A New SU UMa-Type Dwarf Nova, QW Serpentis (= TmzV46)

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Abstract

We report on the results of the QW Ser campaign which has been continued from 2000 to 2003 by the VSNET collaboration team. Four long outbursts and many short ones were caught during this period. Our intensive photometric observations revealed superhumps with a period of 0.07700(4) d during all four superoutbursts, proving the SU UMa nature of this star. The recurrence cycles of the normal outbursts and the superoutbursts were measured to be ~50 days and 240(30) days, respectively. The change rate of the superhump period was \(-5.8 \times 10^{-5}\). The distance and the X-ray luminosity in the range of 0.5-2.4 keV are estimated to be 380(60) pc and \(\log L_X = 31.0 \pm 0.1\) erg s\(^{-1}\). These properties have typical values for an SU UMa-type dwarf nova with this superhump period.

Key words: accretion, accretion disks — stars: novae, cataclysmic variables — stars: dwarf novae — stars: individual (QW Ser)

1. Introduction

Cataclysmic variable stars (CVs) are a group of binary stars consisting of a white dwarf (primary star) and a late-type secondary star (for a thorough review, Warner 1995a). Surface gas of the secondary pouring out from its Roche lobe via the inner Lagrange point is transferred to the primary. The gas is accreted by the white dwarf through an accretion disk in usual CVs.

Dwarf novae are a class of CVs, repeatedly showing large amplitude variations of brightness (2–8 mag) due to changes of the physical status of the accretion disk. SU UMa-type dwarf novae, which originally defined by (Warner 1985), give rise to two types of outbursts: normal outbursts and long lasting superoutbursts. Superhumps are small-amplitude modulations characteristic to SU UMa stars which are observed only during the superoutburst. Prograde precession of the eccentric accretion disk due to the tidal influence has been attributed to the cause of the superhump phenomenon (Whitehurst 1988). The thermal-tidal disk instability model is the currently standard model for the dwarf nova-type outbursts, and has succeeded in reproducing the basic properties of various types of the brightness variation in dwarf novae including SU UMa stars (for a review, see Osaki 1996; for an example of two-dimensinal simulations, Truss et al. 2001). Observations of dwarf novae are, however, still producing problems which challenge the current model.
QW Ser was discovered by Takamizawa (1998) who detected four positive detections in his photographic film collection. He designated this variable star as TmzV46, and suggested it to be a possible dwarf nova, based on its blue color in the USNO A1.0 catalog. Schmeer (1999) detected an outburst at 1999 Oct. 4.114 (UT), confirming the dwarf nova classification. Tracing this outburst, Kato, Uemura (1999) revealed that the outburst duration was between 11 d and 16 d and the decline rate was 0.10 mag d$^{-1}$. Kazarovets et al. (2000) finally gave TmzV46 the permanent variable star name, QW Ser.

QW Ser is identified with USNO B1.0 0983-0296263 ($B1 = 17.57, R1 = 17.44, B2 = 18.20, R2 = 17.42$). The proper motion of this star is listed as ($\mu_{\text{RA}}, \mu_{\text{Dec}}) = (-4(2), -40(2))$ in a unit of mas yr$^{-1}$. QW Ser is also identified with the X-ray source 1RXS J152613.9+081845 (Voges et al. 2000), which has a 52–201 keV count rate of 0.045(18) count s$^{-1}$.

We in this paper report on our observations during four long outbursts in 2000, 2001, 2002, and 2003, which unveiled the SU UMa nature of QW Ser. The next section mentions the observations, and the section 3 describes the details of our observational results. The characteristics of QW Ser will be discussed in the section 4.

2. Observation

The observations were carried out at nine sites with ten sets of instruments. The log of the observations and the instruments are summarized in Table 1. Figure 1 is a finding chart where the local comparison stars used are marked.

The Kyoto and Okayama frames were processed by the PSF photometry package developed by one of the authors (TK) after dark-subtraction and flat-fielding. All the frames obtained at Hida were reduced by the aperture photometry package in IRAF, after de-biasing and flat-fielding. All frames obtained at the CBA Concord and Rome were reduced by aperture photometry after dark subtraction and flat-fielding, using the AIP4WIN software by Berry and Burnell and the QMiPS32 software, respectively. The Crimean images were dark-subtracted, flat-fielded, and analyzed with the profile/aperture photometry package developed by Vitalij P. Goranskij. PSF photometry of the Brno data were performed, using the package Munidos which is based on Daophot II.

The magnitude scale was calibrated using the Henden&Sumner sequence, and all the data were adjusted to match the $V$-band data obtained at Tsukuba and Crimea. The heliocentric correction was applied to the observation times before the following analyses.

1 IRAF is distributed by the National Optical Astronomy Observatories for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.

2 (http://www.willbell.com/aip/index.htm)

3 (http://munipack.astronomy.cz)

4 (ftp://ftp.nofs.navy.mil/pub/outgoing/aah/sequence/summer/qwser.seq)

Fig. 1. Finding chart of QW Ser generated by the astronomical image-data server operated by the National Astronomical Observatory of Japan, making use of Digital Sky Survey 2. North is up, and East is left. The comparison stars used are given their numbers, which are identical with those in Table 1.

3. Result

The campaigns of time-resolved photometry were conducted during four superoutbursts which occurred in 2000 July, 2001 February, 2002 June, and 2003 February. In this section, we describe the detailed results of four campaigns separately.

3.1. The 2000 July superoutburst

The first superoutburst was noticed by P. Schmeer at 2000 July 5.941 (UT). We started observations on July 6, the day when we received the outburst report.

The long-term light curve of the 2000 July superoutburst is drawn in figure 2. The superoutburst lasted for 15 days, and QW Ser declined by an almost constant rate of 0.086 mag d$^{-1}$ during the plateau phase. Then, the variable entered the rapid decline phase of a rate of 1.2 mag d$^{-1}$. While we could not detect a rebrightening, QW Ser seemed to remain about $V = 17.0$ for at least a few days after the superoutburst.

Daily light curves are shown in figure 3. The data obtained on 2000 July 6, the first night of our observations, clearly shows superhumps with an amplitude of 0.16 mag, which first proved the SU UMa nature of this dwarf nova. The superhumps had developed within 2 days from the onset of the outburst (figure 2). The amplitude of the superhumps continued to increase to 0.35 mag by July 8, and then started to decline. The amplitude, however, again developed to 0.26 mag by July 13, and seemed to decline, suggesting the timescale of the variation of the
## Table 1. Log of observations.

| Date          | HJD-2400000 Start-End | Exposure Time (s) | Frame Number | Comp. filter | Instrument | Star* |
|---------------|------------------------|-------------------|--------------|--------------|------------|-------|
| 2000 July 6   | 51732.334–51732.516   | 30                | 297          | 5            | $R_c$      | N     |
| 51732.347–51732.431 | 90               | 64              | 2            | $R_j$        | P         |       |
| 7            | 51733.299–51733.394   | 60                | 60           | 2            | $R_j$      | P     |
| 8            | 51733.952–51734.082   | 30                | 62           | 2            | $V$        | K     |
| 51734.411–51734.508 | 20               | 284             | 2            | no Ma        |           |       |
| 51734.280–51734.301 | 60               | 21              | 2            | $R_j$        | P         |       |
| 9            | 51735.077–51735.118   | 60                | 49           | 2            | $V$        | K     |
| 51735.354–51735.482 | 20               | 380             | 5            | no Ma        |           |       |
| 10           | 51735.948–51736.087   | 60                | 164          | 2            | $V$        | K     |
| 11           | 51737.304–51737.339   | 60                | 35           | 2            | $V$        | P     |
| 51737.406–51737.498 | 30               | 232             | 5            | $R_c$        | N         |       |
| 12           | 51737.970–51738.035   | 60                | 77           | 2            | $V$        | K     |
| 51738.296–51738.382 | 60               | 94              | 2            | $V$        | P         |       |
| 51738.346–51738.500 | 50               | 195             | 5            | $R_c$        | N         |       |
| 13           | 51739.295–51739.380   | 100               | 61           | 2            | $V$        | P     |
| 51739.326–51739.509 | 50               | 230             | 5            | $R_c$        | N         |       |
| 14           | 51740.284–51740.379   | 100               | 70           | 2            | $V$        | P     |
| 15           | 51740.717–51740.790   | 16                | 240          | 2            | no C       |       |
| 51741.281–51741.352 | 100              | 46              | 2            | $V$        | P         |       |
| 16           | 51742.319–51742.394   | 60                | 85           | 2            | $R_j$      | P     |
| 17           | 51743.330–51743.338   | 100               | 3            | 2            | $R_j$      | P     |
| 18           | 51745.328–51745.381   | 100               | 37           | 2            | $R_j$      | P     |
| 19           | 51746.292–51746.304   | 200               | 3            | 2            | $R_j$      | P     |
| 20           | 51747.277–51747.315   | 100               | 21           | 2            | $R_j$      | P     |
| 21           | 51748.356–51748.357   | 100               | 1            | 2            | $R_j$      | P     |
| 22           | 51750.326–51750.346   | 200               | 9            | 2            | $R_j$      | P     |
| 23           | 51751.275–51751.285   | 200               | 4            | 2            | $R_j$      | P     |
| 24           | 51752.287–51752.302   | 200               | 5            | 2            | $R_j$      | P     |
| 25           | 51753.287–51753.310   | 200               | 8            | 2            | $R_j$      | P     |
| 26           | 51754.268–51754.283   | 200               | 7            | 2            | $R_j$      | P     |
| 27           | 51755.269–51755.293   | 200               | 10           | 2            | $R_j$      | P     |
| 28           | 51756.271–51756.279   | 200               | 4            | 2            | $R_j$      | P     |
| 29           | 51757.326–51758.346   | 200               | 9            | 2            | $R_j$      | P     |
| 2001 Feb. 10 | 51951.232–51951.349   | 60                | 135          | 2            | $V$        | K     |
| 11           | 51951.478–51951.725   | 60                | 232          | 2            | $R_c$      | N     |
| 12           | 51952.537–51952.764   | 45                | 232          | 6            | $R_c$      | N     |
| 2002 June 2  | 52428.078–52428.257   | 30                | 340          | 1            | no O25      |       |
| 52428.102–52428.180 | 15               | 254             | 1            | no T         |           |       |
| 3            | 52428.999–52429.227   | 14                | 760          | 2            | no M        |       |
| 52429.054–52429.174 | 30               | 255             | 1            | no O25       |           |       |
| 52429.092–52429.243 | 15               | 628             | 1            | no T         |           |       |
| 52429.140–52429.284 | 30               | 331             | 1            | no O30       |           |       |
| 4            | 52430.087–52430.214   | 30                | 239          | 1            | no O30      |       |
| 52430.128–52430.236 | 30               | 193             | 1            | no O25       |           |       |
| 5            | 52431.036–52431.178   | 10                | 1450         | 1            | no T        |       |
| 6            | 52431.960–52432.059   | 30                | 200          | 3            | $V$        | K     |
| 52431.991–52432.260 | 14               | 904             | 2            | no M         |           |       |
| 52432.038–52432.238 | 30               | 475             | 1            | no O25       |           |       |
| 7            | 52432.998–52433.074   | 30                | 175          | 3            | $V$        | K     |
| 9            | 52435.028–52435.170   | 10                | 539          | 4            | no H        |       |
| 52435.058–52435.236 | 10               | 871             | 1            | no T         |           |       |
| 10           | 52441.020–52441.027   | 20                | 31           | 1            | no O30      |       |
| 15           | 52441.334–52441.335   | 120               | 1            | 2            | $R_j$      | P     |
| 16           | 52441.984–52442.000   | 30                | 29           | 1            | no O25      |       |
| 52442.326–52442.331 | 120              | 2              | 2            | $R_j$      | P         |       |
Table 1. (continued)

| Date | HJD-2400000 | Exposure Time (s) | Frame Number | Comp. Star* | filter | Instrument† |
|------|-------------|-------------------|--------------|------------|--------|-------------|
| 2002 June 20 | 52446.315–52446.322 | 120 | 4 | 2 | $R_{1}$ | P |
| 21 | 52447.311–52447.309 | 60 | 6 | 2 | $R_{2}$ | P |
| 22 | 52448.310–52448.317 | 120 | 5 | 2 | $R_{3}$ | P |
| 23 | 52449.307–52449.312 | 120 | 3 | 2 | $R_{1}$ | P |
| 25 | 52452.308–52452.306 | 240 | 3 | 2 | $R_{1}$ | P |
| 29 | 52456.330–52456.333 | 120 | 2 | 2 | $R_{1}$ | P |
| July 2 | 52457.983–52457.990 | 30 | 15 | 1 | no | O30 |
| 2003 Feb. 24 | 52695.151–52695.375 | 30 | 214 | 1 | no | O25 |
| 25 | 52696.193–52696.372 | 30 | 325 | 1 | no | O25 |
| 27 | 52696.169–52696.220 | 30 | 111 | 2 | no | H |
| 28 | 52698.181–52698.346 | 30 | 307 | 1 | no | O25 |
| 29 | 52698.192–52698.294 | 40 | 214 | 2 | no | K |
| Mar. 5 | 52704.153–52704.245 | 30 | 98 | 1 | no | O25 |

*Comparison star 1: HD 137532 (a close double star of combined $V$ ∼ 9.7, noted in the Henden&Sumner (H&S) sequence, 2: $V=13.411(6)$ and $B-V=0.673(4)$ in the H&S sequence (ID 4), 3: $V=13.120(12)$ and $B-V=0.722(13)$ (ID 3), 6: $V=14.599(0)$ and $B-V=0.638(5)$ (ID 7)

†Instrument N: 40-cm telescope + ST-7 (Brno, Czech), P: 38-cm Telescope + SBIG ST-7 (Crimea, Ukraine), J: 25-cm telescope + Apogee AP-7 (Tsukuba, Japan), M: 28-cm telescope + SBIG ST-7 (Ceccano, Italy), C: 44-cm telescope + Genesis 16#90 (KAF 1602e) (California, USA), O25: 25-cm telescope + SBIG ST-7/ST-7E (Kyoto, Japan), T: 30-cm telescope + SBIG ST-9E (Okayama, Japan), O30: 30-cm telescope + SBIG ST-7/ST-7E (Kyoto, Japan), M: 25-cm telescope + SBIG ST-7 (Okayama, Japan), H: 60-cm telescope + PixCellent S/T 00-3194 (SITe 003AB) (Hida, Japan)

In the light curve of July 9, a 0.25-mag flare with a timescale of about 15 min was present before the superhump maximum around a fraction of HJD of 0.4. The light curve of a local check star relative to the comparison star did not show a special feature around that time.

After subtraction of the linear decline trend, we performed the period analysis using the Phase Dispersion Minimization (PDM) method (Stellingwerf 1978) for the data obtained in July 6–17. The resultant Θ diagram (figure 4) indicates 0.076978(8) d ($f = 12.9907(14)$ cycle d$^{-1}$) to be the best estimated average superhump period ($P_{SH}$). The error of the period was estimated using the Lafleur-Kinman class of methods, as applied by Fernie (1989). The lower panel of figure 4 displays the average superhump light curve which was yielded by folding the detrended light curves by the superhump period.

The timings of the superhump maxima were extracted by fitting the average superhump light curve in figure 4. Table 2 lists the results. The cycle count was set to 1 at the first superhump maximum observed on July 6. Linear regression of the superhump maximum timings yields the following equation:

$$HJD_{\text{max}} = 32.3210(13) + 0.076963(18) \times E.$$  \hspace{1cm} (1)

Figure 5 and table 2 show the results of subtraction of the calculated maximum timings by equation (1) from the observed ones ($O-C1$). The values of $O-C1$ are fitted to the following quadratic polynomial:

$$O - C1 = 0.0017(5) - 1.2(1.2) \times 10^{-5}(E - 60)$$

superhump amplitude to be 5 days. The rise of the superhump gradually but steadily became steeper by July 13, and seemed to get more gradual after that. We can not see a sign of emergence of the secondary hump until July 14, the 9th day of the superoutburst.

![Fig. 2. Long-term light curve of the 2000 superoutburst. The filled squares and down arrows are the visual (or CCD) observations and the upper limits reported to VSNET. The abscissa is JulianDay − 2451700, and the ordinate is Visual(V) magnitude. The open circles with the error bars indicate the daily mean V magnitudes of our data and their standard deviations.](image-url)
Fig. 3. Daily light curves of the 2000 superoutburst during the plateau phase. Each daily dataset is shifted by +0.4 mag. The superhump had already grown to 0.16 mag by July 6, within 2 days from the superoutburst onset. The superhump amplitude increased to 0.35 mag by July 8, then decreased. However, it again increased to 0.26 mag by July 13, then seemed to decrease again. On July 9, we can see a flare of 0.25 mag with a time scale of ∼15 min beside a superhump maximum around a fraction of HJD of 0.4.

Fig. 4. (upper panel) Theta diagram obtained by a PDM period analysis for the data obtained in July 6–17. The best estimated superhump period is 0.076978(8) d (12.9908(13) cycle d⁻¹). (lower panel) The superhump light curve folded by that period.

Fig. 5. O–C diagram of the superhump maximum timings during the 2000 superoutburst. The data is listed in the column O–C1 in table 2. The solid curve represents the quadratic polynomial obtained by fitting the O–C values (equation (2)), showing that the superhump period decreased with a rate of \( P_{SH}/P_{SH} = -4.2(0.8) \times 10^{-5} \).

Table 2. Timings of the superhump maxima during the 2000 July superoutburst.

| HJD−2451700 | E   | O–C1⁺   | O–C2†   |
|-------------|-----|---------|---------|
| 32.3969(08) | 1   | −0.0010 | 0.0021  |
| 32.4711(11) | 2   | −0.0038 | −0.0008 |
| 34.4756(14) | 28  | −0.0003 | −0.0008 |
| 35.0930(15) | 36  | 0.0014  | 0.0003  |
| 35.3995(10) | 40  | 0.0000  | −0.0013 |
| 36.1699(29) | 50  | 0.0008  | −0.0009 |
| 36.3238(36) | 52  | 0.0008  | −0.0009 |
| 37.4201(14) | 66  | 0.0015  | −0.0001 |
| 37.4771(35) | 67  | −0.0004 | −0.0020 |
| 38.0175(15) | 74  | 0.0016  | 0.0004  |
| 38.3256(11) | 78  | 0.0015  | 0.0005  |
| 38.4054(10) | 79  | 0.0044  | 0.0035  |
| 38.4782(17) | 80  | 0.0002  | −0.0006 |
| 39.3244(10) | 91  | −0.0002 | −0.0000 |
| 39.4033(09) | 92  | 0.0017  | 0.0020  |
| 39.4788(09) | 93  | 0.0003  | 0.0007  |
| 40.3235(08) | 104 | −0.0016 | 0.0003  |
| 41.3190(09) | 117 | −0.0066 | −0.0024 |

⁺ Using equation (1).
† Using equation (2).

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\frac{P_{SH}}{P_{SH}} = -4.2(0.8) \times 10^{-5}.
\]

This curve is also drawn in figure 5. The derived index of the quadratic term means that the superhump period decreased with a rate of \( P_{SH}/P_{SH} = -4.2(0.8) \times 10^{-5} \). Note that the superhump period seemed constant in \( E = 35–95 \).
3.2. The 2001 February superoutburst

The data available via the VSNET data browser around the 2001 February superoutburst are 13.2 mag at 2001 January 25.229 (UT), 16.9 mag at 30.86 (UT), and 13.5 mag at February 12.46 (UT). No upper-limit was reported to VSNET during this period. We carried out time-resolved photometry on February 10, 11, and 12. All the data are represented in figure 6. We can see obvious superhumps above the noise level of each dataset. Thus this outburst was surely a superoutburst. The positive detection on January 25 was probably a precursor of this superoutburst.

3.3. The 2002 June superoutburst

This outburst was caught by Rod Stubbings at 2002 May 29.410 (UT) at $m_{\text{vis}} = 13.2$. We started follow-up observations 5 days later. The long-term light curve is presented in figure 7. QW Ser faded with a rate of 0.13 mag d$^{-1}$ between HJD 2452428 and 2452433, but appeared to remain at the same brightness between HJD 2452433 and 2452435. After the superoutburst lasted 14 days, QW Ser remained about $V \sim 17.0$ for at least two weeks.

The superhumps were caught in all the dataset of each night (figure 8). We subtracted a linear decline trend of 0.13 mag d$^{-1}$ from the plateau-phase data, and corrected the second-order color effect of each night run. After this pre-whitening, we analyzed the data by the PDM method. The resultant $\Theta$ diagram and the averaged superhump light curve are in figure 9. The best estimated superhump period of 0.076967(13) d is equal to that in the 2000 superoutburst within the statistical error.

The superhump maximum timings were measured in the way for the 2000 superoutburst, and listed in Table 3. The cycle count was set to 1 at the first superhump maximum observed on June 2. The equation deduced by

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5 [http://vsnet.kusastro.kyoto-u.ac.jp/vsnet/etc/searchobs.html](http://vsnet.kusastro.kyoto-u.ac.jp/vsnet/etc/searchobs.html)
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Figure 9. (upper panel) Theta diagram obtained by a PDM period analysis for the data obtained in 2002 July 2–9. The best estimated superhump period is 0.076967(13) d (12.9926(22) cycle d$^{-1}$). (lower panel) The superhump light curve folded by that period.

Table 3. Timings of the superhump maxima during the 2002 June superoutburst.

| HJD$-2452400$ | E   | O$-C^3$  | O$-C^4$  |
|----------------|-----|----------|----------|
| 28.1587(14)   | 1   | -0.0012  | 0.0017   |
| 28.3459(32)   | 2   | -0.0009  | 0.0018   |
| 29.0834(08)   | 13  | 0.0007   | 0.0010   |
| 29.1581(09)   | 14  | -0.0015  | -0.0014  |
| 29.2357(15)   | 15  | -0.0008  | -0.0009  |
| 30.1533(21)   | 27  | -0.0060  | -0.0078  |
| 31.0836(08)   | 39  | 0.0015   | -0.0012  |
| 32.0085(24)   | 51  | 0.0036   | 0.0009   |
| 32.0902(23)   | 52  | 0.0084   | 0.0057   |
| 32.1631(25)   | 53  | 0.0044   | 0.0017   |
| 35.0760(21)   | 91  | -0.0049  | -0.0021  |
| 35.1550(25)   | 92  | -0.0028  | 0.0002   |

* Using equation (3).
† Using equation (4).

Figure 10 and table 3 show the results of subtraction of the calculated maximum timings by equation (3) from the observed ones (O$-C^3$). Fitting of the O$-C^3$ by a quadratic polynomial converges to

$$O - C^3 = 0.0028(16) + 0.2(3.3) \times 10^{-5}(E - 46) - 2.8(1.2) \times 10^{-6}(E - 46)^2.$$  \hspace{1cm} (4)

This curve is also drawn in figure 10. The $P_{SH}$ decrease rate calculated from the index of the quadratic term in this equation is $P_{SH}/\dot{P}_{SH} = -7.3(3.1) \times 10^{-5}$. This rate is negative, which is indicative of the $P_{SH}$ decrease, and consistent with that observed during the 2000 superoutburst within the error.

3.4. The 2003 February superoutburst

Following the outburst detection ($m_{vis} = 12.6$) by E. Muylleart at 2003 February 23.215 (UT), we started photometric observations on February 24.

Figure 11 exhibits the long-term light curve of the 2003 July superoutburst. The decline rate derived our data was 0.11 mag d$^{-1}$. Then, the variable entered the rapid decline phase of a rate of 1.2 mag d$^{-1}$.

After prewhitening in the same way as for the data of the 2002 superoutburst, we performed the period analysis using the PDM method for the data obtained on February 24, 25, and 27 (figure 12). Although the short coverages of each dataset hinder us from distinguishing the true signal from its aliases, we can safely choose the genuine $P_{SH}$.
of $0.077037(37)$ d ($f = 12.9807(62)$ cycle d$^{-1}$) from the superhump periods during the other superoutbursts. The lower panel of figure 12 presents the average superhump light curve during our observations of this superoutburst. The superhump maximum timings observed were insufficient to significantly deduce the change rate of $P_{SH}$.

4. Discussion

Table 4 summarizes the outbursts reported in Takamizawa 1998 and to VSNET and those detected by the All Sky Automated Survey (Pojmanski 2002). As the maximum magnitude of the 1999 superoutburst (12.2 mag) is suspected to be due to inaccuracy of magnitudes of comparison stars in a finding chart the observer used, the true superoutburst maximum should be around $V = 12.5$. Thus the superoutburst amplitude is $\sim 5.0$ mag. The maximum magnitude of the normal outburst is $V \sim 13.1$. The recurrence cycle of the normal outburst seems to have been rather stable around 50 days. If we assume that a superoutburst was missed around 2001 September, the recurrence cycle of the superoutburst (supercycle) has been also stable, about 220–270 d since 1999, while SU UMa stars showing variable outburst patterns have recently been discovered, such as MN Dra (Nogami et al. 2003b), DI UMa (Fried et al. 1999), SU UMa (Rosenzweig et al. 2000; Kato 2002), V1113 Cyg (Kato 2001), V503 Cyg (Kato et al. 2002a), and DM Lyr (Nogami et al. 2003a). The change rate of the superhump period was $-4.2(0.8) \times 10^{-5}$ during the 2000 superoutburst and $-7.3(3.1) \times 10^{-5}$ during the 2002 superoutburst. They agree with each other within the error.

The superhump period of 0.0770 d is near the mode of the $P_{SH}$ distribution (see e.g. Kolb, Baraffe 1999; Kato et al. 2003a). The delay of the superhump emergence was constrained to be within 2 days during the 2000 July superoutburst. This short delay is in accordance with the relatively long superhump period (see e.g. table 1 in Osaki 1996). All the values of the amplitude of the superoutburst, these outburst cycles, the $P_{SH}$ change rate, the superhump delay, the decline rates of 0.09–0.13 mag d$^{-1}$ during the plateau phase and of 1.2 mag d$^{-1}$ during the rapid decline phase are typical values for an SU UMa star having $P_{SH} = 0.07700$ d (see (Nogami et al. 1997; Kato 1998)). Note that we did not detect a significant change in the decline rate throughout the plateau phase, in contrast to that this rate is expected to become smaller with depletion of the gas in the outer disk (Camizzo 2001).

We can here estimate the distance to QW Ser by applying the relation between the orbital period ($P_{orb}$) and the absolute maximum brightness proposed by Warner (1987). The superhump period is used instead of $P_{orb}$, since the orbital period of QW Ser has not yet been measured and the superhump period is known to be only a few percent longer than $P_{orb}$. The error introduced by this is much smaller than other factors. Since the lack of eclipses in the light curve means that the inclination is not so high, the inclination effect to the observed flux (Warner 1986) should be negligible. The absolute maximum magnitude is thus expected to $M_V = 5.2 \pm 0.2$ from the Warner’s relation. Then the distance is estimated to be 380 ($\pm 60$) pc, taking into account that this maximum magnitude should be compared to the apparent maximum magnitude of the normal outburst in the case of SU UMa-type dwarf novae.
(cf. Kato et al. 2002b; Cannizzo 1998). This distance is smaller than the secure upper limit estimated using the proper motion of QW Ser and the maximum expected velocity dispersion of CVs (Harrison et al. 2000).

The X-ray luminosity in the range of 0.5-2.5 keV can be guessed to be $\log L_X = 31.0 \pm 0.1$ from the ROSAT data and the distance, making use of the formulation given by Verbunt et al. (1997). This luminosity is a little higher than, but not far from the average value of SU UMa stars, which is consistent with that QW Ser has typical properties for an SU UMa-type dwarf nova in other points.

The authors are very thankful to amateur observers for continuous reporting their valuable observations to VSNET. Thanks are also to the anonymous referee for useful comments. We used the data obtained by the All Sky Automated Survey project which are kindly opened into public. This work is partly supported by a Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists (MU and RI), and a grant-in-aid from the Japanese Ministry of Education, Culture, Sports, Science and Technology (No. 13640239, 15037205).

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