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NY Serpentis: SU UMa-type nova in the period gap with diversity of normal outbursts

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Abstract

We present a photometric study of NY Ser, an in-the-gap SU UMa-type nova, in 2002 and 2013. We determined the duration of its superoutburst and the mean period of its superhump are 18 d and 0.10458 d, respectively. We detected in 2013 that NY Ser showed two distinct states separated by a superoutburst. A state of rather infrequent normal outbursts lasted at least 44 d before the superoutburst, and a state of frequent outbursts started immediately after the superoutburst and lasted at least 34 d. Unlike a typical SU UMa star with a bimodal distribution of outburst duration, NY Ser displayed a diversity of normal outbursts. In the state of infrequent outbursts, we detected a wide ~12 d outburst accompanied by 0.098 d orbital modulation but without superhumps ever established in NY Ser. We classified this as a "wide normal outburst." The orbital period was dominant both in quiescence and during normal outbursts in this state. In the state of the most frequent normal outbursts, the 0.10465 d positive superhump period was dominant and coexisted with the orbital modulation. In 2002 we detected the normal outburst of "intermediate" 5–6 d duration that was also accompanied by orbital modulations.

Key words: accretion, accretion disks — novae, cataclysmic variables — stars: dwarf novae — stars: individual (NY Serpentis) — stars: individual (V1006 Cygni)

1 Introduction

Cataclysmic variables (CVs) are close binary stars at the late stage of their evolution (Warner 1995; Hellier 2001 for reviews). In these binaries the late-type star fills its Roche lobe and transfers matter onto the compact component (white dwarf) through an accretion disk. The thermal viscous instability in the accretion disk causes outbursts (Cannizzo 1993; Lasota 2001).

The SU UMa-type star is a subgroup of the short-periodic nonmagnetic CVs occupying a range of orbital periods bounded by the minimum period at ~76 min and the upper limit of the "period gap," 3.18 hr (Knigge 2006). SU UMa stars show the well-known bimodality of outburst duration (van Paradijs 1983; Warner 1995): the narrow "normal" outbursts lasting for a few days and the wide superoutbursts that are longer in duration by a factor of 5–10 in the same system. A typical superoutburst lasts for about two weeks. Several normal outbursts occur between the superoutbursts. The amplitudes of superoutbursts are slightly higher than, or equal to, those of normal outbursts. It was pointed out by van Paradijs (1983) that almost all dwarf novae have a bimodal distribution of the outburst duration. Only SU UMa stars, however, have the wide outbursts (superoutbursts) accompanied by what are called positive superhumps, which are brightness variations with a period a few percent longer than the orbital period.

According to the modern paradigm of the tidal instability, the 3:1 resonance in the accretion disk orbiting the white dwarf in the system with a mass ratio of $q = m_2/m_1 \leq 0.25$, where m_2 is the mass of the late-type star and m_1 is that of the white dwarf, is responsible for its eccentric deformation, resulting in positive superhumps (Whitehurst 1988; Hirose & Osaki 1990; Lubow 1991). Osaki (1996) proposed a thermal-tidal instability model in which the ordinary thermal instability is coupled with the tidal instability.

A detailed study of superoutbursts and the evolution of the positive superhumps is given in a series of papers by Kato et al. (2009, 2010, 2012, 2013, 2014a, 2014b). The duration of a superoutburst varies from system to system, but it is rather stable for the same star (Warner 1995) on different occasions.[1]

On the other hand, the durations of normal outbursts depend both on the orbital period and on the supercycle phase. It was found by the early investigations (van Paradijs 1983) that the duration of the narrow outburst, t_b, for several CVs increases with the orbital period. For SU UMa stars, the empirical correlation between t_b and the orbital period held true for $t_b \sim 2.5$–5 d. Recently, Cannizzo et al. (2012) explored the Kepler light curves of the SU UMa stars, V1504 Cyg and V344 Lyr, and found a systematic increase of t_b between two consecutive superoutbursts: $t_b =$ 1.1–2.9 d for V1504 Cyg and $t_b =$ 2.5–5.0 d for V344 Lyr.

The 2.15–3.18 hr period gap (Knigge 2006) represents a division between the long-period system with a high mass-transfer rate (above the period gap) and the short-period system with a low mass-transfer rate (below the period gap). The evolution of the long-period CV is mainly driven by magnetic braking, while the evolution of the short-period CV is driven by gravitational wave radiation (Kraft 1962; Verbunt & Zwaan 1981; Knigge 2006). According to the theoretical predictions, the secondary loses contact with its Roche lobe at an orbital period of ~3 hr and the secondary makes contact again at an orbital period of ~2 hr. This causes the dearth of CVs in this region of orbital periods, and then this region is called the "period gap." Despite the fact that the number of SU UMa-type stars in the period gap have grown with time (see, for example, Katysheva & Pavlenko 2003; Dai & Qian 2012; Schmidtobreick & Tappert 2006), the properties of these systems are still poorly studied.

[1] There are, however, exceptions especially to systems with low outburst frequencies. The notable example is BC UMa (Romano, 1964). See also Kato (1995).

NY Ser is the first in-the-period-gap SU UMa-type dwarf nova. It was discovered to be an ultraviolet-excess object PG 1510+234 (Green et al. 1986, 1982). Iida, Nogami, and Kato (1995) identified this object as a frequently outbursting dwarf nova. Nogami et al. (1998) detected superhumps during a long outburst in 1996 April, establishing this object as an SU UMa-type. Its supercycle was estimated to be 85–100 d in 1996 by Nogami et al. (1998) and 60–90 d by Patterson et al. (2003), who observed mostly in 1999. NY Ser displayed rather frequent normal outbursts every 6–9 d (Nogami et al. 1998; Iida et al. 1995) that were ∼ 3 d in duration, typical of most SU UMa-type dwarf novae. However, the outburst activity of NY Ser in recent years differed from those of "normal" SU UMa-type stars. Using American Association of Variable Star Observation (AAVSO) data, Kato et al. (2014a) found the existence of outbursts of "intermediate" durations (∼ 4 d) that were observed in 2011 and 2012 in addition to normal outbursts of durations of ∼ 3 d and superoutbursts of longer durations.

The period of positive superhumps of NY Ser has been estimated by both Nogami et al. (1998) and Patterson et al. (2003). However, the details of the period evolution were not defined due to an insufficient amount of data. Only a 3 d series of outbursts was obtained by Nogami et al. (1998) during the 1996 superoutburst and a 5 d series was obtained by Patterson et al. (2003) during the 1999 superoutburst. The analyses yielded periods of 0.106 d and 0.104 d, respectively. This discrepancy in period between these two measurements is probably because the superhump period was measured for different parts of their superoutbursts.

Patterson et al. (2003) found an orbital period of 0.0975 d in quiescence and confirmed this value [0.09756(3) d] on the 8 d baseline covering both quiescence and outburst.

We undertook a photometric study of NY Ser to clarify the peculiarity of its outbursts and the behavior during the different phases of its outburst activity.

2 Observations and data reduction

The photometric CCD observations of NY Ser were carried out in 2002 and 2013. In 2002, the star was observed during the period of ∼ 66 d at the Crimean Astrophysical Observatory (CrAO) and in 2013 during the period of ∼ 100 d at several observatories located at different longitudes. The details of observations are given in e-table 1.[2] Standard aperture photometry (de-biasing, dark subtraction, and flat-fielding) was used for measuring the variable and comparison stars, the latter being the star USNO (Naval Observatory) B1.0 1132-0246239. On 2006 July 7, we measured the brightness of the comparison star relative to the Landolt sequence stars 10971, having $V = 11.493$, $B - V = 0.323$, and $V - R = 0.186$, and 109381, having $V = 11.73$, $B - V = 0.704$, and $V - R = 0.428$. We determined the magnitudes of the comparison star are $B = 16.48$, $V = 15.92$, and $R = 15.56$; B. A. Skiff (2007)[3] gave $V = 15.89$ and $B - V = 0.58$.

Most of the observations were carried out without filters, giving a system close to the R band in our case. The accuracy of a single brightness measurement depended on the telescope, the exposure time, weather conditions, and the brightness of NY Ser. It was 0.007–0.03 mag during the outburst and superoutburst, and 0.05–0.10 mag in quiescence. A much higher accuracy of ∼ 0.005 mag during outbursts and 0.01 mag in quiescence was achieved from the observations with the 2.6 m telescope.

The time of observations is expressed in barycentric Julian Date (BJD). Phase dispersion minimization (PDM: Stellingwerf 1978) is used for period analysis, and 1 σ errors were estimated by the methods of Fernie (1989) and Kato et al. (2010). Before starting to conduct the period analysis, we corrected the differences of zero-point among data obtained with different telescopes and subtracted a long-term trend of the outbursts and the quiescent light curve by a smoothed light curve obtained by locally weighted polynomial regression (LOWESS: Cleveland 1979).

3 2002 light curve

The observations of NY Ser carried out in 2002 are shown in figure 1. The 66 d light curve covered the five outbursts of different durations that were separated on average by 9 d. While there is only an indication of the first outburst, the next two outbursts were observed in sufficient detail. The second outburst was caused between BJD 2452445 and 2452450 and had a duration of at least 5 d (the possibility of 6 d cannot be excluded either). The third outburst occurred at around BJD 2452455 and lasted for ∼ 3 d. The last two outbursts were also separated by ∼ 9 d on average. The outburst on around BJD 2452485 has not been properly defined, but its duration was not shorter than 3 d. The next outburst began on BJD 2452490 and lasted for at least 11 d. In what follows, we call the second outburst in 2002 the 2002 first wide outburst, and the fifth one the 2002 second wide outburst. The mean amplitude of both the wide outbursts was ∼ 2.5 mag.

[2] E-table 1 is available only on the online edition at ⟨http://dx.doi.org/10.1093/pasj/psu099⟩.

[3] UBVRI photometry of faint field stars ⟨http://vizier.nao.ac.jp/viz-bin/Cat?II/277⟩.

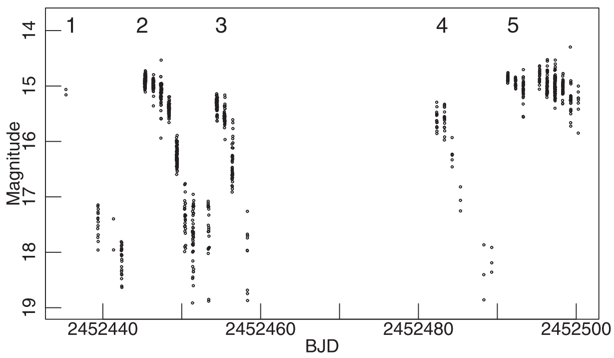

Fig. 1. Overall light curve of NY Ser in 2002.

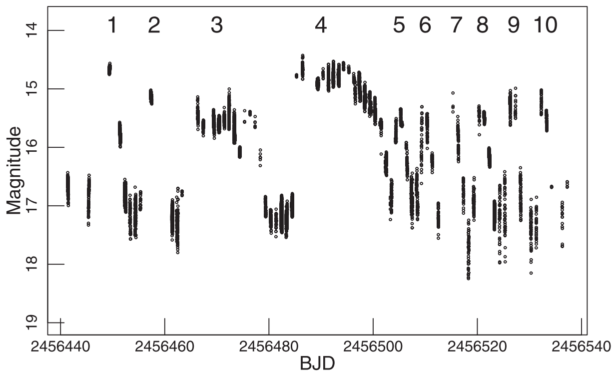

Fig. 2. Overall light curve of NY Ser in 2013.

4 2013 light curve

The long-term light curve of NY Ser in 2013 is presented in figure 2. This overall light curve consists of ten outbursts. Contrary to the "usual" SU UMa-type nova, having a sequence of short-term normal outbursts between superoutbursts, NY Ser demonstrated a large variety of outbursts for the 100 d duration. During the 24 d segment before BJD 2456464, the outburst behavior of NY Ser resembled its known behavior (Nogami et al. 1998; Patterson et al. 2003); the first and second outbursts in figure 2 looked like normal ones separated by ~ 8 d and lasted for 3–3.5 d. Their approximate amplitudes (~ 2.5 mag) are consistent with the previously reported value. The third outburst in figure 2 that appeared approximately at the expected time was, however, entirely different. First, its duration was not shorter than 12 d but not longer than 15 d; this has never happened among the normal outbursts of SU UMa-type stars, but is common to the majority of superoutbursts. Secondly, the mean amplitude of this outburst was probably less than those of the previous normal outbursts and did not exceed 1.8 mag. Thirdly, the profile of this outburst looks rather symmetrical, with a structured maximum lasting at least 11 d. We call the third outburst in 2013 the 2013 first wide outburst below.

After the 5 d minimum following this outburst, the next wide outburst (the fourth outburst in 2013 which we hereafter call the 2013 second wide outburst) resembling a superoutburst in duration was detected. Its amplitude was ~ 2.5 mag and the duration was 18 d, taking into account the precursor-like structure around between BJD 2456485 and 2456487. Note also the prominent round shape of the maximum of this outburst. The slow decline lasted only for 6 d and occurred with a rate of ~ 0.12 mag d^{-1}.

The sequence of six short outbursts with a mean amplitude of ~ 2 mag was observed immediately after the end of the longest outburst and this sequence lasted for 34 d. The frequency of the outbursts changed dramatically; the separation between the first two outbursts was only 5 d (that has never been recorded before) and the rest of the outbursts appeared every 6 d. Note that the amplitudes of the first two outbursts were also the smallest ones, reaching only 1.5 mag.

While the short outbursts are undoubtedly "normal" outbursts according to the accepted definition of such outbursts in SU UMa stars, the nature of the two wide outbursts requires further study. We investigated the nightly short-term periodicity (potential orbital and superhump periods) to clarify the nature of these outbursts.

5 Short-term variability at different states of the dwarf nova activity

In all states of outburst activity in NY Ser, it displayed short-term brightness variations. Some examples of the nightly light curves are shown in figures 3, 4, and 5.

We studied the periodicity of NY Ser for the two data sets at the selected states of its activity in a range of frequencies including the orbital and superhump frequencies. The corresponding periodograms contain indications of a real signal and its one-day aliases. In the case of insufficient quantity and low quality of the data, the formal probability of the real signal is not always higher than that of a false (aliased) signal. So in all the periodograms we preferred the period that coincided with, or was close to, the known periods ever observed in NY Ser.

5.1 2002 first wide outburst

We selected the five light curves for the 2002 first wide outburst (BJD 2452445–2452449). The corresponding PDM analysis of these data (the central part of the outburst) is presented in figure 6. One of the two most significant one-day alias signals on the periodogram points to the 0.09748(17) d period that coincides with the orbital one within the limits of errors. The mean amplitude of the

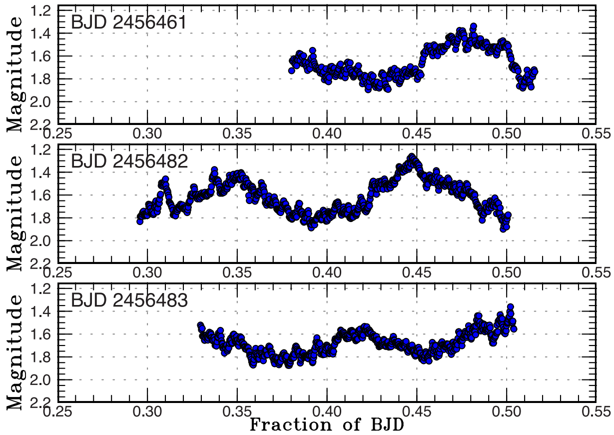

Fig. 3. Example of the light curves during selected nights in the 2013 quiescent state. The magnitudes are given relative to the comparison star.

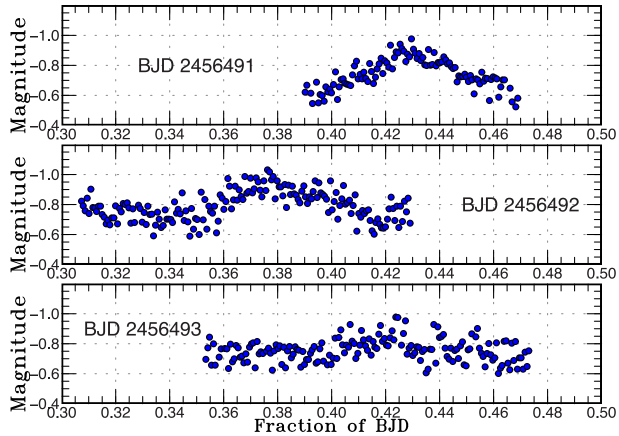

Fig. 5. Example of the nightly light curves during the 2013 superoutburst. The magnitudes are given relative to the comparison star.

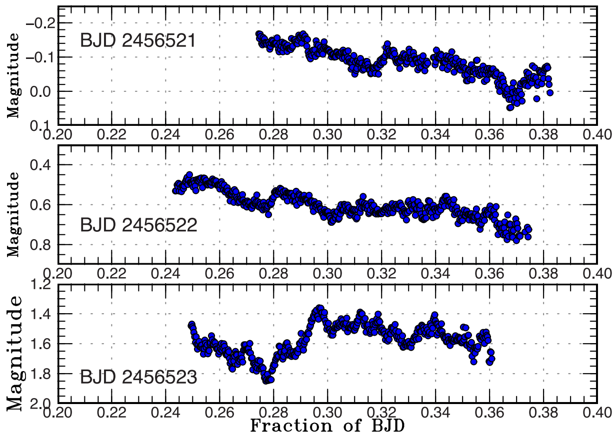

Fig. 4. Example of the light curves for the declining branch of the normal outburst. The magnitudes are given relative to the comparison star.

light curve is ∼ 0.1 mag. Its profile looks like a round maximum with some depression at phase 0.9 and with a sharp minimum. Note that a one-day alias signal points to a 0.108 d period and does not fall in the period range of 0.104 d to 0.106 d that corresponds to the different estimate of the superhump period (Nogami et al. 1998; Patterson et al. 2003).

5.2 2002 second wide outburst

A PDM analysis of the data BJD 2452495–2452499 yielded a period which differs from the previous one (see figure 7). One of the one-day aliased periods, 0.10495(13) d, as is the case above, also falls within the range of published superhump periods (Nogami et al. 1998; Patterson et al. 2003). Since the one-day alias for the 0.10495(13) d period is far from the orbital one, we accept the 0.10495(13) d period as the true one. The phase-averaged light curve is single-humped and has an amplitude of ∼ 0.2 mag.

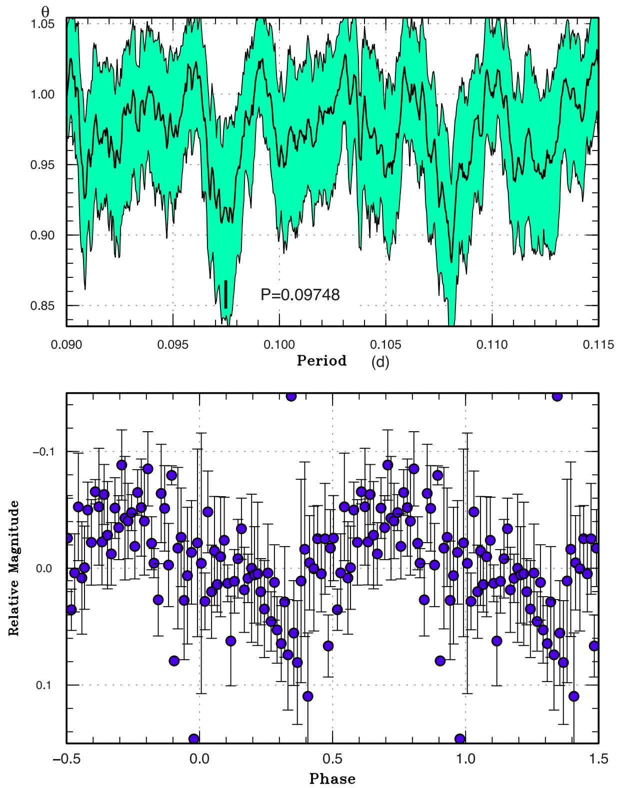

Fig. 6. Above: PDM analysis of the 2002 first wide outburst (BJD 2452445–2452448). The 90% confidence interval for θ is shown by the green strip. The preferable period is marked. Below: Phase-averaged profile of the data folded on the 0.09748 d period. For clarity data are reproduced twice. (Color online)

We identified the first wide outburst having a duration of 5–6 d as a wide normal outburst, while the second wide one represents a fragment of superoutburst, where the outburst on the first three nights probably belongs to the superoutburst precursor.

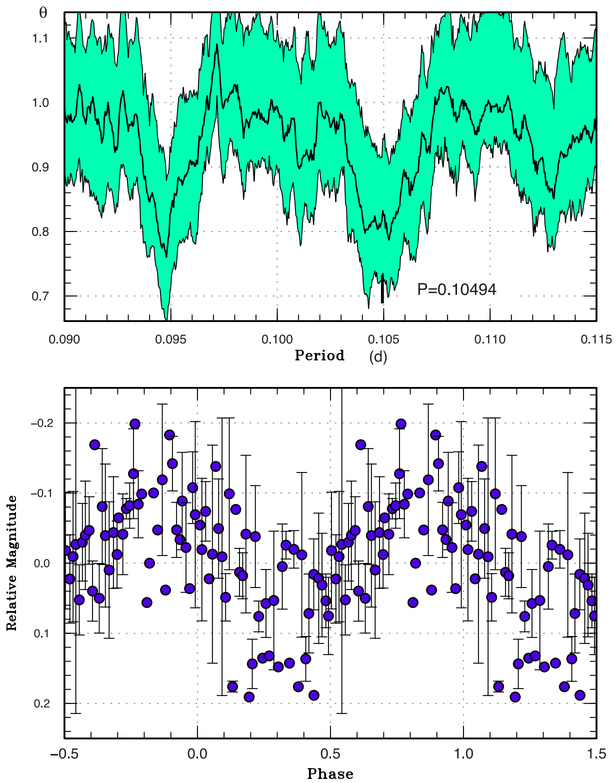

Fig. 7. Above: PDM of the 2002 second wide outburst (superoutburst) (BJD 2452495–BJD 2452499). The 90% confidence interval for θ is shown by the green strip. The preferable period is marked. Below: The averaged light curve of the 0.1049 d period. For clarity data are reproduced twice. (Color online)

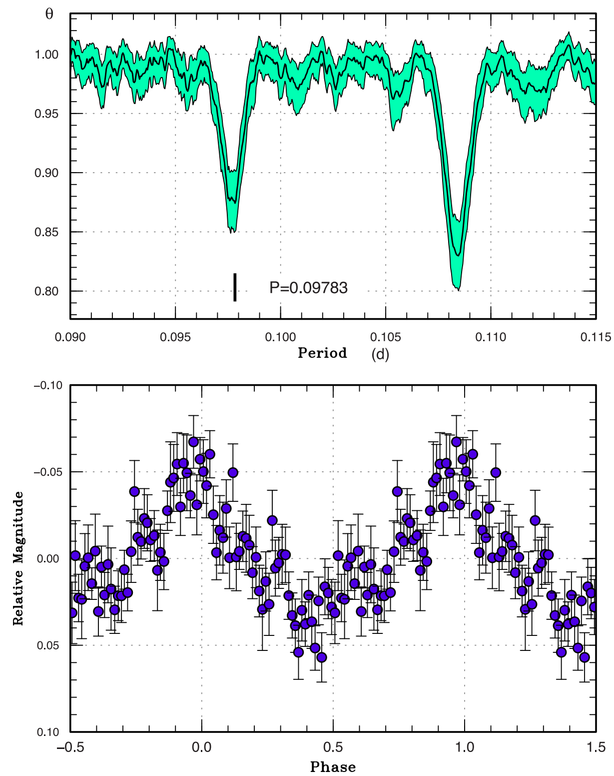

Fig. 8. Above: PDM analysis of the 2013 first wide outburst. The 90% confidence interval for θ is shown by the green strip. The preferable period is marked. Below: The phase-averaged light curve of the 0.09783 d period. For clarity data are reproduced twice. (Color online)

5.3 2013 first wide outburst

The periodogram obtained from the PDM analysis of all the data by using the most densely observed part of this outburst (BJD 2456466–2456474) is shown in figure 8. Contrary to our expectation of detecting superhumps in this wide outburst, the periodogram yields only the period of 0.09783(2) d that coincides with the orbital one. So we classified this outburst as a "wide normal outburst."

5.4 2013 second wide outburst

We selected the data for 12 nights during the period from BJD 2456489 and 2456502 for the next wide outburst following the 5 d quiescence after the previous 12 d outburst, skipping the data of the first two nights. The result of PDM analysis for the de-trending data is shown in figure 9.

The most significant signal points to a period of 0.104531(37) d. This period is close to the positive superhump period obtained from the 2002 superoutburst and to the evaluations reported by Nogami et al. (1998) and Patterson et al. (2003). The mean light curve obtained from this period has a single-humped profile with an ∼ 0.1 mag amplitude. This 18 d wide outburst is identified as a superoutburst.

Using the frequency of these positive superhumps, $F_{\rm sh}$, and the frequency of the known orbital period, $F_{\rm orb}$, we obtain the fractional period excess (in frequency) $\epsilon^* = 1 - (F_{\rm sh}/F_{\rm orb}) = 0.072$.

5.5 Periodicity outside the superoutburst

In figure 3, selected nightly light curves in the quiescent state of NY Ser are shown. One can see strong brightness variations on a scale of ∼ 0.1 d and some low-amplitude oscillations superposed on the light curve. Despite of the same mean brightness, the amplitude of the quiescent light curves is not stable. Thus it reached 0.4 mag on BJD 2456461 and BJD 2456482, but it was only ∼ 0.2 mag on BJD 2456483. Prominent flickering with amplitudes of up to 0.1–0.2 mag was superposed on some quiescent light curves.

Figure 4 shows the nightly light curves of the eighth normal outburst in figure 2 when it proceeded from maximum to quiescence. In magnitude units, the amplitude of brightness modulation gradually increases from ∼ 0.05 to ∼ 0.4 mag over the outburst decline. The shape of the light

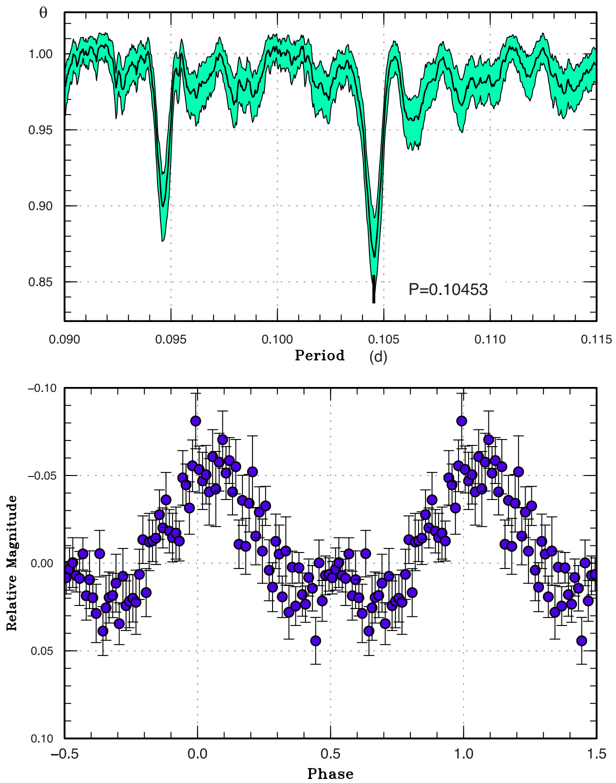

Fig. 9. Above: PDM analysis of the 2013 second wide outburst (superoutburst). The 90% confidence interval for θ is shown by the green strip. The preferable period is marked. Below: The phase-averaged light curve of a formally best period of 0.10453 d. For clarity data are reproduced twice. (Color online)

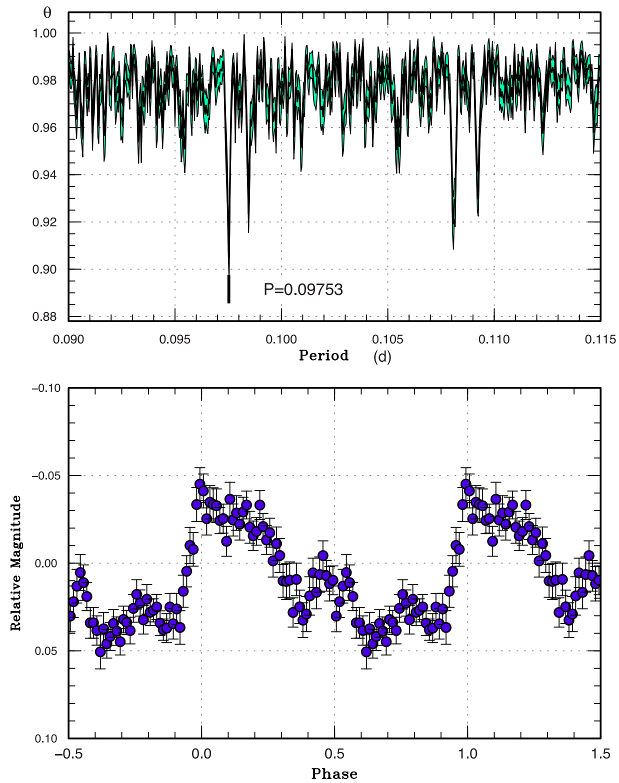

Fig. 10. Above: PDM analysis of all the data before the 2013 superoutburst. The 90% confidence interval for θ is shown by the green strip. The preferable period is marked. Below: Phase-averaged light curve of the 0.09753 d period. For clarity data are reproduced twice. (Color online)

curves at the top of the outburst and during the middle of the declining phase is rather structured.

We searched for periodicity of the observations in 2013 of NY Ser outside the superoutburst state. Taking into account that before the superoutburst NY Ser was in a state of less-frequent normal outbursts than after its superoutburst, we studied the periodicity of these states separately. The first data set included all the data both in minimum and in all normal outbursts before the superoutburst (see figure 10). One can see a strong, sharp signal on the periodogram of the first data set pointing to the period of 0.097531(4) d that coincides with the orbital one. The one-day alias period of 0.108 d is also presented. The phase-averaged light curve has an amplitude of ∼0.1 mag and some dip at a phase of around 0.3–0.4.

The second data set included the data of the highest activity outburst, i.e., the fifth and sixth normal outbursts, and the quiescence around them. The result of PDM analysis is shown in figure 11. This periodogram contains the two strongest signals at periods of 0.10465(12) d and 0.09744(5) d, which we believe to be the period of positive superhumps and the orbital period, respectively.

Our conclusion is that in the state of relatively infrequent outbursts the orbital modulation was the dominant signal both in normal outbursts and in quiescence. In the state of the most frequent outbursts we confidently detected the coexistence of the surviving positive superhumps and the orbital period.

As mentioned above, after this superoutburst the cycle length of the normal outbursts shortened up to 5–6 d. The effect of a change of the normal outburst frequency has been detected in several stars. In V1504 Cyg (Osaki & Kato 2013a) and V344 Lyr (Osaki & Kato 2013b) it was established that the decrease in the frequency of normal outbursts is accompanied by the appearance of negative superhumps and vice versa. The disappearance of negative superhumps was found in V503 Cyg (Kato et al. 2013; Pavlenko et al. 2012) in the stage of frequent normal outbursts. Since NY Ser entered the stage of frequent normal outbursts after the 2013 superoutburst, we checked whether there were negative superhumps or "impulsive" negative superhumps (Osaki & Kato 2013b) in the data in the state of relatively infrequent normal outbursts including the wide outburst.

Using the ratio $\epsilon^*_{\rm p}/\epsilon^*_{\rm n} \sim 7/4$ (Osaki & Kato 2013b), where $\epsilon^*_{\rm p}$ and $\epsilon^*_{\rm n}$ are 0.067 and 0.038, respectively, we

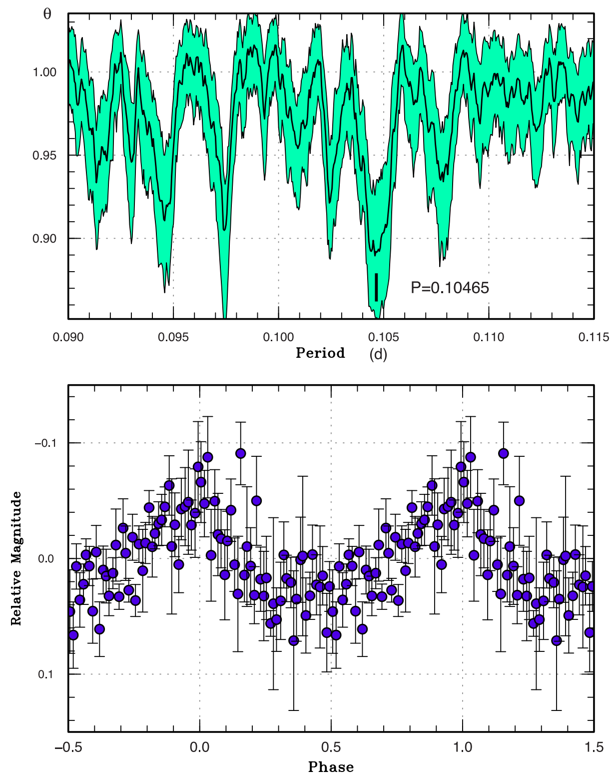

Fig. 11. Above: PDM analysis of the data after the 2013 superouburst limited to the fifth and sixth normal outbursts and the quiescence around them. The 90% confidence interval for θ is shown by the green strip. The preferable period is marked. Below: The phase-averaged light curve of the 0.10465 d period. Note that it is contaminated by the orbital modulation. For clarity data are reproduced twice. (Color online)

found an expected period of negative superhumps to be ∼ 0.09379 d.

We did not find any indications of negative superhumps either for the state with relatively infrequent outbursts or for the state with frequent outbursts.

6 Discussions

6.1 Variation in long-term behavior and its relation to variation in outburst activity

NY Ser has been recorded in the Catalina Real-time Transient Survey (CRTS: Drake et al. 2009) since 2010 May.[4] The quiescent magnitudes of NY Ser before the 2012 season were around 18 mag, while they became brighter (17.0–17.5 mag) in the 2012 and 2013 seasons. This brightening of the quiescent magnitude may suggest an increase in the mass-transfer rate or an increased dissipation in the quiescent disk (e.g., increased quiescent viscosity). Although the cause of such a variation is not clear, this systematic variation of the state in this system may be responsible for the variation in the outburst activity in the last two years.

6.2 NY Ser and SU UMa stars in the period gap

NY Ser is a rare, but not unique, binary among SU UMa-type stars showing some deviation from the bimodality of outbursts. But Warner (1995, and references therein), mentioned that TU Men, the SU UMa dwarf nova with the longest orbital period within the period gap, has a trimodal distribution of outburst widths. The widest outbursts were confirmed to be superoutbursts with a duration of ∼ 20 d; the wide outbursts have a duration of 8 d and the narrow outbursts last only for ∼ 1 d. Another candidate for an object showing a trimodal distribution is YZ Cnc (Patterson 1979). Its period is slightly below the period gap. NY Ser is the first SU UMa dwarf nova possessing a much richer diversity of normal outbursts.

In some respects, the morphology of outbursts of NY Ser is reminiscent of CVs above the period gap (having a longer time scale). Note that the novalike could have the same orbital period as the dwarf nova, but a higher mass-transfer rate. For example, the novalike MV Lyr, located close to the long-period end of the period gap, at some epochs showed a variety of outbursts looking like an alternation of the sequence "wide outburst–several narrow outbursts" without confirmed superhumps (Pavlenko & Shugarov 1999; Honeycutt & Kafka 2004).

The existence of nonmagnetic CVs in the period gap is still an open question. If we apply the theory of magnetic braking (Hameury et al. 1988), it follows that when the secondary becomes fully convective, it shrinks and goes into the Roche lobe that happens at a period of ∼ 3 hr and fills it again at ∼ 2 hr. This simplest evolutionary scenario indicates that there should be no CVs in the period gap. However, from the Ritter and Kolb (RK) catalog (Ritter & Kolb 2003, Edition 7.20), orbital periods in Pavlenko et al. (2010), and E. P. Pavlenko et al. (in preparation) for 1RXS J003828.7+250920 (Kato et al. 2012), there are 26 known dwarf novae in the 2.15–3.18 hr period gap by the middle of 2013. They are listed in table 1. The majority of them, namely 23 systems, are SU UMa-type stars. The distribution of the orbital periods of these SU UMa-type stars is presented in figure 12.

One can see that this distribution is not uniform. The number of systems strongly increases as the orbital period becomes shorter. A little more than half of the SU UMa-type stars are concentrated in a range of 2.18 to 2.3 hr. However, this tendency is apparently applied only to the distribution of SU UMa stars. Knigge (2006) indicates that the

[4] The public data are available at ⟨http://nesssi.cacr.caltech.edu/DataRelease/⟩.

Table 1. Dwarf novae in the gap.

Object name	Orbital period (d)*	Type
TU Mensae	0.1172	SU
V405 Vulpeculae	0.1131+	SU
CI Geminorum	0.11+	SU
CS Indi	0.11	DN
AX Capricorni	0.109+	SU
SDSS J162718.39+120435.0	0.104+	SU
CSS 10531:134052+151341	0.1021	DN
V1239 Herculis	0.1000	SU
MN Draconis	0.100+	SU
OGLE J175310.04−292120.6	0.100+	SU
CSS 120813:203938−042908.04	0.100+	SU
V1006 Cygni	0.09904	DN
NY Serpentis	0.0978	SU
DV Scorpii	0.0950+	SU
V444 Pegasi	0.0947+	SU
CSS 110628:142548+151502	0.094+	SU
V725 Aquilae	0.0939+	SU
1RXS J003828.7+250920	0.094511	SU
SBSS 0150+339	0.093+	SU
CSS 110205:120053−152620	0.093+	SU
CSS 111004:214738+244554	0.0927	SU
AD Mensae	0.0922	SU
TCP J08461690+3115554	0.09138	SU
CSS 080427:131626−151313	0.091+	SU
V589 Herculis	0.0905	SU
GV Piscium	0.090+	SU

*+ means that the orbital period was indirectly determined from the positive superhumps.

number of all CVs inside the gap displays opposite behavior; namely, it increases with orbital period.

The most accepted explanation of the existence of CVs in the period gap is that they are formed in the period gap (they became contact binaries with the orbital period just coinciding with a period in the period gap). We present here two explanations why SU UMa-type stars are more highly concentrated in the shorter period within the period gap.

If we assume that SU UMa stars with an orbital period inside the gap are formed uniformly in the period range, they will evolve within the period gap displaying dwarf nova-type activity. It would lead to a higher number of objects in shorter periods because objects formed in both the shorter and longer periods contribute to the short-period population while only the objects formed in longer periods contribute to the long-period population. This effect resembles the accumulation of SU UMa stars at the short-period boundary during the evolution. This explanation, however, cannot explain why the total number of CVs is larger in the region of longer periods in the period gap.

The second, more plausible explanation is that the 3:1 resonance becomes harder for the SU UMa stars with an increasing orbital period to reach. Considering that the 3:1 resonance responsible for an appearance of superhumps occurs for $q \leq 0.25$ (Whitehurst 1988; Hirose & Osaki 1990; Lubow 1991), we could expect such a condition to be achieved in dwarf novae closer to the lower bound of the period gap. It seems that NY Ser is not capable of achieving the 3:1 resonance in some of long outbursts.

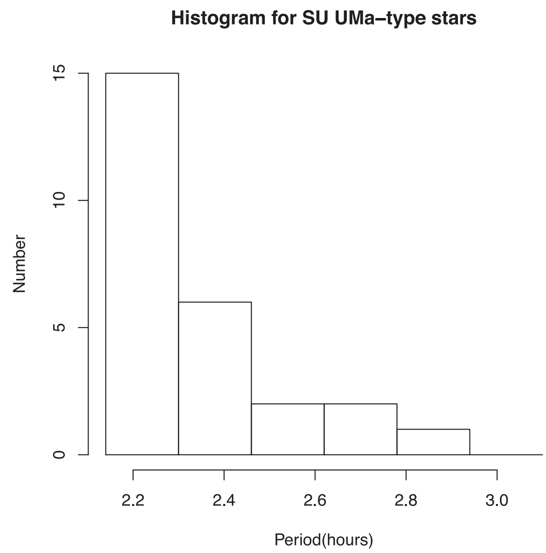

Fig. 12. Distribution of orbital periods of the SU UMa-type stars and dwarf novae in the period gap.

6.3 V1006 Cyg case

From spectroscopic observations (Sheets et al. 2007), the orbital period of V1006 Cyg is 0.09903(9) d, qualifying it for a dwarf nova in the period gap. In the RK catalog, V1006 Cyg is classifed as an SU UMa-type star by referring to a preliminary report on the period (vsnet-alert 9487), which was corrected later (vsnet-alert 9489). We report here the result of analysis of this dwarf nova from the VSNET Collaboration (Kato et al. 2004) obtained during its long outbursts in 2007 and 2009. The light curves of the 2007 and 2009 outbursts are shown in figures 13 and 14.

A PDM analysis yielded the periods, 0.09883(12) d for the 2007 outburst and 0.09892(28) d for the 2009 (see figures 15 and 16), that within the errors coincide with the orbital period discovered from spectroscopy. The amplitude of the light curve for both outbursts is ~0.02 mag. So we found only the orbital modulation in each outburst and there were no indications of the expected superhump period. Since superhumps are not yet detected in V1006 Cyg, we should regard it as an SS Cyg-type star rather than an SU UMa-type star. It is not clear whether these outbursts represent wide ones similar to the NY Ser-like wide outbursts with the orbital modulation,

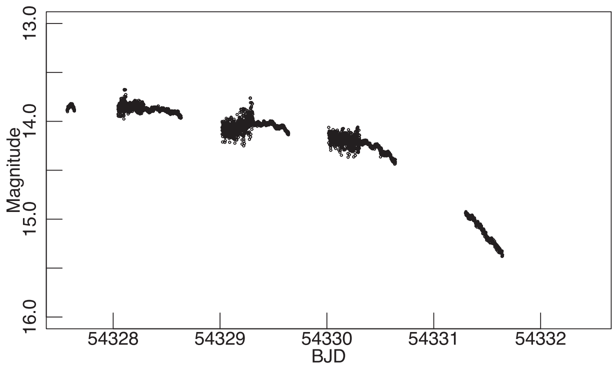

Fig. 13. The 2007 light curve of V1006 Cyg. BJD values mean "BJD−2400000.0."

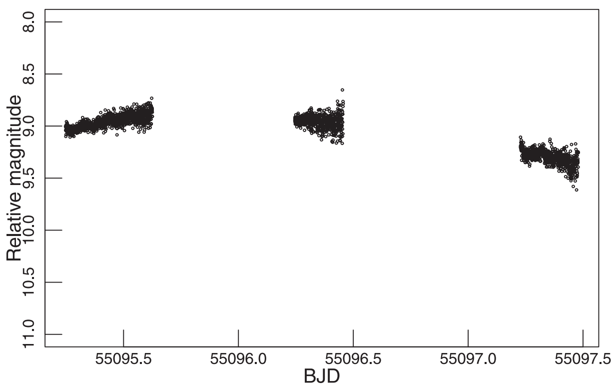

Fig. 14. The 2009 light curve of V1006 Cyg. BJD values mean "BJD−2400000.0."

and similarly in the case of NY Ser or TU Men, one could expect the appearance of superhumps during a much longer outburst. On the other hand, V1006 Cyg would remain a genuine SS Cyg-type star which never reaches the 3:1 resonance. The presence of an apparent SS Cyg-type star having a long outburst without superhumps in the period gap supports our second suggestion that the 3:1 resonance is harder to achieve in longer periods of the period gap, which would explain the distribution of SU UMa stars inside the period gap.

7 Conclusion

In this work we discovered in NY Ser unusually long 12 d outbursts without superhumps but displaying orbital light variations.

In his monograph considering the SU UMa-type stars, Warner (1995) wrote: "if dwarf novae are ever found with superoutbursts lacking superhumps they will define a class of their own." NY Ser could be an example of an intermediate subclass of dwarf novae possessing some properties of cataclysmic variables below the period gap or above it.

In the state of relatively infrequent outbursts the orbital modulation was the dominant signal both during normal

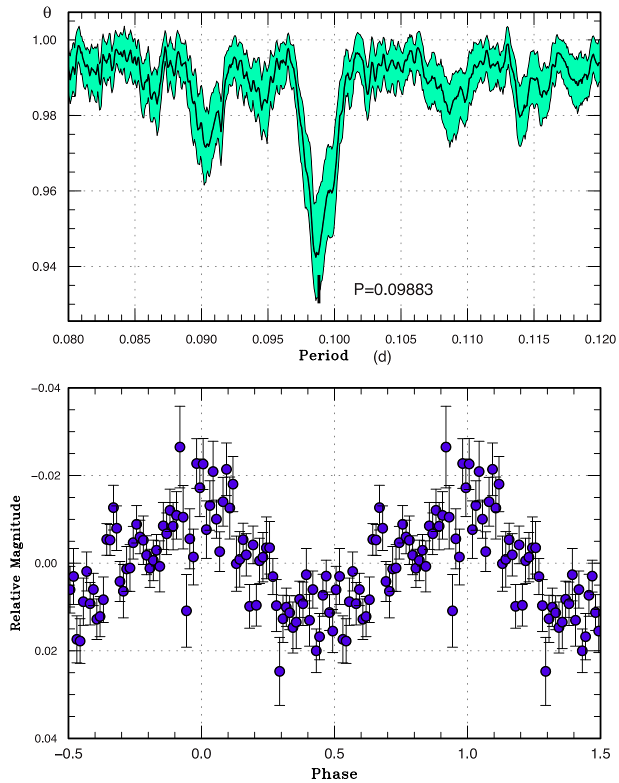

Fig. 15. Above: PDM analysis of the data of V1006 Cyg (the 2007 outburst). The 90% confidence interval for θ is shown by the green strip. The preferable period is marked. Below: Phase-averaged light curve of the 0.09883 d period. For clarity data are reproduced twice. (Color online)

outbursts and in quiescence. In the state of the most frequent outbursts immediately followed by the 2013 superoutburst, we confidently detected the coexistence of the surviving positive superhumps and the orbital period.

We were not able to detect a sufficient number of the superhump maxima during the superoutburst because of the limited length of nightly light curves. We leave the study of the evolution of the positive superhumps in this system for the future. We hope that within the future international multilongitude campaign we could also define the frequency of the appearance of a different type of normal outbursts and understand the phenomenon of this unique dwarf nova that could bring us closer to understanding the evolution of CVs inside the period gap.

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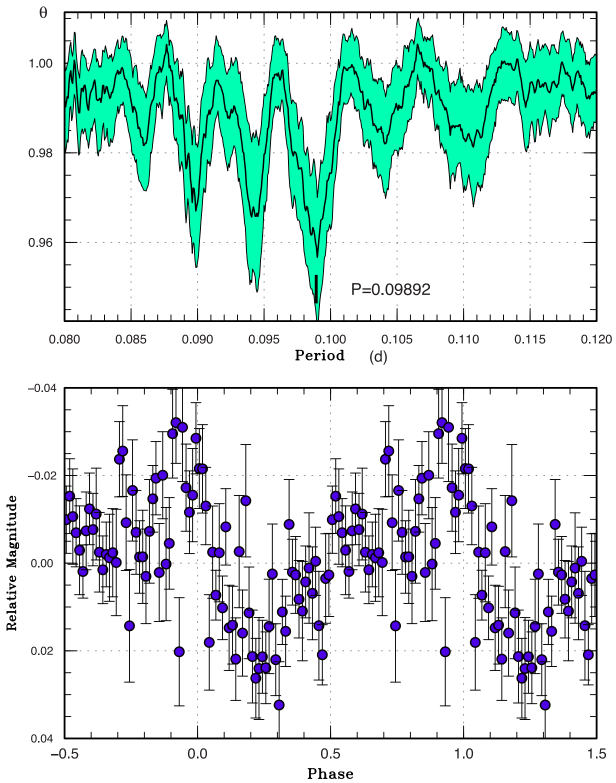

Fig. 16. Above: PDM analysis of the data of V1006 Cyg (the 2009 outburst). The 90% confidence interval for θ is shown by the green strip. The preferable period is marked. Below: Phase-averaged light curve of the 0.09892 d period. For clarity data are reproduced twice. (Color online)

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Supporting Information

Additional Supporting Information may be found in the online version of this article: E-table 1.

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