ASASSN-16dt and ASASSN-16hg: Promising Candidates for a Period Bouncer

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\textbf{Abstract}

We present optical photometry of superoutbursts in 2016 of two WZ Sge-type dwarf novae (DNe), ASASSN-16dt and ASASSN-16hg. Their light curves showed a dip in brightness between the first plateau stage with no ordinary superhumps (or early superhumps) and the second plateau stage with ordinary superhumps. We find that the dip is produced by slow evolution of the 3:1 resonance tidal instability and that it would be likely observed in low mass-ratio objects. The estimated mass ratio ($q \equiv \frac{M_2}{M_1}$) from the period of developing (stage A) superhumps (0.06420(3) d) was 0.036(2) in ASASSN-16dt. Additionally, its superoutburst has many properties similar to those in other low-$q$ WZ Sge-type DNe: long-lasting stage A superhumps, small superhump amplitudes, long delay of ordinary superhump appearance, and slow decline rate in the plateau stage with superhumps. The very small mass ratio and observational characteristics suggest that this system is one of the best candidates for a period bouncer – a binary accounting for the missing population of post-period minimum cataclysmic variables. Although it is not clearly verified due to the lack of detection of stage A superhumps, ASASSN-16hg might be a possible candidate for a period bouncer on the basis of the morphology of its light curves and the small superhump amplitudes. Many outburst properties of period-bouncer candidates would originate from the small tidal effects by their secondary stars.

\textbf{Key words:} accretion, accretion disks - novae, cataclysmic variables - stars: dwarf novae - stars: individual (ASASSN-16dt, ASASSN-16hg)

1. Introduction

Dwarf novae (DNe) are a subtype of cataclysmic variables (CVs), and are close binary systems composed of a white dwarf (the primary), typically a late-type main sequence star (the secondary), and an accretion disk around the primary. They go through episodic abrupt increases of luminosity which are called “outbursts” (see Warner 1995 for a review).

WZ Sge-type stars are an extreme subclass of DNe, and belong to SU UMa-type DNe. They have small mass ratios, and predominantly show superoutbursts defined as long-duration (more than $\sim$2 weeks) and large-amplitude (more than $\sim$6 mag) outbursts with superhumps (see Kato 2015 for a review and references therein). The superoutbursts and superhumps are believed to be caused due to the tidal instability, which is triggered when the disk expands beyond the 3:1 resonance radius.
The evolutionary status of CVs which have low mass ratios, including WZ Sge-type DNe is still unclear (see Knigge et al. (2011) and references therein). One of the unsolved problems is the gap between the theoretically predicted and observational populations of period bouncers. Period bouncers are CVs past the period minimum, and evolve toward longer orbital periods due to the change of mass-radius relation of the secondary star. This change is triggered by that the thermal timescale becomes longer than the mass-loss timescale or that the secondary degenerates to a brown dwarf at the final stage of the CV evolution (Rappaport et al. 1982; Chabrier et al. 2009). Only a few period bouncer candidates have so far been found, although existing theory predicts that period bouncers should constitute most of the CV population (Kolb 1993). For example, Littlefair et al. (2006) and Littlefair et al. (2008) detected that the companion stars in 4 eclipsing CVs having periods close to the period minimum may be brown dwarfs by modeling their eclipsing light curves. It was demonstrated that one of the systems has a very low-mass brown-dwarf companion by spectroscopic observations (Hernández Santisteban et al. 2016). Unda-Sanzana et al. (2008) found a CV which would have a brown-dwarf companion and a very low mass ratio. Aviles et al. (2010) also detected a brown-dwarf binary with a likely small mass ratio.

Recently, several period-bouncer candidates possibly filling the gap between the theories and observations have been discovered among WZ Sge-type DNe via photometric observations (Kato et al. 2013b; Nakata et al. 2014). These objects showed peculiar rebrightenings, and have very small mass ratios and relatively long orbital periods as WZ Sge-type DNe (more than 0.06 d). Their mass ratios were estimated using a new method which requires the stage A superhump periods and orbital periods (Kato, Osaki 2013). As for SSS J122221.7−311523, one of these candidates, the evidence suggesting a brown-dwarf companion has also been found (Neustroev et al. 2017). Nakata et al. (2014) also discussed that the detected fraction of these candidates can account for the theoretically expected population of period bouncers. In addition, Kimura et al. (2016) reported that one of WZ Sge-type DNe, which showed a peculiar main superoutburst, may have a small mass ratio. The common properties in this kind of objects are as follows: (1) repeating rebrightenings or dips in brightness at the main superoutburst stage, (2) long-lasting stage A superhumps, (3) large decrease of the superhump period at the stage A to B transition in the objects with repeating rebrightenings, (4) small superhump amplitudes ($< 0.1$ mag), (5) long delay of ordinary superhump appearance, (6) slow fading rates at the plateau stage of superoutburst with ordinary superhumps, and (7) large outburst amplitude at the time of appearance of ordinary superhumps (Table 1; Sec. 7.8 of Kato 2015).

In this paper, we report on our optical photometry of the 2016 superoutbursts of two WZ Sge-type objects, ASASSN-16dt and ASASSN-16hg. Their outbursts were detected on April 1st, 2016 and April 30th, 2016 by the All-Sky Automated Survey for Supernovae (ASAS-SN) (Shappee et al. 2014; Davis et al. 2015), respectively, and these two objects were regarded as bright CV candidates by that survey because of the large outburst amplitudes.\footnote{http://www.astronomy.ohio-state.edu/asassn/transients.html} ASASSN-16dt has a quiescent counterpart PSO J122625.408−113302.953 ($g = 20.76(5)$ mag) and its position is (RA:) 12h26m25.41s, (Dec:) −11°33′03″ (J2000.0) (Flewelling et al. 2016). ASASSN-16hg has a GALEX UV source and the quiescence magnitude in NUV band is 22.8(4) mag. The position of this object is (RA:) 22h48m41.03s, (Dec:) −35°04′40″ (J2000.0). After our observational campaigns, these two objects were regarded as WZ Sge-type DNe by the long delay of superhump appearance and/or early superhumps, and the rebrightenings just after the main superoutbursts. We discuss the properties of these two objects, comparing with those of other period-bouncer candidates.

2. Observation and Analysis

Time-resolved CCD photometric observations were performed at 11 sites by the Variable Star Network (VSNET) collaboration team (Table E1). The logs of the observations of ASASSN-16dt and ASASSN-16hg with clear filter are given in Table E2 and E3, respectively. In this study, the data from the American Association of Variable Star Observers (AAVSO) archive\footnote{<http://www.aavso.org/data/download/>} are also contained. We converted all of the observation times to barycentric Julian date (BJD). We applied zero-point corrections to each observer by adding constants before making the analyses. The magnitude scale of each site was adjusted to that of the Bervi Monard system (MLF in Table E2), where USNO-B1.0 0784-0248445 (RA: 12h26m16.102,
Table 1. Properties of candidates for a period bouncer (The candidates are limited to the DNe which have been through outbursts).

| Object                          | $P_{shB}$ (d) | Amp† | Delay§ | Decrease# | Profile¶ | Decline** | References†† |
|---------------------------------|---------------|------|--------|-----------|----------|-----------|--------------|
| MASTER J2112                    | 0.060221(9)   | 0.10 | ~12    | 2.2%      | B        | 0.127(1)  | 1            |
| MASTER J2037                    | 0.061307(9)   | 0.11 |        | 2.2%      | B, slow  | 0.052(1)  | 1            |
| SSS J1222                       | 0.07649(1)    | 0.12 | ≥9     | 0.93%     | E, slow  | 0.020(1)  | 2, 3         |
| OT J1842                        | 0.07234       | 0.08 | ~30    |           | E, slow  | 0.045(1)  | 2, 4         |
| OT J1735                        | –             | –    | –      |           | slow     | 0.038(1)  | 5            |
| OT J0754                        | 0.070758(6)   | 0.05 | ~14    | 2.2%      | B        | 0.087(1)  | 7, 8         |
| OT J2304                        | 0.06635(1)    | 0.13 | –      | 1.3%      | slow     | 0.034(0)  | 6            |
| ASASSN-14cv                      | 0.06045(1)    | 0.07 | 11     | 1.7%      | D        | 0.094(1)  | 8            |
| PNV J1714                       | 0.060084(4)   | 0.09 | 11     | 2.0%      | B        | 0.108(1)  | 7, 8         |
| OT J0600                        | 0.063310(4)   | 0.06 | –      | 2.1%      | B        | 0.080(1)  | 7, 8         |
| PNV J172929                     | 0.06028(2)    | 0.12 | 11     | 1.7%      | D        | 0.094(1)  | 8            |
| ASASSN-15jd                      | 0.064981(8)   | 0.09 | 09     | –         | e        | 0.088(2)  | 9            |
| ASASSN-15gn                      | 0.06364(3)    | 0.10 | 11     | –         | –        | 0.0635(7) | 10           |
| ASASSN-15hm                      | 0.06183(2)    | 0.10 | 12     | 2.2%      | –        | 0.080(3)  | 10           |
| ASASSN-15kh                      | 0.06048(2)    | 0.08 | ≥13    | 1.7%      | –        | 0.0601(6) | 10           |
| ASASSN-16bu                      | 0.06051(7)    | 0.10 | 9      | 0.62%     | slow     | 0.024(1)  | 10           |
| ASASSN-16js                      | 0.06093(2)    | 0.23 | 10     | 1.2%      | –        | 0.085(1)  | 11           |
| ASASSN-16dt                      | 0.064610(1)   | 0.08 | ~23    | 0.79%     | E, slow  | 0.028(6)  | This work    |
| ASASSN-16hg                      | 0.062371(14)  | 0.12 | ≥6     | –         | e, B     | 0.090(2)  | This work    |

*Objects' name: MASTER J211258.65+242145.4, MASTER OT J203749.39+552210.3, SSS J122221.7−311523, OT J184228.1+483742, OT J173516.9+154708, OT J075418.7+381225, OT J230425.8+062546, PNV J17144255−2943481, OT J060009.9+142615 and PNV J17292916+0054043, respectively.
†Period of stage B superhumps.
‡Mean amplitude of superhumps. Unit of mag.
§Delay time of ordinary superhump appearance. Unit of days.
#Decrease rate of stage B superhump period in comparison with stage A superhump period.
¶Characteristic shapes of light curves. B: multiple rebrightenings (type-B), D: no rebrightening (type-D), E: double superoutbursts (type-E), e: a small dip in the middle of the plateau, slow: extremely slow fading rate less than ~0.05 [mag d^−1].
**Fading rate of plateau stage. Unit of mag d^−1.
††1: Nakata et al. (2013), 2: Kato et al. (2013b), 3: Neustroev et al. (2017), 4: Katysheva et al. (2013), 5: Kato et al. (2014b), 6: Nakata et al. (2014), 7: Nakata et al. in preparation, 8: Kato et al. (2015), 9: Kimura et al. (2016), 10: Kato et al. (2016), 11: Kato et al. (2017)

Dec:–11°35′03″97, V = 13.6) was used as the comparison star in the photometry of ASASSN-16dt, and that of the Franz-Josef Hambsch system (HaC in Table E2), where UCAC4 276−217322 (RA: 22h48m45.56s, Dec:–34°58′50″8, V = 14.4) was used as the comparison star in the photometry of ASASSN-16hg, respectively. The constancy of each comparison star was checked by nearby stars in the same images. The data reduction and the calibration of the comparison stars were performed by each observer. The magnitude of each comparison star was measured by the AAVSO Photometric All-Sky Survey (APASS: Henden et al. 2016) from the AAVSO Variable Star Database.

We used the phase dispersion minimization (PDM) method (Stellingwerf 1978) for period analyses. The global trends of the light curves were subtracted by locally-weighted polynomial regression (LOWESS: Cleveland 1979) before the PDM analyses. We computed the 1σ errors of the best estimated periods by these analyses using the methods of Fernie (1989) and Kato et al. (2010).

In estimating the robustness of the PDM result, we used a variety of bootstraps. We made 100 samples, each of which includes randomly the 50% of observations, and performed PDM analyses for the samples. The result of the bootstrap is represented in the form of 90% confidence intervals in the resultant $\theta$ statistics.

3. ASASSN-16dt

3.1. Overall Light Curve

We show the overall light curve of the 2016 superoutburst of ASASSN-16dt in figure 1. The superoutburst probably began on BJD 2457479 and the object showed a rapid rise at the very early stage. A first plateau stage continued for at least 15 days during BJD 2457482.1–
A dip of brightness was observed in the days BJD 2457499 and BJD 2457500. A rapid increase in brightness was observed for the following ~2 days, and the second plateau stage continued for about two weeks during BJD 2457504.0–2457516.8. A rapid fading was seen on BJD 2457518. There were no observations during BJD 2457524–2457530. A rebrightening was detected for a few days during BJD 2457531.8–2457534.5.

3.2. Early Superhumps

Before the rapid decrease on BJD 2457499, double-waved modulations with a constant period, $0.06420(2)$ d, were detected. They lasted during BJD 2457482.1–2457493.0. After BJD 2457483, the humps became noisy. We regard them as early superhumps. Figure 2 represents the results of the PDM analysis and the phase-averaged profile of the early superhumps.

3.3. Ordinary Superhumps

During the dip (on BJD 2457502), ordinary superhumps started to develop. The $O-C$ curve of times of superhump maxima, the amplitudes of superhumps, and the light curves during BJD 2457502.8–2457522.1 are shown in the upper panel, the middle panel and the lower panel of figure 3, respectively. We determined the times of maxima and amplitudes of ordinary superhumps in the same way as in Kato et al. (2009). Some points with large errors were removed in calculating the $O-C$ and amplitudes. The resultant times are given in Table E4. We regarded the term of stage A as BJD 2457502.8–2457506.8 ($0 \leq E \leq 58$) from both the $O-C$ curve and the variations of the superhump amplitudes. We determine the term of stage B as being BJD 2457506.8–2457516.8 ($62 \leq E \leq 214$), from the nonlinear behavior on the $O-C$ curve and the decreasing amplitudes of superhumps. No stage C superhumps were found. The superhumps continued after the termination of the main superoutburst. At the post-superoutburst stage during BJD 2457519.9–2457522.0 ($263 \leq E \leq 295$), the superhumps having a longer period than the stage B superhumps were detected.

4. ASASSN-16hg

4.1. Overall Light Curve

The overall light curve of the 2016 superoutburst in ASASSN-16hg is shown in figure 5. The first plateau stage continued for more than 6 days before a dip in brightness on BJD 2457590. Soon after the dip, the system became bright again and the second plateau stage began and continued for a week during BJD 2457591.6–2457597.9. We detected two rebrightenings after the main superoutburst.

4.2. Ordinary Superhumps

We have found ordinary superhumps in the second plateau stage and at the beginning of the next decay.
Our curve.

burst stages were not clearly distinguished in the O

No. ] The 2016 Superoutbursts of ASASSN-16dt and ASASSN-16hg 5

The 2016 Superoutbursts of ASASSN-16dt and ASASSN-16hg

The O−C curve of times of superhump maxima during BJD 2457502.8–2457522.1 (the second plateau stage of the main superoutburst in ASASSN-16dt).

An ephemeris of BJD 2457502.925071±0.0053055 E was used for drawing this figure. Middle panel: amplitudes of superhumps. Lower panel: light curves. The horizontal axis in units of BJD and cycle number is common to these three panels.

The O−C curve of times of superhump maxima, the amplitudes of superhumps and the light curves during the interval are displayed in the upper, middle and lower panels of figure 6, respectively. We determined the times of superhump maxima during BJD 2457502.8–2457522.1 (the second plateau stage of the main superoutburst in ASASSN-16dt) and obtained the period of superhump period during stage B was \(P_{\text{sh,B}} = 0.06237(1) \text{ d} \) (see the upper panel of figure 7). The derivative of the superhump period during stage B was \(P_{\text{dot}} = 0.6(1.7) \times 10^{-5} \text{s}^{-1} \). The mean profile of the stage B superhumps is also shown in the lower panel of figure 7.

5. Discussion

5.1. Mass Ratio Estimation from Stage A Superhumps

We can estimate the mass ratio in ASASSN-16dt using the method proposed by Kato, Osaki (2013), assuming that the early superhump period is identical to the orbital period (Kato 2002; Ishioka et al. 2002). According to Hirose, Osaki (1990), the dynamical precession rate, \(\omega_{\text{dyn}}\), is expressed as follows:

\[
\omega_{\text{dyn}}/\omega_{\text{orb}} = Q(q)R(r),
\]

where the \(Q(q)\) and \(R(r)\) are the functions of a mass ratio and a given radius in an accretion disk, respectively (see equations (1) and (2) in Kato, Osaki (2013) for the detailed expressions). Under the assumption that the stage A superhumps are the representation of the dynamical precession at the 3:1 resonance radius, we can derive the value of mass ratio by substituting the 3:1 resonance radius, which is expressed as a function of the mass ratio as \(r_{3:1} = 3^{-2/3}(1 + q)^{-1/3}\), into equation (1). The estimated mass ratio with this method is \(q = 0.036(2)\) as for ASASSN-16dt. This is shown on the \(q-P_{\text{orb}}\) plane in figure 8 with the mass ratios of other period-bouncer candidates and ordinary SU UMa-type DNe derived from Kato et al. (2017). The derived errors originate from the errors of period estimations in Sec. 3. The very small mass ratio suggests ASASSN-16dt is one of the best candidates for a period bouncer. Our result agrees with the empirical relation between rebrightening types and mass ratios, which was suggested in Kato (2015). The \(q\) values of candidates for a period bouncer are displayed in Table 2 with those of ordinary WZ Sge-type dwarf novae. Several objects close to the period minimum, which showed repeating rebrightenings, have been shown to be promising period-bouncer candidates because they share the outburst properties with the extremely low-\(q\) period-bouncer candidates, and have longer orbital periods than the group of WZ Sge-type DNe whose orbital periods are close to the theoretical period minimum (see also Table 1). The three objects having longer orbital periods than the promising period-bouncer candidates in figure 8 are not regarded as being of this kind, since they do not share the aforementioned properties (see also the 4th paragraph in Sec. 1).

It is shown that some of the objects given in Table 2 would have brown-dwarf secondaries (Littlefair et al. 2008; Savoury et al. 2011; Hernández Santisteban et al. 2016; Neustroev et al. 2017). There may be a possibility that these objects come from zero-age detached white-dwarf and brown-dwarf binaries. Actually, one object which seems to be a pre-CV candidate having a brown-dwarf secondary has recently found (Rappaport et al. 2017). According to Politano (2004), however, \(\sim 80\%\) of this kind of detached binaries have small orbital periods less than 0.054 d, and the fraction of them to the total population of zero-age CVs seems to be smaller than
5.2. Dip in Brightness during Main Superoutburst

The dips in brightness during the main superoutbursts were observed in both ASASSN-16dt and ASASSN-16hg. Rebrightenings in WZ Sge-type stars are classified into five types according to the profiles of the light curves: type-A (long duration rebrightening), type-B (multiple rebrightening), type-C (single rebrightening), type-D (no rebrightening), and type-E (double superoutbursts consisting of a plateau stage with early superhumps and another plateau stage with ordinary superhumps) (Imada et al. 2006; Kato et al. 2009; Kato et al. 2014b), and ASASSN-16dt belongs to WZ Sge-type objects with double superoutbursts. This object is an analogue of SSS J122221.7−311523 and OT J184228.1+483742 (Kato et al. 2013b; Katysheva et al. 2013; Neustroev et al. 2017). ASASSN-16hg is the second object showing an intermediate light curve between the single plateau stage (in type-A–D rebrightenings) and the double ones (in type-E rebrightening). The details of the classification with the morphology of plateau stages are described in Kimura et al. (2016). In addition, the duration of stage A superhumps is normally long in the candidates (Kato et al. 2013b; Nakata et al. 2014), and also in ASASSN-16dt, the stage A superhumps continued for a long interval, ∼4 days.

The characteristic morphology of the light curves seems to represent the slow development of the 3:1 resonance which is believed to cause ordinary superhumps since the resonance keeps the disk in the hot state in WZ Sge-type DNe after the disappearance of the 2:1 resonance (Osaki, Meyer 2003). Lubow (1991a) proposed that the growth time of the 3:1 resonance tidal instability is inversely proportional to the square of the mass ratio. The small mass ratio and the morphology of the 2016 superoutburst in ASASSN-16dt are in good agreement with this theory. In addition, the slow growth of the 3:1 resonance is expected to produce the long-lasting stage A superhumps in small-q
Table 2. Mass ratios of candidates for a period bouncer.

| Object   | \( P_{\text{orb}} \) (d) | \( P_{\text{shA}} \) (d) | \( q \) | References
|----------|--------------------------|--------------------------|-------|----------|
| SDSS J1507 | 0.046258                 | –                        | 0.0625(4) | 1        |
| SDSS J1433 | 0.054241                 | –                        | 0.069(3)  | 2, 3     |
| SDSS J1501 | 0.056841                 | –                        | 0.067(3)  | 1        |
| SDSS J1035 | 0.057007                 | –                        | 0.057(1)  | 4        |
| ASASSN-16bu | 0.0593(1)                | 0.06089(7)               | 0.10(1)*  | 5        |
| PNV J1714  | 0.059558(3)             | 0.06130(2)               | 0.076(1)*  | 6, 7     |
| PNV J172929| 0.05973                 | 0.06133(7)               | 0.073(2)*  | 7        |
| MASTER J2112| 0.059732(3)             | 0.06158(5)               | 0.081(2)*  | 8        |
| ASASSN-14cv | 0.059917(4)             | 0.06168(2)               | 0.077(1)*  | 6, 7     |
| ASASSN-16js | 0.060337(5)             | 0.0617(1)                | 0.056(5)*  | 9        |
| MASTER J2037| 0.0605(2)               | 0.0627(1)                | 0.097(8)*  | 8        |
| SDSS J1057 | 0.062792                 | –                        | 0.055(2)  | 1        |
| ASASSN-16dt | 0.06420(3)              | 0.06512(1)               | 0.036(2)*  | This work|
| OT J1842   | 0.07168(1)              | 0.07287(8)               | 0.042(3)*  | 10       |
| SSS J1222  | 0.07025(5)              | 0.07721(1)               | 0.032(2)*  | 11, 12   |

*Objects’ name; MASTER J2112, MASTER J2037, SSS J1222, OT J1842, PNV J1714, PNV J172929, SDSS J1057, SDSS J1035, SDSS J1433, SDSS J1501, SDSS 1433, and SDSS 1507 represent MASTER OT J211258.65+242145.4, MASTER OT J203749.39+552210.3, SSS J122221.7−311523, OT J184228.1+483742, PNV J17144255−2943481, PNV J17292916+005403, SDSS J105754.25+275947.5, SDSS J10353.02+055415.3, SDSS J143317.78+550123.4, and SDSS J150722.30+523039.8, respectively.

|  |  |  |  |
|--------------|--------------|--------------|--------------|
|  | Orbital period. |  | Mass ratio. The index * represents the mass ratio derived by the method in Kato, Osaki (2013). |
| \( P_{\text{orb}} \) | Mass ratio. | References
| \( P_{\text{shA}} \) | References
| \( q \) | 1: McAllister et al. (2017), 2: Littlefair et al. (2008), 3: Hernández Santisteban et al. (2016), 4: Savoury et al. (2011), 5: Kato et al. (2016), 6: Nakata et al. in preparation, 7: Kato et al. (2015), 8: Nakata et al. (2013), 9: Kato et al. (2017), 10: Kato, Osaki (2013), 11: Kato et al. (2013b), 12: Neustroev et al. (2017). |

The delays of ordinary superhump appearance are typically long in the candidates for a period bouncer (see Table 1), whilst those in ordinary WZ Sge-type stars are concentrated between 5–10 [d] (Kato 2015). This feature is also clearly confirmed in the 2016 superoutburst of ASASSN-16dt. Figure 9 shows the relation between superhump period and delay time in WZ Sge-type DNe. On the other hand, it is uncertain whether the delay of the superhump appearance was long in ASASSN-16hg since there was no observation of the initial part of the developing ordinary superhumps (stage A superhumps) (see Sec. 4.2).

5.3. Long Delay of Superhump Appearance

The delays of ordinary superhump appearance are typically long in the candidates for a period bouncer (see Table 1), whilst those in ordinary WZ Sge-type stars are concentrated between 5–10 [d] (Kato 2015). This feature is also clearly confirmed in the 2016 superoutburst of ASASSN-16dt. Figure 9 shows the relation between superhump period and delay time in WZ Sge-type DNe. On the other hand, it is uncertain whether the delay of the superhump appearance was long in ASASSN-16hg since there was no observation of the initial part of the developing ordinary superhumps (stage A superhumps) (see Sec. 4.2).

5.4. Small Amplitude of Superhumps

Kimura et al. (2016) pointed out that the average superhump amplitudes are small, less than 0.1 mag, in most of the candidates for a period bouncer (Table 1). Our results on ASASSN-16dt and ASASSN-16hg reinforce this observation (see also figures 3 and 6). We compare the variation of superhump amplitudes of the candidates for
Fig. 6. Upper panel: $O - C$ curve of the times of superhump maxima during BJD 2457591.6–2457598.8 (the second plateau stage of the main superoutburst in ASASSN-16hg). An ephemeris of BJD 57591.6610+0.0623475 E was used for drawing this figure. Middle panel: amplitudes of superhumps. Lower panel: light curves. The horizontal axis in units of BJD and cycle number is common to these three panels.

Fig. 7. Stage B superhumps in the second plateau stage of the 2016 superoutburst of ASASSN-16hg are represented. The area of gray scale means 1 σ errors. Upper: Θ-diagram of our PDM analysis. Lower: Phase-averaged profile.

A period bouncer and those of ordinary SU UMa-type systems having orbital periods ranging between 0.06–0.07 d in figure 10 as in Kimura et al. (2016). In plotting this figure, we measured the amplitudes using the template fitting method described in Kato et al. (2009) and took the starting point of the cycle count from the start of stage B. Since superhump amplitudes are known to depend on the orbital periods and the inclination angles (Kato et al. 2012), the data of ASASSN-16js are excluded from this figure. This object may have high inclination, which is judged from the large amplitudes of its early superhumps, ∼0.2 mag (Kato et al. 2017). It is known that the higher the inclination is, the larger the amplitudes of early superhumps are (Kato 2015). We excluded the data with large errors more than 0.03 mag and of eclipsing systems.

During the 3:1 resonance, the disk becomes elliptical due to the tidal force of the secondary; the orbiting secondary passes the major axis of the disk with the superhump period when the ordinary superhumps are observed. Some particles in the tail of the eccentric disk are periodically absorbed to the secondary, and the time variations of the released energy by the viscous dissipation in the outer disk corresponds the superhump variations (Hirose, Osaki 1990). It has been proposed that the tidal torques exerted by the secondary significantly affect viscous dissipation in the outer disk (Ichikawa, Osaki 1994). In the small-$q$ objects, the tidal force from the secondary would be less than that in the large-$q$ objects. The disk would be less elliptical and the liberated energy by the tidal dissipation would be small. Thus the reason why period-bouncer candidates show small-amplitude superhumps seems to be related to the weak tidal effect by the secondary in small-$q$ objects.

5.5. Slow Fading Rate of Plateau Stage

The fading rates of the plateau stage with ordinary superhumps in the superoutbursts of period-bouncer candidates are often small (Sec. 7.8 in Kato 2015). In particular, all of the three period-bouncer candidates including ASASSN-16dt, which showed double superoutbursts, had extremely low decline rates (see Table 1). They also have very small mass ratios, and the durations of the superoutbursts are long – more than 40 days (see also Kato et al. 2013b). One period-bouncer candidate with type-B rebrightenings and four other candidates whose rebrightening types have not yet been identified showed slow declines (see also Table 1). The relation between the fading...
No.  The 2016 Superoutbursts of ASASSN-16dt and ASASSN-16hg

Fig. 8. $q - P_{\text{orb}}$ relation of the candidates for a period bouncer and ordinary WZ Sge-type DNe. The star, diamonds, rectangles and circles represent ASASSN-16dt, other candidates for a period bouncer among the identified WZ Sge-type DNe, the candidates for a period bouncer among eclipsing CVs, and ordinary WZ Sge-type DNe. The dash and solid lines represent an evolutionary track of the standard evolutionary theory and that of the modified evolutionary theory, respectively, which are derived from Knigge et al. (2011).

Fig. 9. $P_{\text{SH}}$ vs. delay time of ordinary superhump appearance. The circles and diamonds indicate ordinary WZ Sge-type stars derived from Fig. 19 in Kato (2015) and the candidates for a period bouncer. The star represents ASASSN-16dt.

Fig. 10. Variation of superhump amplitudes in the SU UMa-type objects with $0.06 < P_{\text{orb}} \leq 0.07$. The diamonds and circles represent the candidates for a period bouncer and ordinary SU UMa-type DNe, respectively. The data of the period-bouncer candidates are derived from Nakata et al. (2013); Kato et al. (2013b); Nakata et al. (2014); Kato et al. (2015); Kato et al. (2016); Kimura et al. (2016); Kato et al. (2017), and those of ordinary SU UMa-type DNe are derived from Kato et al. (2009); Kato et al. (2010); Kato et al. (2012); Kato et al. (2013a); Kato et al. (2014b); Kato et al. (2014a); Kato et al. (2015); Kato et al. (2016); Kato et al. (2017).

Fig. 11. Fading rate vs. superhump period in stage B. The circles, triangles, and diamonds represent ordinary SU UMa-type DNe, WZ Sge-type DNe, and candidates for the period bouncer, respectively. The stars indicate ASASSN-16dt and ASASSN-16hg. The data of the ordinary SU UMa-type DNe and WZ Sge-type DNe are derived from Kato et al. (2014b).

6. Conclusions

We have reported on our photometric observations of two WZ Sge-type DNe, ASASSN-16dt and ASASSN-16hg, and discussed their similar properties to those of period-bouncer candidates. The important findings are summarized as follows:

- The median value of the fading rates in the period-bouncer candidates is $0.06 \text{ mag } \text{d}^{-1}$, while that in ordinary WZ Sge-type stars is $0.10 \text{ mag } \text{d}^{-1}$.
- The decline timescale is proportional to $\alpha^{-0.7}$ (equation (49) in Osaki (1989)). Here $\alpha$ represents the viscous parameter in the hot state, and the combination of ordinary $\alpha$ due to magnetohydrodynamical instability plus the viscosity resulting from the tidal torque (Balbus, Hawley 1991; Ichikawa, Osaki 1994). The slow fading rate in period bouncers would therefore be attributed to the weaker tidal torque in low-$q$ objects.
ASASSN-16dt and ASASSN-16hg underwent outbursts with a dip in brightness at their main superoutbursts. This implies that the 3:1 resonance grew slowly in their outbursts, and that these objects have low mass ratios.

The mass ratio in ASASSN-16dt, estimated from the method of Kato, Osaki (2013) via the stage A superhump period (0.06512(1) d) is 0.036(2), which is much lower than the theoretically expected mass ratio at the period minimum. The relatively long orbital period estimated from the early superhumps and the very low mass ratio are enough to judge that this object is one of the best period-bouncer candidates. This object also showed many features similar to those in other candidates for a period bouncer, featuring long-lasting stage A superhumps and early superhumps, small-amplitude superhumps, and a slow decline rate at the plateau stage.

Although it is uncertain whether the development of the superhumps in ASASSN-16hg was slow due to no detection of the stage A superhumps, this object might be a possible period-bouncer candidate on the basis of the morphology of the plateau stage which resembles that during the 2015 superoutburst in ASASSN-15jd (Kimura et al. 2016) and its small superhump amplitude.

Many outburst properties of the period-bouncer candidates would be explained by the small tidal effect by the secondary in small-q systems.

The outburst behavior of candidates for a period bouncer is different from that of ordinary WZ Sge-type stars. It should be confirmed whether this behavior is inherent to the period bouncers, by identifying observational properties of many candidates. Some of the candidates given in Table 2 have not experienced outbursts. It would be interesting to monitor their behavior when they enter outbursts.

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Supporting information

Additional supporting information can be found in the online version of this article: Supplementary tables E1, E2, E3, E4 and E5.

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| CODE | Telescope (& CCD) | Observatory (or Observer) | Site |
|------|------------------|----------------------------|------|
| BSM  | 25cmSC+Moravian G2-1600 | Flarestar Observatory | San Gwann, Malta |
| deM  | 35cmSC+QSI-516wsg | Observatorio Astronomico del CIECEM | Huelva, Spain |
| DKS  | 25cmACF | Rolling Hills Observatory | USA |
| HaC  | 40cmIRDK+FLI-ML16803 | Remote Observatory Atacama Desert (ROAD) | San Pedro de Atacama, Chile |
| Ioh  | 30cmSC+ST-9XE CCD | Hiroshi Itoh | Tokyo, Japan |
| MLF  | 30cmRCX400+ST8-XME | Berto Monard Calitzdorp | South Africa |
| MGW  | 43.1cm PlanewaveCDK + FLI PL4710 CCD | Gordon Myers | Siding Spring, Australia |
| KU1  | 40cmSC+Apogee U6 | Kyoto U. Team | Kyoto, Japan |
| SGE  | 43cmCDK+STXL-11002 | Sierra Remote Observatories | Auberry, CA, USA |
| SPE  | 51cm PlanewaveCDK + SBig STL 168303 | Warrumbungle & Dubbo Observatory | Australia |
| UJH  | 23cmSCT+QSI-583ws | Joseph Ulowetz | USA |

*see the annotation in Table E2.*
Table E3. Log of observations of the 2016 outburst in ASASSN-16dt.

| Start* | End*   | Mag| Error| N§ | Obs‖ |
|--------|--------|----|------|----|-----|
| 57482.1006 | 57482.2068 | 13.199 | 0.019 | 84 | SPE |
| 57483.5701 | 57483.7663 | 13.417 | 0.020 | 110 | HMB |
| 57484.5278 | 57484.7140 | 13.501 | 0.029 | 124 | HMB |
| 57485.0301 | 57485.2374 | 13.491 | 0.025 | 116 | SPE |
| 57485.2343 | 57485.4249 | -0.018 | 0.018 | 549 | MLF |
| 57485.5292 | 57485.7608 | 13.563 | 0.021 | 102 | HaC |
| 57486.2857 | 57486.4086 | 0.064 | 0.014 | 351 | MLF |
| 57486.5348 | 57486.7581 | 13.623 | 0.015 | 106 | HMB |
| 57487.2795 | 57487.3615 | 0.122 | 0.012 | 237 | MLF |
| 57487.5282 | 57487.7552 | 13.710 | 0.020 | 108 | HaC |
| 57488.5268 | 57488.7504 | 13.793 | 0.016 | 106 | HaC |
| 57489.2968 | 57489.4274 | 0.282 | 0.014 | 376 | MLF |
| 57489.5268 | 57489.7497 | 13.868 | 0.017 | 106 | HaC |
| 57490.0690 | 57490.1896 | 13.874 | 0.012 | 94 | SPE |
| 57490.5248 | 57490.7470 | 13.925 | 0.019 | 96 | HMB |
| 57491.7255 | 57491.7457 | 14.000 | 0.017 | 11 | HaC |
| 57492.5232 | 57492.7410 | 14.046 | 0.024 | 95 | HaC |
| 57493.2464 | 57493.4544 | 0.561 | 0.018 | 598 | MLF |
| 57493.5602 | 57493.7401 | 14.145 | 0.019 | 64 | HaC |
| 57494.5236 | 57494.7371 | 14.204 | 0.015 | 137 | HaC |
| 57495.5177 | 57495.7343 | 14.262 | 0.032 | 120 | HMB |
| 57495.7321 | 57495.8591 | 13.944 | 0.030 | 180 | SGE |
| 57496.8774 | 57497.0056 | 14.283 | 0.010 | 162 | MGW |
| 57499.5158 | 57499.7530 | 16.774 | 0.352 | 124 | HMB |
| 57500.5370 | 57500.7504 | 16.749 | 0.701 | 37 | HaC |
| 57500.8773 | 57501.0057 | 16.694 | 0.357 | 156 | MGW |
| 57502.8776 | 57503.0052 | 17.742 | 0.129 | 161 | MGW |
| 57504.2149 | 57504.4214 | 0.978 | 0.040 | 567 | MLF |
| 57504.3673 | 57504.5505 | 14.572 | 0.043 | 207 | deM |
| 57504.8605 | 57505.1721 | 14.203 | 0.033 | 389 | MGW |
| 57504.9694 | 57505.0386 | -0.567 | 0.054 | 195 | KU1 |
| 57505.2143 | 57505.5014 | 0.639 | 0.039 | 823 | MLF |
| 57505.2921 | 57505.4930 | 14.223 | 0.046 | 193 | BSM |
| 57505.3857 | 57505.5202 | 14.266 | 0.037 | 150 | deM |
| 57505.5493 | 57505.7691 | 14.150 | 0.040 | 294 | DKS |
| 57505.9719 | 57506.1719 | 14.111 | 0.039 | 248 | MGW |
| 57506.5123 | 57506.7358 | 14.223 | 0.036 | 130 | HMB |
| 57506.8985 | 57507.1090 | 14.092 | 0.034 | 263 | MGW |
| 57507.5114 | 57507.7671 | 14.230 | 0.036 | 103 | HaC |
| 57508.5115 | 57508.7649 | 14.285 | 0.036 | 121 | HMB |
| 57508.9882 | 57509.1964 | 14.282 | 0.168 | 305 | Ioh |
| 57509.5110 | 57509.7620 | 14.341 | 0.033 | 119 | HaC |
| 57510.2135 | 57510.4897 | 0.769 | 0.037 | 784 | MLF |
| 57510.5097 | 57510.7592 | 14.418 | 0.029 | 136 | HaC |
| 57511.0128 | 57511.0548 | -0.425 | 0.045 | 118 | KU1 |
| 57511.2339 | 57511.4076 | 0.894 | 0.030 | 497 | MLF |
| 57511.5121 | 57511.7565 | 14.487 | 0.028 | 132 | HMB |
| 57512.0048 | 57512.0523 | 14.489 | 0.024 | 30 | SPE |
| 57512.2163 | 57512.4337 | 0.897 | 0.027 | 619 | MLF |
Table E2. Log of observations of the 2016 outburst in ASASSN-16dt (continued).

| Start*  | End*  | Mag† | Error‡ | N§ | Obs∥ |
|---------|-------|------|--------|----|------|
| 57512.5091 | 57512.7300 | 14.549 | 0.029 | 125 | HaC  |
| 57512.8567 | 57513.1718 | 14.462 | 0.028 | 387 | MGW  |
| 57513.1065 | 57513.1898 | 14.591 | 0.025 | 64 | SPE  |
| 57513.2467 | 57513.4953 | 1.045 | 0.032 | 717 | MLF  |
| 57513.3047 | 57513.4691 | 14.573 | 0.041 | 166 | BSM  |
| 57513.5085 | 57513.7281 | 14.622 | 0.069 | 103 | HaC  |
| 57513.6198 | 57513.7287 | 14.668 | 0.021 | 85 | BJA  |
| 57513.8567 | 57514.1253 | 14.539 | 0.021 | 336 | MGW  |
| 57514.2284 | 57514.4699 | 1.118 | 0.036 | 587 | MLF  |
| 57514.5454 | 57514.7371 | 14.595 | 0.031 | 212 | DKS  |
| 57514.5834 | 57514.7549 | 14.493 | 0.040 | 170 | UJH  |
| 57514.8542 | 57515.1715 | 14.629 | 0.027 | 397 | MGW  |
| 57515.5091 | 57515.7304 | 14.798 | 0.062 | 113 | HaC  |
| 57515.5454 | 57515.7477 | 14.692 | 0.037 | 272 | DKS  |
| 57515.5852 | 57515.6621 | 14.534 | 0.046 | 35 | UJH  |
| 57516.0414 | 57516.1724 | 14.740 | 0.087 | 45 | Ioh  |
| 57516.5506 | 57516.7373 | 14.896 | 0.026 | 78 | HaC  |
| 57516.5512 | 57516.7362 | 14.781 | 0.040 | 187 | DKS  |
| 57518.5068 | 57518.7364 | 16.521 | 0.168 | 117 | HaC  |
| 57519.8462 | 57520.0213 | 18.005 | 0.134 | 177 | MGW  |
| 57520.0184 | 57520.0209 | 3.267 | 0.278 | 3 | KU1  |
| 57520.5076 | 57520.7301 | 18.318 | 0.384 | 100 | HaC  |
| 57521.5070 | 57521.7289 | 18.539 | 0.376 | 98 | HaC  |
| 57521.8505 | 57522.0214 | 18.451 | 0.152 | 213 | MGW  |
| 57522.8520 | 57523.1295 | 18.614 | 0.113 | 186 | MGW  |
| 57530.5033 | 57530.5044 | 18.526 | 0.002 | 2 | HaC  |
| 57531.5030 | 57531.5041 | 18.530 | 0.040 | 2 | HMB  |
| 57531.8460 | 57532.1077 | 18.158 | 0.222 | 172 | MGW  |
| 57532.5027 | 57532.5038 | 15.157 | 0.003 | 2 | HMB  |
| 57532.9298 | 57533.1074 | 14.994 | 0.061 | 119 | MGW  |
| 57533.5023 | 57533.5034 | 15.437 | 0.019 | 2 | HaC  |
| 57534.5026 | 57534.5037 | 16.479 | 0.046 | 2 | HaC  |
| 57535.5020 | 57535.5031 | 18.445 | 0.302 | 2 | HaC  |
| 57537.8864 | 57537.8879 | 18.433 | 0.115 | 2 | MGW  |
| 57538.8439 | 57538.8455 | 18.442 | 0.188 | 2 | MGW  |
| 57539.8442 | 57539.8457 | 18.512 | 0.283 | 2 | MGW  |
| 57542.4941 | 57542.4951 | 19.788 | 0.152 | 2 | HaC  |
| 57543.4998 | 57543.5009 | 19.343 | 0.325 | 2 | HaC  |
| 57544.4993 | 57544.5004 | 19.203 | 0.249 | 2 | HaC  |
| 57547.4998 | 57547.5009 | 19.261 | 0.115 | 2 | HaC  |
| 57548.5008 | 57548.5019 | 19.607 | 0.607 | 2 | HaC  |
| 57551.4941 | 57551.4952 | 19.230 | 0.112 | 2 | HaC  |

*BJD − 2400000.0.
†Mean magnitude.
‡1σ of mean magnitude.
§Number of observations.
∥Observer’s code: SPE (Peter Starr), HaC (Franz-Josef Hambsch), MLF (Berto Monard), SGE (Geoff Stone), MGW (Gordon Myers), deM (Enrique de Miguel), KU1 (Kyoto Univ. Team), BSM (Stephen M. Brincat), DKS (Shawn Dvorak), Ioh (Hirosi Itoh), BJA (Boardman James) and UJH (Joseph Ulowetz)
Table E3. Log of observations of the 2016 outburst in ASASSN-16hg.

| Start * | End * | Mag † | Error ‡ | N § | Obs ‖ |
|---------|-------|-------|---------|-----|------|
| 57482.1006 | 57586.9298 | 14.450 | 0.026 | 126 | HaC |
| 57587.5914 | 57587.9316 | 14.573 | 0.033 | 124 | HaC |
| 57588.1796 | 57588.3012 | 15.827 | 0.042 | 65 | KU1 |
| 57589.1455 | 57589.2971 | 15.919 | 0.055 | 86 | KU1 |
| 57590.6285 | 57590.9299 | 14.838 | 0.038 | 106 | HaC |
| 57590.6264 | 57590.9293 | 15.367 | 0.083 | 101 | HaC |
| 57591.6232 | 57591.9304 | 14.866 | 0.081 | 118 | HaC |
| 57592.6389 | 57592.9300 | 14.733 | 0.050 | 112 | HaC |
| 57593.6371 | 57593.9296 | 14.839 | 0.056 | 113 | HaC |
| 57594.7362 | 57594.9297 | 14.967 | 0.041 | 65 | HaC |
| 57595.6319 | 57595.9309 | 15.075 | 0.047 | 95 | HaC |
| 57596.6855 | 57596.9303 | 15.185 | 0.031 | 121 | HaC |
| 57597.6264 | 57597.9300 | 15.324 | 0.037 | 137 | HaC |
| 57598.6237 | 57598.9295 | 16.262 | 0.144 | 138 | HaC |
| 57599.6210 | 57599.9281 | 18.176 | 0.392 | 126 | HaC |
| 57600.7491 | 57600.9295 | 18.736 | 0.441 | 89 | HaC |
| 57603.7192 | 57603.7192 | 18.403 | – | 1 | HaC |
| 57604.7336 | 57604.7336 | 15.578 | – | 1 | HaC |
| 57605.7310 | 57605.7310 | 16.637 | – | 1 | HaC |
| 57606.7283 | 57606.7283 | 18.031 | – | 1 | HaC |
| 57608.7227 | 57608.7227 | 15.622 | – | 1 | HaC |
| 57609.7199 | 57609.7209 | 16.703 | 0.012 | 2 | HaC |
| 57610.7175 | 57610.9250 | 18.200 | 0.250 | 189 | HaC |

* BJD – 2400000.0.
† Mean magnitude.
‡ 1σ of mean magnitude.
§ Number of observations.
‖ Observer’s code: see the annotation in Table E2.
Table E4. Times of superhump maxima in ASASSN-16dt.

| E   | Max       | Error | O − C | N  |
|-----|-----------|-------|-------|----|
| 0   | 57502.9004 | 0.0012 | -0.0247 | 65 |
| 1   | 57502.9716 | 0.0008 | -0.0181 | 64 |
| 21  | 57504.2745 | 0.0005 | -0.0070 | 149 |
| 22  | 57504.3356 | 0.0007 | -0.0104 | 148 |
| 23  | 57504.4028 | 0.0007 | -0.0079 | 156 |
| 25  | 57504.5329 | 0.0007 | -0.0069 | 50  |
| 31  | 57504.9243 | 0.0002 | -0.0031 | 65  |
| 32  | 57504.9887 | 0.0002 | -0.0033 | 63  |
| 33  | 57505.0547 | 0.0002 | -0.0019 | 65  |
| 34  | 57505.1197 | 0.0002 | -0.0015 | 65  |
| 36  | 57505.2494 | 0.0004 | -0.0010 | 148 |
| 37  | 57505.3147 | 0.0004 | -0.0002 | 200 |
| 38  | 57505.3793 | 0.0003 | -0.0002 | 215 |
| 39  | 57505.4454 | 0.0003 | 0.0013  | 262 |
| 40  | 57505.5101 | 0.0004 | 0.0013  | 108 |
| 41  | 57505.5745 | 0.0004 | 0.0011  | 68  |
| 42  | 57505.6390 | 0.0003 | 0.0011  | 69  |
| 43  | 57505.7049 | 0.0003 | 0.0024  | 70  |
| 48  | 57506.0299 | 0.0003 | 0.0045  | 63  |
| 49  | 57506.0938 | 0.0006 | 0.0038  | 65  |
| 50  | 57506.1587 | 0.0004 | 0.0041  | 47  |
| 56  | 57506.5464 | 0.0006 | 0.0042  | 31  |
| 57  | 57506.6115 | 0.0005 | 0.0047  | 29  |
| 58  | 57506.6779 | 0.0009 | 0.0065  | 29  |
| 62  | 57506.9337 | 0.0003 | 0.0039  | 65  |
| 63  | 57506.9993 | 0.0003 | 0.0049  | 63  |
| 64  | 57507.0630 | 0.0003 | 0.0041  | 64  |
| 71  | 57507.5157 | 0.0008 | 0.0046  | 19  |
| 72  | 57507.5827 | 0.0005 | 0.0070  | 30  |
| 73  | 57507.6449 | 0.0005 | 0.0046  | 14  |
| 74  | 57507.7117 | 0.0009 | 0.0068  | 14  |
| 87  | 57508.5507 | 0.0005 | 0.0061  | 31  |
| 88  | 57508.6136 | 0.0006 | 0.0044  | 22  |
| 89  | 57508.6807 | 0.0007 | 0.0069  | 21  |
| 90  | 57508.7405 | 0.0010 | 0.0022  | 21  |
| 94  | 57509.0044 | 0.0010 | 0.0077  | 60  |
| 95  | 57509.0661 | 0.0007 | 0.0048  | 90  |
| 96  | 57509.1266 | 0.0007 | 0.0007  | 95  |
| 102 | 57509.5199 | 0.0015 | 0.0064  | 23  |
| 103 | 57509.5855 | 0.0007 | 0.0075  | 28  |
| 104 | 57509.6483 | 0.0012 | 0.0057  | 20  |
| 105 | 57509.7150 | 0.0010 | 0.0078  | 21  |
| 113 | 57510.2308 | 0.0003 | 0.0069  | 127 |
| 114 | 57510.2936 | 0.0003 | 0.0050  | 149 |
| 116 | 57510.4223 | 0.0003 | 0.0045  | 148 |
| 118 | 57510.5519 | 0.0005 | 0.0050  | 42  |
| 119 | 57510.6181 | 0.0009 | 0.0066  | 21  |
| 120 | 57510.6829 | 0.0008 | 0.0068  | 21  |
| 121 | 57510.7510 | 0.0016 | 0.0102  | 17  |
| 129 | 57511.2585 | 0.0005 | 0.0010  | 145 |
| 130 | 57511.3257 | 0.0005 | 0.0036  | 149 |
Table E4. Times of superhump maxima in ASASSN-16dt (continued).

| E  | Max\(^1\)  | Error  | O − C\(^\dagger\) | N\(^\S\) |
|----|------------|--------|-------------------|--------|
| 131| 57511.3881 | 0.0006 | 0.0015            | 128    |
| 134| 57511.5819 | 0.0007 | 0.0015            | 37     |
| 135| 57511.6469 | 0.0016 | 0.0019            | 21     |
| 136| 57511.7104 | 0.0013 | 0.0008            | 21     |
| 141| 57512.0316 | 0.0013 | -0.0010           | 30     |
| 144| 57512.2265 | 0.0009 | 0.0002            | 120    |
| 145| 57512.2919 | 0.0004 | 0.0010            | 147    |
| 146| 57512.3573 | 0.0004 | 0.0017            | 149    |
| 147| 57512.4256 | 0.0006 | 0.0055            | 106    |
| 149| 57512.5517 | 0.0006 | 0.0024            | 42     |
| 150| 57512.6152 | 0.0022 | 0.0013            | 19     |
| 151| 57512.6799 | 0.0010 | 0.0014            | 19     |
| 152| 57512.7418 | 0.0020 | -0.0013           | 15     |
| 154| 57512.8690 | 0.0003 | -0.0033           | 48     |
| 155| 57512.9360 | 0.0004 | -0.0009           | 65     |
| 156| 57513.0018 | 0.0004 | 0.0003            | 62     |
| 157| 57513.0665 | 0.0005 | 0.0004            | 65     |
| 158| 57513.1325 | 0.0004 | 0.0019            | 103    |
| 163| 57513.4509 | 0.0005 | -0.0027           | 199    |
| 166| 57513.6463 | 0.0006 | -0.0011           | 55     |
| 167| 57513.7092 | 0.0007 | -0.0028           | 38     |
| 170| 57513.9048 | 0.0004 | -0.0010           | 65     |
| 171| 57513.9709 | 0.0004 | 0.0005            | 63     |
| 172| 57514.0354 | 0.0005 | 0.0005            | 65     |
| 173| 57514.0967 | 0.0005 | -0.0028           | 65     |
| 175| 57514.2292 | 0.0040 | 0.0005            | 69     |
| 176| 57514.2910 | 0.0008 | -0.0023           | 123    |
| 177| 57514.3561 | 0.0013 | -0.0018           | 115    |
| 178| 57514.4225 | 0.0008 | 0.0000            | 149    |
| 181| 57514.6159 | 0.0010 | -0.0004           | 176    |
| 182| 57514.6785 | 0.0012 | -0.0023           | 136    |
| 183| 57514.7412 | 0.0012 | -0.0043           | 116    |
| 185| 57514.8640 | 0.0011 | -0.0107           | 47     |
| 186| 57514.9381 | 0.0006 | -0.0011           | 65     |
| 187| 57515.0012 | 0.0004 | -0.0026           | 63     |
| 188| 57515.0648 | 0.0006 | -0.0036           | 65     |
| 189| 57515.1308 | 0.0006 | -0.0022           | 65     |
| 196| 57515.5853 | 0.0025 | 0.0001            | 117    |
| 197| 57515.6400 | 0.0012 | -0.0098           | 97     |
| 198| 57515.7086 | 0.0015 | -0.0057           | 88     |
| 211| 57516.5537 | 0.0020 | -0.0003           | 53     |
| 212| 57516.6127 | 0.0025 | -0.0059           | 122    |
| 213| 57516.6737 | 0.0011 | -0.0095           | 124    |
| 214| 57516.7433 | 0.0043 | -0.0045           | 92     |
| 263| 57519.9120 | 0.0008 | -0.0008           | 64     |
| 264| 57519.9789 | 0.0021 | 0.0015            | 44     |
| 293| 57521.8583 | 0.0007 | 0.0077            | 44     |
| 294| 57521.9259 | 0.0014 | 0.0107            | 65     |
| 295| 57521.9903 | 0.0009 | 0.0105            | 64     |

\(^*\)Cycle counts.
\(^1\)BJD−2400000.0.
\(^\dagger\)C = 2457502.925071 + 0.0653055 E.
\(^\S\)Number of points used for determining the maximum.
Table E5. Times of superhump maxima in ASASSN-16hg.

| E | Max† | Error | O − C‡ | N§ |
|---|------|-------|--------|----|
| 0 | 57591.6600 | 0.0065 | -0.0010 | 18 |
| 1 | 57591.7237 | 0.0037 | 0.0003 | 18 |
| 2 | 57591.7863 | 0.0013 | 0.0006 | 19 |
| 3 | 57591.8442 | 0.0015 | -0.0038 | 21 |
| 4 | 57591.9102 | 0.0015 | -0.0002 | 20 |
| 16 | 57592.6570 | 0.0012 | -0.0015 | 16 |
| 17 | 57592.7208 | 0.0014 | -0.0001 | 18 |
| 18 | 57592.7796 | 0.0016 | -0.0037 | 19 |
| 19 | 57592.8439 | 0.0017 | -0.0017 | 21 |
| 20 | 57592.9060 | 0.0016 | -0.0020 | 21 |
| 32 | 57593.6548 | 0.0022 | -0.0013 | 15 |
| 33 | 57593.7179 | 0.0011 | -0.0006 | 18 |
| 34 | 57593.7767 | 0.0012 | -0.0041 | 19 |
| 35 | 57593.8421 | 0.0017 | -0.0011 | 20 |
| 36 | 57593.9059 | 0.0016 | 0.0004 | 20 |
| 50 | 57594.7769 | 0.0021 | -0.0015 | 16 |
| 51 | 57594.8361 | 0.0018 | -0.0046 | 17 |
| 52 | 57594.9042 | 0.0015 | 0.0011 | 17 |
| 64 | 57595.6516 | 0.0017 | 0.0003 | 14 |
| 65 | 57595.7146 | 0.0048 | 0.0010 | 15 |
| 66 | 57595.7729 | 0.0016 | -0.0030 | 16 |
| 67 | 57595.8356 | 0.0015 | -0.0027 | 16 |
| 68 | 57595.9068 | 0.0015 | 0.0061 | 15 |
| 81 | 57596.7117 | 0.0018 | 0.0006 | 15 |
| 82 | 57596.7738 | 0.0032 | 0.0003 | 27 |
| 83 | 57596.8389 | 0.0030 | 0.0030 | 28 |
| 84 | 57596.8956 | 0.0022 | -0.0026 | 28 |
| 96 | 57597.6508 | 0.0027 | 0.0044 | 14 |
| 97 | 57597.7086 | 0.0029 | -0.0001 | 15 |
| 98 | 57597.7678 | 0.0033 | -0.0032 | 25 |
| 99 | 57597.8382 | 0.0059 | 0.0048 | 28 |
| 100 | 57597.8903 | 0.0047 | -0.0055 | 28 |
| 114 | 57598.7596 | 0.0037 | -0.0090 | 23 |

*Cycle counts.
†BJD−2400000.0.
‡ C = 245791.6610+0.0623475 E.
§ Number of points used for determining the maximum.