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The nature of V359 Centauri revealed: New long-period SU UMa-type dwarf nova

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Abstract. We detected four outbursts of V359 Cen (possible nova discovered in 1939) between 1999 and 2002. Time-resolved CCD photometry during two outbursts (1999 and 2002) revealed that V359 Cen is actually a long-period SU UMa-type dwarf nova with a mean superhump period of 0.08092(1) d. We identified its supercycle length as 307–397 d. This secure identification of the superhump period precludes the previously supposed possibility that V359 Cen could be related to a WZ Sge-type system with a long persistence of late superhumps. The outburst characteristics of V359 Cen are, however, rather unusual in its low occurrence of normal outbursts.

Key words. accretion, accretion disks – novae, cataclysmic variables – stars: dwarf novae – stars: individual: V359 Cen

1. Introduction

Cataclysmic variables (CVs) are close binary systems consisting of a white dwarf and a red dwarf secondary transferring matter via the Roche lobe overflow (for a review of CVs, see Warner 1995a). CVs are subdivided into several categories, including dwarf novae (DNe) and novae. Both DNe and novae are characterized by the presence of a sudden increase of brightness (outburst). Although the mechanisms of DN-type outbursts (cf. Osaki 1996) and nova outbursts (cf. Starrfield & Sparks 1987; Starrfield 1999; Starrfield et al. 2000) are different, observational discrimination between rarely outbursting DNe and novae can be sometimes difficult (see Downes & Margon 1981 and Kato et al. 2001b for classical and recent examples, respectively). Since rarely outbursting DNe can be easily confused with very fast novae, these confusions may have skewed our statistical view of classical novae (Downes 1986; Liller & Mayer 1987; Shafter 1997).

A large fraction of such confusions turned out to be SU UMa-type dwarf novae or WZ Sge-type dwarf novae (Kato et al. 2001b). SU UMa-type dwarf novae are a subclass of DNe. WZ Sge-type dwarf novae are still enigmatic, both in theory and to observations, SU UMa-type dwarf novae, which very infrequently (once in ~10 yr) show large-amplitude (~8 mag) outbursts (Bailey 1979; Downes & Margon 1981; Patterson et al. 1981; O'Donoghue et al. 1991). All SU UMa-type dwarf novae, including WZ Sge-type dwarf novae, show superhumps during their long, bright outbursts (superoutbursts). (For a recent review of dwarf novae and SU UMa-type dwarf novae, see Osaki 1996 and Warner 1995b, respectively.) Superhumps have periods (superhump period: $P_{\rm SH}$) a few percent longer than the orbital periods ($P_{\rm orb}$) (Vogt 1980; Warner 1985), which is believed to be a consequence of the apsidal motion (Osaki 1985; Molnar & Kobulnicky 1992) of a tidally induced eccentric accretion disk (Whitehurst 1988; Hirose & Osaki 1990; Lubow 1991). WZ Sge-type dwarf novae are known to show a different kind of (super) humps during the earliest stage of superoutbursts (Kato et al. 1996; Matsumoto et al. 1998;

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Ishioka et al. 2002; Osaki & Meyer 2002; Kato 2002a). These (super) humps in WZ Sge-type dwarf novae have periods close to $P_{\rm orb}$, which can be easily distinguished from usual SU UMa-type superhumps. The presence of superhumps thus provides a powerful photometric tool in discriminating novae and SU UMa-type/WZ Sge-type dwarf novae once an object undergoes another outburst.

V359 Cen was originally discovered as a possible nova by A. Opolski (see Duerbeck 1987). The object was visible on 19 plates taken between 1939 April 20 and 27, and the recorded maximum was $m_{\rm pg}$ = 13.8 (Duerbeck 1987). After an examination of Harvard plates of the corresponding epoch and Opolski's finding chart, Duerbeck (1987) suggested a 21.0 mag quiescent counterpart. The true nature of the object, however, remained uncertain. The object was even proposed to be a nova in the Galactic halo. From distant nova candidates, Kato et al. (2001b) selected V359 Cen as a candidate for a rarely outbursting dwarf nova. A finding chart of the proposed quiescent counterpart was presented in Duerbeck (1987).

Munari & Zwitter (1998) tried to study the proposed quiescent counterpart spectroscopically, but the attempt failed because of its faintness (V fainter than 20.5). Gill & O'Brien (1998) obtained a deep image around V359 Cen, and showed that the profile is indistinguishable from that of a normal star; there was no evidence of a nova shell.

The situation dramatically changed when one of the authors (Rod Stubbings) detected the second historical outburst on 1999 July 13 (vsnet-alert 3216)[1]. The object further underwent outbursts in 2000 May, 2001 April and 2002 June. We photometrically observed two outbursts (1999 July and 2002 June) and revealed that V359 Cen is an SU UMa-type dwarf nova. Woudt & Warner (2001) obtained time-resolved CCD photometry following the 1999 July outburst and detected a periodicity of 0.0779 d (112 min), but interpretation of this period remained rather uncertain.

2. Observations

The 1999 observation by the MOA team was performed using a 61 cm Ritchey-Chrétien Cassegrain telescope (f/6.25) with the MOA-cam2 (Yanagisawa et al. 2000), constructed with three SITe back-illuminated CCDs (2047×4095 pixels). The MOA blue filter (MOA B) covers 395–620 nm and MOA red filter covers 620–1050 nm. The exposure times were 300 and 180 s for the 1999 July 14 and 15 data, respectively. The magnitudes of the object were measured with Dophot package. The absolute calibration of the magnitudes was done using an ensemble of ~40 neighboring stars, whose zero-point was determined using about 100 LMC standard stars measureed with the Hubble Space Telescope. The MOA magnitudes can be linked to the standard V and $R_{\rm c}$ systems using Eq. (1), where red and blue denote MOA red and MOA blue magnitudes (Noda et al. 2002). Since the blue and red observations were not completely simultaneous, we list the magnitudes on the MOA photometric system in Table 1.

$$V = \text{blue} - 0.16(\text{blue} - \text{red}) + const_1$$
$$R_{\rm c} = \text{red} + 0.29(\text{blue} - \text{red}) + const_2. \quad (1)$$

The 2002 observations were undertaken by the VSNET Collaboration[2]. The equipment and reduction software are summarized in Table 2. The Kyoto observations were analyzed using the Java$^{\rm TM}$-based PSF photometry package developed by one of the authors (TK). The other observers performed aperture photometry. The magnitudes were given relative to GSC 7750.220, whose constancy during the observation was confirmed by a comparison with USNO-A1.0 0450.13739601. All systems are close to $R_{\rm c}$. The journal of the 2002 observations are summarized in Table 3.

Barycentric corrections to the observed times were applied before the following analysis.

3. Astrometry and quiescent counterpart

Astrometry of the outbursting V359 Cen was performed on CCD images taken by R. Santallo (2002 June 1). An average of measurements of five images (GSC−2.2 system, about 20 reference stars; internal dispersion of the measurements was ~$0\farcs05$) has yielded a position of $11^{\rm h}$ $58^{\rm m}$ $15\fs330$, $-41°46'08\farcs44$ (J2000.0). The position agrees with the GSC−2.2 star at $11^{\rm h}58^{\rm m}15\fs322$, $-41°46'08\farcs35$ (epoch 1995.392 and magnitudes r = 18.46, b = 19.15) and the USNO−A2.0 star at $11^{\rm h}58^{\rm m}15\fs330$, $-41°46'09\farcs16$ (epoch 1982.262 and magnitudes r = 17.7, b = 18.7).

This identification confirms the quiescent magnitude (V = 18.7) reported by Woudt & Warner (2001). The quiescent magnitudes (21 or V fainter than 20.5) reported by Duerbeck (1987) and Munari & Zwitter (1998) seem to be underestimated. An examination of POSS I red plate (limiting magnitude R ~ 18.5) shows that the object was near the detection limit (presumably a result of a large air-mass). This impression may have affected the estimate by Duerbeck (1987).

The failure by Munari & Zwitter (1998) in obtaining a quiescent spectrum is, however, difficult to reconcile with the value of V = 18.7. Since a few dwarf novae categorized to established or suspected SU UMa-type dwarf novae are known to show high and low states in quiescence (HT Cas: Zhang et al. 1986; Wood et al. 1995; Robertson & Honeycutt 1996; IR Com: Richter & Greiner 1995; Kato et al. 2002a and less established BZ UMa: Kaluzny 1986). Although it is still premature to draw a firm conclusion, V359 Cen may belong to a small class of SU UMa-type dwarf novae with high/low transitions in quiescence.

4. Long-term light curve

Figure 1 shows the long-term visual light curve of V359 Cen constructed from the observations reported to the VSNET Collaboration. Large and small dots represent positive and negative (upper limit) observations, respectively. Four outbursts (1999 July, starting on JD 2451373; 2000 May, on JD 2451680;

[1] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert3000/msg00216.html

[2] http://www.kusastro.kyoto-u.ac.jp/vsnet/

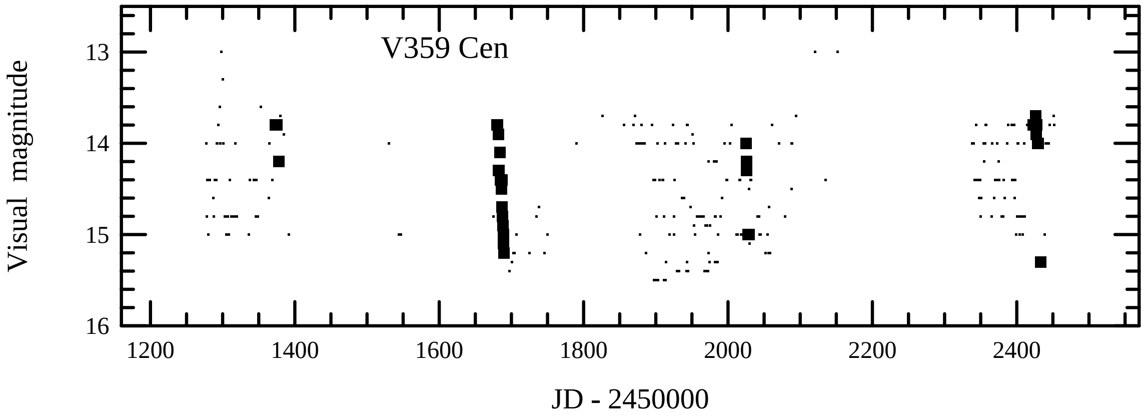

Fig. 1. Long-term visual light curve of V359 Cen constructed from the observations reported to the VSNET Collaboration. Large and small dots represent positive and negative (upper limit) observations, respectively. Four outbursts are clearly seen.

Table 1. MOA photometric data.

BJD−2 400 000	Filter	MOA mag	Error
51373.945931	red	−12.354	0.023
51373.950698	blue	−12.551	0.028
51373.955478	red	−12.354	0.018
51373.960247	blue	−12.486	0.025
51373.965014	red	−12.262	0.017
51373.969783	blue	−12.502	0.015
51373.974551	red	−12.192	0.020
51373.979319	blue	−12.431	0.016
51373.984088	red	−12.136	0.020
51373.988867	blue	−12.399	0.019
51373.993635	red	−12.174	0.014
51373.998404	blue	−12.475	0.010
51374.003171	red	−12.171	0.012
51374.007940	blue	−12.491	0.009
51374.773159	blue	−12.616	0.030
51374.776677	blue	−12.607	0.027
51374.780195	blue	−12.580	0.027
51374.783725	blue	−12.551	0.031
51374.787244	blue	−12.520	0.031
51374.790762	blue	−12.520	0.024
51374.794291	blue	−12.519	0.025
51374.797810	blue	−12.528	0.033
51374.801351	blue	−12.473	0.040
51374.804881	blue	−12.479	0.032
51374.809256	blue	−12.487	0.029
51374.812774	blue	−12.473	0.020

Table 2. Equipment of the 2002 CCD photometry.

Observer	Telescope	CCD	Software
Nelson	32-cm Newtonian	ST-8E	AIP4Win
Santallo	20-cm SCT	ST-7E	AIP4Win
Monard	30-cm SCT	ST-7E	AIP4Win
Kyoto	30-cm SCT	ST-7E	Java[a]

[a] See text.

Table 3. Journal of the 2002 CCD photometry.

2002 Date		Start–End[a]	Exp(s)	N	Obs[b]
May	29	52423.932–52424.061	30	270	N
	31	52425.773–52425.867	24	164	S
June	1	52426.786–52426.921	15	360	S
	1	52426.883–52426.996	60	111	N
	2	52427.851–52428.026	30	357	N
	2	52427.870–52427.925	60	55	S
	3	52428.918–52428.998	45	129	N
	3	52428.954–52428.993	10	146	K
	5	52430.743–52430.847	60	76	S
	5	52430.954–52430.962	10	30	K
	6	52431.954–52431.968	10	44	K
	6	52432.182–52432.433	45	356	M

[a] BJD−2 400 000.
[b] N (Nelson), S (Santallo), K (Kyoto team), M (Monard).

2001 April, on JD 2452025 and 2002 June, on JD 2452422) are clearly seen. The intervals between the detected outbursts are in the range of 307–397 d. Although there were unavoidable seasonal gaps in observations, these values seem to be a representative outburst cycle length. The observed maximum magnitudes of the outbursts were ~13.8. This constancy of the maximum magnitudes likely precludes the previously supposed possibility that the maximum of the 1939 outburst was missed (Duerbeck 1987).

5. The 1999 outburst

Figure 2 shows the enlarged light curve of V359 Cen during the 1999 outburst. The data are from the MOA observations. Although complete phase coverage was impossible because of the short available runs, the object clearly exhibited variations with amplitudes of ~0.15 mag, which can be attributed to superhumps.

A period analysis of the MOA blue data using Phase Dispersion Minimization (PDM; Stellingwerf 1978) has yielded the theta diagram presented in Fig. 3. Although a unique alias selection is impossible from these data only, we

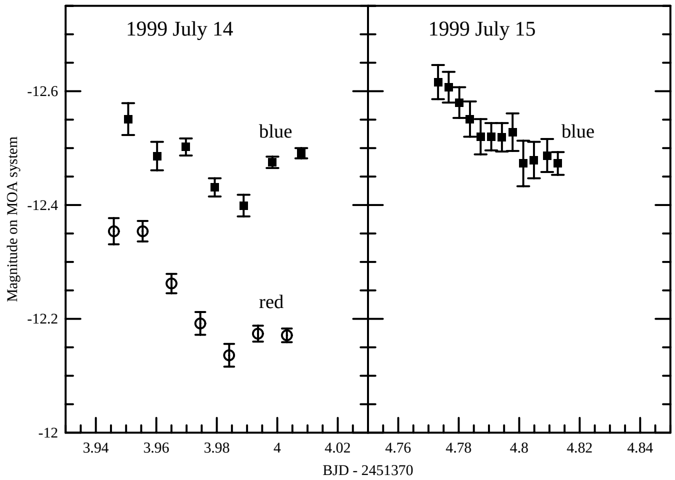

Fig. 2. Superhumps of V359 Cen during the 1999 outburst. The data are from the MOA observations. Filled squares and open circles represent blue and red observation, respectively. The magnitudes are based on the MOA photometric system.

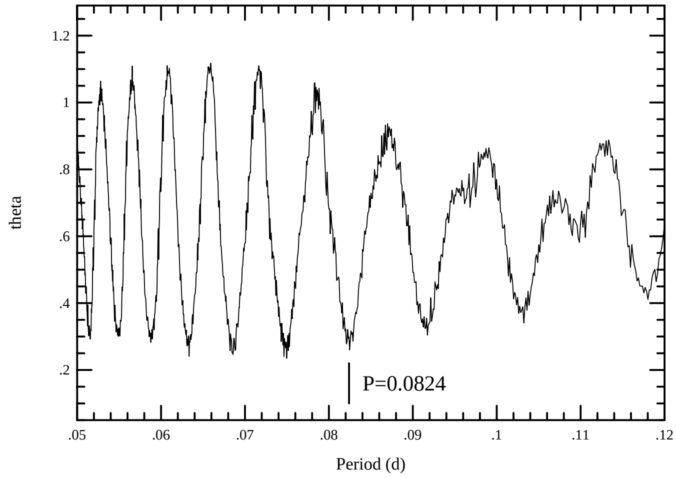

Fig. 3. Period analysis of the MOA blue observations. The denoted superhump period is the bast-selected alias based on the 2002 observation.

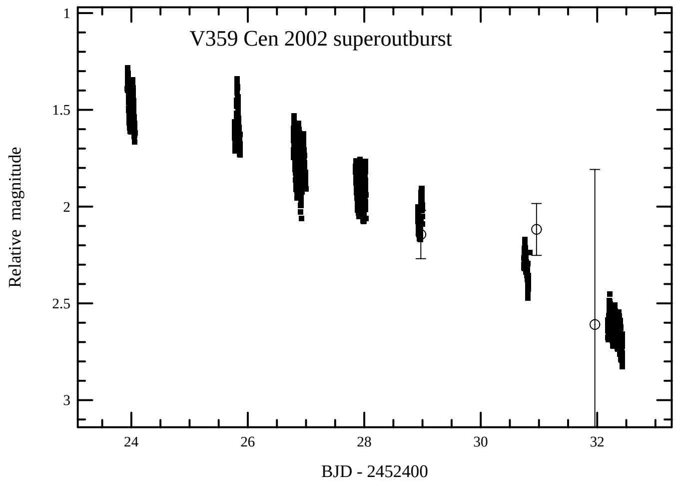

Fig. 4. Light curve of the 2002 superoutburst of V359 Cen. The magnitudes are relative to GSC 7750.220 and are on a system close to R_c. Open circles with errors represent nightly averaged Kyoto observations.

can safely choose the correct alias of P_{SH} = 0.0824(4) d based on the later determination of the superhump period (Sect. 6.2).

6. The 2002 outburst

6.1. Course of the outburst

The 2002 outburst was detected by Rod Stubbings on May 28 at m_{vis} = 13.8 (vsnet-alert 7356)[3]. CCD time-resolved photometry started within a day following this detection. Figure 4 shows the overall light curve of the 2002 superoutburst. The magnitudes are relative to GSC 7750.220 and are on a system close to R_c. After two days of the outburst, the system started to fade linearly at a rate of 0.16 mag d^{-1}. This slowly and linearly fading phase (often referred to as *superoutburst plateau*) is very characteristic of an SU UMa-type superoutburst (Warner 1980; Warner 1985).

The mean decline rate of 0.16 mag d^{-1} during the plateau phase is larger than those of other SU UMa-type dwarf novae (Table 4) with similar P_{SH} to that of V359 Cen (cf. Sect. 6.2). Since a higher mass-transfer rate from the secondary star tends to thermally stabilizes the accretion disk and reduce the decay rate (e.g. Osaki 1995), a rather exceptionally large decay rate in V359 Cen may be a result of a systematically smaller mass-transfer rate.

Table 4. Mean decline rates of SU UMa-type dwarf novae.

Object	P_{SH} (d)	Mean rate[a]	Ref.
HV Aur	0.0855	0.035	1
TU Crt	0.0854	0.092	2
AW Gem	0.0794	0.08	3
TT Boo	0.0781	0.11	4

[a] Mean decline rate (mag d^{-1}) during the superoutburst plateau.
References: 1: Nogami et al. (1995), 2: Mennickent et al. (1998), 3: Kato (1996), 4: Kato (1995).

6.2. Superhump period and evolution

Figure 5 shows enlarged nightly light curves. Superhumps are clearly visible on all observed nights. Figure 6 shows the result of a PDM period analysis of the 2002 data between May 31 and June 6 (superoutburst plateau). The linear declining trend has been subtracted before the analysis. The resultant best P_{SH} is 0.08092(1) d. The selection of the correct alias has been confirmed by independent period analyses of individual long continuous runs. This period established that V359 Cen is a long-period SU UMa-type dwarf nova. Figure 7 shows the phase-averaged profile of superhumps. The rapidly rising and slowly fading superhump profile is characteristic to an SU UMa-type dwarf nova (Warner 1980, 1985).

We extracted the maxima times of superhumps from the light curve by eye. The averaged times of a few to several

[3] http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert7000/msg00356.html

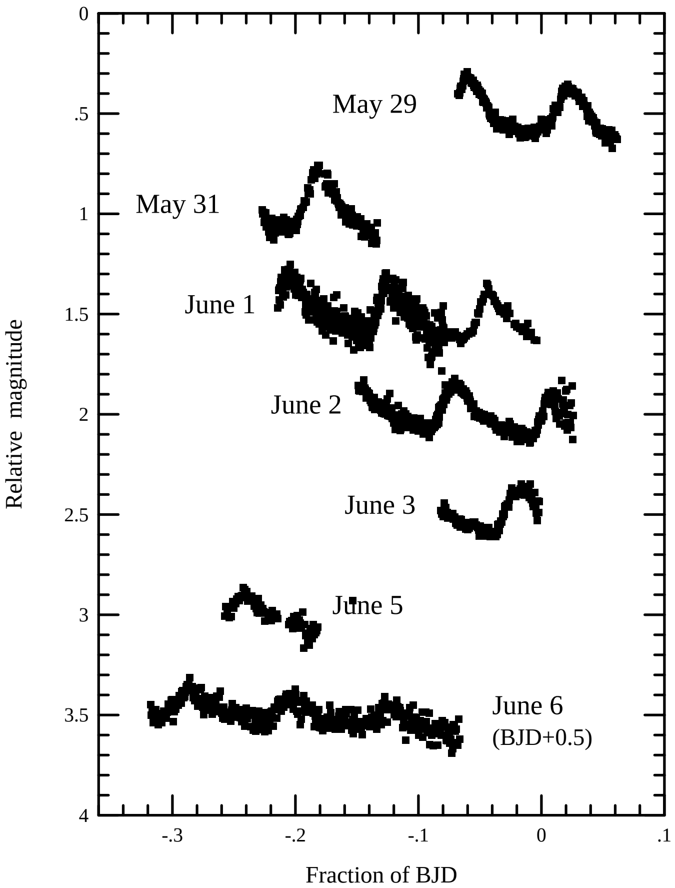

Fig. 5. Nightly light curves. Superhumps are clearly visible on all nights.

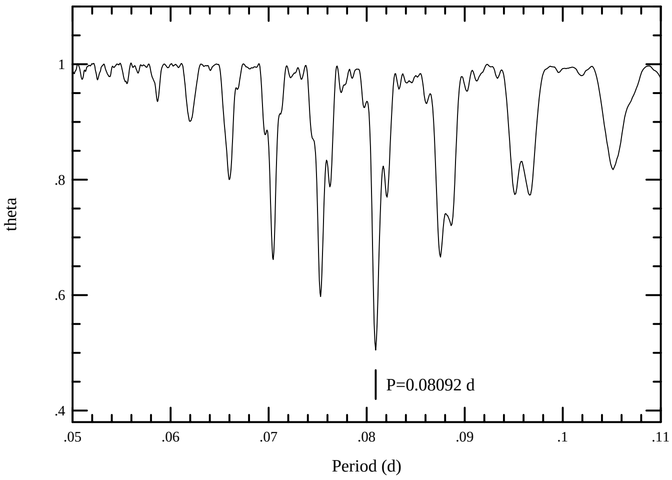

Fig. 6. Period analysis of the 2002 data between May 31 and June 6 (superoutburst plateau). The linear declining trend has been subtracted before the analysis.

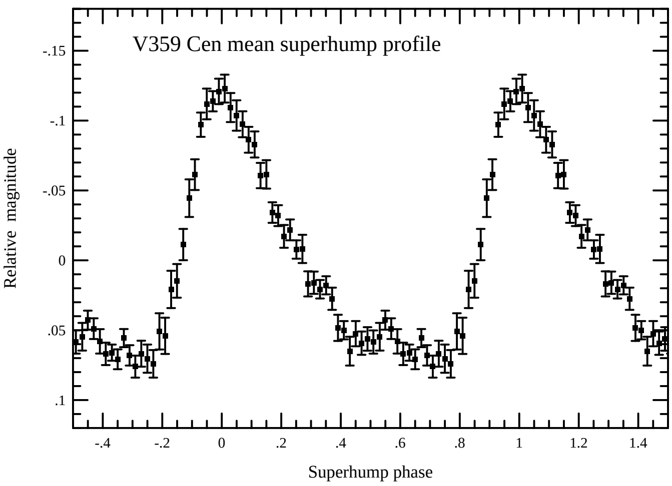

Fig. 7. Mean superhump profile of V359 Cen.

points close to the maximum were used as representatives of the maxima times. The errors of the maxima times are usually less than ~0.002 d. The resultant superhump maxima are given in Table 5. The values are given to 0.0001 d in order to avoid the loss of significant digits in a later analysis. The cycle count (E) is defined as the cycle number since BJD 2452423.939. A linear regression to the observed superhump times gives the following ephemeris:

$$\mathrm{BJD(maximum)} = 2452423.9503 + 0.08108E. \qquad (2)$$

Figure 8 shows the (O−C)'s against the mean superhump period (0.08108 d) from Eq. (2). Although the general trend can be expressed by a negative quadratic term of $\dot{P} = -10.8(1.5) \times 10^{-6}$ d cycle^{-1}, or $\dot{P}/P = -13.3(1.9) \times 10^{-5}$, superhump maxima with $E \geq 23$ can be well expressed by a constant period of $P = 0.08094$ d and |O−C|'s less than 0.005 d. This finding indicates that the superhump period was virtually constant during the plateau phase (the nominal $\dot{P}$ during this period is $-5.3(2.8) \times 10^{-6}$ d cycle^{-1}). A sudden change between $E = 0$ and $E = 23$ can be interpreted as a result of rapid evolution of superhumps during the earliest stage of the superoutburst. The "textbook" evolutionary time-scales (2–3 d) of superhumps in long-period SU UMa-type dwarf novae (Warner 1985) also support this interpretation. The large period change of P_{SH} observed during the earliest stage of the 2002 superoutburst may explain the slight discrepancy of the periods between the 1999 and 2002 observations (the 1999 observation corresponds to the earliest stage of a superoutburst). The period determined from $0 \leq E \leq 23$ observations is 0.0817 d, sufficiently longer than the most likely orbital period (Sect. 7.2), precludes the possibility of WZ Sge-type early (super)humps as the origin of these early modulations.

6.3. Super-QPOs

Some SU UMa-type dwarf novae are known to show large-amplitude, highly coherent quasi-periodic oscillations (QPOs) during the evolution stage of superhumps (Kato et al. 1992; Kato 2002b). These QPOs are sometimes referred to as "super-QPOs". The light curve of V359 Cen on May 29 shows a hint of such QPOs. The lower panel of Fig. 9 shows residuals of the May 29 light curve after subtracting the superhump signal by using a Fourier decomposition of the superhump profile up to the third harmonics, and subtracting a slow linear trend. Small-amplitude modulations with a typical time scale of ~0.02 d are present. Figure 10 shows a power spectrum of the residual shown in the lower panel of Fig. 9. The strongest power

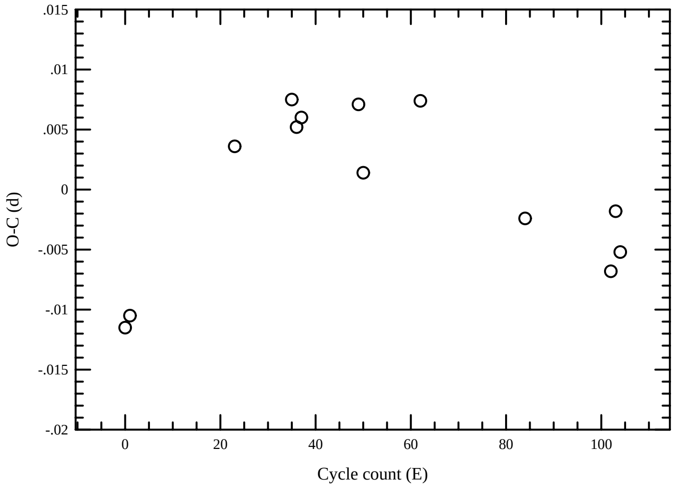

Fig. 8. O−C diagram of superhump maxima. The O−C's are calculated against Eq. (2).

Table 5. Times of superhump maxima.

E^a	BJD−2 400 000	O−C^b
0	52423.9388	−0.0115
1	52424.0209	−0.0105
23	52425.8188	0.0036
35	52426.7956	0.0075
36	52426.8744	0.0052
37	52426.9563	0.0060
49	52427.9303	0.0071
50	52428.0057	0.0014
62	52428.9847	0.0074
84	52430.7587	−0.0024
102	52432.2138	−0.0068
103	52432.2999	−0.0018
104	52432.3774	−0.0052

[a] Cycle count since BJD 2452423.939.
[b] O−C calculated against Eq. (2).

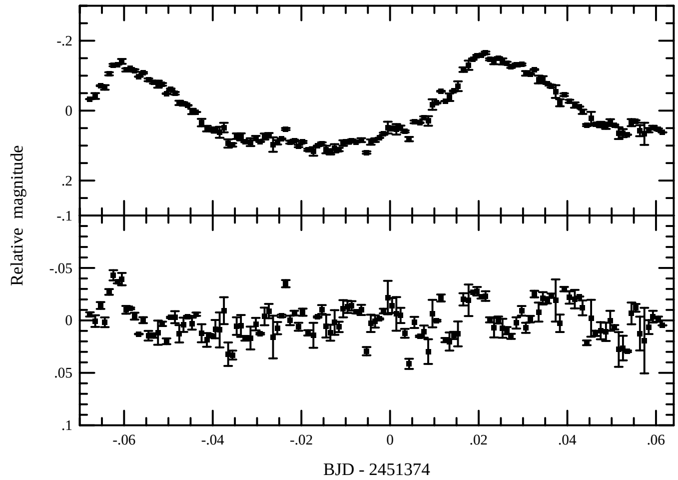

Fig. 9. (Upper) enlarged light curve on May 29. (Lower) residuals of the May 29 light curve after subtracting the superhump signal and a slow linear trend. Small-amplitude modulations with a typical time scale of ~0.02 d are present.

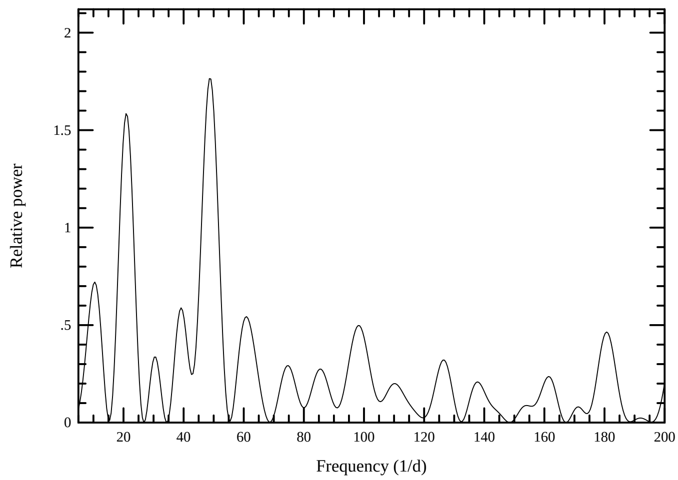

Fig. 10. Power spectrum of the QPO signal. The strongest power is present at a frequency of ~49 d^{-1}, which corresponds to a period of ~0.02 d.

is present at a frequency of ~49 d^{-1}, which corresponds to a period of ~0.02 d.

Although the QPOs were not as prominent as seen in SW UMa (Kato et al. 1992) or (Kato 2002b), the absence of similar signals on later nights suggest that this variation is a kind of super-QPOs. As shown in Sect. 6.2, the epoch of the detection of QPOs corresponds to the rapidly evolving stage of superhumps. This finding further supports an idea that super-QPOs are associated with the growth of superhumps (Kato et al. 1992; Kato 2002b)

7. V359 Cen as an SU UMa-type dwarf nova

7.1. Outburst characteristics

Table 6 lists the observed parameters of the four recorded outbursts. All the recorded outbursts have durations longer than 4 d, which indicate that all the recorded outbursts were superoutbursts. The intervals between these outbursts (307–397 d) are thus regarded as the supercycle of this SU UMa-type dwarf nova. Since the present duty cycle of observations is about 50%, there remains a small possibility that the true supercycle is the half of this value. Further dense monitoring is strongly encouraged to completely exclude this possibility. It is well established that almost all well-studied SU UMa-type dwarf novae with similar supercycle lengths show a few to ~ten normal outburst within one supercycle (Warner 1995b; Nogami et al. 1997). Since normal outbursts of SU UMa-type dwarf novae are usually only 0.5–1.0 mag fainter than superoutbursts (Warner 1985), some of such normal outbursts should have been detected. The present non-detection of normal outbursts seems to suggest that V359 Cen has fewer normal outbursts than in usual SU UMa-type dwarf novae. Although future deeper monitoring for normal outbursts is absolutely needed, the occurrence of normal outbursts in V359 Cen may be effectively suppressed by an unknown mechanism; similar instances have been reported in other SU UMa-type dwarf novae (Kato 2001; Kato et al. 2002b). If normal outbursts are entirely missing, V359 Cen would become the first long-period analog of V844 Her which has been known to show only superoutbursts (Kato & Uemura 2000: P_{SH} = 0.05592 d, supercycle lengths = 220–290 d). Similar SU UMa-type dwarf novae with predominance of superoutbursts are highly concentrated in the short period region (cf. Kato & Uemura 2000). V359 Cen may be an exceptional object in its combination of outburst characteristics and the superhump (or orbital) period.

We also note that the outburst characteristics of V359 Cen also resemble those of long-period SU UMa-type dwarf novae EF Peg (Howell et al. 1993; Kato 2002b) and V725 Aql (Uemura et al. 2001). Both EF Peg and V725 Aql only infrequently show normal outbursts, which is exceptional among long-P_{orb} SU UMa-type dwarf novae (cf. Warner 1995b). While long outburst recurrence times imply that these systems have low mass-transfer rates (Ichikawa & Osaki 1994; Osaki 1996), recent detailed calculations of the evolution of CVs (e.g. Podsiadlowski et al. 2001) suggest that mass-transfer rates are higher in long-period systems even if the effect of stellar core evolution is properly taken into account. These systems (EF Peg, V725 Aql and possibly V359 Cen) may be violating the modern evolutionary scenario of CVs. Future determination of the binary parameters and stellar composition analysis of these systems are therefore strongly encouraged.

7.2. Superhump excess and late superhumps

Woudt & Warner (2001) tentatively identified their photometric period (112 min) as late superhumps (Haefner et al. 1979; Vogt 1983; van der Woerd et al. 1988; Hessman et al. 1992), which are known to have similar periods with ordinary superhumps (i.e. a few percent longer than P_{orb}), but have phases of ~0.5 different from those of ordinary superhumps. Since this signal was observed long after then cessation of the 1999 outburst, Woudt & Warner (2001) suggested that V359 Cen may have shown a long persistence of late superhumps as was observed in a WZ Sge-type dwarf nova in EG Cnc (Kato et al. 1997; Patterson et al. 1998).

The present correct identification of the superhump period, however, indicates that the 112 min periodicity observed by Woudt & Warner (2001) can not be attributed to superhumps, but can be better understood to represent P_{orb}. This observation, on the contrary to the suggestion by Woudt & Warner (2001), indicates that the superhumps or late superhumps in V359 Cen must have decayed more rapidly, as in other usual SU UMa-type dwarf novae (see Kato et al. 2001a for a recent example of the decay of late superhumps). V359 Cen is thus unlikely related to WZ Sge-type dwarf novae which always show long persistence of late superhumps.

By adopting P_{orb} = 0.0779 d, we obtain a fractional superhump excess ($\epsilon = P_{SH}/P_{orb} - 1$) of 3.9% for the best P_{SH} is 0.08092(1) d (cf. Sect. 6.2). Using the "mean" P_{SH} = 0.08108 d from the entire 2002 superoutburst, we obtain ϵ = 4.1%. These fractional superhump excesses are not unusual for an SU UMa-type dwarf nova with this P_{orb} (Molnar & Kobulnicky 1992; Patterson 1998), suggesting that V359 Cen should have a normal binary mass ratio $q = M_2/M_1$ in spite of its rather unusual outburst characteristics.

Table 6. List of outbursts.

JD start[a]	JD end[a]	Maximum	Duration (d)
51372.9	51377.9	13.8	>5
51680.0	51690.0	13.8	>10
52025.0	52029.0	14.0	>4
52422.9	52433.0	13.8	>10

[a] JD−2 400 000.

8. Summary

We detected four outbursts of V359 Cen (possible nova discovered in 1939) between 1999 and 2002. Time-resolved CCD photometry during two outbursts (1999 and 2002) revealed that V359 Cen is actually a long-period SU UMa-type dwarf nova with a mean superhump period of 0.08092(1) d. We identified its supercycle length as 307–397 d. This secure identification of the superhump period precludes the previously supposed possibility that V359 Cen could be related to a WZ Sge-type system with a long persistence of late superhumps. The outburst characteristics of V359 Cen are, however, rather unusual in its low occurrence of normal outbursts. The fractional superhump excess is 3.9–4.1%, which suggests that V359 Cen should have a normal binary mass ratio in spite of its rather unusual outburst characteristics. We also obtained a secure identification of the quiescent counterpart and discussed on the possibility of high/low state changes. The evolution of superhumps and their period change was closely followed. We also detected super-QPO-type variation (period ~0.02 d) during the earliest stage of the 2002 superoutburst.

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References

Bailey, J. 1979, MNRAS, 189, 41P
Downes, R. A. 1986, ApJ, 307, 170
Downes, R. A., & Margon, B. 1981, MNRAS, 197, 35P
Duerbeck, H. W. 1987, Space Sci. Rev., 45, 1
Gill, C. D., & O'Brien, T. J. 1998, MNRAS, 300, 221

Haefner, R., Schoembs, R., & Vogt, N. 1979, A&A, 77, 7
Hessman, F. V., Mantel, K.-H., Barwig, H., & Schoembs, R. 1992, A&A, 263, 147
Hirose, M., & Osaki, Y. 1990, PASJ, 42, 135
Howell, S. B., Schmidt, R., DeYoung, J. A., et al. 1993, PASP, 105, 579
Ichikawa, S., & Osaki, Y. 1994, in Theory of Accretion Disks-2, ed. W. J. Duschl, J. Frank, F. Meyer, E. Meyer-Hofmeister, & W. M. Tscharnuter (Dordrecht: Kluwer Academic Publishers), 169
Ishioka, R., Uemura, M., Matsumoto, K., et al. 2002, A&A, 381, L41
Kaluzny, J. 1986, IAU Circ., 4287
Kato, T. 1995, Inf. Bull. Variable Stars, 4243
Kato, T. 1996, PASJ, 48, 777
Kato, T. 2001, Inf. Bull. Variable Stars, 5071
Kato, T. 2002a, PASJ, 54, L11
Kato, T. 2002b, PASJ, 54, 87
Kato, T., Baba, H., & Nogami, D. 2002a, PASJ, 54, 79
Kato, T., Hirata, R., & Mineshige, S. 1992, PASJ, 44, L215
Kato, T., Matsumoto, K., Nogami, D., Morikawa, K., & Kiyota, S. 2001a, PASJ, 53, 893
Kato, T., Nogami, D., Baba, H., et al. 1996, PASJ, 48, L21
Kato, T., Nogami, D., Matsumoto, K., & Baba, H. 1997, preprint, ftp://vsnet.kusastro.kyoto-u.ac.jp/pub/vsnet/preprints/EG_Cnc/
Kato, T., Poyner, G., & Kinnunen, T. 2002b, MNRAS, 330, 53
Kato, T., Sekine, Y., & Hirata, R. 2001b, PASJ, 53, 1191
Kato, T., & Uemura, M. 2000, Inf. Bull. Variable Stars, 4902
Liller, W., & Mayer, B. 1987, PASP, 99, 606
Lubow, S. H. 1991, ApJ, 381, 259
Matsumoto, K., Nogami, D., Kato, T., & Baba, H. 1998, PASJ, 50, 405
Mennickent, R. E., Patterson, J., O'Donoghue, D., et al. 1998, Ap&SS, 262, 1
Molnar, L. A., & Kobulnicky, H. A. 1992, ApJ, 392, 678
Munari, U., & Zwitter, T. 1998, A&AS, 128, 277
Noda, S., Takeuti, M., Abe, F., et al. 2002, MNRAS, 330, 137
Nogami, D., Kato, T., Masuda, S., & Hirata, R. 1995, Inf. Bull. Variable Stars, 4163
Nogami, D., Masuda, S., & Kato, T. 1997, PASP, 109, 1114
O'Donoghue, D., Chen, A., Marang, F., et al. 1991, MNRAS, 250, 363
Osaki, Y. 1985, A&A, 144, 369
Osaki, Y. 1995, PASJ, 47, L11
Osaki, Y. 1996, PASP, 108, 39
Osaki, Y., & Meyer, F. 2002, A&A, 383, 574
Patterson, J. 1998, PASP, 110, 1132
Patterson, J., Kemp, J., Skillman, D. R., et al. 1998, PASP, 110, 1290
Patterson, J., McGraw, J. T., Coleman, L., & Africano, J. L. 1981, ApJ, 248, 1067
Podsiadlowski, P., Han, Z., & Rappaport, S. 2001, MNRAS, submitted [astro-ph/0109171]
Richter, G. A., & Greiner, J. 1995, in Cataclysmic Variables, ed. A. Bianchini, M. Della Valle, & M. Orio (Dordrecht: Kluwer Academic Publishers), 177
Robertson, J. W., & Honeycutt, R. K. 1996, AJ, 112, 2248
Shafter, A. W. 1997, ApJ, 487, 226
Starrfield, S. 1999, Phys. Rep., 311, 371
Starrfield, S., & Sparks, W. M. 1987, Ap&SS, 131, 379
Starrfield, S., Truran, J. W., & Sparks, W. M. 2000, New Astron. Rev., 44, 81
Stellingwerf, R. F. 1978, ApJ, 224, 953
Uemura, M., Kato, T., Pavlenko, E., Baklanov, A., & Pietz, J. 2001, PASJ, 53, 539
van der Woerd, H., van der Klis, M., van Paradijs, J., Beuermann, K., & Motch, C. 1988, ApJ, 330, 911
Vogt, N. 1980, A&A, 88, 66
Vogt, N. 1983, A&A, 118, 95
Warner, B. 1985, in Interacting Binaries, ed. P. P. Eggelton, & J. E. Pringle (Dordrecht: D. Reidel Publishing Company), 367
Warner, B. 1995a, Cataclysmic Variable Stars (Cambridge: Cambridge University Press)
Warner, B. 1995b, Ap&SS, 226, 187
Whitehurst, R. 1988, MNRAS, 232, 35
Wood, J. H., Naylor, T., Hassall, B. J. M., & Ramseyer, T. F. 1995, MNRAS, 273, 772
Woudt, P. A., & Warner, B. 2001, MNRAS, 328, 159
Yanagisawa, T., Muraki, Y., Matsubara, Y., et al. 2000, Exper. Astron., 10, 519
Zhang, E.-H., Robinson, E. L., & Nather, R. E. 1986, ApJ, 305, 740