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THE REVISION OF APSIDAL MOTION IN V541 Cyg: NO DISCREPANCY WITH THEORY

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The eclipsing binary V541 Cyg (GSC 2656.3703, $V_{\rm max} = 10^{\rm m}\!.35$, $P = 15^{\rm d}\!.34$) was discovered by Kulikowski (1953). It is a detached pair of nearly equal stars (B9.5 V + B9.5 V) with a highly eccentric orbit (e = 0.48). The light curve has two deep minima: Min I = $0^{\rm m}\!.728$, Min II = $0^{\rm m}\!.713$ V, the primary one being three times longer than the secondary one (DI = $0^{\rm P}\!.0480$, DII = $0^{\rm P}\!.0165$). The relativistic term should dominate in the apsidal advance of the orbit: $\dot\omega_{\rm rel}/\dot\omega_{\rm class} = 5.7$ – the highest rate among such systems.

Khaliullin (1985) was the first to obtain a photoelectric light curve and to calculate a photometric orbit of V541 Cyg. Using the photographic light curve published 20 years earlier by Karpowicz (1961), he also found the apsidal motion in the system not to be in conflict with the theory, though in wide error limits. Wolf (1995), Guinan et al. (1996) concluded from more numerous eclipse times that the observed rate of apsidal advance was significantly slower than that expected by theory. Lacy (1998) provided the first spectroscopic orbit and calculated, for the first time, the absolute properties of the system. His data yielded the theoretical rate of apsidal advance to be as:

$$\dot\omega_{\rm theor} = \dot\omega_{\rm rel} + \dot\omega_{\rm class} = 0^\circ\!.74 + 0^\circ\!.15 = 0^\circ\!.89 \pm 0^\circ\!.03/100\,{\rm yr}.$$

At the same time, Lacy calculated, from 8 photoelectric times of minima, the observed rate of the periastron advance to be: $\dot\omega_{\rm obs} = 0^\circ\!.60 \pm 0^\circ\!.1/100\,{\rm yr}$ – 67% of the predicted value. Having in mind the short (only 15 years) history of photoelectric observations of minima and their small number, one could not expect this value to be final. So we have continued observations of the star and reanalysed all timings of light minima available from literature in order to get a more accurate value of $\dot\omega_{\rm obs}$.

We observed the star in September–November 1998 at the Moscow (70-cm reflector) and at the Crimean (60-cm reflector) observatories of Moscow University with the help of UBV photometer (EMI 9789) constructed by I. M. Volkov. We used GSC 2656.4241 ($10^{\rm m}\!.0$ V, A2V) as the comparison star and GSC 2656.1627 ($9^{\rm m}\!.6$ V, F0V) as the check one. During one night we observed a secondary minimum and combining the observations of three nights we have reconstructed one primary minimum. All observations were obtained in V band, close to the standard Johnson's V system. We have got 589 individual points during 5 nights. The resulting light curve is represented in Figure 1. Every point in this plot represents the mean value of 2 or 3 individual points. Observations by Khaliullin (1985) were analysed along with our new data according to common procedure, and the

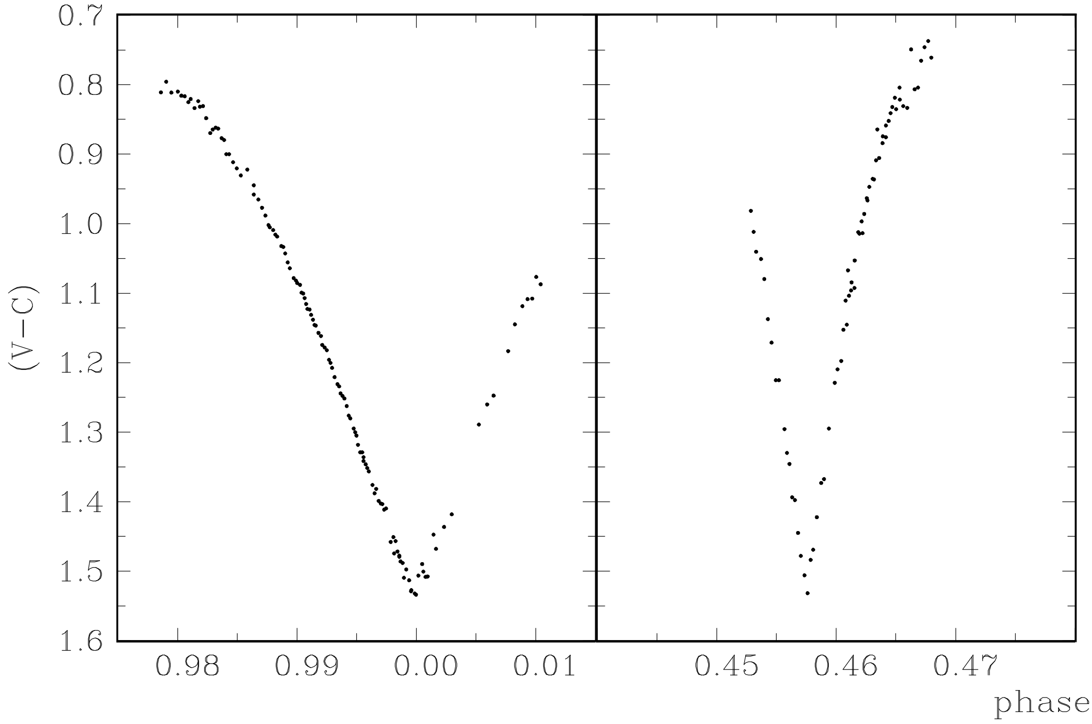

Figure 1. A plot of the V–band light curve.

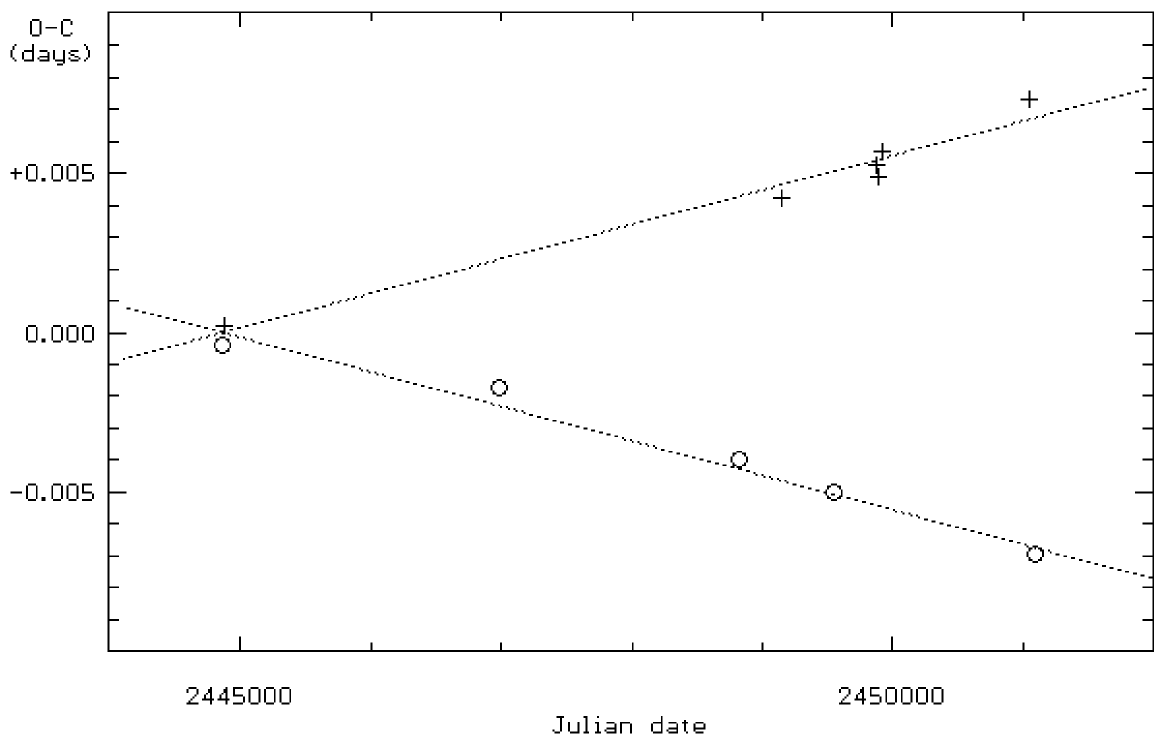

Figure 2. The residuals for the times of minima of V541 Cyg showing the difference of periods. The individual primary and secondary minima are denoted by circles and crosses respectively.

Table 1: Timings of light minima for V541 Cyg

$\mathrm{MinI}_\odot$ 24...	(O−C), d	Source
44882.2148	−0.00044	Khaliullin (1985)
44889.2196	+0.00021	Khaliullin (1985)
46998.8424	+0.00054	Lines et al. (1989)
49168.4951	−0.00040	Agerer (1994)
48839.3870	+0.00025	Diethelm (1992)
49560.2668	−0.00003	Lacy et al. (1995)
49889.3770	−0.00015	Wolf (1995)
49904.7145	−0.00055	Guinan et al. (1996)
49935.3911	+0.00023	Lacy et al. (1998)
51070.3967	+0.00065	present paper
51109.3918	−0.00032	present paper

resulting times of light minima are collected in Table 1. We put photoelectric timings by other authors in this Table too. We have checked all available data including old photographic and visual observations, but they happened to be of no use despite of great time gap between their epoch and the modern one. Moreover, we had to exclude some photoelectric timings with errors exceeding 5σ limit. We did not use observations by Diethelm (1995) – 11 CCD points in secondary minimum and Diethelm (1996) – 24 CCD points in primary minimum. Maybe the small number of observations resulted in the poor accuracy of these timings. So 5 primary and 6 secondary minima make up the resulting Table. Mean errors of individual moments are $\pm 0\overset{\mathrm{d}}{.}00040$ for primary minima and $\pm 0\overset{\mathrm{d}}{.}00045$ for secondary ones. Analysing these data with the least–squares method one can obtain the following ephemeris:

$$\mathrm{MinI}_\odot = \underset{\pm 2}{2444882.2152} + \underset{\pm 10}{15\overset{\mathrm{d}}{.}3378740} \times E,$$

$$\mathrm{MinII}_\odot = \underset{\pm 2}{2444889.2194} + \underset{\pm 11}{15\overset{\mathrm{d}}{.}3379072} \times E.$$

The difference of the two periods is illustrated by the graph in Figure 2, where circles designate primary minima and crosses, a secondary minima. This diagram is plotted with the mean period. The two periods differ by:

$$\Delta \mathrm{P} = \mathrm{PII} - \mathrm{PI} = \underset{\pm 20}{0\overset{\mathrm{d}}{.}0000332} = \underset{\pm 17}{2\overset{\mathrm{s}}{.}87}.$$

Using the traditional procedure and absolute parameters of V541 Cyg from Lacy (1998), we obtain: $\dot\omega_{\rm obs} = 0\overset{\circ}{.}86 \pm 0\overset{\circ}{.}05/100\,\mathrm{yr}$, or the period of apsidal rotation: $\mathrm{U} = 41675 \pm 2500$ years. Comparing this result with the theory, we see that there is no discrepancy between theory and observations within error limits:

$$\dot\omega_{\rm theor} = \underset{\pm 3}{0\overset{\circ}{.}89} \simeq \underset{\pm 5}{0\overset{\circ}{.}86} = \dot\omega_{\rm obs}.$$

We suggest, for subsequent investigations of the system, to use moments for Khaliullin (1985) data from our present paper, as here they were recalculated with better accuracy. We are ready to provide all our data including Khaliullin's old points via e-mail.

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