Photometric Studies of a WZ Sge-Type Dwarf Nova Candidate, ASAS160048-4846.2

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Abstract

We report on our time-resolved CCD photometry during the 2005 June superoutburst of a WZ Sge-type dwarf nova candidate, ASAS160048-4846.2. The ordinary superhumps underwent a complex evolution during the superoutburst. The superhump amplitude experienced a regrowth, and had two peaks. The superhump period decreased when the superhump amplitude reached to the first maximum, successively gradually increased until the second maximum of the amplitude, and finally decreased again. Investigating other SU UMa-type dwarf novae which show an increase of the superhump period, we found the same trend of the superhump evolution in superoutbursts of them. We speculate that the superhump regrowth in the amplitude has a close relation to the increase of the superhump period, and all of SU UMa-type dwarf novae with a superhump regrowth follow the same evolution of the ordinary superhumps as that of ASAS 160048-4846.2.

Key words: accretion, accretion disks — stars: dwarf novae — stars: individual (ASAS160048-4846.2) — stars: novae, cataclysmic variables — stars: oscillations

1. INTRODUCTION

Cataclysmic variables (CVs) are close binaries containing a white dwarf (primary) and a late-type star (secondary). The secondary fills its Roche-lobe and transfers gas to the primary, so that an accretion disk is formed around it (for a review, see e.g. Warner 1995; Hellier 2001; Connon Smith 2007). Dwarf novae are a subclass of CVs.

SU UMa-type stars are a subgroup of dwarf novae which show two types of outbursts: normal outbursts, and superoutbursts. During the superoutbursts, repetitive modulations with an amplitude of 0.1-0.3 mag, called superhumps, are shown. The period of the superhumps is a few percent longer than the orbital period of the system. The thermal-tidal instability model is the most acceptable one for explaining the general behavior of SU UMa-type dwarf novae (Osaki 1989). According to the tidal-instability theory, an accretion disk becomes unstable due to the gravitational interaction with the secondary star when it reaches a critical radius of the 3:1 resonance (Whitehurst 1988). Superhumps can be explained by a beat phenomenon of the precession of a tidally-distorted disk and the orbital motion.

WZ Sge-type dwarf novae are one of the subtypes of SU UMa-type dwarf novae with the shortest orbital periods among SU UMa stars (see e.g. Kato et al. 2001b). Their observational properties are (1) the extremely long supercycle (over 5 years), which is a period between two successive superoutbursts, (2) the large amplitude of superoutbursts over 6 mag (4-5 mag in many SU UMa-type stars), (3) the absence of normal outbursts, and (4) the presence of double-peaked humps, called early superhumps, before emergence of the ordinary superhumps. Although the clear definition of the WZ Sge type is still controversial, its representative members where at least two outbursts have been observed so far and the supercycle was measured are AL Com (Kato et al. 1996, Patterson et al. 1996), EG Cnc (Kato et al. 2004a), HV Vir (Ishioka et al. 2003), WZ Sge itself (Kato et al. 2004b), and GW Lib (Imada et al. in preparation).

On 2005 June 9, ASAS 160048-4846.2 (hereafter ASAS 1600) was initially discovered by the All Sky Automated Survey (Pojmanski 2002) as an eruptive object. This is the only one recorded superoutburst. In the light curves of this superoutburst, Imada & Monard (2006), hereafter called Paper I, found double-peaked humps with a period of 0.06381(41) days, before ordinary superhumps emerged with a period of 0.064927(3) days. Based on evidence for early superhumps, they identified ASAS 1600 as a promising candidate for WZ Sge-type dwarf novae.

In this paper, we reanalysed the data reported in Paper I, and report on the evolution of the ordinary superhumps. The details of the observations and the analyses are summarized in the section 3. We will discuss the superhump evolution and the WZ Sge nature of ASAS 1600 in the section 4, and put conclusions in the last section 5.
2. OBSERVATION

Time-resolved CCD photometry was carried out in 12 consecutive nights between 2005 June 9 and June 20 at Tiegerpoort (South Africa) using a 32 cm telescope. The exposure time was 30 s with a readout-time of a few seconds. We used no filter during our run, so that the resultant data are close to those of the $R_c$ system. After excluding bad data, we used 10511 datapoints for the following analyses. The journal of the observations is summarized in table 1.

After dark-subtraction and flat-fielding, we performed aperture photometry using AIP4WIN, which is an image-editing software. Differential photometry was carried out using UCAC2 160053.1-484433 ($R=11.9$) as a comparison star, whose constancy was checked by UCAC2 160043.6-484628 ($R=12.8$).

The heliocentric correction to the observation times was applied before the following analyses.

3. RESULTS

The resulting light curve of the 2005 superoutburst of ASAS 1600 is presented in figure 1. The object had a plateau stage, fading at a constant rate of 0.12 mag day$^{-1}$, which lasted at least 12 days. After the end of the plateau stage, ASAS 1600 underwent a rebrightening outburst with the maximum magnitude $V=14.3$, which was observed on HJD 2453548 by R. Stubbings (vsnet-outburst 6503). However, we have no other information about the rebrightening.

During the 2005 superoutburst, clear ordinary superhumps were detected between HJD 2453534 and HJD 2453542. On HJD 2453533, we can see humps which hint growth into the ordinary superhumps (see figure 4 of Paper I). Figure 2 represents the change of the amplitude of the ordinary superhumps during the 2005 superoutburst. We estimated the amplitude by eye, and its typical error is an order of 0.01 mag. The superhump amplitude reached to the first maximum on HJD 2453535, and gradually declined until HJD 2453539. Afterword, the amplitude decreased. That indicates the regrowth of the superhump amplitude occurred. Figure 3 shows the daily phase-averaged light curves folded by 0.064927(3) days, which is the period of the ordinary superhumps ($P_{SH}$) measured in Paper I.

We measured the maximum times of the superhumps by eye (table 2). The cycle count ($E$) was set to be 1 at the first observed superhump maximum. A linear regression to the observed maximum timings is represented by the following equation:

$$HJD_{\text{max}} = 0.06496(2) \cdot E + 2453533.4517(14).$$  \hspace{1cm} (1)

Using this equation, we drew an $O-C$ diagram for the maximum timings of the superhumps in figure 4. The typical error is an order of 0.002 days, which will not affect the main results. As can be seen in this figure, the behavior of the $P_{SH}$ consists of three phases. At the first and the last stage of our run, corresponding to around $E = 30$ and $E = 100$, the superhumps period shows a decreasing trend. However, in the middle stage (about $30 < E < 100$), the superhump period clearly increases. We fitted the $O-C$ diagram between $28 < E < 109$ by the following quadratic,

$$O-C = 3.74(31) \times 10^{-6} \cdot E^2 - 5.22(43) \times 10^{-4} \cdot E + 1.74(14) \times 10^{-2}. \hspace{1cm} (2)$$

From this equation, the mean change rate of the superhump period between $28 < E < 109$ is estimated to be $P_{\text{dot}} = P_{SH}/P_{SH} = 11.5(9) \times 10^{-5}$ days cycle$^{-1}$. Such evolution of the superhump period can be seen in some SU UMa-type dwarf novae with short orbital period (e.g. HV Vir, Ishioka et al. 2003).
### Table 1. Log of observation.

| Date       | HJD-2400000(start) | HJD-2400000(end) | $N^*$ |
|------------|--------------------|-----------------|------|
| 2005 June 9| 53531.3679         | 53531.6275      | 587  |
| 2005 June 10| 53532.3213       | 53532.4210      | 274  |
| 2005 June 11| 53533.3779       | 53533.6062      | 648  |
| 2005 June 12| 53534.2413       | 53534.6269      | 1087 |
| 2005 June 13| 53535.2450        | 53535.5638      | 900  |
| 2005 June 14| 53536.3708        | 53536.5904      | 565  |
| 2005 June 15| 53537.2351        | 53537.5609      | 920  |
| 2005 June 16| 53538.1772        | 53538.5896      | 1151 |
| 2005 June 17| 53539.1764        | 53539.5496      | 1032 |
| 2005 June 18| 53540.1777        | 53540.5589      | 1061 |
| 2005 June 19| 53541.1757        | 53541.5859      | 1150 |
| 2005 June 20| 53542.1793        | 53542.5915      | 1136 |

$^*$ Number of frames.

### Table 2. Timings of the superhump maxima.

| $E^*$ | HJD-2400000 | $O - C^\dagger$ (days) | $E^*$ | HJD-2400000 | $O - C^\dagger$ (days) |
|-------|-------------|------------------------|-------|-------------|------------------------|
| 1     | 53533.4935  | -0.0231                | 2     | 53533.5651  | -0.0165                |
| 13    | 53534.2966  | 0.0005                 | 14    | 53534.3624  | 0.0014                 |
| 15    | 53534.4298  | 0.0038                 | 16    | 53534.4938  | 0.0028                 |
| 17    | 53534.5609  | 0.0050                 | 18    | 53534.6220  | 0.0011                 |
| 28    | 53535.2761  | 0.0057                 | 29    | 53535.3415  | 0.0061                 |
| 30    | 53535.4069  | 0.0066                 | 31    | 53535.4696  | 0.0043                 |
| 32    | 53535.5350  | 0.0047                 | 45    | 53536.3753  | 0.0006                 |
| 46    | 53536.4402  | 0.0006                 | 47    | 53536.5043  | -0.0003                |
| 48    | 53536.5701  | 0.0006                 | 59    | 53537.2832  | -0.0009                |
| 60    | 53537.3473  | -0.0017                | 61    | 53537.4140  | 0.0000                 |
| 62    | 53537.4781  | -0.0008                | 63    | 53537.5451  | 0.0012                 |
| 73    | 53538.1905  | -0.0029                | 74    | 53538.2579  | -0.0005                |
| 75    | 53538.3219  | -0.0014                | 76    | 53538.3878  | -0.0005                |

$^*$ Cycle count.

$^\dagger$ Using equation (1).
4. DISCUSSION

4.1. Superhump Period

During a superoutburst, the superhump period had been believed to decrease or stay constant in SU UMa-type dwarf novae in general (e.g. Warner 1985; Patterson et al. 1993), although only one unambiguous sign of the increase of $P_{SH}$ was discovered during the superoutburst of OY Car (Krzeminski & Vogt 1985). The decrease of the superhump period was explained by a shrinkage of the accretion disk (Lubow 1992), or an inward-propagation of eccentric perturbations generated at the 3:1 resonance radius in the accretion disk (Whitehurst 1994).

However, since Semeniuk et al. (1997b) reported that SW UMa had shown an increasing trend of $P_{SH}$ during the 1996 superoutburst, researchers have revealed that some SU UMa-type dwarf novae exhibit the increase of $P_{SH}$. Such systems are mainly WZ Sge-type dwarf novae and SU UMa-type dwarf novae with short orbital periods. Kato et al. (1998) proposed that the accretion disk of short orbital period systems can expand beyond the 3:1 resonance radius during superoutbursts and the eccentricity wave originated at the 3:1 resonance can propagate outward. The outward-propagation of the eccentricity may lead to the phenomena of the increase of $P_{SH}$ (see also Kato et al. 2004a). Kato et al. (2001b) suggested that the increase of $P_{SH}$ appear to be related to a low mass ratio and/or a low mass transfer rate.

Recently, Osaki & Meyer (2003) classified superoutbursts of SU UMa-type dwarf novae based on the mass ratio ($q = M_2/M_1$) and disk radius, and showed that a system with a large mass ratio ($\sim 0.2$) can exhibit two types of superoutburst. Following this idea, Uemura et al. (2005) explained the behavior of the superoutbursts of TV Crv\(^1\). They proposed that the changing of $P_{SH}$ ($P_{\dot{\text{d}}} = P_{\dot{\text{d}}} / P_{SH}$) depends on whether a superoutburst has a precursor or not. Their interpretation is indicated below: if a large amount of matter is accumulated beyond the 3:1 resonance radius at the outburst maximum, the dammed matter prevents the disk from rapid cooling, leading to a superoutburst without a precursor. In this case, the eccentricity originated at the 3:1 resonance radius can propagate outward, and $P_{SH}$ can increase during the superoutburst. Further, the discovery of the infrared excess observed in the late stage of WZ Sge-type superoutburst also supports their interpretation for the changing of $P_{SH}$ (Uemura et al. 2008).

In ASAS 1600, the $P_{SH}$ changed more complexly than had been documented. Figure 4 represents an $O-C$ diagram for the timings of the superhump maxima listed in table 2. As we mentioned in section 3, in the middle part (around $30 < E < 100$), the $O-C$ diagram demonstrates an increasing trend of $P_{SH}$, and the $P_{\dot{\text{d}}}$ derivative between $28 < E < 109$ is $P_{\dot{\text{d}}} = 1.15(9) \times 10^{-5}$ days cycle\(^{-1}\). However, in the early (around $E = 30$) and the last part (around $E = 100$), the $O-C$ diagram shows a decreasing trend of $P_{SH}$. Some well observed SU UMa

\(^1\) Kato et al. (in prep.) reanalyzed the data of the superoutbursts of TV Crv and suggest that the interpretation of the superhump period by Uemura et al. (2005) could not be confirmed.
stars, e.g. AL Com (Howell et al. 1996, Patterson et al. 1996), HV Vir (Ishioka et al. 2003) and TT Boo (Olech et al. 2004), showed an $O-C$ diagram with the same trend as that of ASAS 1600. These systems seem to follow the general tendency pointed out by Olech et al. (2003). They investigated the $O-C$ diagrams of some SU UMa-type dwarf novae, and proposed that almost all SU UMa-type dwarf novae show the decrease of $P_{SH}$ both at the beginning and at the end of the superoutburst, but the increasing trend at the middle phase.

We listed SU UMa-type dwarf novae which show an increase of $P_{SH}$ so far (table 3). Because we judged from the shape of the $O-C$ diagram, they include systems which have not been regarded as such. We reexamined them, and found that most of the well observed SU UMa-type dwarf novae with an increase of $P_{SH}$ also show a decrease of $P_{SH}$ at the beginning or end stage, or both. This also supports the claim by Olech et al. (2003).

4.2. Superhump Evolution

ASAS 1600 showed a regrowth of the ordinary superhumps in the amplitude like well investigated systems with an increase of $P_{SH}$ as described in the previous section. On HJD 2453535, the superhump amplitude became $\sim 0.24$ mag at the first maximum. After that, it gradually diminished, and reached $\sim 0.13$ mag on HJD 2453539. However, the superhump amplitude regrew up to the second maximum of $\sim 0.17$ mag on HJD 2453540, thereafter, it gradually became smaller again.

Additionally, from figure 2 and 4, we found that the superhump period decreased when the superhump amplitude reached to the first maximum, successively gradually increased until the second maximum of the amplitude, and finally decreased again during the 2005 superoutburst of ASAS 1600. The correlation between the amplitude and the period of the superhumps can be found in most SU UMa-type dwarf novae which show an increase of $P_{SH}$ (see the systems listed in table 3 with both $*$ and $\dot{\gamma}$). Therefore, we suppose that the regrowth of the superhump amplitude have a close relation to the increase of $P_{SH}$, and most SU UMa-type dwarf novae with a superhump regrowth may follow the same evolution of the ordinary superhump as ASAS 1600. The statement about the superhump period by Olech et al. (2003) seems to be applicable to such systems.

RZ LMi, however, showed only a gradual increase of the superhump period during the whole course of the 2004 April superoutburst, and this star does not seem to follow our scenario (Olech et al. 2008) \(^2\). RZ LMi is an ER UMa-type star, which is the most active subgroup of SU UMa-type dwarf novae (Nogami et al. 1995). The superhumps in ER UMa stars have been pointed out to be somewhat different from typical ones in normal SU UMa stars (e.g. Kato et al. 2003), and Osaki (1995) suggested that the extreme superoutburst properties of RZ LMi can not be simply explained in the frame of the thermal-tidal insta-

\(^2\) According to Rutkowski et al. (submitted to A&A), one of ER UMa stars, DI UMa also showed only an increase of the superhump period.

4.3. Is ASAS 1600 a WZ Sge-type Dwarf Nova?

The double-peaked humps were discovered with a period very close to the orbital period in the early stage of the 2005 superoutburst of ASAS 1600 (Paper I), and, therefore, this object was identified as a promising candidate of WZ Sge-type dwarf novae. In 2006 May, the next year of the superoutburst, normal outburst of ASAS 1600 was observed by R. Stubbings with $V \sim 14.2$ (vsnet-outburst 6880), which seems to contradict the property (3) of WZ Sge-type dwarf novae. However, AL Com, one of the established WZ Sge-type dwarf novae, also have undergone some normal outbursts (in 1961, 1965, 1974, 1975, and possibly 1976 (Howell & Szkody 1988, Nogami et al. 1997)), hence, the WZ Sge-type identification of ASAS 1600 can not judged to be wrong only by this point.

Kato et al. (2008) proposed that, in WZ Sge-type dwarf novae with an extremely small mass ratio ($q = M_2/M_1$), the 2:1 resonance can be strong enough to suppress the outward-propagation of the eccentricity originated at the 3:1 resonance and, therefore, the $P_{SH}$ is almost constant. On the other hand, in systems with a similar or slightly larger $q$, such as RZ Leo (Ishioka et al. 2001), BC UMa (Maehara et al. 2007) and some SU UMa-type stars, the outward-propagation of the eccentricity is not restricted and, therefore, the $P_{SH}$ can be increase. In Paper I, using an empirical relation (Patterson et al. 1998), authors estimated the mass ratio of ASAS 1600 to be $q = 0.109(4)$ which is slightly large, compared with that of the typical WZ Sge-type dwarf novae. In section 3, we determined the $P_{\text{tot}}$ of ASAS 1600 to be $11.5(9) \times 10^{-5}$ days cycle$^{-1}$. Based on the idea by Kato et al. (2008), these results indicate that ASAS 1600 is a system with a weak 2:1 resonance. ASAS 1600 does not seem to be a typical WZ Sge-type dwarf nova, but, at least, a very close to WZ Sge-type dwarf nova.

5. CONCLUSION

We photometrically studied the 2005 superoutburst of a dwarf nova ASAS 1600. Our conclusion is summarized below:

1. ASAS 1600 showed a regrowth of the ordinary superhumps in the amplitude during the 2005 superoutburst, which is frequently found in SU UMa-type dwarf novae with an increase of $P_{SH}$.

2. During the 2005 superoutburst, the superhump period decreased when the superhump amplitude reached to the first maximum, successively gradually increased until the second maximum of the amplitude, and finally decreased again. This course of
Table 3. SU UMa-type dwarf novae with the $P_{SH}$ increasing phase.

| Object           | $P_{SH}$ (days) | $P_{SH}^3$ | Reference                                    |
|------------------|-----------------|------------|----------------------------------------------|
| V485 Cen *       | 0.04216         | 28(3)      | Olech (1997)                                 |
| E1 Psc           | 0.04637         | 12(2)      | Uemura et al (2002)                          |
| VS 0329+1250     | 0.053394        | 2.1(0.8)   | Shafter et al. (2007)                        |
| V844 Her (2002)  | 0.05584         | 4.4(1.2)   | Oizumi et al. (2007)                         |
| V844 Her (2006)  | 0.055883        | 10.9(1.0)  | Oizumi et al. (2007)                         |
| AL Com (1995) *† | 0.0572          | 1.9(0.5)   | Howell et al. (1996), Patterson et al. (1996) |
| ASAS J002511+1217.2 *† | 0.05687 | 8.7(0.4)   | Templeton et al. (2006)                      |
| WZ Sge (2001) *  | 0.05736         | 0.2(0.3)   | Patterson et al. (2002)                      |
| SW UMa (1996) *  | 0.05818         | 8.9(1.0)   | Semeniuk et al. (1997b), Nogami et al. (1998) |
| SW UMa (2000) *† | 0.058096        | 6.9(0.4)   | Soejima et al. (in prep.)                    |
| SW UMa (2002) *† | 0.058261        | 9.1(0.7)   | Soejima et al. (in prep.)                    |
| SW UMa (2006) *† | 0.058063        | 7.9(1.4)   | Soejima et al. (in prep.)                    |
| HV Vir (1992)    | 0.05820         | 5.7(0.6)   | Kato et al. (2001b)                          |
| HV Vir (2002) †‡ | 0.05826         | 7.8(7)     | Ishioka et al. (2003)                        |
| RZ LMi (2004 Apr)| 0.05944         | 7.6(1.9)   | Olech et al. (2008)                          |
| RZ LMi (2005 Apr)| 0.05940         | 4.5(2.5)   | Olech et al. (2008)                          |
| WX Cet (1998) ‡  | 0.05949         | 8.5(1.0)   | Kato et al. (2001a)                          |
| WX Cet (2001) *  | 0.059563        | 16         | Sterken et al. (2007)                        |
| WX Cet (2004) ‡  | 0.059585        | 16         | Sterken et al. (2007)                        |
| FL TrA †         | 0.059897        | 8.4(5.0)   | Imada et al. (2008)                          |
| EG Cnc           | 0.06043         | 1.7(1)     | Kato et al. (2004a)                          |
| V1028 Cyg *†‡    | 0.06154         | 8.7(0.9)   | Baba et al. (2000)                           |
| BC UMa †         | 0.06258         | 3.2(0.8)   | Maehara et al. (2007)                        |
| GO Com *†‡       | 0.06306         | 18(3)      | Imada et al. (2005)                          |
| VI159 Ori *†‡    | 0.0641          | 4.2(1.1)   | Patterson et al. (1995)                      |
| OY Car (1980)    | 0.064631        | 8.9(1.6)   | Krzeminski & Vogt (1985)                     |
| ASAS 1600 *†‡     | 0.064927        | 11.5(9)    | this work                                    |
| TV Crv (2001)    | 0.06503         | 8.0(0.7)   | Uemura et al. (2005)                         |
| KS UMa (2003) *† | 0.07009         | 21(12)     | Olech et al. (2003)                          |
| RZ Sge (1996) † | 0.07039         | 0.6(5.1)   | Semeniuk et al. (1997a)                      |
| VW Crb *         | 0.07287         | 9.3(0.9)   | Nogami et al. (2004)                         |
| TT Boo (2004) *†‡ | 0.07796         | 12.3(4.8)  | Olech et al. (2004)                          |
| RZ Leo *†‡       | 0.07853         | 5.9(1.0)   | Ishioka et al. (2001)                        |

* Dwarf novae with a regrowth of ordinary superhumps.
† Dwarf novae which show a decrease of $P_{SH}$ at the beginning stage.
‡ Dwarf novae which show a decrease of $P_{SH}$ at the end stage.
§ The unit is 10$^{-5}$ days cycle$^{-1}$.
∥ Reference to Kato et al. (in prep.).
the superhump evolution seems to be common in SU UMa-type dwarf novae with a superhump regrowth.

3. ASAS 1600 does not seem to be a typical WZ Sge-type dwarf nova, but, at least, a very close to typical WZ Sge-type dwarf nova.

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