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

Received 8 September 2010 / Accepted 9 December 2010

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, $V_{\text{max}} = 9.95$ 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 that Guthnick & Prager (1936) incor-
rectly classified the star as a $\delta$ 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 ephemdris this classification is not very secure.

Although the first photoelectric light curve has been pub-
lished by Demircan et al. (1988), there was no light curve analy-
sis 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)


2. The period analysis

2.1. V456 Oph

The set of published times of minima for V456 Oph is quite ex-
tensive, covering more than 70 years. Regrettably, the old min-
ima 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 af-

"
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, Max – 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

\[
\text{Prim. Min.} = 2453923.9358 + 1.01660124 \cdot E, \tag{1}
\]

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 \(i = 90^\circ\) for the first time. After that we used for the second attempt the inclination \(i = 87.88^\circ\) (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, 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 a psidal 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

\[
\text{Prim. Min.} = 2451491.6075 + 1.14023698 \cdot E, \tag{2}
\]

\[
\text{Sec. Min.} = 2451491.5802 + 1.14023698 \cdot E. \tag{3}
\]

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 \(i = 90^\circ\) 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 1. New and recalculated CCD minima times of V456 Oph.

| \(HJD - 2400000\) | Error | Type | Filter | Observer/Reference |
|----------------|-------|------|-------|----------------------|
| 48113.4210 | 0.0005 | Pri | V | Paschke, IBVS 596 |
| 48113.4228 | 0.0010 | Pri | C | Paschke – recalculated |
| 52724.0338 | 0.0011 | Pri | V | ASAS |
| 52724.5831 | 0.0012 | Sec | V | ASAS |
| 53089.7944 | 0.0003 | Pri | V | Sobotka–OMC, IBVS 5809 |
| 53089.7913 | 0.0012 | Pri | V | OMC – recalculated |
| 53909.8267 | 0.0004 | Pri | V | Sobotka–OMC, IBVS 5809 |
| 53909.8262 | 0.0007 | Pri | V | OMC – recalculated |
| 53123.3237 | 0.0005 | Pri | V | OMC |
| 53188.8637 | 0.0044 | Sec | V | ASAS |
| 53305.0449 | 0.0042 | Sec | V | ASAS |
| 53533.6062 | 0.0019 | Sec | V | ASAS |
| 53637.2415 | 0.0005 | Sec | V | ASAS |
| 54099.6066 | 0.0034 | Pri | V | ASAS |
| 54099.1978 | 0.0028 | Sec | V | ASAS |
| 54232.7073 | 0.0009 | Pri | C | Pi of the sky |
| 54635.9393 | 0.0012 | Sec | V | ASAS |
| 54644.4230 | 0.0037 | Pri | V | ASAS |
| 54742.8314 | 0.0009 | Pri | V | Zasche–OMC, IBVS 5931 |
| 54742.8311 | 0.0004 | Pri | V | OMC – recalculated |
| 54749.9329 | 0.0002 | Pri | V | OMC |
| 54766.7134 | 0.0012 | Sec | V | Paschke–OMC, IBVS 5931 |
| 54766.7132 | 0.0003 | Sec | V | OMC – recalculated |
| 54769.7640 | 0.0011 | Sec | V | Zasche–OMC, IBVS 5931 |
| 54769.7643 | 0.0006 | Sec | V | OMC – recalculated |
| 54930.2912 | 0.0006 | Sec | V | OMC |
| 55016.6307 | 0.0018 | Sec | V | ASAS |
| 55017.1438 | 0.0035 | Pri | V | ASAS |
| 55352.4298 | 0.0003 | Pri | R | This paper |
| 55356.4491 | 0.0004 | Pri | R | This paper |
| 55357.5104 | 0.0008 | Pri | R | This paper |
| 55379.3608 | 0.0005 | Sec | R | This paper |
| 55382.4909 | 0.0019 | Sec | R | This paper |

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

| Parameter | V456 Oph | V490 Cyg |
|-----------|----------|----------|
| \(P\) [d] | 1.01660124 | 1.14023698 |
| \(e\) | 0.017 (9) | 0.045 (15) |
| \(\omega\) [deg] | 351.1 (1.6) | 342.42 (3.4) |
| \(\omega\) [deg/cycle] | 0.044 (3) | 0.060 (12) |
| \(U\) [yr] | 22.6 (1.3) | 18.8 (3.2) |
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  |
| 52612.4350   | 0.0007 | Pri  | V      | Integral/OMC       |
| 52613.024    | 0.0002 | 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      | Krajič – IBVS 5690 |
| 53260.6752   | 0.0003 | Sec  | C      | Krajič – IBVS 5690 |
| 53660.3244   | 0.0005 | Pri  | I      | Agerer – IBVS 5731 |
| 53660.331    | 0.0005 | Pri  | V      | Diehl – 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          |
| 55445.34992  | 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-Devlinney algorithm (Wilson & Devlinney 1971) was used for the analysis. The “detached binary” mode (in Wilson & Devlinney mode 2) was used with several assumptions. First, the ephemerides (HJD₀ and P) and the apsidal motion parameters (ε, ω, and ∆ω) 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 T₁ were set and the other relevant parameters were adjusted for the best fit. We changed the q and T₁ values in the wide range of values to obtain the best fit according to the rms value and also the physical plausibility of the fit. This means during that the fitting process we scanned the parameter space in a grid of (0.1 to 1.2) and in T₁ from 15 400 K to 6500 K.

We fitted the other light curve parameters, which are the luminosities L₁ and L₂ in the V filter, the temperature of the secondary T₂, the inclination i, the Kopal’s modified potentials Ω₁ and Ω₂, the synchronicity parameters F₁ and F₂, the third light l₃. 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 l₁, l₂, l₃, 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. G₁ = 1.0, A₁ = 0.32, and A₂ = 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 l₃ = (0±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: M₁ = 1.46 Mₜ, M₂ = 1.41 Mₜ, M₀₁R₁ = 1.51 Rₜ, M₂R₂ = 1.49 Rₜ. 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 (FO+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] | $M$ | $U$ [yr] | Reference                  |
|----------|---------|---------|-----|----------|----------------------------|
| V456 Oph | B3      | 1.1402  | 0.035 | 18.8     | This paper                 |
| V381 Cas | B3      | 1.749   | 0.0253 | 19.74    | Wolf et al. (2010)         |
| U Oph*   | B5+B5   | 1.6735  | 0.00305 | 20.88    | Vaz et al. (2007)          |
| V456 Oph | F5+F?   | 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.

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.

Acknowledgements. Based on data from the OMC Archive at LAEFF, pre-processed by ISDC. We thank the “ASAS” team and also the “Pi of the sky” team for making all of the observations easily public available. This work was supported by the Czech Science Foundation grant no. P209/10/7115 and also by the Research Programme MSM0021620860 of the Czech Ministry of Education. Mr. Anton Paschke is also acknowledged for sending us his photometric data and also Mr. Kamil Hornoch for the observational assistance. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France, and of NASA’s Astrophysics Data System Bibliographic Services.

References

Brancewicz, H. K., & Dworak, T. Z. 1980, AcA, 30, 501
Burd, A., Cwiok, M., Czykowski, H., et al. 2005, NewA, 10, 409
Caton, D. B., & Smith, A. B. 2005, IBVS, 5595, 1
Claret, A. 2004, A&A, 424, 919
Demircan, O., Derman, E., & Selam, S. 1988, IBVS, 3237, 1
Dietrich, R. 2006, IBVS, 5713, 1
Giménez, A., & García-Pelayo, J. M. 1983, Ap&SS, 92, 203
Giménez, A., & Bastero, M. 1995, Ap&SS, 226, 99
Guthnick, P., & Prager, R. 1936, AN, 260, 393
Hegedüs, T. 1988, BICDS, 35, 15
Hoffmeister, C. 1935, AN, 255, 401
Houdashelt, M. L., Bell, R. A., & Sweigart, A. V. 2000, AJ, 119, 1448
Hübischer, J., Paschke, A., & Walter, F. 2006, IBVS, 5731, 1
Hübischer, J., Steinbach, H.-M., & Walter, F. 2009, IBVS, 5889, 1
Hübischer, J., Lehmann, P. B., Monninger, G., Steinbach, H.-M., & Walter, F. 2010, IBVS, 5941, 1
Krajci, T. 2006, IBVS, 5690, 1
Kwee, K. K., & van Woerden, H. 1956, BAN, 12, 327
Lucy, L. B. 1968, ApJ, 151, 1123
Malkov, O. Y. 2007, MNARS, 382, 1073
Mas-Hesse, J. M., Giménez, A., Domingo, A., & the OMC team 2004, 5th INTEGRAL Workshop on the INTEGRAL Universe, 552, 729
Paschke, A. 1990, BBSAG, 96, 1
Pojmanski, G. 2002, AcA, 52, 397
Prša, A., & Zwitter, T. 2005, ApJ, 628, 426
Roman, N. G. 1956, ApJ, 123, 246
Smith, A. B., & Caton, D. B. 2007, IBVS, 5745, 1
Sobotka, P. 2007, IBVS, 5809, 1
Soydugan, E., Soydugan, F., Demircan, O., & Iبانoğlu, C. 2006, MNARS, 370, 2013
Svechnikov, M. A., & Kuznetsova, E. F. 1990, Sverdlovsk: Izd-vo Ural’skogo universiteta, 1990
Tassoul, J.-L., & Tassoul, M. 1992, ApJ, 395, 259
van Hamme, W. 1993, AJ, 106, 2096
Vaz, L. P. R., Andersen, J., & Claret, A. 2007, A&A, 469, 285
Wachmann, A. A. 1940, ANZi, 22, 10
Wachmann, A. A. 1948, AAAAN, 11, 5
Wilson, R. E., & Devinney, E. J. 1971, ApJ, 166, 605
Wolf, M., Kučákiová, H., Kolasa, M., et al. 2006, A&A, 456, 1077
Wolf, M., Zejda, M., & de Villiers, S. N. 2008, MNARS, 388, 1836
Wolf, M., Šmírler, L., Kučákiová, H., et al. 2010, New A, 15, 530
Zacharias, N., Monet, D. G., Levine, S. E., et al. 2004, BAAS, 36, 1418
Zasche, P. 2010, IBVS, 5931, 1