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Curious Variables Experiment (CURVE) CCD photometry of QW Serpentis in superoutburst and quiescence

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Abstract. We report extensive photometry of the dwarf nova QW Ser throughout its February 2003 superoutburst untill quiescence. During the superoutburst the star displayed clear superhumps with a mean period of $P_{\rm sh} = 0.07703(4)$ days. In the quiescence we observed a double humped wave characterized by a period of $P = 0.07457(2)$ days. As both periods obey the Stolz-Schoembs relation with a period excess equal to $3.30 \pm 0.06\%$, the latter period is interpreted as the orbital period of the binary system

Key words. stars: individual: QW Ser – stars: binaries: close – stars: novae, cataclysmic variables

1. Introduction

QW Ser (TmzV46, USNO-A2.0 0975-07829422) was discovered by Takamizawa (1998), who detected three significant brightenings of the star on JD 2 449 620, 2 449 716 and 2 450 906. Photometric behavior and color of QW Ser suggested that it was a dwarf nova. In October 1999, Schmeer (1999) reported another outburst of QW Ser. Subsequent observations were made by Kato & Uemura (1999). According to them, the initial decline of 0.73 ± 0.20 mag observed during the first seven days of the outburst was followed by a much slower decrease of the brightness. The reported rate of mean decline of 0.1 mag per day was neither consistent with those of superoutbursts in SU UMa-type stars nor long outbursts of SS Cyg-type dwarf novae, thus the definitive classification of QW Ser remained an open question.

The February 2003 outburst of QW Ser was reported by Muyllaert (2003), who caught the star at a magnitude of 12.5 on 2003 Feb. 23.715 UT. Observations of Schmeer (2003) reported at a later date indicated that the star reached 12.5 mag on Feb. 21.199 UT.

2. Observations and data reduction

Observations of QW Ser reported in the present paper were obtained during 14 nights between February 23, 2003 and May 04, 2003 at the Ostrowik station of the Warsaw University Observatory. The data was collected using the 60-cm Cassegrain telescope equipped with a Tektronics TK512CB back-illuminated CCD camera. The scale of the camera was 0.76″/pixel providing a 6.5′ × 6.5′ field of view. The full description of the telescope and camera was given by Udalski & Pych (1992).

We monitored the star in "white light". This was due to the lack of an autoguiding system, not yet implemented after a recent telescope renovation. Thus we did not use any filters to shorten the exposures in order to minimize guiding errors.

The exposure times were from 60 to 90 s during the bright state and from 200 to 350 s in the minimum light.

A full journal of our CCD observations of QW Ser is given in Table 1. In total, we monitored the star during 36.47 hours and obtained 896 exposures.

All the data reductions were performed using a standard procedure based on the IRAF[1] package and the profile photometry has been derived using the DAOphotII package (Stetson 1987).

Relative unfiltered magnitudes of QW Ser were determined as the difference between the magnitude of the variable and the magnitude of the comparison star GSC 0927:464 (RA = $15^{\rm h}26^{\rm m}18.1^{\rm s}$, Dec = +08°17′50.3″) located 1.1 arcmin to the east of the variable. This comparison star is marked in the chart displayed in Fig. 1.

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[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.

Table 1. Journal of the CCD observations of QW Ser.

Date of 2003	Start 2 452 000. +	End 2 452 000. +	Length [hr]	No. of frames
Feb. 23/24	694.53928	694.68717	3.549	174
Feb. 24/25	695.50857	695.69560	4.489	197
Feb. 25/26	696.55102	696.68165	3.135	160
Feb. 26/27	697.55928	697.68020	2.902	136
Mar. 07/08	706.61633	706.66486	1.165	17
Mar. 24/25	723.49079	723.60672	2.782	28
Mar. 26/27	725.46410	725.58953	3.010	30
Mar. 29/30	728.47971	728.60005	2.888	24
Mar. 31/01	730.48924	730.59647	2.574	23
Apr. 24/25	75446824	754.58584	2.822	29
Apr. 25/26	755.43301	755.50438	1.713	21
Apr. 29/30	759.46412	759.47453	0.250	3
May 03/04	763.43619	763.53926	2.473	23
May 04/05	764.41933	764.53249	2716	31
Total	–	–	36.468	896

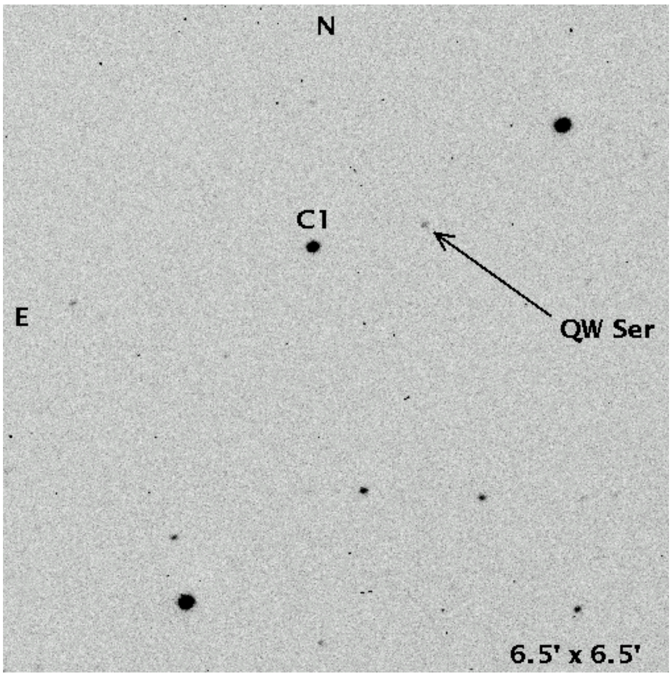

Fig. 1. Finding chart for QW Ser covering a region of 6.5×6.5 arcmin. The position of the comparison star is shown. North is up, East is left.

The typical accuracy of our measurements varied between 0.001 and 0.009 mag in the bright state and between 0.009 and 0.091 mag in the minimum light. The median value of the photometry errors was 0.004 and 0.031 mag, respectively.

3. Light curves

Figure 2 presents the photometric behavior of QW Ser as observed between February and May 2003. Relative magnitudes of the variable were transformed to the visual scale using the photographic magnitude of our comparison star equal to 13.59 ± 0.40 mag and taken from the GSC Catalog (Lasker et al. 1999). Additionally, open circles denote the visual and

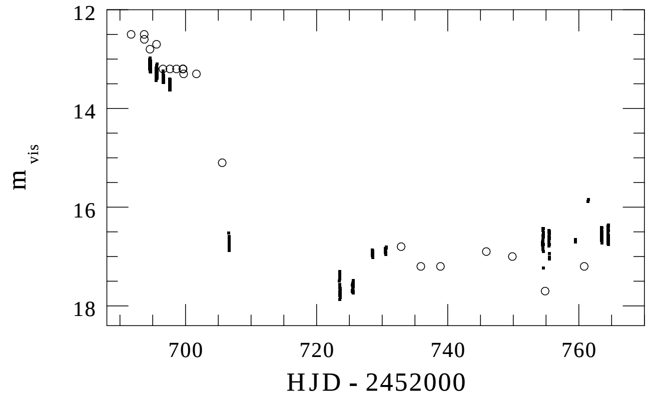

Fig. 2. The general photometric behavior of QW Ser during its 2003 superoutburst. Visual estimates collected in the VSNET archive are shown as open circles and CCD observations described in this paper as dots.

CCD estimates made by amateur astronomers and published in the VSNET mailing list. Our transformation of "white light" observations is based on the photographic magnitude of the comparison star and it is a rough estimate, which is used only to show the general behavior of the star. The true brightness of the QW Ser may differ even by about 0.5 mag from that shown in Fig. 2.

It is difficult to determine the exact time of the beginning of the superoutburst. The maximal brightness of 12.5 mag was reported by Schmeer (2003) on Feb. 21.199 UT. Previous estimates of the brightness of QW Ser were made a week earlier and found the star in quiescence. Presence of the clear superhumps with an amplitude as high as 0.23 mag during our first run on Feb. 23/24 may suggest that Schmeer's observations correspond to the real beginning of the superoutburst. Thus our first observing run is most probably the fourth night of the superoutburst.

Our observations from Mar. 07/08 catch the star around minimum light. Observations by Dubovsky (2003) made on Mar. 7.099 UT indicate that the brightness of QW Ser was then at a magnitude of 15.1 i.e. about two magnitudes brighter than our determination from the subsequent night. Thus we conclude that the superoutburst of QW Ser lasted until Mar. 07/08 i.e. 15 days.

Figure 3 shows the light curves of QW Ser during four consecutive nights of the February 2003 superoutburst. The superhumps are clearly visible in each run. Their amplitude is 0.23, 0.21, 0.18 and 0.16 mag from the first to fourth night, respectively.

The lights curves of the eight longest runs from the period Mar. 07/08 – May 04/05 are displayed in Fig. 4. The magnitude of the star varied during this interval with an amplitude sometimes exceeding 0.5 mag, thus suggesting the presence of a periodic signal in the data (see Sect. 5).

4. Superhumps

From each light curve of QW Ser in superoutburst we removed the first or second order polynomial and analyzed them using ANOVA statistics and two harmonic Fourier series

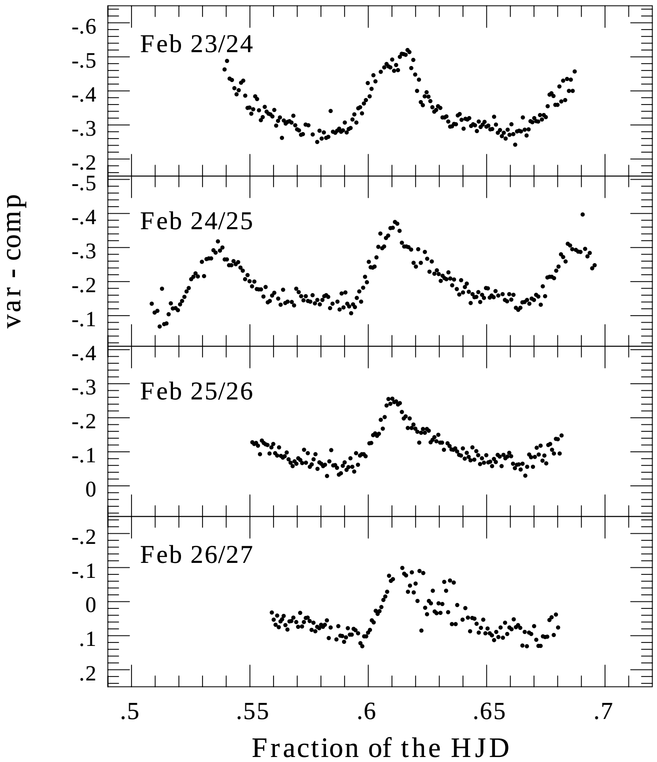

Fig. 3. The light curves of QW Ser observed during four consecutive nights in February 2003.

(Schwarzenberg-Czerny 1996). The resulting periodogram is shown in Fig. 5. The most prominent peak is found at a frequency of $f = 12.98 \pm 005$ c/d, which corresponds to the period $P_{sh} = 0.07704(30)$ days (110.9 ± 0.4 min). The peak visible at 6.5 c/d is a ghost of the main frequency arising due to the use of two harmonics. The harmonic peak at 26 c/d appears to be real. The inset in Fig. 5 shows the magnification of the power spectrum around the main frequency. Apart from this main peak and its aliases the inset shows no other significant periodicities.

The light curves of QW Ser in superoutburst were prewhitened with the main period and its first harmonic. The power spectrum of the resulting light curve shows no clear peaks except second, third and fourth harmonics of the main frequency.

For nights from the superoutburst we determined six times of maxima and nine times of minima of the superhumps. They are shown in Table 2 together with their cycle numbers E. The least squares linear fit to the data from Table 2 gives the following ephemeris for the maxima:

$$\mathrm{HJD}_{\mathrm{max}} = 2\,452\,694.6154(24) + 0.07674(13) \cdot E \qquad (1)$$

and for the minima:

$$\mathrm{HJD}_{\mathrm{min}} = 2\,452\,694.5829(27) + 0.07726(11) \cdot E. \qquad (2)$$

Combination of both O–C determinations of the period with its value derived from the power spectrum analysis gives the mean value of the superhump period as equal to $P_{sh} = 0.07703(4)$ days i.e. 110.92 ± 0.06 min.

The O–C departures from the ephemeris (1) and (2) are given also in Table 2. They show no clear trend, thus we

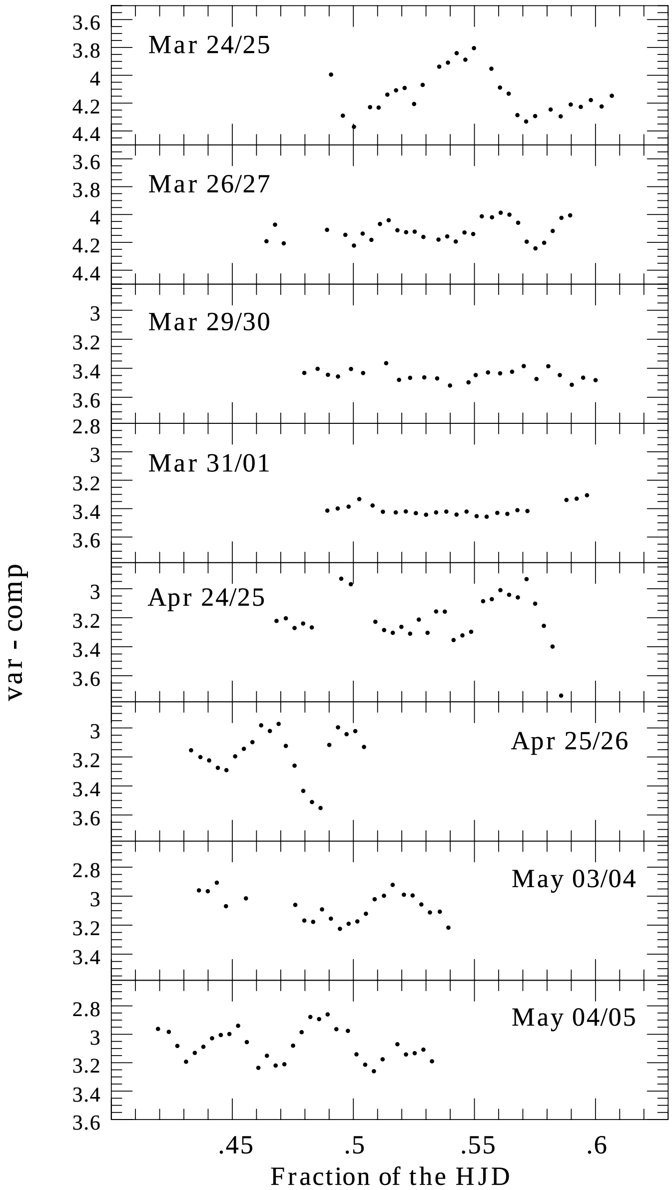

Fig. 4. The light curves of QW Ser observed during the eight longest runs from period Mar. 07/08–May 04/05.

Table 2. Times of extrema in the light curve of QW Ser in February 2003.

Maxima			Minima		
E	HJD	O–C	E	HJD	O–C
0	694.617	0.021	0	694.580	−0.037
12	695.536	0.003	1	694.661	0.011
13	695.612	−0.019	12	695.513	0.039
14	695.685	−0.062	13	695.593	0.074
26	696.610	−0.008	14	695.663	−0.020
39	697.613	0.062	26	696.589	−0.034
			27	696665	−0.051
			39	697.598	0.019
			40	697.671	−0.030

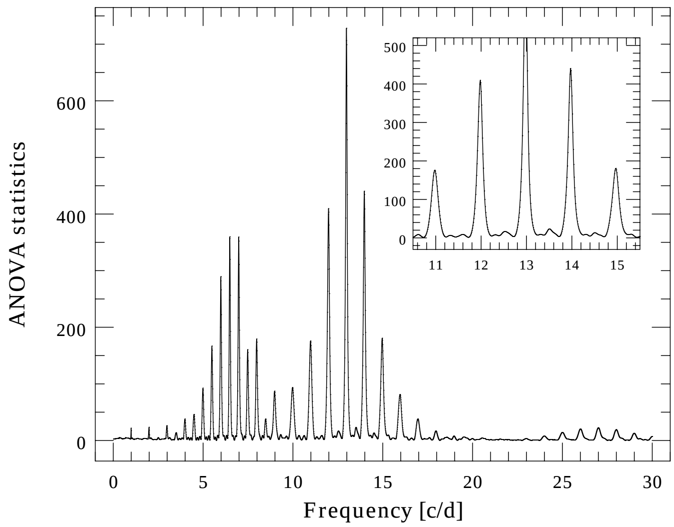

Fig. 5. ANOVA power spectrum of the light curve of QW Ser. The inset shows the magnification of the power spectrum around main frequency.

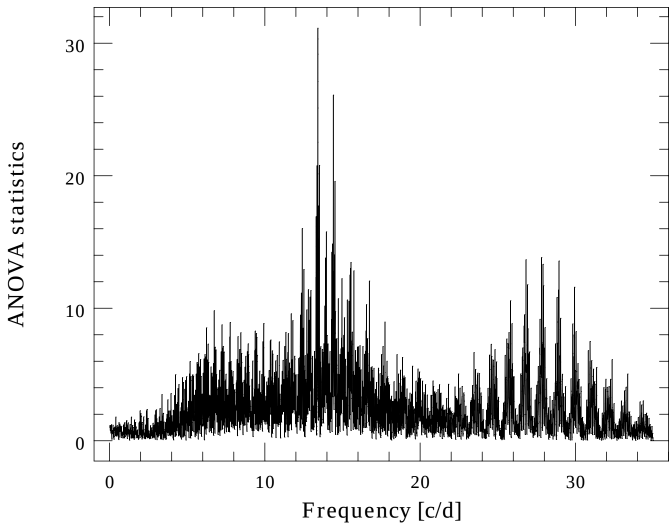

Fig. 6. ANOVA power spectrum of the light curve of QW Ser from the period Mar. 07/08 – May 04/05.

conclude that our observational coverage of the superoutburst was too weak for a valuable determination of the superhump period derivative.

5. Quiescence

During the period Mar 07/08–May 04/05 QW Ser was observed in a minimum light of around 17 mag. The ANOVA power spectrum for this period is shown in Fig. 6. Before calculation, the light curves were prewhitened using the first order polynomial.

The resulting periodogram yields a clear peak at a frequency of $f = 13.410 \pm 0.003$ c/d, which corresponds to a period of $P = 0.07457(2)$ days (107.38 ± 0.03 min).

A significant group of high peaks is also visible close to the first harmonic of the main period at a frequency around 26.8 c/d. It is due to the shape of the light curve, which often displayed a double wave structure (see Fig. 4 and nights Mar. 26/27, Apr. 5/26 and May 04/05, for example).

We have prewhitened our original light curve of QW Ser using the main periodicity and its first harmonic. The power spectrum of the resulting light curve shows no significant peaks in the period range of 0–50 c/d indicating that in quiescence QW Ser is a monoperiodic object.

6. Discussion

The first detection of superhumps with a period of $P_{\rm sh} = 0.07703(4)$ during the 2003 superoutburst of QW Ser unambiguously proves that this star belongs to the group of SU UMa-type dwarf novae.

Superhumps occur at a period slightly longer than the orbital period of the binary system. They are most probably a result of the accretion disc precession caused by the gravitational perturbations from the secondary. These perturbations are most effective when the disc particles moving on eccentric orbits enter the 3:1 resonance. Then the superhump period is simply the beat period between orbital and precession rate periods:

$$\frac{1}{P_{\rm sh}} = \frac{1}{P_{\rm orb}} - \frac{1}{P_{\rm prec}}. \tag{3}$$

The precession rate of the eccentric disc was first discussed by Osaki (1985). Based on a nonresonant free-particle orbit at the disk edge he derived the following expression for the precession rate:

$$\frac{P_{\rm orb}}{P_{\rm prec}} = \frac{3}{4}\frac{q}{\sqrt{1+q}}\left(\frac{R}{a}\right)^{3/2} \tag{4}$$

where a is the binary separation, R is the disc radius and q is the mass ratio M_2/M_1. At the 3:1 resonance we can assume that $R \approx 0.46a$ and hence:

$$\frac{P_{\rm orb}}{P_{\rm prec}} \approx \frac{0.233q}{\sqrt{1+q}}. \tag{5}$$

Defining the period excess ϵ as:

$$\epsilon = \frac{\Delta P}{P_{\rm orb}} = \frac{P_{\rm sh} - P_{\rm orb}}{P_{\rm orb}} \tag{6}$$

from Eq. (5) we can simply derive the relation between the period excess and the mass ratio:

$$\epsilon \approx \frac{0.23q}{1+0.27q}. \tag{7}$$

From the observational point of view it was first noticed by Stolz & Schoembs (1984) that ϵ grows with $P_{\rm orb}$. This relation is not only obeyed by the ordinary SU UMa stars but also by the permanent superhumpers (Skillman & Patterson 1993).

Figure 7 shows the Stolz & Schoembs relation for 44 ordinary SU UMa-type stars (open circles) and 10 stars other than dwarf novae (filled circles). Data for this graph are taken from Patterson (1998) and the newest alerts published in the VSNET archive.

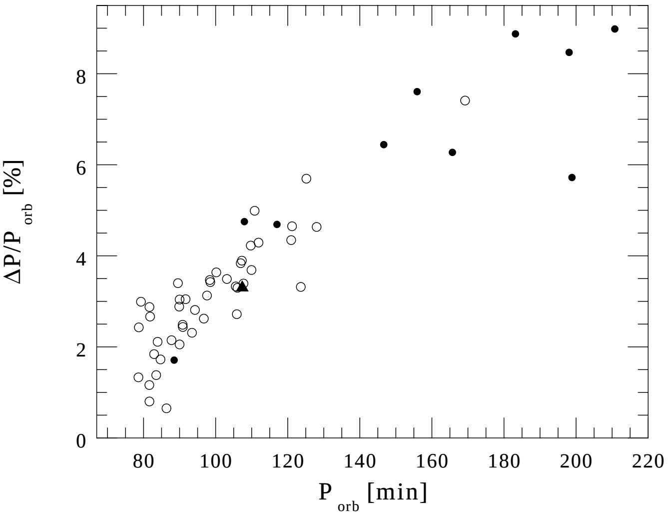

Fig. 7. Stolz & Schoembs relation for 44 ordinary SU UMa stars (open circles) and 10 stars other than dwarf novae (filled circles). The position of QW Ser is denoted by the solid triangle.

The double wave structure of brightness modulations observed in QW Ser during quiescence and the period of these modulations, which is slightly shorter than the superhump period, strongly suggests that we have detected the orbital period of the binary system. Double humped waves characterized by the orbital period of the binary are observed in some SU UMa stars with high inclinations of orbit (see for example WZ Sge, AL Com and V485 Cen – Patterson et al. 1996, 1998; Olech 1997). The period excess for QW Ser is then $\epsilon = 0.033 \pm 0.006$. According to the Eq. (7) this corresponds to the mass ratio $q = 0.15$.

In Fig. 7 QW Ser is plotted using a filled triangle. Error bars are of the same size as the symbol. It is clear that both periods observed in the light curve of this star conform to the Stolz & Schoembs relationship. This is a strong argument for our interpretation that modulations observed in quiescence are connected to the orbital period of the binary system.

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