and V490 Cyg. The system V456 Oph has been studied both photometrically via an analysis of its light curve observed by the INTEGRAL/OMC and by the period analysis of all available times of minima. V490 Cyg has been studied by means of a period analysis only. Many new times of minima for both systems have recently been observed and derived. This allows us for the first time to study in detail the processes that affect both binaries. The main result is the discovery that both systems have eccentric orbits. For V456 Oph we deal with the eccentric eclipsing binary system with the shortest orbital period known (about 1.016 day), while the apsidal motion period is about 23 years. V490 Cyg represents the eclipsing system with the shortest apsidal motion period (about 18.8 years only). The two components of V456 Oph are probably of spectral type F. We compare and discuss the V456 Oph results from the light curve and the period analysis, but a more detailed spectroscopy is needed to confirm the physical parameters of the components more precisely.

Key words. binaries: eclipsing – stars: individual: V456 Oph – stars: individual: V490 Cyg – stars: fundamental parameters

1. Introduction

The eccentric eclipsing binaries (EEBs) provide a great opportunity for studying the stellar structure of the stars as well as testing the General Relativity outside the solar system. The $O-C$ diagram analysis, which investigates the revolution of the line of apsides in the system has been described elsewhere, e.g. Giménez & García-Pelayo (1983), Giménez & Bastero (1995). Nevertheless, new contributions to this topic with new systems are still welcome, especially for cases where the apsidal motion period is adequately short and a few periods are covered. This is the case for the two somewhat neglected systems V456 Oph and V490 Cyg.

1.1. V456 Oph

V456 Oph (=AN 108.1935 = SAO 123842, V_{max} = 9.95 mag) has been discovered as a variable star by Hoffmeister (1935), with the remark that it is a "short-periodic one, but probably not rapidly changing". After than Guthnick & Prager (1936) incorrectly classified the star as a δ Cep one with a preliminary period of about 14.6 d. No such variation has been detected with the present data. The only spectral classification is that by Roman (1956), who indicated the spectral type A5, but with a remark that because of underexposed plates and uncertain ephemerides this classification is not very secure.

Although the first photoelectric light curve has been published by Demircan et al. (1988), there was no light curve analysis of the system performed until today. The same applies to the spectroscopic analysis, which has not yet been carried out, so the mass ratio of the pair in not known. Soydugan et al. (2006)

included the binary in the catalogue of systems located in the instability strip, which means that it possibly contains a δ Scu component. However, no indication of pulsations in V456 Oph has been detected.

1.2. V490 Cyg

V490 Cyg (=AN 76.1939, V_{max} = 12.81 mag) is an Algol-type eclipsing binary, even though the SIMBAD database lists V490 Cyg as a β Lyrae one. The system has been discovered as a variable by Wachmann (1940), and its light curve coverage is too poor for any reliable analysis. Its spectral type was derived to be F8, while Svechnikov & Kuznetsova (1990) give an estimate of the spectral types F8+[G4]. Hegedüs (1988) included this system in his list of stars with possible apsidal motion, but since then it was not studied in detail. Other credible information about the physical properties of the components is missing because there is so little spectroscopy and photometry of this system.

2. The period analysis

2.1. V456 Oph

The set of published times of minima for V456 Oph is quite extensive, covering more than 70 years. Regrettably, the old minima are only photographic and their scatter is so large that one cannot use them for any reliable analysis. We used only the more precise photoelectric and CCD ones, which were published after 1970. These minima roughly follow the linear ephemerides given in GCVS, but there some variations are clearly visible.
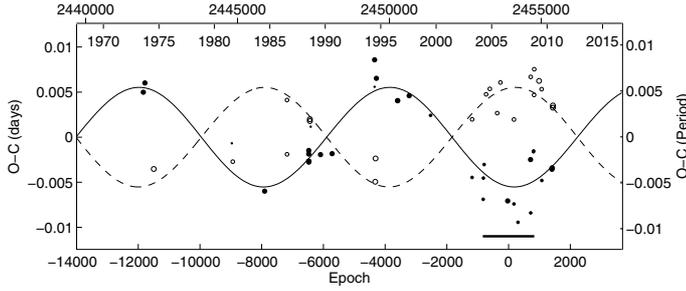
Fig. 1. O−C diagram of V456 Oph. The lines represent the fit according to the apsidal motion hypothesis (see text and Table 2), the solid line stands for the primary, while the dashed line stands for the secondary minima, dots stand for primary and open circles for the secondary minima. The black line near the bottom axis represents the time interval covered with the OMC data used for the light curve analysis.

We tried to collect all available minima times and also to derive some new ones. A few of the already published ones were recalculated once again and corrected for the final analysis. Besides these minima times, we also used the photometry of V456 Oph obtained with the robotized and automated telescopes working today. These are

- ASAS – the automated survey, *V* filter, Pojmanski (2002), http://www.astrouw.edu.pl/asas/
- OMC – the OMC camera onboard the INTEGRAL satellite, using the *V* filter, Mas – Hesse et al. (2004), https://sdc.laeff.inta.es/omc/
- Pi of the sky – the automated telescope, unfiltered, Burd et al. (2005), http://grb.fuw.edu.pl/pi/

Sixteen new minima times were derived from these surveys, and some of the published ones were computed again (see Table 1). Our new minima times were observed in the Ondřejov observatory with the 65-cm telescope. We used the Kwee & van Woerden (1956) method for all these minima. The mean linear light elements suitable for observations are

$$\text{Prim. Min.} = 2453923.9358 + 1.01600124 \cdot E, \qquad (1)$$

which were also used for deriving the proper epochs and types of the minima times written in Table 1.

If we plot these data points in the O−C diagram, the difference between primary and secondary minima is clearly visible. Following the method of apsidal motion analysis as described in Giménez & García-Pelayo (1983), we tried the computation with orbital inclination $i = 90°$ for the first time. After that we used for the second attempt the inclination $i = 87.88°$ (see Sect. 3), which resulted in almost the same parameters (owing to the term $\cot^2(i)$, which is nearly 0 for our inclination). In Fig. 1 we plot the final fit with the apsidal motion hypothesis on all used data points. This leads to the parameters of the motion of apsides given in Table 2. All uncertainties of the parameters were calculated from the covariance matrix of the fit and from the uncertainty of the inclination. Evidently the apsidal period is very short, about only 23 yr, which places this system among one those with the shortest apsidal motion.

2.2. V490 Cyg

The system V490 Cyg has much lower published times of minima observations. The first rough times-of-minima estimates are those by Wachmann (1948) from his photometry in the 1930's,

Table 1. New and recalculated CCD minima times of V456 Oph.

HJD - 2400000	Error	Type	Filter	Observer/Reference
48113.4210	0.003	Pri	*C*	Paschke, BBSAG 96
48113.42288	0.00108	Pri	*C*	Paschke – recalculated
52724.03387	0.0011	Pri	*V*	ASAS
52724.54831	0.0012	Sec	*V*	ASAS
53089.7944	0.0003	Pri	*V*	Sobotka–OMC, IBVS 5809
53089.79189	0.0012	Pri	*V*	OMC – recalculated
53091.8267	0.0004	Pri	*V*	Sobotka–OMC, IBVS 5809
53091.82625	0.00037	Pri	*V*	OMC – recalculated
53123.32379	0.00045	Pri	*V*	OMC
53188.86367	0.0044	Sec	*V*	ASAS
53305.70440	0.0042	Sec	*V*	OMC
53553.60602	0.0019	Sec	*V*	ASAS
53657.24154	0.00059	Sec	*V*	OMC
54099.69661	0.0034	Pri	*V*	ASAS
54099.19798	0.0028	Sec	*V*	ASAS
54232.79073	0.0009	Pri	*C*	Pi of the sky
54653.93939	0.0012	Sec	*V*	ASAS
54654.43230	0.0037	Pri	*V*	ASAS
54742.8314	0.0009	Pri	*V*	Zasche–OMC, IBVS 5931
54742.83119	0.00045	Pri	*V*	OMC – recalculated
54749.94329	0.00032	Pri	*V*	OMC
54766.7134	0.0012	Sec	*V*	Zasche–OMC, IBVS 5931
54766.71352	0.00032	Sec	*V*	OMC – recalculated
54769.7640	0.0011	Sec	*V*	Zasche-OMC, IBVS 5931
54769.76438	0.00066	Sec	*V*	OMC – recalculated
54930.29129	0.00056	Sec	*V*	OMC
55016.65047	0.0018	Sec	*V*	ASAS
55017.14834	0.0035	Pri	*V*	ASAS
55352.42998	0.00003	Pri	*R*	This paper
55356.49413	0.00004	Pri	*R*	This paper
55357.51014	0.00008	Pri	*R*	This paper
55379.36085	0.00005	Sec	*R*	This paper
55382.40909	0.00019	Sec	*R*	This paper

Table 2. The parameters of the apsidal motion fit for V456 Oph and V490 Cyg.

Parameter	V456 Oph	V490 Cyg
HJD_0	2453923.9358 (27)	2451491.5931 (51)
P [d]	1.01600124 (24)	1.14023698 (23)
P_a [d]	1.01612627 (25)	1.14042668 (23)
e	0.017 (9)	0.045 (15)
ω [deg]	351.1 (1.6)	342.42 (3.4)
$\dot{\omega}$ [deg/cycle]	0.044 (3)	0.060 (12)
U [yr]	22.6 (1.3)	18.8 (3.2)

but these have such a large scatter that they cannot be used for any reliable analysis. However, he also noticed that the secondary minimum is not symmetric with regards to the primary one. Nevertheless, a possible eccentricity and apsidal motion have never been studied since then. The more precise photoelectric and CCD observations have been measured since 1999, but there are only 12 published minima.

A few new CCD observations were obtained in the Ondřejov observatory with the same telescope as for V456 Oph, and two new minima times were also derived from the INTEGRAL/OMC data. The new measurements and the already published ones are presented in Table 3. The suitable linear ephemerides for observations are

$$\text{Prim. Min.} = 2451491.6075 + 1.14023698 \cdot E, \qquad (2)$$

$$\text{Sec. Min.} = 2451491.5802 + 1.14023698 \cdot E. \qquad (3)$$

The minima times presented in Table 3 were used for the period analysis, which we did by applying the apsidal motion hypothesis. The only difference in analysis between V490 Cyg and V456 Oph was the assumption of an inclination $i = 90°$ for V490 Cyg because we had no light curve analysis. The difference between primary and secondary is clearly visible, reaching up to 47 minutes, which is surprisingly high for a binary with

Table 3. New and already published minima times of V490 Cyg.

HJD - 2400000	Error	Type	Filter	Observer/Reference
51487.6184	0.0002	Sec	V	Caton – IBVS 5595
51491.5776	0.0004	Pri	V	Caton – IBVS 5745
51495.5994	0.0002	Sec	V	Caton – IBVS 5745
52612.43506	0.0047	Pri	V	Integral/OMC
52613.024	0.002	Sec	V	Sobotka – IBVS 5809
52813.7080	0.0002	Sec	V	Caton – IBVS 5595
52841.6237	0.0002	Pri	V	Caton – IBVS 5595
53256.6755	0.0001	Pri	C	Krajci – IBVS 5690
53260.6752	0.0003	Sec	C	Krajci – IBVS 5690
53660.3244	0.0005	Pri	I	Agerer – IBVS 5731
53660.331	0.0005	Pri	V	Diethelm – IBVS 5713
53913.46115	0.0002	Pri	R	This paper
53934.54462	0.0010	Sec	R	This paper
54335.35387	0.0013	Pri	R	This paper
54685.4130	0.0046	Pri	I	Agerer – IBVS 5889
54694.53781	0.0032	Pri	V	Integral/OMC
55096.4362	0.0004	Sec	I	Agerer – IBVS 5941
55376.3966	0.0002	Pri	R	This paper
55392.35998	0.0002	Pri	R	This paper
55405.44030	0.0002	Sec	R	This paper
55445.34892	0.0002	Sec	R	This paper
55462.45268	0.0002	Sec	R	This paper
55470.43426	0.0002	Sec	R	This paper
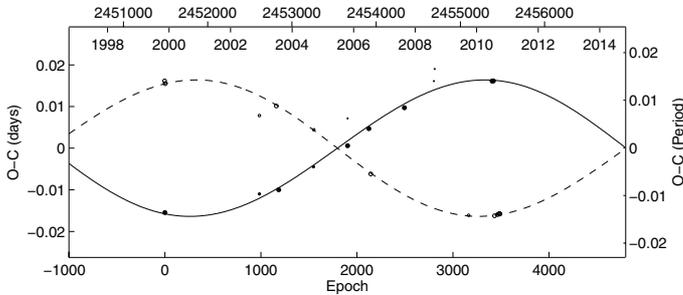
Fig. 2. O−C diagram of V490 Cyg. The lines represent the fit according to the apsidal motion hypothesis (see text and Table 2), the solid line stands for the primary, while the dashed line stands for the secondary minima, dots stand for the primary and open circles for the secondary minima.

such a short orbital period. The analysis led to the parameters of the apsidal motion presented in Table 2. Obviously the resulting value of the apsidal motion period of about 18.8 years is even shorter than for V456 Oph; we are therefore dealing with the shortest apsidal motion period known among the EEBs today.

3. Light curve analysis

The whole light curve of V456 Oph was observed with the OMC camera onboard the INTEGRAL satellite, a description of which is given in Mas – Hesse et al. (2004). The standard *V* filter was used, but the optical telescope has an aperture of only 5 cm in diameter. We obtained several hundred observations, of which we used 449 for the analysis.

The programme PHOEBE (ver. 0.29, Prša & Zwitter 2005), based on the Wilson-Devinney algorithm (Wilson & Devinney 1971) was used for the analysis. The "detached binary" mode (in Wilson & Devinney mode 2) was used with several assumptions. First, the ephemerides (HJD_0 and P) and the apsidal motion parameters (e, ω, and $\dot{\omega}$) were adopted from the period analysis, because the minima times cover a longer time span, therefore these quantities are derived with higher precision. Secondly, the mass ratio q and temperature of the primary component T_1 were set and the other relevant parameters were adjusted for the best fit. We changed the q and T_1 values in the wide range of values to obtain the best fit according to the rms value and also the
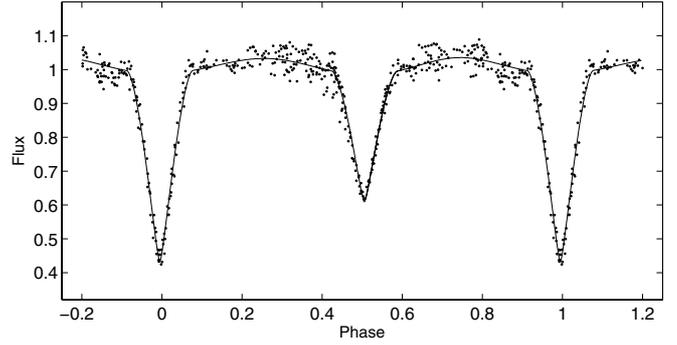

Fig. 3. PHOEBE light curve solution of V456 Oph based on the OMC data, the solid line represents our final solution (see the text and Table 4).

Table 4. The light curve parameters of V456 Oph.

Parameter	Value	Parameter	Value
T_1 [K]	6840	$L_1/(L_1 + L_2)$ (V)	$59 \pm 4\%$
T_2 [K]	6700 ± 430	$L_2/(L_1 + L_2)$ (V)	$41 \pm 3\%$
$q \, (= M_2/M_1)$	0.96 ± 0.15	F_1	1.097 ± 0.402
i [deg]	87.88 ± 0.81	F_2	0.843 ± 0.356
Ω_1	5.09 ± 0.32	x_1	0.505 ± 0.021
Ω_2	5.08 ± 0.29	x_2	0.504 ± 0.019
R_1/a	0.249 ± 0.05	R_2/a	0.247 ± 0.04

physical plausibility of the fit. This means during that the fitting process we scanned the parameter space in q ranging from 0.1 to 1.2 and in T_1 from 15 400 K to 6500 K.

We fitted the other light curve parameters, which are the luminosities L_1 and L_2 in the *V* filer, the temperature of the secondary T_2, the inclination i, the Kopal's modified potentials Ω_1 and Ω_2, the synchronicity parameters F_1 and F_2, the third light l_3. The limb-darkening coefficients were automatically interpolated by the PHOEBE programme from van Hamme's tables (see van Hamme 1993), using the linear cosine law for the values of $T_{\rm eff}$ and $\log g$ of both components resulting from the analysis. The values of the gravity brightening and bolometric albedo coefficients were set at their suggested values for convective atmospheres (see Lucy 1968), i.e. $G_1 = G_2 = 0.32$, $A_1 = A_2 = 0.5$.

The best fit was achieved with the light curve parameters given in Table 4, and the figure with the final fit is plotted in Fig. 3. Nonzero eccentricity is clearly visible from this plot, which is quite surprising in a binary with such a short orbital period. No other EEB with a shorter period is known today. The value of the third light is $l_3 = (0 \pm 4)\%$, which indicates that there is no other visible companion to the system in the *V* filter (under the assumption that this component is also located on the main sequence). We made several attempts with nonzero values of the third light, but these did not lead to a satisfactory solution.

Because there is no spectroscopic analysis, the precise physical parameters cannot be computed directly, but need to be roughly estimated with the assumption that both components are located on the main sequence. We derived the following values: $M_1 = 1.46 \, M_\odot$, $M_2 = 1.41 \, M_\odot$, $R_1 = 1.51 \, R_\odot$, $R_2 = 1.49 \, R_\odot$. These are only very preliminary values, but lead to spectral types of about F1 + F2 for the two components. We obtained roughly the same result (F0+F1) with the standard mass-luminosity relation for the main sequence stars (e.g. Malkov 2007), applying the luminosity ratio derived from the light curve analysis.

Table 5. The EEBs with the shortest apsidal motion period.

System	Spectr.	P [d]	e	U [yr]	Reference
V490 Cyg		1.1402	0.045	18.8	This paper
V381 Cas	B3	1.7459	0.0253	19.74	Wolf et al. (2010)
U Oph*	B5+B5	1.6773	0.00305	20.88	Vaz et al. (2007)
V456 Oph	?F1+F2?	1.0160	0.017	22.6	This paper
GL Car*	B0+B1	2.4222	0.146	25.2	Wolf et al. (2008)
V478 Cyg	B0+B0	2.8809	0.0158	27.1	Wolf et al. (2006)

Notes. * Triple system.

The parameters are very different from what one could expect for a main sequence star of spectral type A5 (Roman 1956), and the masses are also different from those estimated by Brancewicz & Dworak (1980), but the presented values provided the best light curve fit, and the parameters of the apsidal motion also agree well with the theoretical values (see below). The spectral type presented by Roman (1956) was only estimated on the basis of poor photographic spectra. On the other hand, there is also the *BVR* photometry in the NOMAD catalogue (Zacharias et al. 2004), from which $B - V = 0.279$ mag and $V - R = 0.165$ mag. These values indicate (Houdashelt et al. 2000) that the temperature of the system is about 6500 K, therefore of the spectral type about of F5.

4. Discussion

For the light curve analysis of the system V456 Oph the ephemerides and the apsidal motion parameters were fixed, but another approach could be to compute these parameters directly also from the light curve. The problem is that the data coverage for the light curve is rather fairly in time (about only 1/5 of the apsidal period), and the data for the light curve have relatively high scatter as well.

The eclipsing binaries, V456 Oph and V490 Cyg, with their respective apsidal motion periods of about only 20 years place these systems among a few unique ones with apsidal periods below 30 years (see Table 5).

Our next task was to derive the averaged internal structure constant as well and to compare it with the theoretical value. This task was done after subtraction of the relativistic term, which resulted for V456 Oph in the value $\dot\omega_{\rm rel} = 0.0011$ deg/cycle, about only 2.5% of the total apsidal motion rate. Therefore, the internal structure constant is

$$\log k_{2,\,\rm obs} = -2.44 \pm 0.20.$$

The surprisingly high value of the uncertainty is mainly caused by the error of the relative radii from the light curve analysis. We can compare this value with the stellar evolution grids (e.g. by Claret 2004) and the theoretical values of $k_{2,\rm theor}$. Using the value of $\log M = 0.1725$ ($M = 1.49\,M_\odot$), we obtained the value of

$$\log k_{2,\rm theor} = -2.41 \pm 0.05$$

for the main sequence star with an age between 0 and 1.5×10^9 yr. This could be interpreted as a rough estimation of maximum age for this system. No other eccentric eclipsing binary with such a late spectral type is known today. Therefore a detailed analysis of its spectra would be very welcome.

5. Conclusions

We performed the first detailed photometric and period analysis of the two eclipsing systems V456 Oph and V490 Cyg, which yielded the parameters of the apsidal motion with periods of about only 23 and 19 years. With the orbital period of V456 Oph of only about 1.016 days we are dealing with the shortest orbital period among the apsidal motion systems, while the period of apsidal motion of 18.8 years of V490 Cyg makes this system the shortest among the EEBs. However, because we lack a spectroscopic analysis, some of the physical parameters were only roughly estimated and apparently contradict each other. New times of minima observations as well as a detailed spectroscopic analysis are needed.

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