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Period studies and photometric models for two EB-type binaries EU Hya and AW Vul

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Abstract New photometry for two Algol-type binaries, EU Hya ($P = 0.7782$ d) and AW Vul ($P = 0.8065$ d), was carried out using the 60-cm telescope at Xinglong station of National Astronomical Observatories, Chinese Academy of Sciences. With the updated Wilson-Devinney code, photometric elements were derived from the multi-color light curves. The modeled results indicate that the two systems are near-contact binaries, whose secondary components fill their Roche lobes. The fill-out factors of the primaries are $f_{\rm p} = 81.2\,(\pm0.2)\%$ for EU Hya and $f_{\rm p} = 82.4\,(\pm0.3)\%$ for AW Vul. Period analysis implies that there exists a downward parabola with a light-time orbit from the $(O-C)$ curve. This kind of periodic oscillation may be attributed to the light-time orbit effect of a third companion. The long-term period decrease may be caused by mass and angular momentum loss. When the orbital period decreases, the fill-out factor of $f_{\rm p}$ will increase. Our results indicate that the primaries will also eventually fill their Roche lobes. EU Hya and AW Vul may possibly evolve from semi-detached binaries into contact ones.

Key words: eclipsing binaries — stars: individual (EU Hya and AW Vul) — the third companion

1 INTRODUCTION

EU Hya (=BD $-6.2694°$) was photographically discovered by Hoffmeister (1931). The magnitude at maximum brightness and the depth of primary minimum of this binary are 10.1 mag and 0.7 mag (Malkov et al. 2006), respectively. Wood et al. (1980) identified its spectral type as F6, which was updated to be F2 (Rao et al. 1996). Kordylevesky (1947, 1948, 1951, 1953, 1958) published some visual primary eclipses. Based on 20 visual or plate light minimum times, Busch & Haussler (1972) determined an ephemeris, i.e., Min.I $=$ HJD $2438359.786 + 0.778212 \times E$. The orbital period of EU Hya was subsequently updated to be 0.7782075 d (Kulkarni 1979), 0.77820650 d (Gu et al. 1993) and 0.77820666 d (Kreiner et al. 2001). Photoelectric observations of EU Hya were carried out by Kulkarni (1979) and Gu et al. (1993), who concluded that EU Hya is a detached binary with $q_{\rm ph} = 0.205$ from the light curves (LCs) in B and V bands. However, Rao et al. (1996) reanalyzed Kulkarni (1979)'s data and obtained a semi-detached configuration with a mass ratio of $q_{\rm ph} = 0.212$. The orbital period changes were suggested by Gu (1994), who obtained a quadratic ephemeris with period decreasing at a rate of $dP/dt = -1.54 \times 10^{-7}$ d yr^{-1}. Moreover, Qian & Boonrucksar (2003) pointed out that its $(O-C)$ curve is described by a downward parabola with a sinusoidal curve. The orbital period decreases at a rate of $\frac{dP}{dt} = -4.8 \times 10^{-8}$ d yr^{-1}. The period and amplitude for the cyclic variation are $T = 26.5$ yr and $A = 0.0104$ d, respectively.

Another variable star, AW Vul (=AN 314.1930), was found by Hoffmeister (1930). Its spectral type is F0+K1IV (Hoffman et al. 2006). The color index is $B - V = -0.8$ and its visual magnitude ranges from 10.8 mag to 11.9 mag (Malkov et al. 2006). Whitney (1955) refined its period to 0.80645 d, which was also later revised to be 0.80645138 d (Kreiner et al. 2001). Based on 24 times of light minima, Wood & Forbes (1963) derived a quadratic ephemeris with a period decrease rate of $\frac{dP}{dt} = -2.42 \times 10^{-7}$d yr^{-1}. Sasselov (1982) published the visual LC, while Schmidt & Reiswig (1993) obtained several CCD observations. Kaitchuck et al. (1985) spectroscopically observed this binary in the H_β-H_γ region in order to detect the emission lines radiated by a transient disk. AW Vul is listed in the catalog of Algols (Budding et al. 2004) as a possible triple system (Hoffman et al. 2006). Liakos et al. (2011) obtained complete $BVRI$ LCs. The photometric solution shows that AW Vul is a semi-detached binary with $q_{\rm ph} = 0.55\,(\pm0.01)$. Based mostly on visual minima, they obtained a light-time orbit from the $(O-C)$ curve, whose period and eccentricity are $P_3 = 38\,(\pm1)$ yr and $e_3 = 0.7\,(\pm0.1)$, respectively.

In this paper, we present new multi-color observations for two EB-type binaries EU Hya and AW Vul in Section 2. Based on all eclipsing times, orbital period studies are preformed in Section 3. In Section 4, we update photometric solutions from our light curves. In the last section, we discuss their possible evolutionary states and give the interpretations of period variations for two systems.

2 OBSERVATIONS

CCD photometry of two binaries, EU Hya and AW Vul, was acquired from 2009 to 2011, with the 60-cm telescope (Yang & Wei 2009) at the Xinglong station (XLS) of National Astronomical Observatories, Chinese Academy of Sciences (NAOC). A set of standard Johnson-Cousins $UBVRI$ filters was mounted in this telescope. The image reduction was made using the IMRED and APPHOT packages of IRAF in a standard way. All individual observations in BVR bands, as HJD versus Δm, are available on request.

EU Hya was photometrically observed from 2012 January 20 to April 2. In total, we obtained 524 effective images in B, 501 in V and 495 in R bands. The comparison and check stars were TYC 4875-1477-1 and TYC 4875-0950-1 respectively. We adopted exposure times of 70 s, 60 s and 30 s for BVR bands, respectively. The scatters of individual data are better than 0.01 mag in each band. BVR LCs are displayed in the left panel of Figure 1 as magnitude differences vs. phases, in which phases are calculated by Kreiner et al. (2001) with a period of $P = 0.78488636$ d. The secondary eclipse is brighter than the primary one by up to 0.48 mag in B, 0.47 mag in V and 0.46 mag in R bands.

The photometry of AW Vul was acquired on 2009 September 20, October 20, 23 and 24, and November 18 and 27. The comparison and check stars were HD 340421 and HD 340423, respectively. For BVR bands, the exposure times were 50 s, 40 s and 30 s respectively, which depended on weather conditions. A total of 474, 468 and 468 images in B, V and R bands was obtained respectively. The BVR LCs are shown in the right panel of Figure 1, in which the phases were computed by Kreiner et al. (2001) with a period of 0.80645138 d. The shape of the LCs is typical of the β Lyrae-type. The amplitudes of variable light are 1.17, 1.05 and 0.94 mag for B, V and R bands respectively. Photometric standard deviations for BVR bands are ±0.008 mag, ±0.007 mag and ±0.006 mag, respectively.

Table 1 New Eclipsing Times for EU Hya and AW Vul

Star	HJD	Error	Min.	Band
AW Vul	2455097.14380	±0.00087	II	B
	2455097.14487	±0.00072	II	V
	2455097.14449	±0.00058	II	R
	2455126.98376	±0.00113	II	B
	2455126.98255	±0.00069	II	V
	2455126.98119	±0.00075	II	R
	2455153.99700	±0.00020	I	B
	2455153.99695	±0.00020	I	V
	2455153.99680	±0.00019	I	R
EU Hya	2455947.26761	±0.00024	I	B
	2455947.26762	±0.00019	I	V
	2455947.26742	±0.00025	I	R
	2456018.08563	±0.00030	II	B
	2456018.08547	±0.00026	II	V
	2456018.08551	±0.00031	II	R

Table 2 All Collected Eclipsing Times for EU Hya

HJD	Epoch	Method	Min	$(O-C)_i$ (d)	$(O-C)_f$ (d)	Ref.
2430470.310	−22941.0	vi	I	−0.0235	−0.0010	[1]
2434126.336	−18243.0	vi	I	−0.0124	+0.0040	[1]
2435862.497	−16012.0	p	I	−0.0305	−0.0079	[1]
2435876.525	−15994.0	p	I	−0.0102	+0.0125	[1]
2437403.351	−14032.0	p	I	−0.0256	−0.0073	[1]
2437669.503	−13690.0	p	I	−0.0203	−0.0044	[1]
...	...	...	...	...	...	...
2455627.4243	+9386.0	CCD	I	+0.0041	+0.0015	[28]
2455640.6550	+9403.0	CCD	I	+0.0053	+0.0027	[29]
2455882.6741	+9714.0	CCD	I	+0.0021	+0.0010	[28]
2455947.2676	+9797.0	CCD	I	+0.0045	+0.0039	[30]
2455978.0007	+9836.5	CCD	II	−0.0016	−0.0020	[31]
2456018.0855	+9888.0	CCD	I	+0.0055	+0.0053	[30]

Notes: The complete table is only listed on *http://www.raa-journal.org /docs/Supp/ms2598table2.pdf*. References: [1] Busch & Haussler 1972; ...; [28] Brno 2014; [29] Diethelm 2011; [30] Present work; [31] Nagai 2014.

3 POSSIBLE PERIOD VARIATIONS

From our data, several eclipsing times for two variables were determined by using a quadratic curve fitting method. Table 1 lists the individual data and their errors. For AW Vul and EU Hya, we collected all available times of light minima, which were used to construct the $(O-C)$ curves. Although "vi" and "pg" data have low accuracy, discarding them would cause a total loss of information about period variations. Therefore, all data were used to construct the $(O-C)$ curves. For the various measurement methods, we applied weights 1 and 10 to "p", "vi" and "pg" measurements, as well as "pe" and "CCD" ones, which is similar to the previously studied binary UU Leo (Yang 2013).

3.1 EU Hya

The period variations of EU Hya were investigated by Gu (1994) and Qian & Boonrucksar (2003). The latter derived a quadratic ephemeris with a 26.5-year cyclic oscillation from 39 eclipsing times before 2001. Therefore, we reanalyzed its period variations based on all available eclipsing times (i.e., 12 plate, 21 visual, 13 pe and 21 CCD ones).

Table 2 lists 67 compiled data, covering the time from 1942 to 2012. By using Kreiner et al. (2001)'s ephemeris,

$$\text{Min. I} = \text{HJD } 2448323.1725 + 0.77820666\,\text{d} \times E\,, \quad (1)$$

the observed values minus the calculated ones, $(O-C)_i$, are given in Table 2, and are shown in the upper panel of Figure 2.

The $(O-C)_i$ curve for EU Hya may be presumably fitted by a quadratic curve with a light-time orbit (Irwin

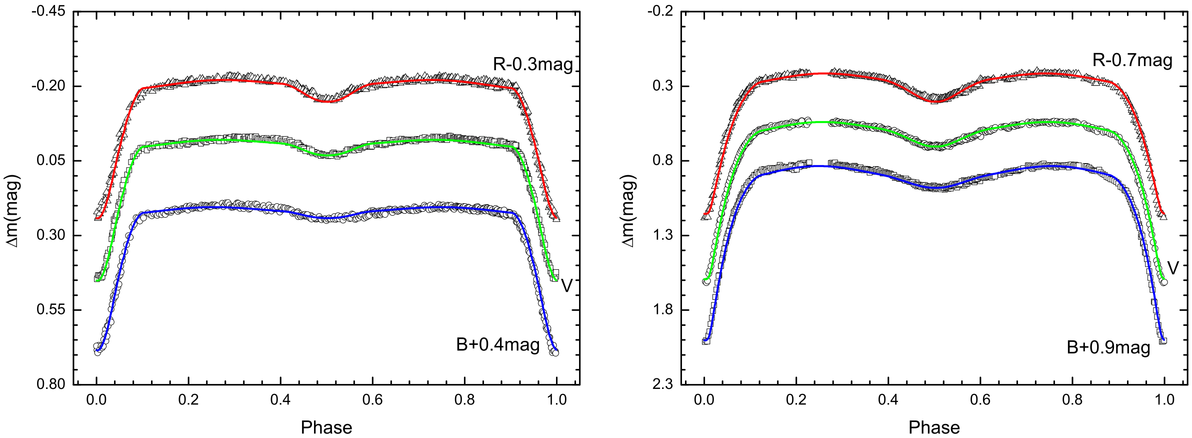

Fig. 1 BVR light curves for EU Hya (*left*) and AW Vul (*right*), which were obtained from 2009 Autumn to 2012 Summer using the 60-cm telescope at XLS of NAOC.

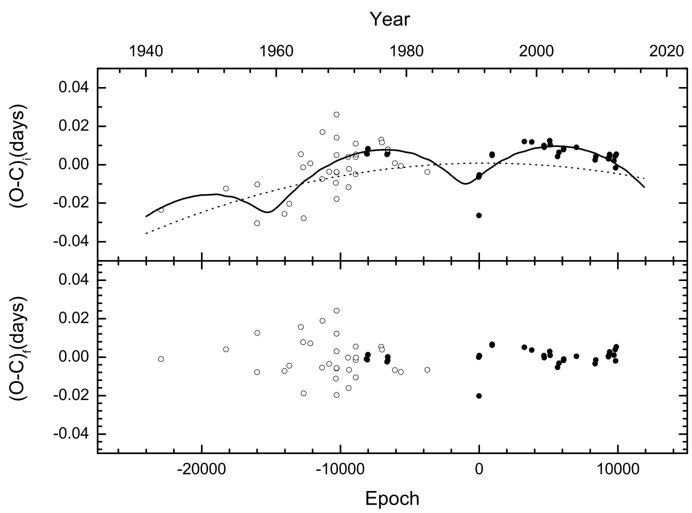

Fig. 2 Residuals of $(O - C)_i$ (*upper*) and $(O - C)_f$ (*lower*) for EU Hya. The open circles represent p, vi and pg data, while the filled circles refer to pe and CCD ones. Equation (2) and its quadratic part are plotted by the solid and dotted lines, respectively.

1952). Therefore, the final ephemeris formula is given as follows,

$$\text{Min.I} = T_0 + PE + QE^2 + \tau\,, \tag{2}$$

and

$$\tau = \frac{a_{12}}{c} \times \left[\frac{1-e^2}{1+e\cos\nu}\sin(\nu+\omega) + e\sin\omega\right], \tag{3}$$

whose parameters for the light-time orbit are adopted from Irwin (1952). Using the Levenberg-Marquardt technique (Press et al. 1992), we simultaneously derived the fitted parameters, which are tabulated in Table 3. The final residuals of $(O - C)_f$ are given in Table 2, and plotted in the lower panel of Figure 2. The solid and dotted lines represent Equation (2) and only its quadratic part, respectively. Although large scatter exists in some low-precision data, the curve of residuals was fitted well and no regularity is apparent. From the fitted parameters of Table 3, a continuous period decrease rate and modulated period are determined to be $dP/dt = -5.73\,(\pm0.60) \times 10^{-8}\mathrm{d\,yr^{-1}}$ and $P_3 = 30.1\,(\pm0.3)$ yr respectively, which are larger than the previous result of Qian & Boonrucksar (2003).

3.2 AW Vul

For another variable star AW Vul, Liakos et al. (2011) recently proposed a light-time effect with a modulated period of $38\,(\pm1)$ yr from 253 eclipsing times. After we checked the catalog of light minimum times (Kreiner et al. 2001), the number of light minima should be 242. A total of 10 p, 197 vi, 1 pg, 1 pe and 33 CCD observations are listed in Table 4. With Kreiner et al. (2001)'s ephemeris,

$$\text{Min.I} = \text{HJD}\ 2446285.4653 + 0.80645138\,\text{d} \times E\,, \tag{4}$$

we easily calculated the residuals of $(O - C)_i$, which are also given in Table 4. The corresponding curve is shown in the upper panel of Figure 3. A trend of the orbital period secularly decreasing may be reasonable for the semi-detached binary. After some iterations, we can yield the fitted parameters of Equation (2), which are tabulated in

Table 3 Fitted Parameters of Equations (2) and (3) for EU Hya and AW Vul

Parameter	EU Hya	AW Vul
T_0 (HJD)	2448323.1733 (±0.0007)	2446285.4656 (±0.0004)
P (d)	0.77820672 (±0.0005)	0.8064582 (±0.00000003)
Q (d)	$6.10\,(\pm 0.64) \times 10^{-11}$	$-2.18\,(\pm 0.36) \times 10^{-11}$
P_3 (yr)	30.1 (±0.3)	36.3 (±1.0)
$A = a_{12}/c$ (d)	0.0106 (±0.0007)	0.0056 (±0.0005)
e	0.595 (±0.014)	0.296 (±0.033)
ω (arc)	4.613 (±0.076)	2.583 (±0.124)
$H_{\rm p}$ (HJD)	2447512 (±90)	2451758 (±370)

Table 4 The Collected Minima of Light for AW Vul

HJD	Epoch	Method	Min	$(O-C)_i$ (d)	$(O-C)_f$ (d)	Ref.
2426319.340	−24758.0	vi	I	−0.0020	−0.0041	[1]
2426485.471	−24552.0	vi	I	+0.0000	−0.0014	[1]
2426506.445	−24526.0	vi	I	+0.0062	+0.0048	[1]
2426510.473	−24521.0	vi	I	+0.0020	+0.0006	[1]
2426531.438	−24495.0	vi	I	−0.0007	−0.0020	[1]
2426556.441	−24464.0	vi	I	+0.0023	+0.0011	[2]
...	...	...	...	...	...	...
2455394.3186	+11295.0	CCD	I	−0.0150	−0.0009	[94]
2455473.3508	+11393.0	CCD	I	−0.0151	−0.0009	[96]
2455791.4992	+11787.5	pe	II	−0.0117	+0.0030	[97]
2455819.3192	+11822.0	CCD	I	−0.0143	+0.0004	[97]
2455828.9970	+11834.0	CCD	I	−0.0139	+0.0008	[98]
2456563.6713	+12745.0	CCD	I	−0.0168	−0.0013	[99]

Notes: The entire table is only listed on *http://www.raa-journal.org/docs/Supp/ms2598table4.pdf*. References: [1] Pagaczewski 1934; [2] Tsesevitch 1954; .... [94] Liakos & Niarchos 2010; [95] Hubscher & Monninger 2011; [96] Hübscher 2011; [97] Hübscher & Peter 2012; [98] Nagai 2012; [99] Samolyk 2013.

Table 3. The final residuals $(O-C)_f$ in Table 4 are shown in the lower panel of Figure 3. A long-term period decrease rate is $dP/dt = -1.92\,(\pm 0.33) \times 10^{-8}$ d yr^{-1}. The modulated period of $P_3 = 36.3\,(\pm 1.0)$ yr from Equation (3) is a little smaller than the previous result of $P_3 = 38\,(\pm 1)$ yr (Liakos et al. 2011).

4 REVISED PHOTOMETRIC ELEMENTS

Multi-color LCs of EU Hya and AW Vul were both modeled by using an updated version of the Wilson-Devinney code (Wilson & Devinney 1971, Wilson 1990). The stellar atmosphere model was applied (Kurucz 1993). Due to lack of values for $q_{\rm sp}$ (i.e., spectroscopic mass ratio), a "q-search" process was performed to search for a reliable mass ratio. The same values for fixed parameters (i.e., g, A, x and y) were adopted as those for the previously studied binary UU Leo (Yang 2013). During the process of solving for the LCs, other parameters of i, q, T_2, Ω_1 and L_1 were adjustable.

4.1 EU Hya

Kulkarni (1979) and Gu (1994) concluded that EU Hya is a detached binary. However, Rao et al. (1996) suggested that it is a semi-detached one. To resolve these inconsistencies, more analysis is needed to obtain a new photometric solution from BVR observations. The mean effective temperature of the more massive component was fixed to $T_1 = 6900$ K from the spectral type F2V (Rao et al. 1996). Our analysis indicates that EU Hya is an Algol-type binary. The resulting curve of $\Sigma - q$ is displayed in the left panel of Figure 4. A minimum value for Σ is found at $q = 0.14$. When the free parameters are extended to include q, the final photometric solution is obtained and is listed in Table 5. The left panel of Figure 1 displays the computed LCs as solid lines. The fill-out factor is $f_{\rm p} = 81.2\,(\pm 0.2)\%$. The mass ratio of $q_{\rm ph} = 0.137\,(\pm 0.002)$ is a little smaller than the previous results of 0.205 (Gu et al. 1993) and 0.212 (Rao et al. 1996), which may result from normalized variations in LCs.

4.2 AW Vul

For AW Vul, the mean effective temperature was adopted as $T_1 = 7300$ K from the spectral type F0 (Liakos et al. 2011). New BVR LCs in the right panel of Figure 1 were simultaneously analyzed. A series of attempted solutions were obtained for some fixed mass ratios from $q = 0.3$ to 1.0 with an interval of 0.05. The result indicates that AW Vul is an Algol-type binary. The associated q-Σ curve is shown in the right panel of Figure 4, in which a mini-

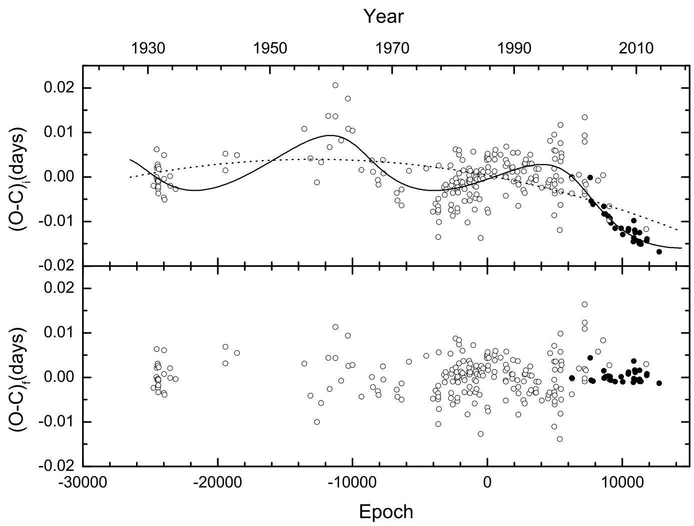

Fig. 3 Residuals of $(O-C)_i$ (*upper*) and $(O-C)_f$ (*lower*) for AW Vul. Other symbols are the same as in Figure 2.

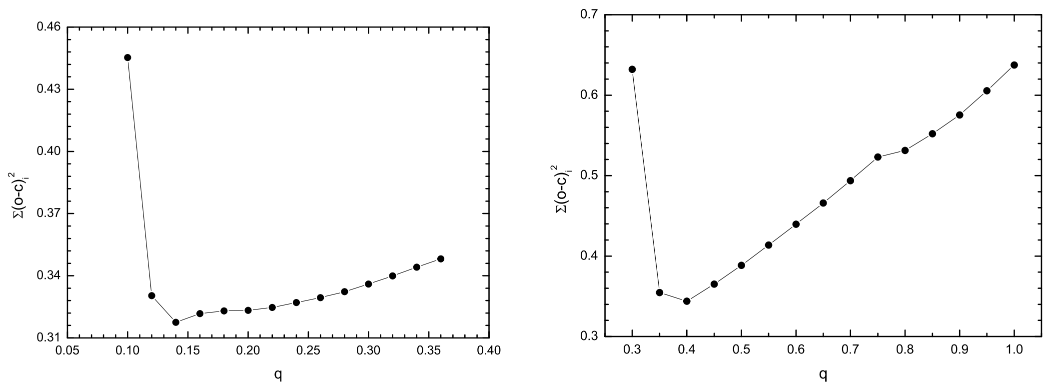

Fig. 4 The derived curves of $\sum(q)$ for EU Hya (*left*) and AW Vul (*right*) from BVR light curves.

mum of $\Sigma(O-C)_i^2 = 0.2576$ is given at $q = 0.4$. At this point, the adjustable parameters were then expanded to include q and the third light of $l_3 = L_3/(L_1 + L_2 + L_3)$. The final photometric solution is obtained and listed in Table 5. The computed LCs from the photometric solution are shown in the right panel of Figure 1 as solid lines. The mass ratio of $q_{\rm ph} = 0.418\,(\pm 0.005)$ is smaller than the value of $0.55\,(\pm 0.01)$ (Liakos et al. 2011). The fill-out factor of the primary component is $f_1 = 82.4\,(\pm 0.3)\%$. The weak contributions of the third light to the total light are $l_{3B} = 0.41\,(\pm 0.07)\%$, $l_{3V} = 0.62\,(\pm 0.07)\%$ and $l_{3R} = 0.86\,(\pm 0.06)\%$, which are much smaller than the value of $\sim 3\%$ obtained by (Liakos et al. 2011).

5 DISCUSSION

From the previous LC models, we updated the photometric elements for EU Hya and AW Vul. Because of the lack of published spectroscopic solutions, the absolute parameters of these binaries cannot be obtained directly. From the table of Harmanec (1988), the mass and its error for the primary component are approximately estimated from the spectral type with an uncertainty of less than one spectral subclass. Combining the photometric solution, other parameters are also determined and listed in Table 6. The more massive components in the two binaries are shown in the Hertzsprung-Russell diagram in Figure 5, in which the zero age main sequence (ZAMS), terminal age main sequence (TAMS) and evolutionary tracks for solar chemical compositions are adopted from Girardi et al. (2000). The primaries for AW Vul and EU Hya are located between the ZAMS and TAMS lines, indicating that the higher luminosities and temperatures for their masses may result from energy transfer from the secondaries.

For Figures 2 and 3, a quadratic curve with a light-time orbit may exist in both $(O-C)$ curves. This case may occur in many other near-contact binaries, such as ZZ Cyg (Yang et al. 2015), AV Hya, DZ Cas (Yang et al. 2012), UU Lyn (Zhu et al. 2007), TV Cas (Hoffman et al. 2006), HL Aur (Qian et al. 2006), RU UMi (Zhu et al. 2006), and RZ Dra (Erdem et al. 2011). Applegate (1992)'s mechanism may be the origin of the cyclic changes in the $O-C$ diagram, which is based on binary systems with spectral types of the secondaries later than F5 (Hall 1989). However, this conclusion was ruled out by Liao & Qian (2010), who showed that the percentage of cyclic changes is similar for

Table 5 Updated Photometric Elements for EU Hya and AW Vul

Parameter	EU Hya	AW Vul
$q = M_2/M_1$	$0.137\,(\pm 0.002)$	$0.418\,(\pm 0.005)$
$i\,(^\circ)$	$79.8\,(\pm 0.3)$	$87.0\,(\pm 0.3)$
T_1(K)	6900	7300
Ω_1	$2.8782\,(\pm 0.0092)$	$3.1836\,(\pm 0.0084)$
$X_1,\ Y_1$	$+0.644,\ +0.248$	$+0.645,\ +0.258$
$x_{1B},\ y_{1B}$	$+0.787,\ +0.284$	$+0.772,\ +0.311$
$x_{1V},\ y_{1V}$	$+0.691,\ +0.292$	$+0.677,\ +0.300$
$x_{1R},\ y_{1R}$	$+0.597,\ +0.288$	$+0.581,\ +0.293$
T_2(K)	$4150\,(\pm 18)$	$4564\,(\pm 10)$
$\Omega_2 = \Omega_{in}$	2.0673	2.7146
$X_2,\ Y_2$	$+0.572,\ +0.245$	$+0.627,\ +0.156$
$x_{2B},\ y_{2B}$	$+0.825,\ +0.090$	$+0.837,\ -0.120$
$x_{2V},\ y_{2V}$	$+0.782,\ +0.201$	$+0.794,\ +0.033$
$x_{2R},\ y_{2R}$	$+0.727,\ +0.276$	$+0.727,\ +0.131$
$L/(L_1+L_2)_B$	$0.9895\,(\pm 0.0014)$	$0.9682\,(\pm 0.0187)$
$L/(L_1+L_2)_V$	$0.9772\,(\pm 0.0019)$	$0.9385\,(\pm 0.0117)$
$L/(L_1+L_2)_R$	$0.9603\,(\pm 0.0243)$	$0.9036\,(\pm 0.0166)$
l_{3B}	$-$	$0.41\,(\pm 0.07)\%$
l_{3V}	$-$	$0.62\,(\pm 0.07)\%$
l_{3R}	$-$	$0.86\,(\pm 0.06)\%$
$r_{1\rm pole}$	$0.3637\,(\pm 0.0012)$	$0.3584\,(\pm 0.0012)$
$r_{1\rm point}$	$0.3807\,(\pm 0.0015)$	$0.3920\,(\pm 0.0021)$
$r_{1\rm side}$	$0.3745\,(\pm 0.0014)$	$0.3712\,(\pm 0.0014)$
$r_{1\rm back}$	$0.3780\,(\pm 0.0015)$	$0.3820\,(\pm 0.0017)$
$r_{2\rm pole}$	$0.2086\,(\pm 0.0008)$	$0.2859\,(\pm 0.0009)$
$r_{2\rm point}$	$0.3083\,(\pm 0.0087)$	$0.4114\,(\pm 0.0095)$
$r_{2\rm side}$	$0.2168\,(\pm 0.0009)$	$0.2981\,(\pm 0.0010)$
$r_{2\rm back}$	$0.2485\,(\pm 0.0009)$	$0.3307\,(\pm 0.0010)$
$\Sigma(O-C)_i^2$	0.3195	0.2576

Table 6 Absolute Parameters for Two Eclipsing Binaries

Parameter	EU Hya	AW Vul
Spectral	F2	F0
$M_1\ (M_\odot)$	$1.39\,(\pm 0.04)$	$1.48\,(\pm 0.06)$
$R_1\ (R_\odot)$	$1.55\,(\pm 0.07)$	$1.75\,(\pm 0.12)$
$L_1\ (L_\odot)$	$4.89\,(\pm 0.27)$	$7.83\,(\pm 1.05)$
$M_2\ (M_\odot)$	$0.19\,(\pm 0.01)$	$0.62\,(\pm 0.03)$
$R_2\ (R_\odot)$	$1.01\,(\pm 0.05)$	$1.53\,(\pm 0.11)$
$L_2\ (L_\odot)$	$0.27\,(\pm 0.03)$	$0.91\,(\pm 0.13)$

both late-type and early-type close binaries. This indicates that the plausible explanation of the cyclic period variations is the light travel time effect via the presence of a third body (Irwin 1952). The mass function of the additional companion is computed by the following formula,

$$\frac{4\pi^2}{GP_3^2}\times(a_{12}\sin i)^3 = f(m) = \frac{(M_3\sin i)^3}{(M_1+M_2+M_3)^2}\,. \quad (5)$$

Assuming there are coplanar orbits associated with these binary systems, the masses of the third bodies are $M_3 = 0.15\,(\pm 0.02)\ M_\odot$ for AW Vul ($i = 87.0^\circ$) and $M_3 = 0.28\,(\pm 0.03)\ M_\odot$ for EU Hya ($i = 79.8^\circ$). The spectral types of their third components correspond to $\sim$ M6 for AW Vul or $\sim$ M4 for EU Hya (Cox 2000). Therefore, these low-mass dwarfs could not be identified because of their low luminosities.

For EU Hya and AW Vul that have lobe-filling secondaries, their orbital periods are continuously decreasing. This phenomenon may occur in many other binaries (Qian 2000a,b, 2001). This kind of nonconservative evolution of binaries may be attributed to mass transfer, mass loss or angular momentum loss by magnetic wind. Assuming a net mass loss from the secondary (i.e., $\dot{M}/M = \dot{M}_2/M_2$) and an Alfvén radius of $R_a \simeq a$, Tout & Hall (1991)'s formula may be simplified into Yang et al. (2011)'s equation (7) as follows,

$$\frac{\dot{P}}{P} = \frac{5q^2-3q+2}{q}\frac{\dot{M}_2}{M_2}\,. \quad (6)$$

Inserting the related parameters of $\dot{P}$, M_2, q and P into Equation (6), we obtained the mass loss rates of $dM_2/dt = -1.76\,(\pm 0.18)\times 10^{-8}\ M_\odot\ {\rm yr}^{-1}$ for EU Hya

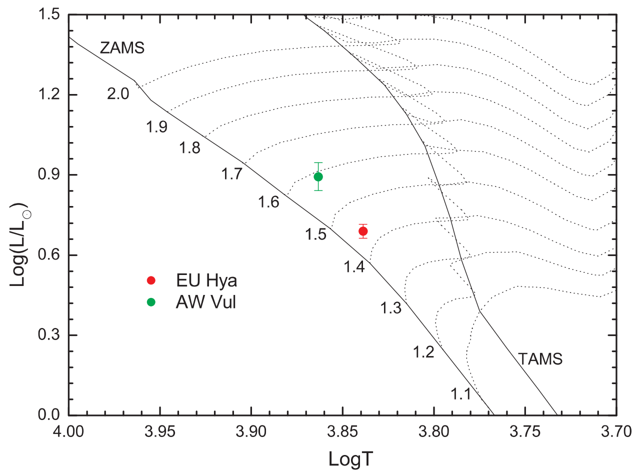

Fig. 5 The evolutionary states of the primaries for AW Vul and EU Hya.

and $dM_2/dt = -3.28\,(\pm 0.56) \times 10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$ for AW Vul. With their period decreasing, the orbit of the binary system will shrink, which will cause the fill-out factor of the primary to increase (Yang & Wei 2009). As the mass and angular momentum are being lost for this kind of near-contact binaries, the shrinkage in the orbit will cause them to evolve into contact systems (Qian 2002). Therefore, EU Hya and AW Vul may be progenitors of W UMa-type binaries (Bradstreet & Guinan 1994).

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References

Applegate, J. H. 1992, ApJ, 385, 621
Bradstreet, D. H., & Guinan, E. F. 1994, in Astronomical Society of the Pacific Conference Series, 56, Interacting Binary Stars, ed. A. W. Shafter, 228
Bron observers, 2014, Brno Contr., 38, 1 *http://var2.astro.cz/EN/brno/index.php*
Budding, E., Erdem, A., Çiçek, C., et al. 2004, A&A, 417, 263
Busch, H., & Haussler, K., 1972, Inf. Bull. Var. Stars, Information Bulletin on Variable Stars, 639, 1
Cox, A. N. 2000, Allen's Astrophysical Quantities (New York: AIP Press; Springer)
Diethelm, R. 2011, Information Bulletin on Variable Stars, 5992, 1
Erdem, A., Zola, S., & Winiarski, M. 2011, New Astron., 16, 6
Girardi, L., Bressan, A., Bertelli, G., & Chiosi, C. 2000, A&AS, 141, 371
Gu, S. 1994, Information Bulletin on Variable Stars, 4078, 1
Gu, S., Liu, Q., Yang, Y., & Wang, B. 1993, Ap&SS, 203, 189
Hall, D. S. 1989, in Bulletin of the American Astronomical Society, 21, 1116
Harmanec, P. 1988, Bulletin of the Astronomical Institutes of Czechoslovakia, 39, 329
Hoffman, D. I., Harrison, T. E., McNamara, B. J., et al. 2006, AJ, 132, 2260
Hoffmeister, C. 1930, Astronomische Nachrichten, 240, 193
Hoffmeister, C. 1931, Astronomische Nachrichten, 242, 129
Hubscher, J., & Monninger, G. 2011, Information Bulletin on Variable Stars, 5959, 1
Hubscher, J., & Lehmann, P. B. 2012, Information Bulletin on Variable Stars, 6026, 1
Irwin, J. B. 1952, ApJ, 116, 211
Kaitchuck, R. H., Honeycutt, R. K., & Schlegel, E. M. 1985, PASP, 97, 1178
Kordylevesky, K., 1947, Roczn. Astr. Obs. Krakow, 18
Kordylevesky, K., 1948, Roczn. Astr. Obs. Krakow, 19
Kordylevesky, K., 1951, Roczn. Astr. Obs. Krakow, 22
Kordylevesky, K., 1953, Roczn. Astr. Obs. Krakow, 24
Kordylevesky, K., 1958, Roczn. Astr. Obs. Krakow, 29
Kreiner, J. M., Kim, C.-H., & Na, I.-s. 2001, An Aatlas of OC Diagrams of Eclipsing Binary Stars (Kraków: Wydawnictwo Naukowe AP)
Kulkarni, A. G. 1979, Photometric Study of Eu-Hydrae, PhD Thesis, Osmania University
Kurucz, R. L. 1993, in Astronomical Society of the Pacific Conference Series, 44, IAU Colloq. 138: Peculiar versus Normal Phenomena in A-type and Related Stars, eds. M. M. Dworetsky, F. Castelli, & R. Faraggiana, 87
Liakos, A., & Niarchos, P. 2010, Information Bulletin on Variable Stars, 5958, 1
Liakos, A., Zasche, P., & Niarchos, P. 2011, New Astron., 16, 530
Liao, W.-P., & Qian, S.-B. 2010, MNRAS, 405, 1930

Malkov, O. Y., Oblak, E., Snegireva, E. A., & Torra, J. 2006, A&A, 446, 785
Nagai, K., 2012, Var. Star Bull. Japan, 53, 1 *http://vsolj.cetus-net.org/bulletin.html*
Nagai, K., 2014, Var. Star Bull. Japan, 55, 1 *http://vsolj.cetus-net.org/bulletin.html*
Pagaczewski, J., 1934, Acta Astron. ser. b, 2, 19
Press, W. H., Teukolsky, S. A., Vetterling, W. T., & Flannery, B. P. 1992, Numerical recipes in FORTRAN. The Art of Scientific Computing (Cambridge: University Press)
Qian, S. 2000a, AJ, 119, 901
Qian, S. 2000b, AJ, 119, 3064
Qian, S. 2001, AJ, 121, 1614
Qian, S. 2002, MNRAS, 336, 1247
Qian, S.-B., & Boonrucksar, S. 2003, PASJ, 55, 499
Qian, S.-B., Zhu, L.-Y., & Boonruksar, S. 2006, New Astron., 11, 503
Rao, P. V., Sarma, M. B. K., & Abhyankar, K. D. 1996, PASP, 108, 967
Samolyk, G. 2013, Journal of the American Association of Variable Star Observers (JAAVSO), 41, 328
Sasselov, D. D. 1982, Contributions of the Public Observatory and Planetarium in Brno, 23, 28
Schmidt, E. G., & Reiswig, D. E. 1993, AJ, 106, 2429
Tout, C. A., & Hall, D. S. 1991, MNRAS, 253, 9
Tsesevitch, V. P., 1954, Odessa Izv. (part 3), 4, 88
Whitney, B. S. 1955, AJ, 60, 453
Wilson, R. E. 1990, ApJ, 356, 613
Wilson, R. E., & Devinney, E. J. 1971, ApJ, 166, 605
Wood, B. D., & Forbes, J. E. 1963, AJ, 68, 257
Wood, F. B., Parker Oliver, J., & Koch, R. H. 1980, A Finding List for Observers of Interacting Binary Stars (Astronomical Series, Philadelphia: University of Pennsylvania Press, 1980, 5th ed.)
Yang, Y.-G., & Wei, J.-Y. 2009, AJ, 137, 226
Yang, Y.-G., Shao, Z.-Y., Pan, H.-J., & Yin, X.-G. 2011, PASP, 123, 895
Yang, Y.-G., Li, L.-H., & Dai, H.-F. 2012, AJ, 144, 50
Yang, Y.-G. 2013, RAA (Research in Astronomy and Astrophysics), 13, 1471
Yang, Yuangui, Zhang, Liyun, Dai, Haifeng, & Li Huali, 2015, New Astronomy, 37, 48
Zhu, L.-Y., Qian, S.-B., & Xiang, F.-Y. 2006, PASJ, 58, 361
Zhu, L.-Y., Qian, S.-B., Boonrucksar, S., He, J.-J., & Yuan, J.-Z. 2007, ChJAA (Chin. J. Astron. Astrophys.), 7, 251