Abstract. We report extensive photometry of the dwarf nova QW Ser throughout its 2003 February superoutburst till quiescence. During the superoutburst the star displayed clear superhumps with a mean period of $P_{sh} = 0.07703(4)$ 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 – binaries: close – novae, cataclysmic variables
Curious Variables Experiment (CURVE).
CCD Photometry of QW Serpentis in Superoutburst and Quiescence

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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 2449620, 2449716 and 2450906. 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 superoutburst 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 2003 February outburst of QW Ser was reported by Muyllaert (2003), who caught the star at a magnitude of 12.6 on 2003 Feb. 23.715 UT. Reported at a later date observations of Schmeer (2003) indicated that 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 Tektronix 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 and 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 filter to shorten the exposures in order to minimize guiding errors.

The exposure times were from 60 to 90 seconds during the bright state and from 200 to 350 seconds 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.

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All the data reductions were performed using a standard procedure based on the IRAF \textsuperscript{1} package and the profile photometry has been derived using the DAOPhotII package (Stetson 1987).

\textsuperscript{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.
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 (R.A. = 15°26′18.1″, Decl. = +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.

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

Fig. 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 photographic magnitude of our comparison star equal to 13.59 ± 0.40 mag and taken from GSC Catalog (Lasker et al. 1999). Additionally, open circles denote the visual and CCD estimates made by astronomy amateurs and published in the VSNET mailing list. Our transformation of "white light" observations is based on the photographic magnitude of the comparison star and we would like to point out that it is a rough estimate, which is used only for showing the general behavior of the star. The true brightness of the QW Ser may differ even by about 0.5 magnitude from this one 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 a 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 subsequent night. Thus we conclude that superoutburst of QW Ser lasted until Mar. 07/08 i.e. 15 days.

Fig. 3 shows the light curves of QW Ser during four consecutive nights of the 2003 February 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 light 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 the periodic signal in the data (see Sec. 5).

4. Superhumps

From each light curve of QW Ser in superoutburst we removed the first or second order polynomial and then analyzed them using ANOVA statistics and two harmonics Fourier series (Schwarzenberg-Czerny 1996). The resulting periodogram is shown in Fig. 5. The most prominent peak is found at a frequency of $f = 12.98 \pm 0.05$ 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...
Combination of both $O - C$ determinations of the period with its value derived from the power spectrum analysis gives the mean value of 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 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 the calculation the light curves were prewhitened using the first order polynomial.

The resulting periodogram yields a clear peak at a frequency of $f = 13.410 ± 0.003$ 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 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. 25/26 and May 04/05, for example).

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

### 6. Discussion

The first detection of the superhumps with a period of $P_{sh} = 0.07703(4)$ 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 the eccentric orbits enter the 3:1 resonance. Then the superhump period is simply the beat period between orbital and precession rate periods:

$$ \frac{1}{P_{sh}} = \frac{1}{P_{orb}} - \frac{1}{P_{prec}} $$

(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:

$$ \frac{P_{orb}}{P_{prec}} = \frac{3}{4} \frac{q}{\sqrt{1 + q}} \frac{R}{a}^{3/2} $$

(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:

$$ \frac{P_{orb}}{P_{prec}} \approx \frac{0.235q}{\sqrt{1 + q}} $$

(5)

Defining the period excess $\epsilon$ as:

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

(6)

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

$$ \epsilon \approx \frac{0.235q}{\sqrt{1 + q}} $$

(7)

From the observational point of view it was first noticed by Stolz & Schoembs (1984) that $\epsilon$ grows with $P_{orb}$.
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.

It fact this relation is not only obeyed by the ordinary SU UMa stars but also by the permanent superhumpers (Skillman & Patterson 1993).

Fig. 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 newest alerts published in the VSNET archive.

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 suggest that we 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 inclination of the orbit (see for example WZ Sge, AL Com and V485 Cen - Patterson et al. 1996, 2002, Olech 1997). The period excess for QW Ser is then \( \epsilon = 0.033 \pm 0.006 \). According to the equation (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 stars conform to the Stolz & Schoembs relationship. This is a strong argument for our interpretation that modulations observed in quiescence are connected with the orbital period of the binary system.

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