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Apsidal motion in BW Aqr

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Abstract. New photoelectric and CCD observations of minima times of the detached eccentric eclipsing binary BW Aqr extended the span of its precise minima times to forty years. We used them to determine the apsidal motion rate of the binary to be $\dot{\omega} = 0\overset{\circ}{.}062(3)\, yr^{-1}$.

Key words: eclipsing binary – apsidal motion

The eclipsing binary BW Aqr (BD $-16°6074$, F7+F8IV, $P = 6\overset{\mathrm{d}}{.}7, V = 10\overset{\mathrm{m}}{.}3, e = 0.18$) was discovered by Miss Leavitt in 1908 (Leavitt, Pickering 1908). Since that time only two apsidal motion rates determinations have been published by Khaliullin, Kozureva (1986): $\dot{\omega} = 0\overset{\circ}{.}070(8)\, yr^{-1}$ and Clausen (1991): $\dot{\omega} = 0\overset{\circ}{.}049(5)\, yr^{-1}$. Due to the fact that they were derived from photographic and a small number of photoelectric observations and significantly differ from each other, we decided to find the apsidal motion rate only from photoelectric and CCD data.

In 1987-1989 we obtained $WBVR$ photometry of the object with the 0.48-m telescope of the Sternberg Astronomical Institute at Tian-Shan Observatory and in 2008 $UBVR$ photometry with the 0.6-m telescope at Stará Lesná Observatory. The procedures of processing of the observations in order to obtain the geometric solution from our light curve and to get precise minima times are the same that we used in our earlier works Volkov, Volkova (2009) and Volkov *et al.* (2010). We treated similarly published photoelectric observations of Khaliullin, Kozureva (1986) and Diethelm (2013) data, reported to us as private communication. We obtained two mean minima times using the ASAS data (Pojmanski 2002). All minima times, determined with the precision higher than $\pm 0^d.0025$, are presented in Table 1. The minima times determined by Bulut (2009) from ASAS observations were not included, due to their lower precision. We have processed Hipparcos (Perryman et al. 1997) data by the same way as ASAS data, but due to a small number of observations, the precision of obtained mean minima times was lower than $\pm 0^d.003$, so we did not use them.

The minima times published by Bulut (2009) cast also doubts on reliability of his value of the BW Aqr apsidal motion rate, which was found to be very close to the value determined by Clausen (1991) 20 years earlier mainly from photographic data.

Table 1. The photoelectric and CCD minima times of BW Aqr.

JD_{hel} 2400000+	type	E	O-C	Remark
41830.8262(4)	I	-830	0.0001	Grønbech et al. (1987)
41988.5990(10)	II	-807	-0.0016	Grønbech et al. (1987)
44545.5846(2)	I	-426	-0.0002	Grønbech et al. (1987)
44851.1838(6)	II	-381	-0.0021	this work from Kh&K data
45607.2978(3)	I	-268	0.0005	this work from Kh&K data
46998.2746(2)	I	-61	-0.0006	this work
47391.2266(3)	II	-3	0.0003	this work
47408.1774(2)	I	0	0.0006	this work
47465.1431(2)	II	8	0.0003	this work
53603.7387(10)	I	922	-0.0012	this work from ASAS data
53660.6904(25)	II	930	-0.0008	this work from ASAS data
54712.4904(8)	I	1087	0.0001	this work
56227.6097(5)	II	1312	-0.0006	this work from Diethelm, 2013

As seen in Fig. 1, the weighted least squares solution of the data presented in Table 1 resulted to determination of:

$Min\ I\ = \ 2447408.1768(2)\ +\ 6^d.7196996(3) \times E,$

$Min\ II\ = 2447411.3853(3)\ +\ 6^d.7196837(5) \times E.$

The difference between P_1 and P_2 enables us to find, from a well-known relation (see equation (1) in Volkov, Khaliullin (2002)), the apsidal motion rate of BW Aqr as $\dot{\omega}_{obs} = 0\overset{\circ}{.}062(3)\, yr^{-1}$ ($U = 5800 \pm 280$ years).

The classical term of the apsidal motion rate, caused by the tidal and rotational distortion of the components, was found from the relations given by Sterne (1939) and Kopal (1978), assuming a synchronous axial rotation of the stars in periastron as $\dot{\omega}_{class} = 0\overset{\circ}{.}032(2)\, yr^{-1}$. To calculate this value, the constants of concentrations of the components $k_{2,1}\ =\ k_{2,2}\ = 0.0050$ were derived, interpolating the tables of Claret and Gimenez (1992) for solar abundances and masses given in Clausen (1991). The relativistic term of the apsidal motion rate was calculated using the formula of Levi-Civita (1937) as $\dot{\omega}_{rel} = 0\overset{\circ}{.}017(1)\, yr^{-1}$. The resulting value of apsidal motion rate is a simple sum of these contributions $\dot{\omega}_{theor} = \dot{\omega}_{class} + \dot{\omega}_{rel} = 0\overset{\circ}{.}049(2)\, yr^{-1}$.

Due to the fact that the masses of the components are known with high precision (Imbert 1987), the value of a relativistic term cannot be changed. It means that the observed classical term has to be equal to $\dot{\omega}_{class} = 0\overset{\circ}{.}045(3)\, yr^{-1}$. We have to find the reason of an apsidal motion rate acceleration. The fast axial rotation of the components can be excluded, because Clausen (1991) declared that their rotational velocities are below the synchronous values. The possibility that the stars are less centrally condensed than predicted by evolutionary models could be a challenge to the theory. The tertiary component on a close orbit could also speed up the apsidal motion rate. Small nonlinearities in the $O-C$ diagram seem to support such solution. Future photometric and spectroscopic monitoring of BW Aqr could help to resolve the problem.

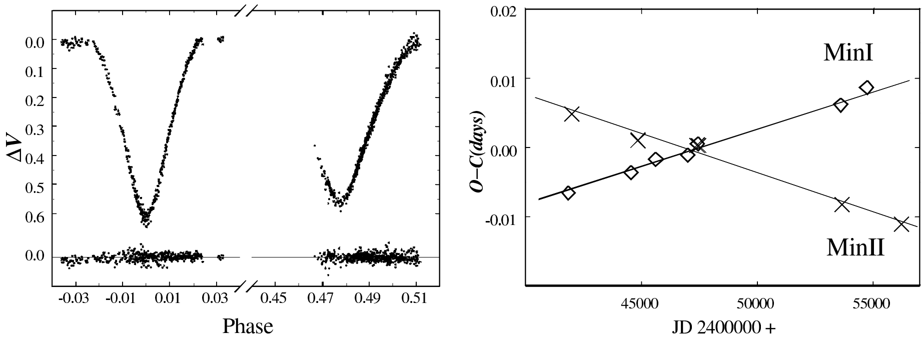

Figure 1. The observations of BW Aqr in minima and residuals from the best fit solution (left). The solution is close to Clausen (1991) and is not presented here. The $O - C$ diagram, constructed with the mean period for the data from Table 1, demonstrates the apsidal motion rate (right).

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