Discovery of Standstills in the SU UMa-Type Dwarf Nova NY Serpentis

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1 Introduction

Dwarf novae are a class of cataclysmic variables, which are close binary systems composed of a white dwarf and a mass-transferring red-dwarf secondary. The transferred matter forms an accretion disk and thermal instability in the disk is believed to cause outbursts, which characterize dwarf novae. It is known that when the mass-transfer rate ($\dot{M}$) is above a certain value ($\dot{M}_{\text{crit}}$), the disk is thermally stable and that the system does not undergo outbursts. These systems are called novalike variables. If the mass-transfer rate is below this, dwarf nova-type outbursts occur [for general information of cataclysmic variables and dwarf novae, see e.g. Warner (1995)].

In dwarf novae with small (less than $\sim$0.25) mass ratios ($q=M_2/M_1$, where $M_1$ and $M_2$ represent the masses of the white dwarf primary and the secondary, respectively), the disk radius can reach the radius of the 3:1 resonance between the binary rotation and the motion in the disk, and the disk then becomes tidally unstable and non-axisymmetric deformation occurs (tidal instability: Whitehurst 1988; Hirose and Osaki 1990; Lubow 1991), which produces superhumps [humps with periods a few to several percent longer than the orbital periods ($P_{\text{orb}}$)] and superoutbursts. Such systems are called SU UMa-type dwarf novae and most of them have $P_{\text{orb}}$ shorter than $\sim$2 hr, below the period gap in the distribution of $P_{\text{orb}}$ of cataclysmic variables.

Some dwarf novae spend intermediate states between the outburst maximum and minimum for considerable durations (tens of days to years), and such states are called standstills. Systems showing standstills are called Z Cam-type dwarf novae. Z Cam-type dwarf novae usually have longer orbital periods longer than $\sim$3 hr, and they are not expected to show SU UMa-type behavior. It is usually considered that Z Cam-type dwarf novae have mass-transfer rates close to $\dot{M}_{\text{crit}}$ and a subtle variation in the mass-transfer rate makes the disk in these systems either thermally stable (standstills) or unstable (dwarf nova state). Although there is no special reason to believe that SU UMa-type dwarf novae and Z Cam-type dwarf novae are completely exclusive, most of known (non-magnetic) cataclysmic variables can be divided into four regions on the $M$-$q$ plane based on the thermal and tidal stability criteria, and Z Cam-type dwarf novae occupy the region slightly below the thermal stability line and $q$ higher than the tidal stability line (Osaki 1996).

There has been an exceptional case of BK Lyn, which had been known as a novalike variable, showed an SU UMa-type state in 2005–2013 (Patterson et al. 2013; Kato et al. 2013; Kato et al. 2014). This object is suspected to be a post-outburst nova which erupted in AD 101 (Patterson et al. 2013). The variation in the activity (mass-transfer
rate) may be affected by the recent nova explosion.

We found that the SU UMa-type dwarf nova NY Ser experienced standstills and that the system developed superoutbursts arising from these standstills first time in all dwarf novae. We report on this phenomenon and discuss the implication on the mechanism of standstills and dwarf nova outbursts.

2 Observations and results

2.1 Overall behavior

The standstill state was noticed T.K. in 2018 February in snapshot observations made by Y.M. (vsnet-alert 2189) and we launched a photometric campaign in the VSNET Collaboration (Kato et al. 2004). We also used the public data from the AAVSO International Database (Kato et al. 2004). The majority of the data were acquired by time-resolved CCD photometry by using 20–60cm telescopes located worldwide. The data analysis followed the description in Kato et al. (2009) [see E-section 1 in Supporting information (SI)]. The details of observations are listed in E-table 1 in SI. The overall light curve is shown in figure 1. NY Ser in the past underwent normal outbursts every 6 to 9 d (Nogami et al. 1998) with occasional superoutbursts. We show a long-term light curve in figure 2. It is very clear that the behavior in 2018 was very different from the one in 2015–2017.

The standstill state, at least starting on 2018 January 20, lasted at least until 2018 March 17. No superhumps were detected during this standstill (vsnet-alert 21972) and the phenomenon was that of a genuine standstill of the Z Cam-type dwarf nova, rather than superhumping novae like state such BK Lyn.

The object then underwent brightening on 2018 March 22 (it was confirmed to be already in outburst state on 2018 March 20 based on snapshot observations from the AAVSO database) and superhumps appeared (vsnet-alert 22026). Following this superoutburst (rapidly faded on 2018 April 3–4), the object entered a phase of repetitive dwarf nova-type outbursts with intervals of 6–7 d (vsnet-alert 22065), which lasted at least up to 2018 May 13. The object was again found to be in a standstill on 2018 May 24 (vsnet-alert 22195). Using all the data, the object showed seven outbursts before entering this standstill. This standstill lasted up to 2018 July 11 and brightening accompanied by developing superhumps was recorded on 2018 July 12 (vsnet-alert 22313). We provided an enlargement of standstill to SO2 in E-figure 1. There were no gap in observations longer than 24 hr and a precursor outburst as in the Kepler observations of V1504 Cyg (Osaki and Kato 2013a, in particular figure 4) and V344 Lyr (Osaki and Kato 2013b) can be safely excluded. This observation made the first clear evidence that a superoutburst can start from a standstill.

2.2 Superhumps

During the superoutburst SO1, superhumps were unambiguously detected (see E-figure 2 in SI). Since the details of superhump timing analysis is not very much related to the main theme of this Letter, we list the times of maxima in E-table 2 in SI. It may be, however, worth noting that long superhump period of 0.10516(3) d was detected during the post-superoutburst phase (with dwarf nova outbursts) between BJD 2458213 and 2458222 (see E-figure 3 in SI). The fractional superhump excess (in frequency) $e^* = 1 - \frac{P_{orb}}{P_{SH}}$, where $P_{SH}$ is the superhump period, was very large [0.0723(2)] using $P_{orb}=0.97558(6)$ d in Sklyanov et al. (2018). If this long superhump period reflects the dynamical precession rate (i.e. pressure effect is negligible, e.g. Kato and Osaki 2013; E-section 2 in SI), the $q$ value is estimated to be 0.23 (assuming the maximum disk size at the 3:1 resonance 0.448 A, where A is the binary separation) and 0.43 for (0.35 A, typical SU UMa-type dwarf novae in the post-superoutburst phase; this condition corresponds to subsection 4.3.2 in Kato and Osaki 2013). The true $q$ would be something between these two extreme values. Since $q$ is expected to lower than $\sim$0.25 to enable superhumps, a post-superoutburst disk larger than typical SU UMa-type dwarf novae is preferred.

Superhumps during the superoutburst SO2 were less well observed, although the developing phase of the superoutburst was observed (E-figure 4 in SI). It is difficult to tell the superhump period with nightly coverage of only one orbital cycle (due to the small solar elongation). The data were, however, sufficient to tell that the humps during this superoutburst cannot be expressed by the orbital period (i.e. these humps were superhumps, and not enhanced orbital humps).

3 Discussion

3.1 Standstills in SU UMa-type dwarf novae

Our observations demonstrated that an SU UMa-type dwarf nova can have a standstill during a supercycle, and that superoutbursts can directly occur from standstills. Such a phenomenon has never been recorded.
Fig. 1. Light curve of NY Ser in 2018. Filled circles, filled square and filled diamonds represent our CCD observations, snapshot observations by Y.M. and AAVSO V-band observations, respectively. Two superoutbursts (SO1 and SO2) occurred following a standstill. After superoutbursts, the object showed ordinary dwarf nova-type outbursts.

Fig. 2. Long-term light curve of NY Ser between 2015 and 2018 using All-Sky Automated Survey for Supernovae (ASAS-SN) V and g observations (Shappee et al. 2014; Kochanek et al. 2017). V and g magnitudes are almost the same in dwarf novae and they are not distinguished. The final part of this figure (marked by a horizontal bar) corresponds to figure 1. It is very clear that the behavior in 2018 was very different from the one in 2015–2017.
The most important finding is that the absence of superhumps or negative superhumps during standstills (see E-figure 5 in SI). These standstills are indeed of purely Z Cam-type ones rather than “permanent superhump” states seen in novalike variables such as BK Lyn. This indicates that the standstills in NY Ser were not maintained by extra tidal torques produced by tidal instability nor a result of a disk tilt (which is supposed to be the cause of negative superhumps).

In Z Cam stars, long-term variation in the mass-transfer rate is considered to be the cause of standstills (Meyer and Meyer-Hofmeister 1983). We tested this possibility by comparing the mean brightness (averaged in the flux unit, all having standard errors of less than 0.01 mag) between the outbursting and standstill states. The mean values were 15.41 (before BJD 2458196, standstill), 15.46 (BJD 2458196–2458261, SO1 and the following outburst state), 15.52 (BJD 2458261–2458312, standstill) and 15.57 (after BJD 2458312, SO2 and the following outburst state). There was no systematic brightness increase during standstills comparable to 0.2 mag difference in some Z Cam stars in Honeycutt et al. (1998), and we can exclude the possibility of the increased mass-transfer as the cause of standstills. The mean brightness, however, gradually faded, probably reflecting the long-term decrease of the mass-transfer rate returning from the unusual state in 2018 back to normal.

Superhumps were newly excited at the onset of each superoutburst. Following the standard thermal-tidal instability model (Osaki 1989; Osaki 1996) this finding indicates that the disk radius gradually increased during standstills and then eventually reached the 3:1 resonance. This observation provides the first evidence that the disk radius can increase during standstills.

Although we are not aware of the precise mechanism of the increase of the disk radius, we consider that the re-distribution of the disk matter after the superoutburst may be responsible for the phenomenon. We should note that a similar transition from dwarf nova-type outbursts to a (quasi-)standstill was recorded during the post-superoutburst state in the WZ Sge-type dwarf nova ASASSN-15po (Namekata et al. 2017). A similar case was found in the helium dwarf nova V803 Cen in 2016 (K. Isogai et al. in preparation).

We recently found that outbursts arising from standstills are more prevalent in Z Cam stars [we called such objects IW And stars, currently a subclass of Z Cam stars Kato (2018)]. Following the present evidence in NY Ser that the disk radius can increase during standstills, we suggested in Kato (2018) that the increase in the disk radius or re-distribution of the disk matter during standstills, might be the cause of such a phenomenon. We consider that this phenomenon is more prevalent in various kinds of dwarf novae and should require more theoretical studies.

3.2 Behavior near limit of tidal stability

NY Ser is an object in the period gap (Nogami et al. 1998; Sklyanov et al. 2018). It has been shown that “long-normal” outbursts (long outbursts without superhumps) were recorded in this object (Pavlenko et al. 2014). The only other known SU UMa-type dwarf novae showing long-normal outbursts are TU Men, (Stolz and Schoembs 1984; Bateson et al. 2000) and V1006 Cyg (Kato et al. 2016; Pavlenko et al. 2018).

NY Ser, TU Men and V1006 Cyg have long orbital periods (longer than 0.095 d), and $q$ values are expected to be close to 0.25, which is the limit to allow tidal instability to develop. In such conditions, tidal instability is expected to be difficult to develop or maintain in these systems. This condition would enable long-normal outbursts to occur (the disk mass is enough to sustain a superoutburst while tidal instability fails to develop). The same condition may enable easy decoupling between thermal and tidal instabilities as proposed in very low $q$ systems (Hellier 2001). We have already suggested that in systems near the border of tidal instability is not strong enough to maintain the disk in the hot state when the cooling wave starts (Kato et al. 2016).

Early quenching of tidal instability and subsequent quenching of a superoutburst may result large amount of matter left in the disk after the superoutburst. This interpretation appears to be strengthened by the recent discoveries of SU UMa-type dwarf novae above the period gap (ASASSN-18yi and ASASSN-18aan, Wakamatsu et al. in preparation), whose multiple post-superoutburst rebrightenings are a signature of the large amount of matter after superoutbursts. The cause of standstill-like behavior in ASASSN-15po and V803 Cen may be this decoupling between thermal and tidal instabilities since both objects are expected to have very low $q$ values.

In the case of long-period systems near the border of tidal instability, the similar decoupling at the high $q$ limit can happen and may cause substantial disk matter to remain even after the superoutburst. If the mass-transfer rate from the secondary is low, this condition would enable to mimic the WZ Sge-type phenomenon (multiple rebrightenings) as in V1006 Cyg (Kato et al. 2016). With a high mass-transfer rate close to the thermal stability, a system like NY Ser can mimic the Z Cam-type behavior by enabling a quasi-steady state produced by the large
disk matter in a post-supernova outburst disk combined with the high mass-transfer rate. This interpretation appears to be consistent with the large post-supernova outburst disk as inferred from the superhump period in subsection 2.2.

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Supporting information
Additional supporting information can be found in the online version of this article: Tables. Figures. Supplementary data is available at PASJ Journal online.

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