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V974 Cyg - A TRIPLE SYSTEM WITH APSIDAL MOTION

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The detached eclipsing binary V974 Cyg (GSC 2660.3690, P = 3.20 days) was selected as a target for a detailed study of apsidal motion due to its displaced secondary minimum, $\phi_{II} = 0.47$. We observed the star during 9 nights in 2007-10 at the Russian Academy of Sciences observatory near Moscow (Zvenigorod, UBV photometer, EMI 9789 photomultiplier), the Crimean observatory of Moscow University, Ukraine (Nauchny, CCD Ap-47p), the Crimean Astrophysical Observatory, Ukraine (Simeiz, CCD VersArray 512UV) and at Stará Lesná Observatory of the Astronomical Institute of the Slovak Academy of Sciences (UBVR photometer, R 2949S photomultiplier). Everywhere we used the same type telescopes - 60cm reflectors "Zeiss-600" and the standard Johnson UBV filters. The nearby star GSC 2660.3950 on the same frame as variable served as a comparison star both for CCD and photoelectric observations. GSC 2660.3723 ($V = 10^{m}.6$) and HD187072 served as a check stars for CCD and photoelectric observations respectively. Using the UBV magnitudes of HD186377 from SIMBAD data base, we derived the absolute magnitudes of the stars under investigation in Stará Lesná observatory, see Table 1. All observations were corrected for atmospheric extinction and transformed to standard Johnson UBV system.

Table 1. The photoelectric magnitudes of the stars

Star	V	$U-B$	$B-V$	remarks
HD186377	5.936(2)	0.191(8)	0.123(7)	HR 7502
HD187072	8.790(5)	0.109(22)	0.113(16)	check
GSC 2660.3950	10.249(7)	0.047(15)	0.384(8)	comparison
V974 Cyg	12.117(7)	0.194(11)	0.227(5)	variable, plato

The CCD-observations in V filter were the most suitable for the analysis of the light curve because of their largest number and highest precision. So we used them to derive the geometrical parameters of the system. As there are no effects of proximity in the light of the system between minima, we used a simple model of two spherical stars revolving in the elliptic orbit. The results are presented in Table 2 and in Fig. 1. B and U observations were used to determine the colours of the components only. We have found that the secondary component is a little bit bluer than the primary, $\Delta(B-V) = 0^{m}.012$. So the

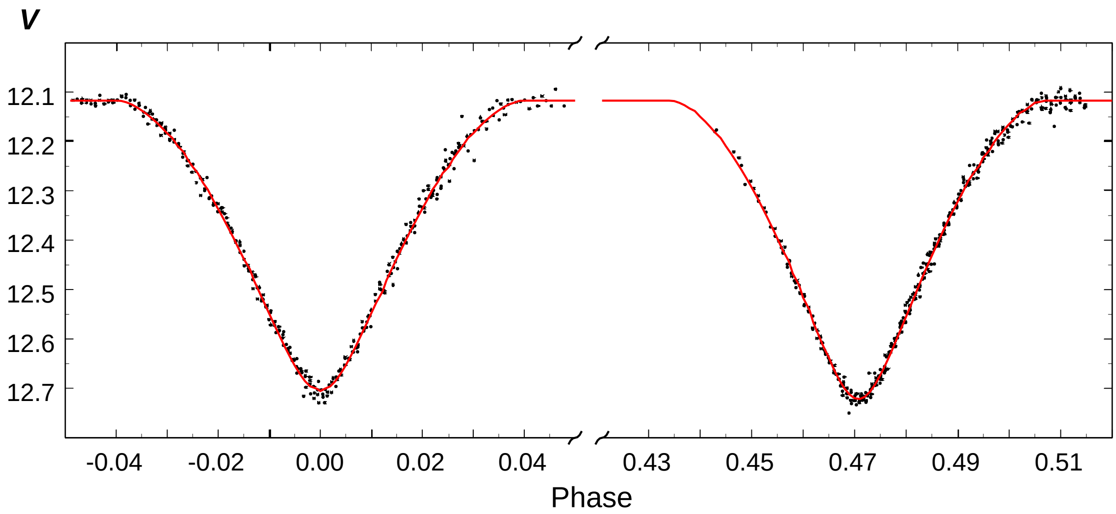

Figure 1. Part of the light curve of V974 Cyg in V filter near both minima. Points denote the individual CCD-observations, the line stands for the theoretical fit, according to parameters from Table. 2.

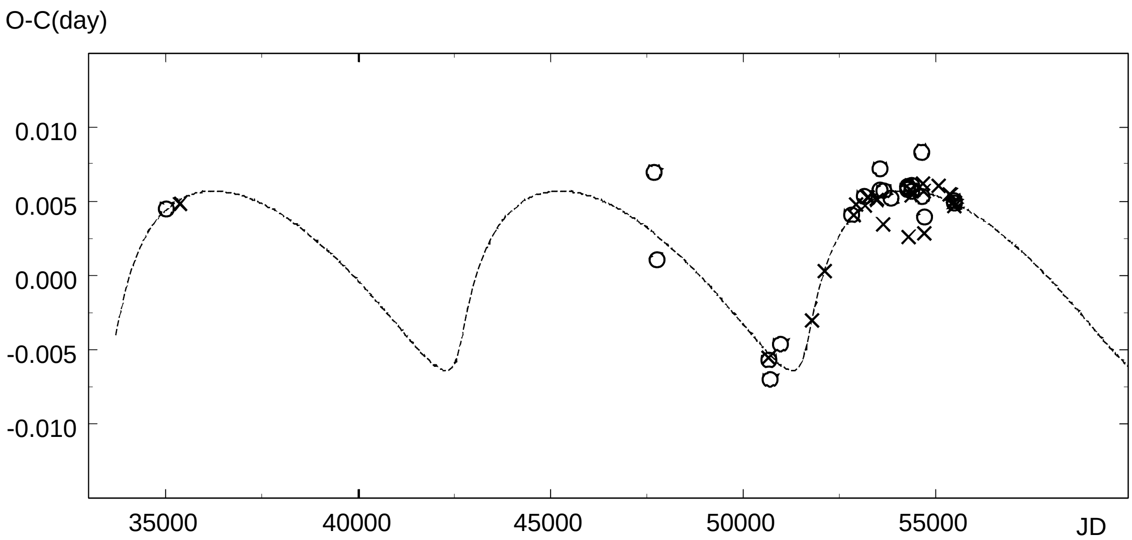

Figure 2. The deviations of minima times from the linear formulae given in this paper (O-C). Circles - primary minima, crosses - secondary ones

Table 2. Light curve solution of V974 Cyg

r_1	0.118 ± 0.002	L_{1V}	0.492 ± 0.020
r_2	0.120 ± 0.003	L_{2V}	0.508 ± 0.020
i	88.03 ± 0.02	$u_{1,2}$	0.49 *
e	0.061 ± 0.003	σ	$0\overset{m}{.}0121$
ω	220.8 ± 0.4		

* linear limb darkening coefficients, fixed from Wade and Rucinski (1985)

secondary component is almost 100K hotter than the primary one, Popper (1980). Our geometrical solution supports this conclusion as the radius of the secondary component was found to be a little bit larger, see Table 2. Therefore, the secondary component should be considered as a primary one. But to avoid confusion, we, in this article, leave all the same. The unreddened index $(B-V)_0$ of the star is enclosed in the interval from 0.02 to 0.16. We can not obtain this value more accurately until we get the spectra of the components. For our estimations we take the middle of this interval. Using Popper's (1980) calibration for $B-V$ we obtained the effective temperatures of the components. Then using empirical mass-luminosity relation and Kepler third law we estimated the absolute parameters of the components. The results are presented in Table 3.

Table 3. The absolute parameters of V974 Cyg

Parameter	Primary component	Secondary component
$M/M_\odot$	1.91 ± 0.11	1.95 ± 0.14
$R/R_\odot$	1.70 ± 0.05	1.72 ± 0.05
$\log L/L_\odot$	1.12 ± 0.09	1.16 ± 0.12
T_{eff}	8500 ± 300 K	8600 ± 300 K

Superimposing the synthetic light curve over the individual night observations by means of the least squares method we obtained nine new individual times of minima, see Table 4.

Table 4. Times of minima for V974 Cyg

HJD − 2,400,000	Eclipse Type	Cycle	Residual, (days)
54340.3335(9)	II	1145	+0.0001
54372.3773(3)	II	1155	−0.0003
54646.4445(2)	I	1241	−0.0003
54686.4103(13)	II	1253	+0.0001
54710.5313(14)	I	1261	−0.0016
55359.3373(2)	II	1463	+0.0004
55468.2868(1)	II	1497	−0.0000
55476.3869(3)	I	1500	+0.0002
55484.3087(3)	II	1502	−0.0002

Using our timings and all available data from literature - Wachmann (1961), Frank (1993), Caton and Smith (2005), Smith and Caton (2007), Lacy (2004, 2006, 2007, 2009), Hübscher et al. (2006), Diethelm (2008), Lampens et al. (2010), Brát et al. (2007, 2008) we have found that the $O-C$ diagram of V974 Cyg indicates the presence of the third body together with the rotation of the line of apsides. Because the photographic times of minima given by Wachmann are not so precise, we have averaged his data into one primary and one secondary minima. By the least squares method we found the elements of the third body orbit together with the velocity of the apsidal line rotation. We used formulae from Martynov (1973). Due to the apsidal line rotation the periods of primary and secondary minima differ:

$$\begin{aligned}\text{HJD Min I} &= 2{,}450{,}669.764(2) + 3.2044121(5) \cdot E,\\ \text{HJD Min II} &= 2{,}450{,}671.272(2) + 3.2044153(5) \cdot E\ .\end{aligned}$$

The parameters of the third body orbit are:

P_3 (period) $= 9000 \pm 100$ days, i.e. 24.6 years
T_0 (time of periastron) = J.D. 2442660 ± 80
A (semiamplitude) $= 0.0077 \pm 0.0002$ day
$e = 0.74 \pm 0.12$
$\omega = 327^\circ \pm 5^\circ$

Assuming a coplanar orbit ($i_3 = 90^\circ$) we can obtain an estimation about a lower limit of mass of the third component $M_{3,\rm min} = 0.4 M_\odot$. The observed rate of the apsidal motion: $\dot\omega_{obs} = 0^\circ.26(5)$ year^{-1}. Theoretical rate can be estimated from Levi-Civita (1937) equation for relativistic and Kopal (1978) for classical parts of the apsidal motion. Claret and Gimenez (1992) models for solar abundance and for the age $\simeq$ 500 million years, give the constants of internal structure as $k_{21} = k_{22} = 0.0042$. So we have: $\dot\omega_{theor} = \dot\omega_{rel} + \dot\omega_{class} = 0.07(3) + 0.15(2) = 0^\circ.22(4)$ year^{-1}. The two values are consistent within their respective errors.

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