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QZ Aurigae: An eclipsing cataclysmic variable with a white dwarf of almost equivalent mass to its companion

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Abstract

We present CCD photometric monitoring of the classic nova QZ Aurigae (Nova Aur 1964) since 2008 with the 2.4-m telescope at Lijiang station of Yunnan Astronomical Observatory in China, as well as the 2.16-m telescope and the 85-cm telescope at Xionglong station of the National Astronomical Observatory in China. By utilizing eight new eclipse timings and the data from the last literature, published almost 20 years ago, we construct the $O-C$ diagram of this system to analyze the orbital period variation. We find no evidence of long-term orbital period variations in QZ Aur. Moreover, the light curves showing the main eclipse process of the white dwarf suggest the presence of a bright spot component and a disk, as commonly found in nova-like variables. This may reveal high mass accretion and high mass transfer in this system. However, even high mass transfer rates from the donor are inconsistent with our result of no period variations, unless the mass ratio is almost equal to 1. Hence, the observed results here possibly support that the mass of the primary white dwarf is extremely close to that of the donor star in the eclipsing binary QZ Aur.

Key words: binaries: close — binaries: eclipsing — novae: cataclysmic variables — stars: individual (QZ Aurigae)

1 Introduction

The classical nova QZ Aur (= Nova Aur 1964) was initially detected as a fast nova taking 23–30 d for the declining time after the eruption maximum (Sanduleak 1975; Gessner 1975). After sinking into oblivion for over 15 yr, QZ Aur was found to be an eclipsing binary system with a relatively long orbital period of 8.58 hr, and to possess a typical V magnitude of 17.18 mag in quiescent state with colors $B-V=0.47$, $V-R=0.29$, and $V-J=1.4$ (Campbell & Shafter 1991; Szkody 1992). Afterwards, a preliminary spectral study was undertaken by Szkody and Ingram (1994); however, there was no trace of the existence of the secondary. Campbell and Shafter (1995)—hereafter CS95—presented a set of multi-color photometric data and spectroscopic observations to estimate some systemic parameters. The eclipse depth in the B band was detected to be about 1.2 mag. As typical behavior of the cataclysmic variables, the outstanding Balmer emission lines were shown in the spectrum of QZ Aur, accompanied by

Table 1. New observations on the eclipsing binary QZ Aur.

Observation date	Start time (HJD) (+2400000)	End time (HJD) (+2400000)	Methods	Filter*	Telescopes†
2008 Nov. 28	54799.13670	54799.22330	CCD	*V*	2.4 m
2008 Dec. 26	54827.05330	54827.09730	CCD	*R*	2.4 m
2009 Jan. 21	54853.15250	54853.17850	CCD	*V*	2.4 m
2010 Jan. 11	55208.11072	55208.20720	CCD	*B*	2.16 m
2012 Feb. 13	55971.00996	55971.08594	CCD	*N*	2.4 m
2012 Feb. 15	55973.18079	55973.21225	CCD	*N*	2.4 m
2012 Nov. 07	56239.15200	56239.21288	CCD	*N*	2.16 m
2013 Jan. 17	56309.93960	56309.98397	CCD	*N*	85 cm

∗ *N* represents no filter (white light).

† Explanations of the telescopes: 2.4 m: the 2.4-m telescope at LiJiang station of Yunnan Astronomical Observatory (YNAO); 85 cm and 2.16 m: the 85-cm and 2.16-m telescopes at Xinglong station of the National Astronomical Observatory (NAO).

strong He II emission. It was also found that the secondary has a temperature of about $T_2 = 5200$ K, which corresponds to a spectral type near K0 *V* for a main sequence star. So, its radius was estimated to closely approximate that of the sun. Based on their model, the acceptable mass ratio q (M_2/M_1) is in the range of 0.8–1.

In the case of QZ Aur, orbital period analysis by using photometric data was obtained nearly 20 years ago (CS95). However, it was insufficient and unclear to figure out the long-term evolution of the binary system since the data in their work only covers about 2000 cycles. QZ Aur subsequently slipped into relative obscurity again, and no further studies concentrating on this object have been made until now. The change of orbital period can in principle be measured via ($O - C$) eclipsing timings for long-period eclipsing cataclysmic variables (Qian et al. 2007; Dai & Qian 2010). Hence, new CCD photometric observations on the eclipsing binary QZ Aur are presented in this work to investigate the secular variation of the orbital period and its secular evolution.

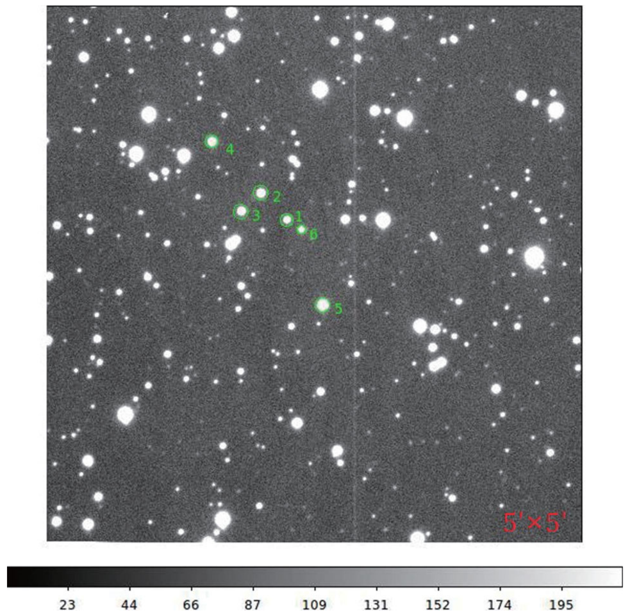

Fig. 1. One CCD image of QZ Aur in white light. No. 2 ($\alpha_{2000} = 05^{h}28^{m}35.^{s}34$, $\delta_{2000} = +33^{\circ}18'33.''9$) refers to the comparison star, while No.3 ($\alpha_{2000} = 05^{h}28^{m}36.^{s}09$, $\delta_{2000} = +33^{\circ}18'22.''7$) to the check star.

2 New observations and reductions

Since 2008, CCD photometric observations of QZ Aur were carried out with the 2.4-m RC telescope at the Lijiang Gao Meigu observational base of Yunnan Astronomical Observatory (YNAO), and the 2.16-m reflecting telescope and the 85 cm telescope at Xinglong station of the National Astronomical Observatory (NAO) in China. The 2.4-m RC telescope was fitted with the PI VersArray 1300B CCD camera. The AIMO 1242 × 1152 BFOSC CCD camera was used at the 2.16-m telescope.[1] The 85-cm telescope was equipped with the AP7 512 × 512 CCD photometric system. The filter systems adopted in the observations were very close to the standard Johnson–Cousins–Bessel system (Zhou et al. 2009). During the observations, the clocks of the control computers serving the CCD cameras were calibrated against UTC time by the GPS receivers' clocks. One of the CCD frames is displayed in figure 1. In order to construct the differential light curves, two nearby stars (No. 2 and No. 3 in figure 1) that have similar brightness in the same field of view as the target were chosen as the comparison star and the check star, respectively. All the frames were corrected after bias and flat-field subtraction. PHOT (measure magnitudes for a list of stars) of the aperture photometry package of IRAF was put into use to reduce the observed data. The information on our photometric observations is given in table 1. The fifth column of table 1 shows the filters adopted during the observations, where *N* represents no filters (white light).

[1] ⟨http://www.xinglong-naoc.org/gcyq/list.jsp?telescope=216cm⟩.

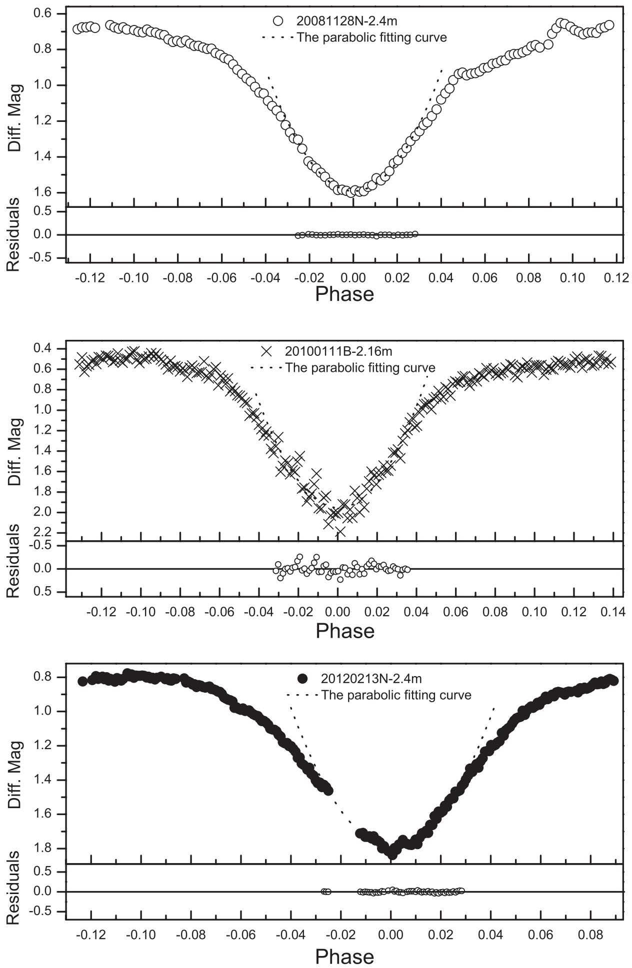

Fig. 2. Differential light curves of QZ Aur on 2008 November 28, 2010 January 11, and 2012 February 13, marked with the open circles, the crosses and the solid circles, respectively. The dotted lines refer to the parabolic fitting curves for the eclipse timings.

Three differential light curves of QZ Aur on 2008 November 28, 2010 January 13 and 2012 November 11, mainly covering the whole eclipse process, are displayed in figure 2. The averaged depth of eclipse in white light is about 1.0 mag, while that in the *B* passband about 1.3–1.4 mag. In the upper panel of figure 2, the eclipse profile on 2008 November 28 plausibly shows the egress of a hot spot component. A small flickering (> 0.1 mag) emerging during the end of eclipse egress has striking similarity to that observed on 1990 October 23 in the *V* passband (CS95). The flickering, however, disappeared in the light curves of the other two days.

Eight new mid-eclipse timings in Heliocentric Julian Day (HJD) were determined from our CCD photometric data by means of the least-squares parabolic fitting method (see figure 2 for an example). Composed of our new timings and old data from the literature (CS95), all available eclipse timings of QZ Aur from 1990 to 2013 spanning nearly 2.3×10^4 cycles are listed in table 2. All the eclipse timings

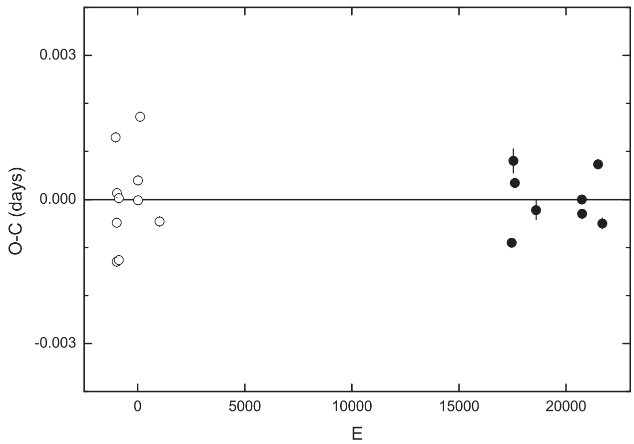

Fig. 3. $O-C$ diagram of the eclipsing classical nova QZ Aur. The open circles refer to the old data, and the solid circles refer to the new data.

Table 2. Eighteen eclipse timings of eclipsing binary QZ Aur.

JD. Hel. (+2400000)	Errors (d)	*E* (cycles)	$O-C$ (d)	Min.	Ref.*
48188.0124	0.0001	−1027	+0.001295	I	(1)
48205.8846	0.0001	−977	−0.001300	I	(1)
48206.9579	0.0001	−974	−0.000487	I	(1)
48208.7460	0.0001	−969	+0.000133	I	(1)
48242.7080	0.0001	−874	+0.000024	I	(1)
48243.7792	0.0001	−871	−0.001263	I	(1)
48560.8793	0.0001	16	−0.000015	I	(1)
48561.9522	0.0001	19	+0.000398	I	(1)
48598.7756	0.0001	122	+0.001722	I	(1)
48921.9497	0.0001	1026	−0.000460	I	(1)
54799.18162	0.00006	17466	−0.000905	I	(2)
54827.06801	0.00025	17544	+0.000803	I	(2)
54853.16475	0.00010	17617	+0.000343	I	(2)
55208.15760	0.00020	18610	−0.000222	I	(2)
55971.05404	0.00006	20744	−0.000003	I	(2)
55973.19872	0.00005	20750	−0.000298	I	(2)
56239.17849	0.00043	21494	+0.000733	I	(2)
56309.95964	0.00011	21692	−0.000499	I	(2)

*(1) Campbell and Shafter (1995). (2) This paper.

were calculated from the primary eclipse for QZ Aur, as denoted in the fifth column of table 2. To calculate the $O-C$ values, the ephemeris obtained in their paper are put to use. After linear correction, the new epochs and the average orbital period of QZ Aur in HJD are derived as:

$$\text{Min.I (HJD)} = 2448555.1594(2) + 0^{\rm d}.35749589(2) \times E, \quad (1)$$

where E is the cycle number. The $O-C$ values with respect to equation (1) are listed in column 4 of table 2. As shown in figure 3, the $O-C$ diagram of QZ Aur indicates no obvious evidence for a non-zero value of $\dot{P}$. That is to say, the orbital period does not appear to be either increasing or decreasing with time in the long-term evolution. Note that the scatter of new observed data points is smaller than that of the old ones.

3 Discussion and conclusions

We have carried out comprehensive photometric monitoring on the eclipsing binary system QZ Aur. Photometric data spanning more than four years are obtained from our observations. Eight new eclipse timings together with the old data from the literature are adopted to calculate the $O-C$ values. The $O-C$ diagram of QZ Aur presents no obvious trend of long-term variation.

Some properties suggest that the long-period binary QZ Aur is more likely to behave as a nova-like cataclysmic variable rather than a dwarf nova (CS95). As commonly believed, the nova-like variables belong to a subclass of non-magnetic cataclysmic variables where high mass accretion obtains and the brightness of the system is typically dominated by a very bright accretion disk (Warner 1995). For QZ Aur, the observed light curves imply the existence of a bright spot during the eclipse egress as usually found in the nova-like variables, which leads to a comparatively high mass accretion. An out-of-eclipse magnitude variation in the differential light curves may show the high/low states, known as a feature of nova-like variables (Honeycutt & Kafka 2004 and the references therein). Based on the CCD observations of the AAVSO database, the long-term luminosity variation of QZ Aur over the last eight years reveals no typical nova outburst in this source. Hence, its relatively long orbital period and the lack of intermittent eruptions prevent this source from being classified as a dwarf nova.

Since the mass loss from a low-mass binary like QZ Aur is usually very small, it can be neglected. The period change is due to a conservative mass transfer from the donor to the white dwarf, according to the well-known equation

$$\frac{\dot{P}}{P} = 3\frac{(q-1)}{M_2}\dot{M}_2. \tag{2}$$

It can lead to a decrease in orbital period if the mass transfer is from the more massive donor to the less massive white dwarf. On the contrary, an increase in orbital period is caused while the mass ratio is inverted and the mass transfer is from the less massive donor to the more massive white dwarf, as mostly presented in the cataclysmic variable stars. Although high mass transfer already obtains in the system, it can not result in the variation of orbital period as long as the mass ratio is very close to one. It is noted that neither an increase nor a decrease is found in the observed orbital period of QZ Aur. This result possibly supports that the mass of the white dwarf is very close to that of the donor. If so, it can be constrained to be quite an accurate value.

Moreover, the mass ratio of a cataclysmic variable is believed to be of great importance, because it dominates the behaviour of mass transfer from the donor star to the white dwarf, and thus the evolution of the binary system. In the case of QZ Aur, its location in the q versus M_2 diagram (Thoroughgood et al. 2004), which describes the mass transfer stability, in principle indicates that the mass transfer in this system can be both dynamically and thermally stable. Driven by the mass transfer process, material is continually transferred from the lobe-filling donor to the white dwarf, whose mass continues to grow. A binary system with both components possessing the same mass experiences a critical evolutionary state that is of particularly significance in understanding binary evolution. Before and after this state, the orbital period of QZ Aur should be decreasing and increasing, respectively. Therefore, more long-term photometric monitoring and eclipse timings are required in the future in order to check this result.

Acknowledgments

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