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A photometric study of the detached binary WY Hydrae with twin components

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ABSTRACT

We present a multicolor photometry for the eclipsing binary WY Hydrae, observed on four nights of 2008 December. From our new observations and Carr's data, the photometric solutions were deduced by using the updated W–D program. The results show that WY Hya is a detached binary with a mass ratio of $q = 0.970(\pm0.005)$.

By analyzing the $O–C$ curve, it is found that there exists either a continuous period increase or a cyclic variation. From Eq. (2), the orbital period of WY Hya secularly increases at a rate of $dP/dt = +3.56(\pm0.37) \times 10^{-7}$ days/yr, which may be interpreted by some mass transfer for the near-contact configuration or tidal dissipation. From Eq. (3), the period and semi-amplitude of the periodic oscillation are $P_3 = 95.4(\pm4.2)$ yr and $A = 0^d.0087(\pm0^d.0003)$, respectively. This may be likely attributed by light-time effect via the presence of the assumed third body. Assumed in the coplanar orbit with the binary, the mass of the third body should be $M_3 = 0.18\ M_\odot$. If the unseen additional companion exists, it will extract angular momentum from the binary system. Finally, WY Hya with high fill-out factors (i.e., $f_{1,2} > 80\%$), may evolve into a semi-detached configuration.

1. Introduction

The light variability of WY Hydrae (=AN 109.1934, $\alpha_{J2000.0} = 08^h14^m10^s.94$ and $\delta_{J2000.0} = +00^\circ29'43.''52$) was found by Jensch (1934), who classified it as an Algol-type binary with a period of $0^d.358005$. Then its period was doubled as $0^d.7160082$ by Struve (1949), who determined its spectral type of A5 or A7 at maximum light. Kreiner et al. (2001) revised its spectral type to A6 with a color index of B-V = +0.5. Based on 121 light minimum times, they also determined a linear ephemeris as follows,

$$\mathrm{Min.I} = \mathrm{HJD}\ 2440570.979 + 0.7160070 \times E. \qquad (1)$$

Carr (1971) published three-color photoelectric observations, indicating that WY Hya possessed an EB-type light curve with eclipses of nearly equal depth. Based on Carr's (1971) observations, Giuricin et al. (1981) derived a photometric solution by using Wood's (1972) method. The results show this binary consists of two detached twin components. Therefore, WY Hya with an extreme mass ratio of $q \sim 1$, was included in the observing program.

2. CCD Photometry

Photometric observations of WY Hya were carried out on 2008 December 27, 28, 30 and 31, using the 60-cm telescope at the Xinglong Station of the National Astronomical Observatories of China (NAOC). This telescope was equipped with a Princeton Instrument 1024×1024 CCD, whose effective field of view is $17' \times 17'$. The standard Johnson-Cousins $UBVR_cI_c$ system was used. The reductions of observations were done using the IMRED and APPHOT packages in IRAF. Zero and flat-fielding corrections were applied to the images. Extinction corrections were small and were not made to the observations. In the observing process, the comparison star ($\alpha_{J2000.0} = 08^h14^m03^s.92$ and $\delta_{J2000.0} = +00^\circ41'26.''4$) and the check one ($\alpha_{J2000.0} = 08^h14^m17^s.53$ and $\delta_{J2000.0} = +00^\circ24'24.''9$) were used. Typical integration times for *BVR* bands were 80 s, 40 s, and 30 s, respectively. A total of 531 images in the *B* band, 542 images in the *V* band and 538 images in the *R* band were obtained. The heliocentric Julian dates versus the magnitude differences, in the sense of the variable minus the comparison, are available on request. The errors of individual points do not exceed $0^m.01$. Using the K–W method (Kwee and van Woerden, 1956), three light minimum times listed Table 1, were determined from our new observations.

3. Possible period variations

Many light minimum times for WY Hya have been published in the literature. Early eclipsing times with 147 data entries were collected by Kreiner (2004). After 2004, another 22 times were subsequently published in IBVS 5672 (Nelson, 2006), IBVS 5741 (Zejda et al., 2006), IBVS 5843 (Ogłoza, 2008) and IBVS 5871

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Table 1
New CCD light minimum times of WY Hya.

JD(*Hel.*)	Min	Error	Band
2454828.12397	I	0.00024	*B*
2454828.12410	I	0.00025	*V*
2454828.12447	I	0.00021	*R*
2454829.19823	II	0.00029	*B*
2454829.19817	II	0.00030	*V*
2454829.19825	II	0.00033	*R*
2454831.24640	I	0.00014	*B*
2454831.34591	I	0.00028	*V*
2454831.34589	I	0.00019	*R*

(Diethelm, 2009), JAAVSO 36, 37 and 38 (Bialozynski and Poklar, 2008; Samolyk, 2009, 2010), and VSOLJ 44 and 45 (Nagai, 2006, 2007), AAVSO 12 (Baldwin and Samolyk, 2007). Together with our new three CCD times, we have compiled a total of 176 light minimum times (i.e., 24 photographic, 99 visual, 3 photoelectric and 50 CCD), which covers 80 yr from 1929 to 2009. Using the period of Eq. (1), we can calculate the residuals *O–C* for those eclipsing times, which are shown in Fig. 1. From the upper parts of this figure, there exists a long gap from 1934 (i.e., HJD 2427545.383; Jensch, 1934) to 1968 (i.e., HJD 2439941.614; Baldwin, 1974) except two visual points. Weight 1 was assigned for the visual or photographic data, while weight 10 for the photoelectric or CCD ones. Additionally, the light minimum time of HJD 2453389.6753 (Ogłoza, 2008) was discarded due to large error for the CCD measurement and much derivation from the general trend.

Although there exists much larger scatter for visual or photographic observations, the *O–C* curve indicates to be a secular period increase during the past 25,000 days. A least-squares method leads to the following equation,

$$O{-}C = -0.0038(\pm 0.0009) + 0.17(\pm 0.5)E + 3.49(\pm 0.36) \times 10^{-11}E^2. \qquad (2)$$

The weighted sum of the squares of residuals from Eq. (2) is $\Sigma\omega_i(O{-}C)_i^2 = 0.0088\ \mathrm{days}^2$. Their corresponding residuals $(O{-}C)_1$ are displayed in the lower part of Fig. 1 (left panel). Eq. (2) was constructed as a solid line in the upper part of this figure.

An alternative description for the (*O–C*) curve is that the parabolic curve of Eq. (2) may be a part of a cyclic variation with a longer period. Therefore, the (*O–C*) curve was fitted with a linear component plus a sinusoidal curve. Using the Levenberg–Marquardt technique (Press et al., 1992), a weighted nonlinear least-squares fitting method yielded the following equation,

$$O{-}C = 0.0036(\pm 0.0003) + 3.9(\pm 0.3) \times 10^{-7}E + 0.0087(\pm 0.0003) \times \sin[1.29(\pm 0.06) \times 10^{-4}E + 3.9618(\pm 0.0372)]. \qquad (3)$$

The weighted sum of the squares of residuals is $\Sigma\omega_i(O{-}C)_i^2 = 0.0072\ \mathrm{days}^2$, which is a bit smaller than the value derived from Eq. (2). The computed residuals $(O{-}C)_2$ are shown in the lower part of Fig. 1 (right panel). The solid and dotted lines represent all contributions of Eq. (3) and its linear part in the upper part of Fig. 1 (right panel). The period and the semi-amplitude for this cyclic variation are $P_3 = 95.4(\pm 4.2)$ yr and $A = 0^d.0087(\pm 0^d.0003)$, respectively. The observing interval of light minimum times (i.e., 80 yr) for WY Hya covers only ~84% of the complete period. Due to small difference between the $\Sigma\omega_i(O{-}C)_i^2$ from Eqs. (2) and (3), we did not decide which one represents the true period change. Therefore, it is necessary to obtain more light minimum times to check the nature of period changes of this star.

4. Light curve analysis

For the eclipsing binary WY Hya, new CCD observations in 2008 (i.e., LC_1) and Carr's (1971) photoelectric ones (i.e., LC_2) were used to deduce the photometric solution by using the 2003 version of the W–D program (Wilson and Devinney, 1971; Wilson, 1979, 1990). The effective temperature for Star 1 was fixed at T_1 = 8000 K, which is the same as the value from Giuricin et al. (1981). The corresponding logarithmic bolometric (i.e., *X* and *Y*) and monochromatic (i.e., *x* and *y*) limb-darkening coefficients were interpolated from van Hamme's (1993) tables. Following Lucy (1967) and Rucinski (1973), gravity darkening exponents and bolometric albedo coefficients were set at the values of $g_{1,2}$ = 1.0 and $A_{1,2}$ = 1.0, which are appropriate for stars with radiative envelopes. The commonly adjustable parameters are as follows: the orbital inclination, *i*, the mass ratio, *q*, the mean effective temperature of Star 2, T_2, the potentials of both components, Ω_1 and Ω_2, the monochromatic luminosity of Star 1, L_1. Using the stellar atmosphere model (Kurucz, 1993), the relative brightness of Star 2 was calculated.

The *BVR* light curves (i.e., LC_1 in 2008) for WY Hya are shown in the left panel of Fig. 2, where phases are computed with the period of $P = 0^d.7160070$ of Eq. (1). The symmetric light curves of LC_1 were applied to search for a photometric mass ratio. A series of solutions

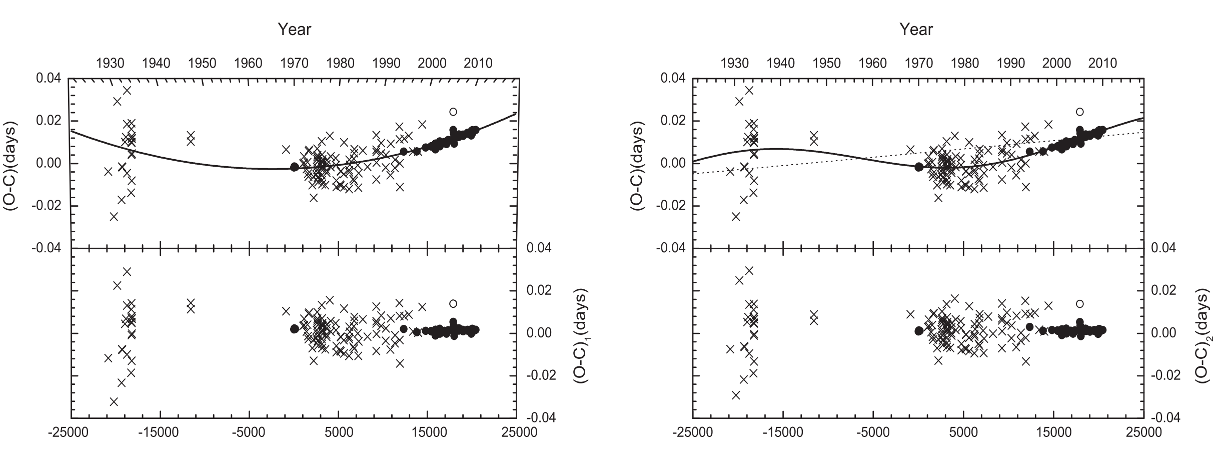

Fig. 1. The (*O–C*) curve (upper panel) and the corresponding residuals (lower panel) for WY Hya. The solid circles represent photometric or CCD observations, while the crosses refer to photographic and visual ones, respectively. The open circle is the discarded eclipse time, i.e., HJD 2453389.6753 (Ogłoza, 2008).