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A new photometry and period analysis of the Algol-type binary XZ And

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HIGHLIGHTS

- We model new BVR light curves.
- We detected a periodicity in the $O-C$ curve and provided two possible mechanisms.
- The secular period increase may result from mass transfer.
- We proposed the possible evolutionary statue.

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ABSTRACT

We present multi-color photometry of the eclipsing binary XZ And, obtained on 2010 October and November with the 60-cm telescope at Xinglong station of National Astronomical Observatories of China. Using the updated W–D program, the photometric elements were deduced from *BVR* light curves. The results imply that XZ And is a classic Algol-type binary, whose secondary component fills its Roche lobe. The mass ratio and fill-out factor of the primary are $q = 0.474(\pm0.003)$ and $f_1 = 68.3(\pm0.6)\%$, respectively.

Based on photometric and CCD light minimum times, we constructed the $O-C$ curve, which may be described by an upward parabolic line with a quasi-cyclic variation, i.e., light-time orbit. The period and semi-amplitude are $P_{mod} = 32.30(\pm0.06)$ yr and $A = 0.^{d}0368(\pm0.^{d}0008)$, respectively. This kind of cyclic variation may result from either magnetic activity of the secondary star or light-time effect due to the unseen third body. The long-term period increases at a rate of $dP/dt = +5.37(\pm0.41) \times 10^{-7}$ d yr^{-1}, which may be interpreted by the conservative mass transfer from the secondary component to the primary one. With period increasing, the binary may become wider. Finally, XZ And (i.e., $2.15M_{\odot} + 1.02M_{\odot}$) will transformed into a binary system consisting of a WD and an unevolved companion.

1. Introduction

The light variability of XZ And (=BD + 41°367, $\alpha_{J2000.0} = 01^{h}56^{m}51.^{s}53$ and $\delta_{J2000.0} = +42°06'02.''15$) was discovered by Miss Leavitt (Shapley, 1923). Hill et al. (1975) preliminarily determined a spectral type of A4IV-V, while Halbedel (1984) reclassified it as A1V. The variable's magnitude ranges from $10.^{m}8$ to $11.^{m}9$ and the color index is $B - V = -0.8$ (Malkov et al., 2006). Visual observations were published by Leiner (1926); Kordylewska (1931); Lause (1934) and Lause (1936), respectively. Blitzstein (1954) and Reinhardt (1967) obtained two sets of photoelectric light curves, which were analyzed by Giuricin et al. (1980) who derived a mass ratio of 0.4. Dugan and Wright (1939) determined a period of $1.^{d}357283$ and found some irregular variations in the $(O-C)$ curve. Demircan et al. (1995) summarized 16 linear ephemerides for XZ And, implying that changes may exist in its orbital period. Based on different databases of eclipse times, several authors subsequently attempted to model the distorted $(O-C)$ curve in two ways (i.e., sine curves, and an upward parabola with a cyclic sine-shape modulation). The cyclic modulation possibly includes one period (Frieboes-Conde and Herczeg, 1973), two periods (Odinskaya and Ustinov, 1952; Todoran, 1967; Borkovits and Hegedüs, 1996; Selam and Demircan, 1999), and three ones (Demircan et al., 1995). The $(O-C)$ curve of XZ And was alternatively characterized by a secular period variation superimposed with a cyclic oscillation (Kreiner, 1971; Kreiner, 1976; Rafert, 1982). Due to those inconsistent results for XZ And, it is necessary to reanalyze the orbital period changes.

In this paper, new photometry of XZ And is presented. The primary aim is to study period variation and evolutionary state. Multi-color observations and data reduction are described in Section 2. The period changes are reanalyzed in Section 3 and photometric models considered in Section 4. Finally, some results of XZ And are briefly discussed in Section 5.

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2. New observations

Complete light curves of XZ And were obtained on eight nights of 2010 October and November, using the 60-cm telescope at the Xinglong station (XLs) of National Astronomical Observatories of China (NAOC). This telescope was equipped with a PI 1024×1024 CCD photometric system. The plate-scale is $0.''99$ per pixel, and the resulting size of the effective field of view is $17' \times 17'$. The standard Johnson–Cousin–Bessel set of *BVRI* filters was used. Data reduction was performed by using the Image Reductions and Analysis Facility (IRAF) software in the standard fashion.

In the observing process, we chose BD+41°379 and TYC 2824-1778-1 as the comparison and check stars. Typical exposure times for *BVR* bands are 45 s,35 s, 25 s, respectively. A total of 2975 effective images (i.e., 994 in *B* band, 989 in *V* band and 992 in *R* band) was obtained. The individual observations (i.e., HJD and Δm) are available on request. The mean errors in the differences between the magnitude of the check star and that of the comparison one were estimated to be ± 0.006 mag, ± 0.005 mag and ± 0.005 mag for *BVR* bands, respectively. The observed light curves are plotted in the left panel of Fig. 1, where phases were computed by a period of $1.^d35727963$ (Kreiner et al., 2001). From this figure, XZ And is a typical EA-type eclipsing binary (Binnendijk, 1975). The variable light amplitudes are $2.^m90$, $2.^m45$ and $2.^m07$ in *BVR* bands, which approximately agree with the estimated value of $2.^m97$ in *B* band from Malkov et al. (2006). Using the 85-cm telescope (Zhou et al., 2009), another photometry of primary eclipse of XZ And was obtained on 2012 October 25, which is shown in the right panel of Fig. 1. From those observations, we determined several light minimum times, which are listed in Table 1.

Table 1
New light minimum timings of XZ And.

JD (Hel.)	Min	Error	Band
2455474.35865	I	±0.00012	B
2455474.35847	I	±0.00014	V
2455474.35870	I	±0.00013	R
2455479.10554	II	±0.00065	B
2455479.10802	II	±0.00048	V
2455479.10332	II	±0.00074	R
2455481.14476	I	±0.00007	B
2455481.14474	I	±0.00010	V
2455481.14493	I	±0.00012	R
2455521.19063	II	±0.00149	B
2455521.18311	II	±0.00099	V
2455521.18505	II	±0.00010	R
2456226.29034	I	±0.00007	B
2456226.29029	I	±0.00008	V
2456226.29032	I	±0.00010	R

3. Reanalyzing period variations

The complicated period variations of XZ And were studied by many authors, who gave some inconsistent results. Due to large measurement errors for visual and photographic observations, the $(O{-}C)$ curve could not be described well, which can be seen directly from the literature such as Borkovits and Hegedüs (1996) and Selam and Demircan (1999). Therefore, we collected all available high-precision observations, including 18 photoelectric and 48 CCD measurements. Table 2 listed those eclipsing times spanning over 64 years from 1948 to 2012. Using the linear ephemeris (Kreiner et al., 2001),

$$\mathrm{Min.I} = \mathrm{HJD}2424152.2546 + 1.^d35727963 \times E, \tag{1}$$

we can calculate the residuals $(O{-}C)$, which are listed in Table 2 and displayed in the upper panel of Fig. 2. From this figure, the general trend of the $(O{-}C)$ curve may be described by an upwards parabolic superimposed with a quasi-cyclic variation, i.e., a light-time orbit (Irwin, 1952). Using the nonlinear least-squares method (Press et al., 1992), we obtained the following equation,

$$O{-}C = 0.0540(\pm 0.0020) + 1.35726055(\pm 0.00000025) \times E + 9.87(\pm 0.08) \times 10^{-10} \times E^2 + \tau \tag{2}$$

and

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

where $A = a_{12}/c$ is the semi-amplitude of the light-time orbit, and several other parameters are taken from Irwin (1952). The fitted parameters are listed as follows, $A = 0.^d0368(\pm 0.^d0008)$, $P_{mod} = 32.30(\pm 0.06)$ yr, $e = 0.191(\pm 0.009)$, $\omega = 3.923(\pm 0.047)$ and $T_p = \mathrm{HJD}2446108.9(\pm 118.0)$. The final residuals are listed in Table 2, and are shown in the lower panel of Fig. 2, where no regularity is apparent. In its upper panel, the solid and dotted lines are Eq. (2) and its parabolic part, respectively. The quadratic term represents a continuous increase of the orbital period at a rate of $dP/dt = +5.37(\pm 0.41) \times 10^{-7}$ d yrs^{-1}. The modulation period is

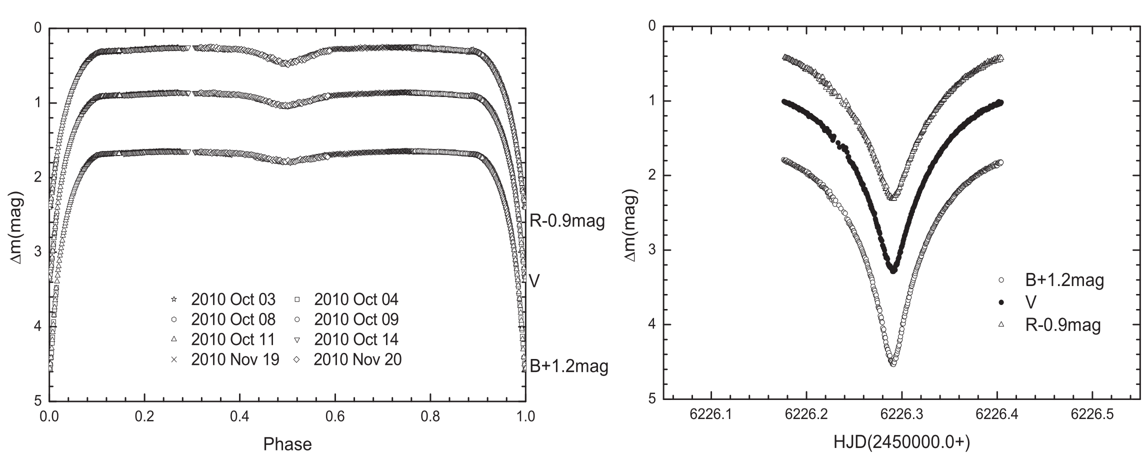

Fig. 1. *Left panel*: *BVR* light curves of XZ And, observed in 2010 using the 60-cm telescope. *Right panel*: the primary eclipse, obtained on 2012 October 25 using the 85-cm telescope.