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Emerging ordinary superhumps as the standard candle for WZ Sge stars

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Abstract

In Kato (2015, arXiv:1507.07659), I suggested that the magnitude when ordinary superhumps appear can be a standard candle for WZ Sge stars. Using Gaia EDR3 parallaxes, I studied 53 WZ Sge stars to examine this suggestion. The analysis indicated that the absolute magnitudes when ordinary superhumps appear are strongly dependent on orbital inclinations, which is consistent with what is expected for the projected area for optical thick accretion disks. I showed that there is a linear relation between these absolute magnitudes and logarithmic amplitudes of early superhumps, which are also dependent on the inclinations. I confirmed that the magnitude when ordinary superhumps appear can be used as the standard candle for WZ Sge stars particularly when the amplitude of early superhumps is observationally known. The resultant median absolute magnitude when ordinary superhumps appear was +5.4 (for an average inclination of 1 radian). A few objects with multiple rebrightenings, which are good candidates for period bouncers, showed slightly fainter absolute magnitudes, although the majority of the same class of objects follows the relation. Using the relation, I derived an empirical relation between the inclination and the amplitude of early superhumps. I applied the relation to MASTER OT J030227.28+191754.5, which was initially considered as a possible optical counterpart of the high-energy neutrino event IceCube-211125A, and concluded that this WZ Sge star was one of the faintest before the outburst and one of the brightest around the optical peak in terms of absolute magnitudes.

1 Introduction

WZ Sge stars are a subclass of dwarf novae and they usually show rare (typically once in a decade) and large-amplitude (typically 8 mag) superoutbursts [for general information of cataclysmic variables and dwarf novae, see e.g. Warner (1995)]. Although WZ Sge stars were originally defined as dwarf novae showing rare, large-amplitude superoutbursts and almost lacking normal outbursts (see e.g. Bailey 1979; Downes and Margon 1981; Downes 1990), this definition remained somewhat ambiguous. Following the dramatic superoutburst of WZ Sge in 2001 (Patterson et al. 2002; Ishioka et al. 2002; Baba et al. 2002), our understanding of WZ Sge stars has been refreshed. It was known that periodic variations having the orbital period were observed in WZ Sge stars during the early phase of their superoutbursts. Patterson et al. (1981) considered that they are orbital humps and that they reflect a greatly enhanced mass-transfer from the secondary. At that time, the only example was the 1978–1979 superoutburst of WZ Sge (Patterson et al. 1981). The number of objects showing this feature gradually increased: HV Vir in 1992 (Kato et al. 2001) [although Barwig et al. (1992); Mendelson et al. (1992); Leibowitz et al. (1994) reported the same feature, they considered the variations to be usual superhumps] and AL Com in 1995 (Kato et al. 1996; Patterson et al. 1996; Howell et al. 1996; Nogami et al. 1997). Following the outburst of AL Com, the presence of double-wave modulations during the early stage of the superoutburst was established. These variations are currently referred to as early superhumps. Osaki and Meyer (2002) identified early superhumps as the manifestation of the 2:1 resonance, in addition to the 3:1 resonance which causes superhumps and superoutbursts in SU UMa stars (Whitehurst 1988; Osaki 1989; Hirose and Osaki 1990; Lubow

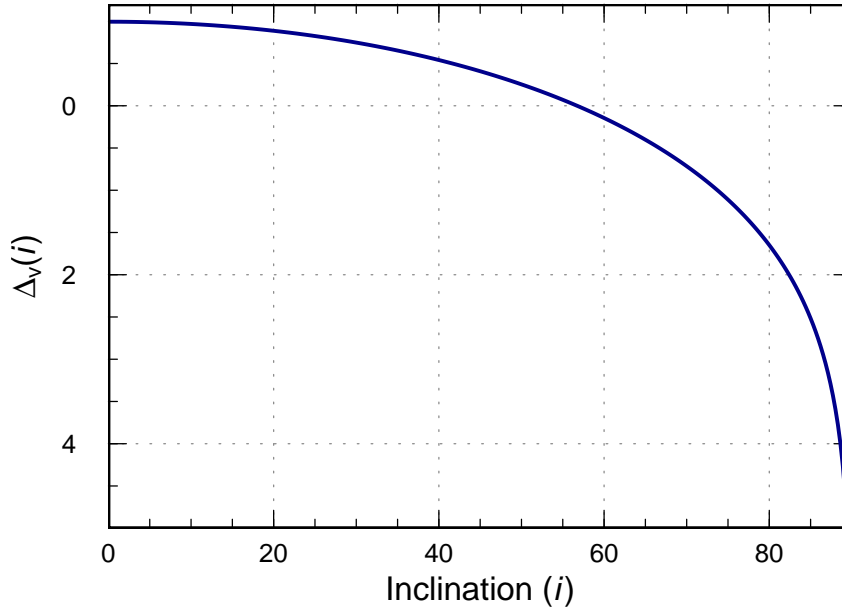


Figure 1: Dependence of the apparent brightness of an optically thick disk on the orbital inclination using equation (1). Fainter magnitudes are displayed lower.

1991) and in WZ Sge stars later during superoutbursts. WZ Sge stars are currently defined as dwarf novae in which the 2:1 resonance plays a role during their superoutbursts (Kato 2015).

In Kato (2015), I suggested in its subsection 7.10 that the brightness of WZ Sge stars when ordinary superhumps appear could be used as the standard candle since the disk is expected to have a size close to the radius of the 3:1 resonance. This could be equally applied to SU UMa stars. There are, however, unavoidable large uncertainties arising from inclinations. Paczyński and Schwarzenberg-Czerny (1980) derived a formula for an optically thick disk (as in dwarf-nova outbursts) considering the projected area and limb darkening of the disk

$$\Delta M_v(i) = -2.5 \log_{10} \left[\left(1 + \frac{3}{2} \cos i \right) \cos i \right], \quad (1)$$

where ΔM_v and i are the correction to produce the visual absolute magnitude and the inclination, respectively. These corrections can become large (Warner 1987; Patterson 2011). This relation is shown in figure 1. Pole-on systems ($i=0$) are observed 1.0 mag brighter than the average and systems with $i=80^\circ$ are nearly 2 mag fainter. The use of the accretion disk as the standard candle is somewhat limited since i is relatively difficult to measure other than in eclipsing systems.

In WZ Sge stars, however, the amplitude of early superhumps is considered to depend on the inclination since early superhumps arise from a geometric effect (to the observer) of vertical structures of the disk (Osaki and Meyer 2002). Uemura et al. (2012) succeeded in reproducing the profile of early superhumps by considering self-eclipse of a vertically extended disk. Kato (2015) used the code by Uemura et al. (2012) and reasonably reproduced the distribution of the observed amplitudes of early superhumps except objects with very large amplitudes (in its subsection 5.5). The amplitudes of early superhumps could thus be used instead of i .

At the time of Kato (2015), WZ Sge stars with known parallaxes were only three (WZ Sge, GW Lib and V455 And). Now that Gaia parallaxes are available (GaiaEDR3: Gaia Collaboration et al. 2021), I calibrated this “standard candle” and studied the dependence on the amplitude of early superhumps.

2 The Data

2.1 Data source

The data were mostly taken from table 5 in Kato (2015). The quiescent magnitudes were replaced by average G magnitudes in Gaia Collaboration et al. (2021). The amplitudes of early superhumps were taken from table

2 in Kato (2015). The full amplitudes of early superhumps (A_{ESH}) correspond to A_2 (mean amplitude) in table 2 in Kato (2015). Some objects in table 5 in Kato (2015) had more recent superoutbursts. If the values were improved, I supplied the data from these superoutbursts. As stated in Kato (2015), the accuracy of the magnitudes at which ordinary superhumps appear is ~ 0.1 mag. In some cases, zero-point calibrations of unfiltered CCD magnitudes caused more uncertainties (particularly in the past). In such cases, I used All-Sky Automated Survey (ASAS-3: Pojmański 2002) V data and All-Sky Automated Survey for Supernovae (ASAS-SN) Sky Patrol V data (Shappee et al. 2014; Kochanek et al. 2017) to obtain well-calibrated magnitudes. Observations from the AAVSO International Database¹ were sometimes used.

Additional objects were taken from Kato et al. (2017, 2020). Some objects (mainly since 2017) reported to VSNET (Kato et al. 2004) were also included to increase the sample. The detailed source of the data of each object is given later in this section. The objects having 1σ errors in Gaia parallaxes typically less than 20% were included in the table. When drawing figures and making statistical analysis, I limited objects with parallax errors less than 10%, corresponding to errors of 0.2 mag. Dwarf novae whose parallaxes are measured to this accuracy are nearby objects and I ignored interstellar extinction. The lack of reddening was confirmed by the blue colors ($BP - RP$) in Gaia magnitudes. In examining the light curves, I also used Public Data Releases of the Zwicky Transient Facility (Masci et al. 2019) observations².

2.2 Notes on individual objects

Simply referring to “magnitude”, here I mean the magnitude when ordinary superhumps appeared.

AL Com: updated using the 2019 April data (Tampo et al. 2021).

EG Cnc: updated using the 2018 October data (Kimura et al. 2021).

HV Vir: the same magnitude was obtained using the 2016 March data (Imada et al. 2018, and also VSNET data).

RZ Leo: updated using the 2022 January data (Outburst detection by Tadashi Kojima. H. Maehara, vsnet-alert 26522³; T. Kato, vsnet-alert 26529⁴ and Y. Tampo, vsnet-alert 26532⁵). The main observers were Kyoto U. team, Hiroshi Itoh, Seiichiro Kiyota, Osaka Kyoiku U. team, Shawn Dvorak, Tamás Tordai, Stephen M. Brincat, Vihorlat Observatory team and Filipp Romanov.

UZ Boo: magnitude updated using snapshot V measurements.

ASAS J102522–1542.4: value updated using ASAS-3 V magnitudes. The amplitude of early superhumps was taken from Kato et al. (2009a).

EZ Lyn: magnitude updated based on V data used in Kato et al. (2009a).

V455 And: magnitude updated based on V data used in Kato et al. (2009a).

OT J111217.4–353829: the epoch of the appearance of ordinary superhumps was somewhat uncertain.

V624 Peg: the epoch of the appearance of ordinary superhumps was somewhat uncertain. The magnitude was from AAVSO V observations.

V1838 Aql: The amplitude of early superhumps was taken from Kato et al. (2014). See also Echevarría et al. (2019).

ASASSN-14cv: early superhumps were reanalyzed in this work. The magnitude was confirmed during the 2020 July–August superoutburst.

V529 Dra: magnitude updated using snapshot V data. First case of double superoutburst (Kato et al. 2013a) and is one of the best candidates for period bouncers.

GS Cet: data from Kato et al. (2017). The magnitude was from ASAS-SN V data.

ASASSN-16eg: data from Wakamatsu et al. (2017). WZ Sge star with an unusually long orbital period.

ASASSN-16js: data from Kato et al. (2017). The magnitude was from ASAS-SN V data.

ASASSN-17el: data from Kato et al. (2020). The amplitude of early superhump was corrected in this work. The magnitude was from ASAS-SN V data.

PNV J20205397+2508145: data from Kato et al. (2020).

¹<<http://www.aavso.org/data-download>>.

²The ZTF data can be obtained from IRSA <<https://irsa.ipac.caltech.edu/Missions/ztf.html>> using the interface <https://irsa.ipac.caltech.edu/docs/program_interface/ztf_api.html> or using a wrapper of the above IRSA API <<https://github.com/MickaelRigault/ztfquery>>.

³<<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/26522>>.

⁴<<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/26529>>.

⁵<<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/26532>>.

HO Cet: data from Kato et al. (2009a). The magnitude was from ASAS-SN *V* data.

V627 Peg: data from Kato et al. (2010).

PNV J17144255–2943481: data from C. Nakata et al. in preparation; reanalyzed in this paper. This object showed five post-superoutburst rebrightenings (Kato 2015).

OV Boo: data from Ohnishi et al. (2019). Population II object (Patterson et al. 2017).

TCP J18154219+3515598: superoutburst in 2017 June⁶ (H. Maehara, vsnet-alert 21098⁷; K. Isogai, vsnet-alert 21101⁸; T. Kato, vsnet-alert 21105⁹; spectrum by P. Berardi¹⁰ and T. Kato, vsnet-alert 21109¹¹). This object showed 10 post-superoutburst rebrightenings (June–September), nine of which were announced on VSNET: R. J. Modic, vsnet-alert 21175¹²; R. J. Modic, vsnet-alert 21224¹³; E. de Miguel, vsnet-alert 21244¹⁴; H. Maehara, vsnet-alert 21268¹⁵; T. Kato, vsnet-alert 21278¹⁶; K. Isogai, vsnet-alert 21302¹⁷; H. Maehara, vsnet-alert 21322¹⁸; R. J. Modic, vsnet-alert 21334¹⁹ and H. Maehara, vsnet-alert 21347²⁰. See also Zubareva et al. (2018). The amplitude of early superhumps is based on re-analysis of the data reported to VSNET. The main observers were Geoff Stone, Tamás Tordai, Enrique de Miguel, Tonny Vanmunster, Lisnyky Observatory team, Kyoto U. team, Vihorlat Observatory team, Stephen M. Brincat, Hiroshi Itoh, Rudolf Novák, Terskol Observatory team, Seiichiro Kiyota, Kiyoshi Kasai, Roger D. Pickard, Natalia Katysheva, Ian Miller, Alexandra M. Zubareva, Javier Ruiz, William Stein, Sergey Yu. Shugarov, Lewis M. Cook, TSHAO Observatory team and Crimean Astrophysical Observatory team.

ASASSN-17pm: also known as PNV J05580574–0011155²¹. Superoutburst in 2017 November–December (T. Vanmunster, vsnet-alert 21624²²; T. Kato, vsnet-alert 21627²³ and T. Kato, vsnet-alert 21646²⁴). The amplitude of early superhump was re-analyzed in this work. There was a short rebrightening, a shallow dip and a long rebrightening. The main observers were Hiroshi Itoh, Crimean Astrophysical Observatory team, Franz-Josef Hamsch, Seiichiro Kiyota, Tonny Vanmunster, Kyoto U. team, Tamás Tordai, Ian Miller and Domenico Licchelli.

ASASSN-18do: the data were not very good around the appearance of ordinary superhumps. Superoutburst in 2018 February–March (T. Vanmunster, vsnet-alert 21906²⁵; T. Kato, vsnet-alert 21921²⁶). This object is eclipsing (T. Kato, vsnet-alert 21933²⁷). The main observers were Tonny Vanmunster, Hiroshi Itoh, Jochen Pietz, Tamás Tordai, Crimean Astrophysical Observatory team, Sergey Yu. Shugarov and Kyoto U. team.

ASASSN-18wa: superoutburst in 2018 September–October (T. Vanmunster, vsnet-alert 22560²⁸; Y. Wakamatsu, vsnet-alert 22565²⁹; Y. Wakamatsu, vsnet-alert 22591³⁰). There was a short gap in the observations after the superoutburst and it was unclear whether there was a post-superoutburst rebrightening. The ZTF data showed a smooth fading tail characteristic to a WZ Sge star. The main observers were Tamás Tordai, Osaka Kyoiku U. team, Tonny Vanmunster, Hiroshi Itoh and Geoff Stone.

ASASSN-19ag: superoutburst in 2019 January (T. Vanmunster, vsnet-alert 22927³¹). Although brightening and growth of ordinary superhumps were recorded, the profile before the growth of ordinary superhumps was

⁶ <<http://www.cbat.eps.harvard.edu/unconf/followups/J18154219+3515598.html>>.

⁷ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21098>>.

⁸ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21101>>.

⁹ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21105>>.

¹⁰ <http://quasar.teoht.it/html/spectra/tcpj18154219+3515598_PB.png>.

¹¹ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21109>>.

¹² <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21175>>.

¹³ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21224>>.

¹⁴ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21244>>.

¹⁵ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21268>>.

¹⁶ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21278>>.

¹⁷ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21302>>.

¹⁸ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21322>>.

¹⁹ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21334>>.

²⁰ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21347>>.

²¹ <<http://www.cbat.eps.harvard.edu/unconf/followups/J05580574–0011155.html>>.

²² <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21624>>.

²³ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21627>>.

²⁴ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21646>>.

²⁵ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21906>>.

²⁶ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21921>>.

²⁷ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/21933>>.

²⁸ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/22560>>.

²⁹ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/22565>>.

³⁰ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/22591>>.

³¹ <<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/22927>>.

not similar to that of early superhumps (T. Kato, vsnet-alert 22937³²). I therefore did not give the amplitude of early superhumps. The object showed at least one post-superoutburst rebrightening in the ZTF data.

TCP J06373299–0935420 = ASASSN-19de: superoutburst in 2019 February–March³³ (spectrum by R. Leadbeater, vsnet-alert 23014³⁴ and T. Kato, vsnet-alert 23036³⁵). There was one post-superoutburst rebrightening (T. Kato, vsnet-alert 23083³⁶). The main observers were Osaka Kyoiku U. team, Hiroshi Itoh, Stephen M. Brincat, Berto Monard, Franz-Josef Hamsch, Seiichiro Kiyota, Arto Oksanen, Masanori Mizutani, Tonny Vanmunster and Yasui Sano. According to vsnet-alert postings, Gianluca Masi also reported observations but I could not receive the data and are not included in this analysis.

TCP J05390410+4748030 = ASASSN-19hh: superoutburst in 2019 March–April³⁷ (T. Vanmunster, vsnet-alert 23068³⁸; T. Kato, vsnet-alert 23072³⁹; T. Kato, vsnet-alert 23120⁴⁰ and T. Kato, vsnet-alert 23124⁴¹). The main observers were Tonny Vanmunster, Seiichiro Kiyota, Hiroshi Itoh, Crimean Astrophysical Observatory team, Vihorlat Observatory team, Tamás Tordai, Stephen M. Brincat, Ian Miller and Lewis M. Cook.

ASASSN-19hl: superoutburst in 2019 March–April (D. Denisenko, vsnet-alert 23090⁴²; T. Kato, vsnet-alert 23103⁴³ and T. Kato, vsnet-alert 23144⁴⁴). The main observers were Berto Monard, Franz-Josef Hamsch and Hiroshi Itoh.

V3101 Cyg: data from Tampo et al. (2020). The amplitude of early superhumps was re-analyzed in this work.

EQ Lyn: data from Tampo et al. (2021).

GY Cet: superoutburst in 2020 July–August (P. Schmeer, vsnet-alert 24446⁴⁵; T. Kato, vsnet-alert 24486⁴⁶ and T. Kato, vsnet-alert 24498⁴⁷). No post-superoutburst rebrightening was present. The main observers were Franz-Josef Hamsch and Berto Monard.

VX For: superoutburst in 2021 January–February (Y. Maeda, vsnet-alert 25264⁴⁸; P. Schmeer, vsnet-alert 25265⁴⁹ and Y. Tampo, vsnet-alert 25288⁵⁰). There were five post-superoutburst rebrightenings (P. Schmeer, vsnet-alert 25358⁵¹; P. Schmeer, vsnet-alert 25386⁵²; R. Stubbings, vsnet-outburst 26651⁵³; P. Schmeer, vsnet-alert 25414⁵⁴ and ASAS-SN $g=14.3$ on 2021 February 28). This object also showed five post-superoutburst rebrightenings in 2009 (Kato et al. 2010) and has been suggested as a period bouncer (Kato 2022). The main observers were Hiroshi Itoh, Berto Monard, Peter Nelson and Franz-Josef Hamsch.

ASASSN-21et = TCP J06154200–2756220: superoutburst in 2021 April–May⁵⁵ (P. Schmeer, vsnet-alert 25637⁵⁶; T. Kato, vsnet-alert 25658⁵⁷ and T. Kato, vsnet-alert 25780⁵⁸). There was no post-superoutburst rebrightening in the ASAS-SN data. The main observers were Berto Monard and Franz-Josef Hamsch.

I only deal with statistics in this paper and the full analysis and figures for these unpublished objects are planned to appear in separate paper(s).

³²<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/22937>.

³³<http://www.cbat.eps.harvard.edu/unconf/followups/J06373299–0935420.html>.

³⁴<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/23014> and https://britastro.org/specdb/data_graph.php?obs_id=3925.

³⁵<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/23036>.

³⁶<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/23083>.

³⁷<http://www.cbat.eps.harvard.edu/unconf/followups/J05390410+4748030.html>.

³⁸<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/23068>.

³⁹<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/23072>.

⁴⁰<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/23120>.

⁴¹<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/23124>.

⁴²<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/23090>.

⁴³<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/23103>.

⁴⁴<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/23144>.

⁴⁵<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/24446>.

⁴⁶<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/24486>.

⁴⁷<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/24498>.

⁴⁸<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/25264>.

⁴⁹<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/25265>.

⁵⁰<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/25288>.

⁵¹<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/25358>.

⁵²<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/25386>.

⁵³<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-outburst/26651>.

⁵⁴<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/25414>.

⁵⁵<http://www.cbat.eps.harvard.edu/unconf/followups/J06154200–2756220.html>.

⁵⁶<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/25637>.

⁵⁷<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/25658>.

⁵⁸<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/25780>.

3 Result and Discussion

3.1 Absolute magnitudes when ordinary superhumps appear

The absolute magnitudes when ordinary superhumps appear [hereafter $M_V(\text{SH})$] are listed in table 1. Note that this table includes objects with relative large errors in parallax. For example, the bright $M_V(\text{SH})$ in HO Cet is likely a result of the uncertainty in the parallax. In this table, I gave 1σ errors estimated from the errors in parallax. They are the main cause of the overall errors of $M_V(\text{SH})$.

Table 1: Brightness when superhumps appear

Object	Year	P^*	Mag1 [†]	Mag2 [‡]	A_{ESH}	ϖ^{\S}	ϖ_{error}	$M_V(\text{SH})^{\parallel}$
WZ Sge	2011	0.05669	15.2	9.9	0.14	22.104	0.030	6.6(0)
AL Com	2019	0.05667	19.7	13.7	0.04	1.903	0.565	5.1(8)
EG Cnc	2018	0.05997	18.8	12.7	0.018	5.361	0.199	6.3(1)
HV Vir	1992	0.05707	19.0	13.3	0.044	3.152	0.261	5.8(2)
RZ Leo	2022	0.07603	18.2	13.1	0.05	3.564	0.149	5.9(1)
QZ Lib	2004	0.06460s	18.8	12.2	–	5.023	0.254	5.7(1)
UZ Boo	2013	0.0620s	19.9	12.8	–	3.086	0.511	5.2(4)
ASAS J102522–1542.4	2006	0.06136	19.3	12.5	0.025	3.675	0.342	5.3(2)
EZ Lyn	2010	0.05901	17.8	12.7	0.067	7.004	0.110	6.9(0)
GW Lib	2007	0.05332	16.5	10.2	0.00	8.846	0.061	4.9(0)
V455 And	2007	0.05631	16.0	11.0	0.22	13.189	0.043	6.6(0)
OT J111217.4–353829	2007	0.05847	20.2	14.4	0.14	2.003	0.531	5.9(7)
SDSS J161027.61+090738.4	2009	0.05687	19.8	14.6	0.05	2.599	0.430	6.7(4)
CRTS J104411.4+211307	2010	0.05909	19.4	13.7	0.030	2.425	0.342	5.6(3)
OT J012059.6+325545	2010	0.05716	19.8	14.2	0.045	3.030	0.427	6.6(3)
V355 UMa	2011	0.05729	17.4	10.8	0.01	6.619	0.064	4.9(0)
V624 Peg	2011	0.05865	18.4	12.2	0.00	4.553	0.193	5.5(1)
BW Scl	2011	0.05432	16.3	10.7	0.10	10.679	0.052	5.8(0)
MASTER OT J211258.65+242145.4	2012	0.05973	20.0	15.2	0.050	1.754	0.493	6.4(7)
V1838 Aql	2013	0.05706	17.9	11.7	0.011	4.940	0.142	5.2(1)
ASASSN-14cl	2014	0.05838	18.2	11.9	0.018	3.825	0.188	4.8(1)
ASASSN-14cv	2014	0.05992	19.1	12.9	0.03	3.407	0.171	5.6(1)
PNV J23052314–0225455	2014	0.05456	19.2	13.4	0.035	2.103	0.299	5.0(3)
PNV J03093063+2638031	2014	0.05615	18.7	12.2	0.018	4.132	0.188	5.3(1)
ASASSN-14jv	2014	0.05442	18.8	12.5	0.017	3.333	0.147	5.1(1)
ASASSN-15bp	2014	0.05563	19.8	13.7	0.014	1.792	0.325	5.0(4)
V1251 Cyg	2008	0.07433	20.2	13.4	0.018	1.965	0.517	4.9(7)
BC UMa	2003	0.06261	18.3	12.6	0.04	3.392	0.126	5.3(1)
V529 Dra	2011	0.07168	20.4	13.7	0.005	1.661	0.488	4.8(8)
CRTS J122221.6–311524	2013	0.07649s	18.9	12.3	–	4.136	0.222	5.4(1)
PNV J06000985+1426152	2014	0.06331s	20.0	12.9	–	1.833	0.706	4.2(11)
GS Cet	2016	0.05597	20.7	14.2	0.065	3.846	1.388	7.1(10)
ASASSN-16eg	2016	0.07548	19.4	13.4	0.05	2.260	0.204	5.2(2)
ASASSN-16js	2016	0.06034	20.5	15.3	0.18	2.475	0.350	7.3(3)
ASASSN-17el	2017	0.05434	18.7	12.6	0.025	2.889	0.120	4.9(1)
PNV J20205397+2508145	2017	0.05651	20.1	14.2	0.06	1.561	0.526	5.2(9)
HO Cet	2006	0.05490	19.3	13.5	0.035	1.134	0.392	3.8(9)
V627 Peg	2010	0.05452	15.6	10.3	0.045	10.079	0.037	5.3(0)

*Orbital or superhump (with a suffix ‘s’) period (d).

†Quiescent brightness.

‡Brightness when ordinary superhumps appear.

§Gaia EDR3 parallax (mas).

∥Absolute magnitude when ordinary superhumps appear. The 1σ error estimated from ϖ_{error} is given.

Table 1: Brightness when superhumps appear (continued).

Object	Year	P^*	Mag1 [†]	Mag2 [‡]	A_{ESH}	ϖ^{\S}	ϖ_{error}	$M_V(\text{SH})^{\parallel}$
PNV J17144255–2943481	2014	0.05956	17.2	12.3	0.05	5.665	0.098	6.1(0)
OV Boo	2017	0.04626	18.2	13.5	0.27	4.715	0.091	6.9(0)
TCP J18154219+3515598	2017	0.06168s	19.1	12.4	0.015	4.600	0.171	5.7(1)
ASASSN-17pm	2017	0.05973	17.8	14.2	0.14	3.363	0.120	6.8(1)
ASASSN-18do	2018	0.05498	20.5	15.9	0.6	1.593	0.671	6.9(12)
ASASSN-18wa	2018	0.05441	20.2	14.4	0.02	2.068	0.949	6.0(13)
ASASSN-19ag	2019	0.06616	20.0	13.0	–	2.512	0.635	5.0(6)
TCP J06373299–0935420	2019	0.06642s	19.2	12.1	0.01	3.432	0.275	4.8(2)
TCP J05390410+4748030	2019	0.05534	19.6	13.7	0.10	2.957	0.318	6.1(2)
ASASSN-19hl	2019	0.05415	19.5	12.9	0.03	2.889	0.274	5.2(2)
V3101 Cyg	2019	0.05352	17.7	10.9	0.045	9.226	0.072	5.7(0)
EQ Lyn	2019	0.0528	18.9	12.0	–	3.223	0.222	4.5(2)
GY Cet	2020	0.05663	18.5	11.9	0.015	3.712	0.181	4.7(1)
VX For	2021	0.06133s	20.4	13.2	–	2.060	0.574	4.8(7)
ASASSN-21et	2021	0.05820	20.2	14.5	0.12	2.816	0.508	6.7(4)

*Orbital or superhump (with a suffix ‘s’) period (d).

†Quiescent brightness.

‡Brightness when ordinary superhumps appear.

§Gaia EDR3 parallax (mas).

∥Absolute magnitude when ordinary superhumps appear. The 1σ error estimated from ϖ_{error} is given.

The distribution of absolute magnitudes when ordinary superhumps appear is shown in figure 2. The mean value is $\langle M_V(\text{SH}) \rangle = +5.57$ and the standard deviation is 0.67 mag. This standard deviation is too large to be directly used as the standard candle. Furthermore, the mean value is not adequate since $M_V(\text{SH})$ does not follow a Gaussian distribution as explained later. The dispersion in $M_V(\text{SH})$ is largely due to the inclination effect as seen in equation (1).

3.2 Correlation with the amplitude of early superhumps

Considering that A_{ESH} is expected to be a function of i , the relation between A_{ESH} and $M_V(\text{SH})$ is shown in figure 3. Systems with large A_{ESH} have fainter $M_V(\text{SH})$ as expected. The relation becomes linear using $\log A_{\text{ESH}}$ (figure 4). The solid line in the figure corresponds to

$$M_V(\text{SH}) = 7.5(3) + 1.28(20) \log_{10} A_{\text{ESH}}. \quad (2)$$

In drawing the figure and making a regression, $M_V(\text{SH})=0.01$ was given for objects with $M_V(\text{SH}) < 0.01$ (The value of 0.01 mag is a realistic upper limit of the detection of early superhumps; use the same value in applying the formula to WZ Sge stars without detectable early superhumps). The standard deviation from this relation is 0.42 mag.

3.3 Special objects and the updated relation

The two most deviating objects were EG Cnc (1.1 mag fainter than this relation) and EZ Lyn (0.9 mag fainter than this relation). One of the possible reason for EG Cnc is that the observations of EG Cnc did not start early enough (Kimura et al. 2021) and A_{ESH} might have been underestimated. EZ Lyn is an eclipsing system and is suggested to be a period bouncer (Zharikov et al. 2008; Pavlenko et al. 2007; Kato et al. 2009b; Kato and Osaki 2013; Amantayeva et al. 2021).

Although TCP J18154219+3515598 with 10 rebrightenings is also 0.5 mag fainter than this relation, ASASSN-14cv with 5–8 rebrightenings [8 in 2014 (Sklyanov et al. 2016; Kato 2015); 5 in 2020, VSNET data] does not show a strong deviation. QZ Lib with four rebrightenings (Kato et al. 2009a; Pala et al. 2018) and PNV

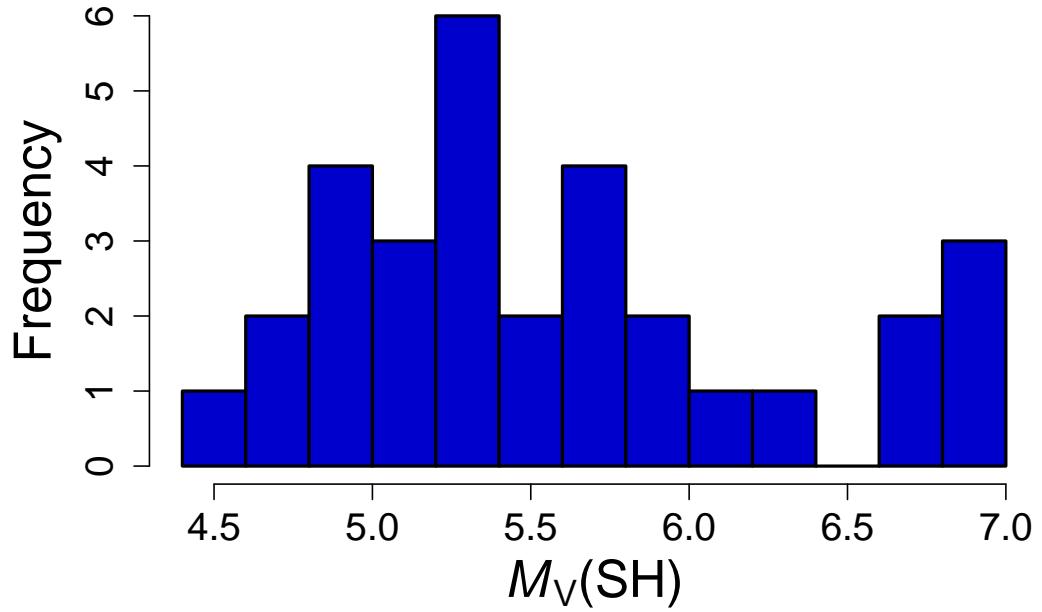


Figure 2: Distribution of absolute magnitudes when ordinary superhumps appear [$M_V(\text{SH})$]. Objects with parallax errors less than 10% were selected.

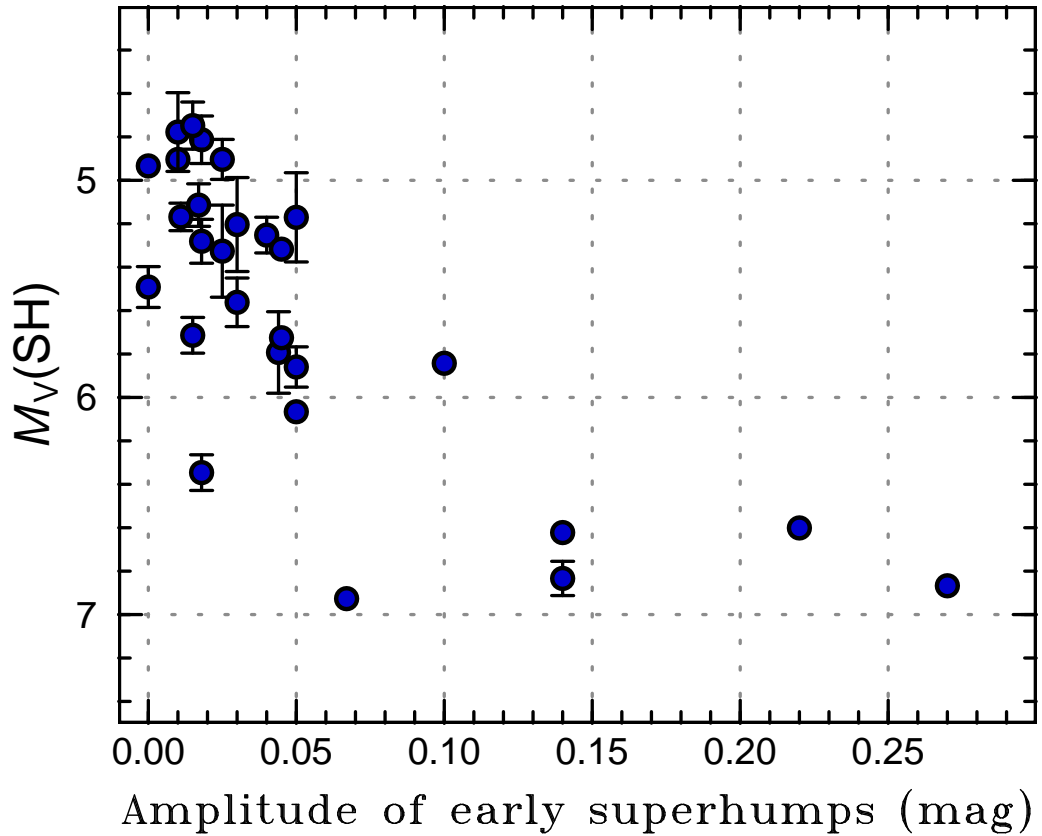


Figure 3: Dependence of absolute magnitudes when ordinary superhumps appear [$M_V(\text{SH})$] on amplitudes of early superhumps. Objects with parallax errors less than 10% were selected. The error bars reflect the errors from parallax measurements.

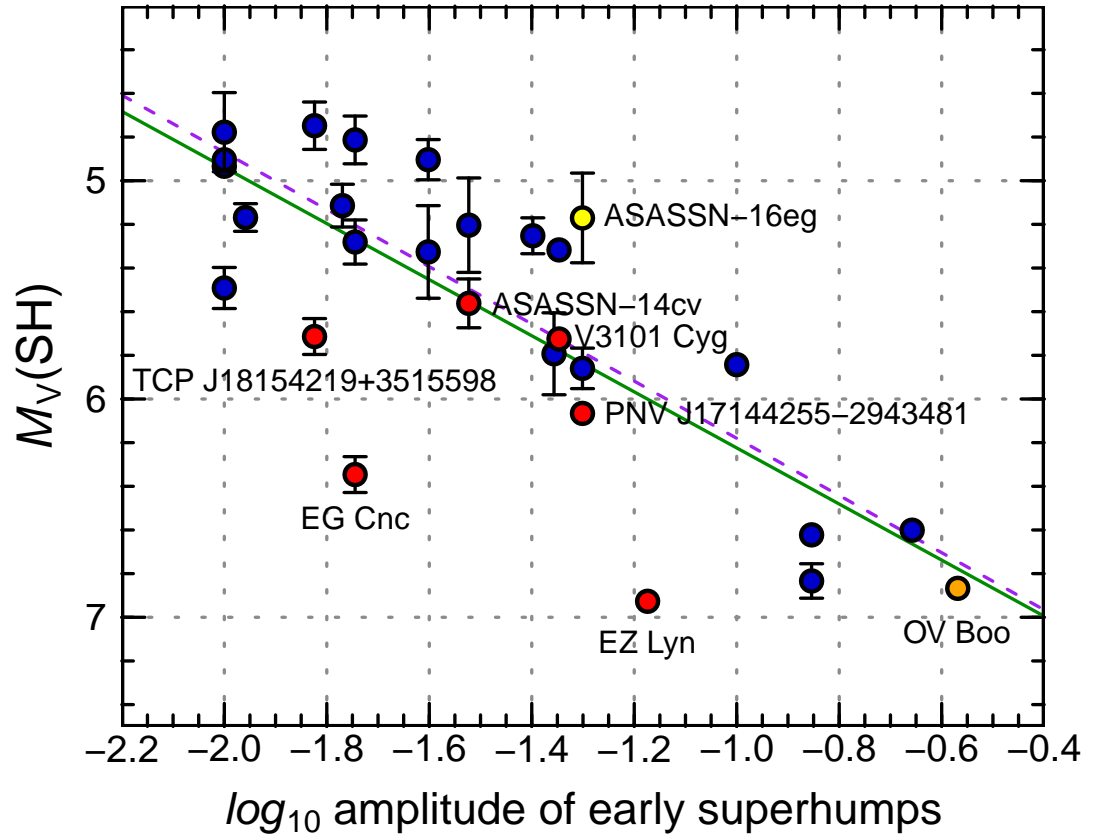


Figure 4: Dependence of absolute magnitudes when ordinary superhumps appear [$M_V(\text{SH})$] on amplitudes of early superhumps in logarithmic scale. Objects with parallax errors less than 10% were selected. Several unusual objects are plotted with different colors. Red marks represent objects with multiple post-superoutburst rebrightenings. (See text for the details). The solid and dashed lines represent equations (2) and (3), respectively. The error bars reflect the errors from parallax measurements.

J17144255–2943481 with five rebrightenings are also on this relation. The very unusual object V3101 Cyg, which showed multiple rebrightenings and superoutbursts following the initial superoutburst (Tampo et al. 2020; Hameury and Lasota 2021), is also on the relation. The most extreme period bouncer in this sample CRTS J122221.6–311524 (Kato et al. 2013b; Neustroev et al. 2017, 2018) is not in figure 4 since A_{ESH} is unknown, but has an ordinary $M_V(\text{SH})=5.4$.

There is a possible reason of the deviation for (some) period bouncers if the deviation is real. They are likely to have small mass ratios (Kato 2022, and references therein) and the tidal torque on the disk is expected to be weak. This may cause a weaker effect of the 2:1 resonance and A_{ESH} may be smaller than in other WZ Sge stars. Since a number of WZ Sge stars with multiple rebrightenings are on the relation, this explanation does not seem to apply to all period bouncers. This possibility needs to be studied further both from the observational and theoretical sides.

The only population II object below the period minimum OV Boo (Littlefair et al. 2007; Patterson et al. 2008; Uthas et al. 2011; Patterson et al. 2017; Ohnishi et al. 2019) is on the relation. This object is located near the period minimum of population II cataclysmic variables and it may not be as unusual as more evolved period bouncers. ASASSN-16eg is a WZ Sge star with a very long orbital period (Wakamatsu et al. 2017). The deviation to the brighter side may reflect the large disk size, but the error in the parallax is still large to draw a definite conclusion.

Disregarding the objects deviating by more than 0.6 mag from equation (2), I obtained

$$M_V(\text{SH}) = 7.5(2) + 1.31(15) \log_{10} A_{\text{ESH}}. \quad (3)$$

The standard deviation from this regression is 0.31 mag. This equation can currently be regarded as the best relation for WZ Sge stars with potential exceptions of evolved period bouncers and systems with very long orbital periods.

3.4 Standard candle for the average inclination

The median value of $M_V(\text{SH})$ for all the objects is +5.38, which can be considered as a value for the average inclination ($=1$ radian $= 57^\circ$). This value can be used as the standard candle if A_{ESH} is unknown, but with a 1σ error of 0.67 mag. Although, errors may be even larger in high-inclination systems, i can probably be estimated using eclipses in such systems and there would be no need for the use of the median $M_V(\text{SH})$.

3.5 Estimation of the inclination from the amplitude of early superhumps

By equating the equation (1) and the equation (3) and using the value of the standard candle of $M_V(\text{SH})=+5.38$ for $i=1$ radian, one can obtain an experimental relation between the amplitude of early superhumps and the inclination (figure 5). Note that this figure is based on an assumption that the relation between $\log A_{\text{ESH}}$ and $M_V(\text{SH})$ is linear. This figure suggests that A_{ESH} is 0.02 mag for the average inclination ($=1$ radian). It is likely that early superhumps are not detectable for $i < 40^\circ$. There is only one object (OV Boo) with $i > 80^\circ$ in our sample. It is possible that the amplitude of early superhumps is saturated for very large i and the linear relation would break. The relation in figure 5 would be helpful for estimating i for objects with moderate A_{ESH} .

4 Application to MASTER OT J030227.28+191754.5

MASTER OT J030227.28+191754.5 = PNV J03022732+1917552 was reported as a possible counterpart (Zhirkov et al. 2021) of IceCube-211125A high-energy neutrino event (IceCube Collaboration 2021). This object had a large outburst amplitude of 10 mag (Zhirkov et al. 2021). It was independently discovered by Y. Nakamura⁵⁹. Due to the large outburst amplitude and the possible association with the neutrino event, it was suspected to be a nova. Early spectroscopy indeed showed narrow emission lines and it was suggested to be either a narrow-lined He(/N) nova or a dwarf nova with an exceptionally large amplitude (Taguchi et al. 2021). The initial spectrum did not resemble that of a dwarf nova and the object was initially favored to be a nova (Paliya 2021). Follow-up observations did not detect very-high-energy gamma-ray flux (Quinn et al. 2021; Ayala 2021a,b). The optical spectrum on the second night clarified that the object is a very high-amplitude dwarf nova (Isogai et al. 2021). CCD images taken 8.5 hr before the neutrino event indicated that the object was already 1 mag above the

⁵⁹ <<http://www.cbat.eps.harvard.edu/unconf/followups/J03022732+1917552.html>>.

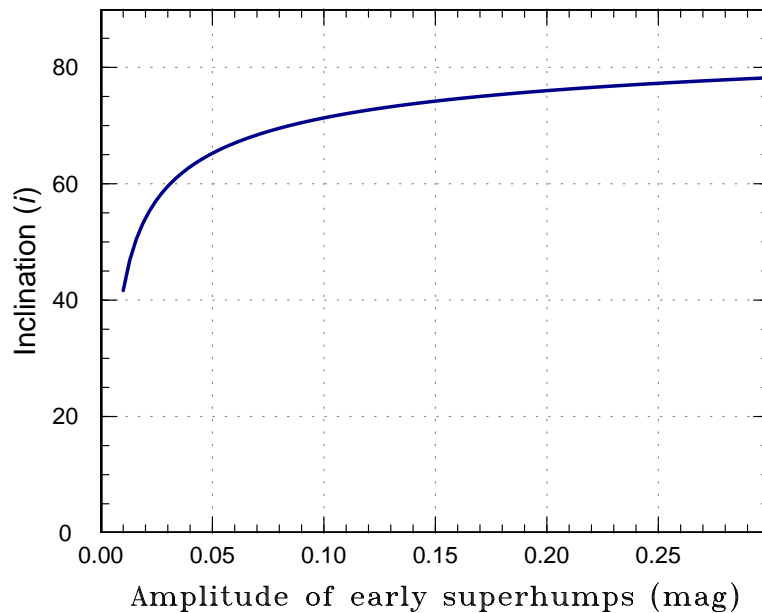


Figure 5: Relation between the amplitude of early superhumps and the inclination.

preoutburst level (Sarneczky et al. 2021). Although this observation suggested the association with the neutrino event less likely, the magnitude might have been too faint to be considered as the ignition of the outburst.

Early superhumps with an amplitude of 0.03 mag were detected (T. Kato, vsnet-alert 26477⁶⁰). The object eventually started to show ordinary superhumps on 2021 December 30, 30–32 d after the outburst detection (T. Kato, vsnet-alert 26501⁶¹). This delay of the appearance of ordinary superhumps was the longest ever observed (Kato 2015).

Due to the unusual nature and the extremely slow development of ordinary superhumps in this object, I applied the present method to estimate the distance and luminosity. Ordinary superhumps appeared at a magnitude of 14.9 (VSNET data; Y. Tambo et al. in preparation). Using the equation (3), $M_V(\text{SH})$ is expected to be +5.6 and the distance modulus is estimated to be 9.3, which corresponds to ~ 720 pc. The SDSS magnitude $g=22.0$ (Abazajian et al. 2009) corresponds to the quiescent absolute magnitude of +12.7, which is one of the faintest recorded in WZ Sge stars (Tambo et al. 2020). The peak V magnitude 11.8 corresponds to $M_V=+2.6$, which is also among the brightest (Tambo et al. 2020).

To examine the possibility if any nuclear reaction was involved in the outburst of this object, I made a comparison with the faintest measurement of an outbursting nova. The recurrent nova T Pyx was recorded on the rise at a magnitude of 13.0 during the 2011 eruption by M. Linnolt (Waagan et al. 2011; Schaefer et al. 2013) [the initial spectrum was taken several hours later by Arai et al. (2015), confirming the nova eruption]. This corresponds to $M_V=+0.7$ and the maximum M_V of MASTER OT J030227.28+191754.5 is still 6 times below this value. The faint brightness of T Pyx during the rise was probably due to the large bolometric correction and the actual upper limit of the luminosity of the white dwarf due to nuclear reaction should be much lower than this estimate (compared to T Pyx) based on the V -band data.

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⁶⁰<<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/26477>>.

⁶¹<<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/26501>>.

contributed by observers worldwide and used in this research. The author is grateful to Naoto Kojiguchi for helping downloading the ZTF data.

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List of objects in this paper

V455 And, V1838 Aql, UZ Boo, OV Boo, GS Cet, GY Cet, HO Cet, EG Cnc, AL Com, V1251 Cyg, V3101 Cyg, V529 Dra, VX For, RZ Leo, GW Lib, QZ Lib, EQ Lyn, EZ Lyn, V624 Peg, V627 Peg, T Pyx, BW Scl, WZ Sge, SU UMa, BC UMa, V355 UMa, HV Vir, ASAS J102522–1542.4, ASASSN-14cl, ASASSN-14cv, ASASSN-14jv, ASASSN-15bp, ASASSN-16eg, ASASSN-16js, ASASSN-17el, ASASSN-17pm, ASASSN-18do, ASASSN-18wa, ASASSN-19ag, ASASSN-19hl, ASASSN-21et, CRTS J104411.4+211307, CRTS J122221.6–311524, IceCube-211125A, MASTER OT J030227.28+191754.5, MASTER OT J211258.65+242145.4, OT J012059.6+325545, OT J111217.4–353829, PNV J03093063+2638031, PNV J06000985+1426152, PNV J17144255–2943481, PNV J20205397+2508145, PNV J23052314–0225455, SDSS J161027.61+090738.4, TCP J05390410+4748030, TCP J06373299–0935420, TCP J18154219+3515598

References

- Abazajian, K. N. et al. (2009) The seventh data release of the Sloan Digital Sky Survey. *ApJS* **182**, 543
- Amantayeva, A., Zharikov, S., Page, K. L., Pavlenko, E., Sosnovskij, A., Khokhlov, S., & Ibraimov, M. (2021) Period bouncer cataclysmic variable EZ Lyn in quiescence. *ApJ* **918**, 58
- Arai, A., Isogai, M., Yamanaka, M., Akitaya, H., & Uemura, M. (2015) Optical low resolution spectroscopic observations of T Pyx during the early phase of 2011 outburst. *Acta Polytechnica CTU proceedings* **2**, 257
- Ayala, H. (2021a) HAWC observations of AT2021afpi/MASTER OT J030227.28+191754.5 (discovered during follow-up observations of IceCube-211125A). *Astron. Telegram* **15079**, 1
- Ayala, H. (2021b) Update on HAWC observations of AT2021afpi/MASTER OT J030227.28+191754.5 (discovered during follow-up observations of IceCube-211125A). *Astron. Telegram* **15088**, 1
- Baba, H. et al. (2002) Spiral structure in WZ Sagittae around the 2001 outburst maximum. *PASJ* **54**, L7
- Bailey, J. (1979) Two cataclysmic variables similar to WZ Sagittae. *MNRAS* **189**, 41P
- Barwig, H., Mantel, K. H., & Ritter, H. (1992) HV Virginis: A new WZ Sge-type dwarf nova. *A&A* **266**, L5
- Downes, R. A., & Margon, B. (1981) On the nature of WX Ceti. *MNRAS* **197**, 35P
- Downes, R. A. (1990) IUE observations of WX Ceti in outburst. *AJ* **99**, 339
- Echevarría, J. et al. (2019) Extensive photometry of V1838 Aql during the 2013 superoutburst. *Rev. Mexicana Astron. Astrof.* **55**, 21
- Gaia Collaboration et al. (2021) Gaia Early Data Release 3. Summary of the contents and survey properties. *A&A* **649**, A1
- Hameury, J.-M., & Lasota, J.-P. (2021) Modelling rebrightenings, reflare, and echoes in dwarf nova outbursts. *A&A* **650**, A114

- Hirose, M., & Osaki, Y. (1990) Hydrodynamic simulations of accretion disks in cataclysmic variables – superhump phenomenon in SU UMa stars. *PASJ* **42**, 135
- Howell, S. B., De Young, J., Mattei, J. A., Foster, G., Szkody, P., Cannizzo, J. K., Walker, G., & Fierce, E. (1996) Superoutburst photometry of AL Comae Berenices. *AJ* **111**, 2367
- IceCube Collaboration (2021) IceCube-211125A: IceCube observation of a high-energy neutrino candidate track-like event. *GRB Coord. Netw. Circ.* **31126**, 1
- Imada, A., Isogai, K., Araki, T., Tanada, S., Yanagisawa, K., & Kawai, N. (2018) OAO/MITSuME photometry of dwarf novae. II. HV Virginis and OT J012059.6+325545. *PASJ* **70**, 2
- Ishioka, R. et al. (2002) First detection of the growing humps at the rapidly rising stage of dwarf novae AL Com and WZ Sge. *A&A* **381**, L41
- Isogai, K. et al. (2021) Spectroscopic and photometric confirmation of MASTER OT J030227.28+191754.5 as a very large-amplitude WZ Sge-type dwarf nova. *Astron. Telegram* **15074**, 1
- Kato, T. (2022) Evolution of short-period cataclysmic variables: implications from eclipse modeling and stage a superhump method (with New Year’s gift). *VSOLJ Variable Star Bull.* **89**, (arXiv:2201.02945)
- Kato, T. (2015) WZ Sge-type dwarf novae. *PASJ* **67**, 108
- Kato, T. et al. (2014) Survey of period variations of superhumps in SU UMa-type dwarf novae. VI: The fifth year (2013–2014). *PASJ* **66**, 90
- Kato, T. et al. (2013a) Survey of period variations of superhumps in SU UMa-type dwarf novae. IV: The fourth year (2011–2012). *PASJ* **65**, 23
- Kato, T. et al. (2009a) Survey of period variations of superhumps in SU UMa-type dwarf novae. *PASJ* **61**, S395
- Kato, T. et al. (2017) Survey of period variations of superhumps in SU UMa-type dwarf novae. IX. The ninth year (2016–2017). *PASJ* **69**, 75
- Kato, T. et al. (2020) Survey of period variations of superhumps in SU UMa-type dwarf novae. X. The tenth year (2017). *PASJ* **72**, 14
- Kato, T. et al. (2010) Survey of Period Variations of Superhumps in SU UMa-Type Dwarf Novae. II. The Second Year (2009–2010). *PASJ* **62**, 1525
- Kato, T., Monard, B., Hamsch, F.-J., Kiyota, S., & Maehara, H. (2013b) SSS J122221.7–311523: Double superoutburst in a best candidate period bouncer. *PASJ* **65**, L11
- Kato, T., Nogami, D., Baba, H., Matsumoto, K., Arimoto, J., Tanabe, K., & Ishikawa, K. (1996) Discovery of two types of superhumps in WZ Sge-type dwarf nova AL Comae Berenices. *PASJ* **48**, L21
- Kato, T., & Osaki, Y. (2013) New method to estimate binary mass ratios by using superhumps. *PASJ* **65**, 115
- Kato, T. et al. (2009b) SDSS J080434.20+510349.2: Eclipsing WZ Sge-type dwarf nova with multiple rebrightenings. *PASJ* **61**, 601
- Kato, T., Sekine, Y., & Hirata, R. (2001) HV Vir and WZ Sge-type dwarf novae. *PASJ* **53**, 1191
- Kato, T., Uemura, M., Ishioka, R., Nogami, D., Kunjaya, C., Baba, H., & Yamaoka, H. (2004) Variable Star Network: World center for transient object astronomy and variable stars. *PASJ* **56**, S1
- Kimura, M. et al. (2021) Multi-wavelength photometry during the 2018 superoutburst of the WZ Sge-type dwarf nova EG Cancri. *PASJ* **73**, 1
- Kochanek, C. S. et al. (2017) The All-Sky Automated Survey for Supernovae (ASAS-SN) light curve server v1.0. *PASP* **129**, 104502
- Leibowitz, E. M., Mendelson, H., Bruch, A., Duerbeck, H. W., Seitter, W. C., & Richter, G. A. (1994) The 1992 outburst of the SU Ursae Majoris-type dwarf nova HV Virginis. *ApJ* **421**, 771

- Littlefair, S. P., Dhillon, V. S., Marsh, T. R., Gänsicke, B. T., Baraffe, I., & Watson, C. A. (2007) SDSS J150722.30+523039.8: a cataclysmic variable formed directly from a detached white dwarf/brown dwarf binary? *MNRAS* **381**, 827
- Lubow, S. H. (1991) A model for tidally driven eccentric instabilities in fluid disks. *ApJ* **381**, 259
- Masci, F.-J. et al. (2019) The Zwicky Transient Facility: Data processing, products, and archive. *PASP* **131**, 018003
- Mendelson, H., Leibowitz, E. M., Brosch, N., & Almozno, E. (1992) HV Virginis. *IAU Circ.* **5509**
- Neustroev, V. V. et al. (2017) The remarkable outburst of the highly evolved post-period-minimum dwarf nova SSS J122221.7–311525. *MNRAS* **467**, 597
- Neustroev, V. V. et al. (2018) Superhumps linked to X-ray emission. The superoutbursts of SSS J122221.7–311525 and GW Lib. *A&A* **611**, A13
- Nogami, D., Kato, T., Baba, H., Matsumoto, K., Arimoto, J., Tanabe, K., & Ishikawa, K. (1997) The 1995 superoutburst of the WZ Sagittae-type dwarf nova AL Comae Berenices. *ApJ* **490**, 840
- Ohnishi, R. et al. (2019) First WZ Sge-type superoutburst in a population II cataclysmic variable. *PASJ* p. submitted
- Osaki, Y. (1989) A model for the superoutburst phenomenon of SU Ursae Majoris stars. *PASJ* **41**, 1005
- Osaki, Y., & Meyer, F. (2002) Early humps in WZ Sge stars. *A&A* **383**, 574
- Paczyński, B., & Schwarzenberg-Czerny, A. (1980) Disk accretion in U Geminorum. *Acta Astron.* **30**, 127
- Pala, A. F., Schmidtobreick, L., Tappert, C., Gänsicke, B. T., & Mehner, A. (2018) The cataclysmic variable QZ Lib: a period bouncer. *MNRAS* **481**, 2523
- Paliya, V. S. (2021) Classical nova AT2021afpi, a possible EM counterpart to IC211125A, is in X-ray outburst. *Astron. Telegram* **15073**, 1
- Patterson, J., McGraw, J. T., Coleman, L., & Africano, J. L. (1981) A photometric study of the dwarf nova WZ Sagittae in outburst. *ApJ* **248**, 1067
- Patterson, J. (2011) Distances and absolute magnitudes of dwarf novae: murmurs of period bounce. *MNRAS* **411**, 2695
- Patterson, J., Augusteijn, T., Harvey, D. A., Skillman, D. R., Abbott, T. M. C., & Thorstensen, J. (1996) Superhumps in cataclysmic binaries. IX. AL Comae Berenices. *PASP* **108**, 748
- Patterson, J. et al. (2017) OV Bootis: Forty nights of world-wide photometry. *Society for Astronom. Sciences Ann. Symp.* **36**, 1
- Patterson, J. et al. (2002) The 2001 superoutburst of WZ Sagittae. *PASP* **114**, 721
- Patterson, J., Thorstensen, J. R., & Knigge, C. (2008) SDSS 1507+52: A halo cataclysmic variable? *PASP* **120**, 510
- Pavlenko, E. et al. (2007) in ASP Conf. Ser. 372, 15th European Workshop on White Dwarfs, ed. R. Napiwotzki, & M. R. Burleigh (San Francisco: ASP) p. 511
- Pojmański, G. (2002) The All Sky Automated Survey. Catalog of variable stars. I. 0^h–6^h quarter of the southern hemisphere. *Acta Astron.* **52**, 397
- Quinn, J., VERISTAS Collaboration, Metzger, B., & Sokoloski, J. (2021) VERITAS observations of AT2021afpi/MASTER OT J030227.28+191754.5 (discovered during follow-up observations of IceCube-211125A). *Astron. Telegram* **15078**, 1
- Sarneczky, K., Vinko, J., & Kiss, L. (2021) Prediscovery detection of AT2021afpi/MASTER OT J030227.28+191754.5, 8 hours before the IceCube-211125A neutrino event. *Astron. Telegram* **15081**, 1

- Schaefer, B. E. et al. (2013) The 2011 eruption of the recurrent nova T Pyxidis: The discovery, the pre-eruption rise, the pre-eruption orbital period, and the reason for the long delay. *ApJ* **773**, 55
- Shappee, B. J. et al. (2014) The man behind the curtain: X-rays drive the UV through NIR variability in the 2013 AGN outburst in NGC 2617. *ApJ* **788**, 48
- Sklyanov, A. S., Pavlenko, E. P., Antonyuk, O. I., Antonyuk, K. A., Sosnovsky, A. A., Galeev, A. I., Pit', N. V., & Babina, Y. V. (2016) Superhump evolution of WZ Sge-type dwarf nova ASASSN-14cv at rebrightening stage. *Astrophys. Bull.* **71**, 293
- Taguchi, K., Shibata, M., Masayuki, Y., Isogai, K., Tampo, Y., Kojiguchi, N., Ito, J., & Kato, T. (2021) Spectroscopic and photometric follow-up of MASTER OT J030227.28+191754.5: a possible “narrow-lined He nova” or large-amplitude dwarf nova. *Astron. Telegram* **15072**, 1
- Tampo, Y. et al. (2021) Spectroscopic and photometric observations of dwarf nova superoutbursts by the 3.8 m telescope Seimei and the Variable Star Network. *PASJ* **73**, 753
- Tampo, Y. et al. (2020) First detection of two superoutbursts during the rebrightening phase of a WZ Sge-type dwarf nova: TCP J21040470+4631129. *PASJ* **72**, 49
- Uemura, M., Kato, T., Ohshima, T., & Maehara, H. (2012) Reconstruction of the structure of accretion disks in dwarf novae from the multi-band light curves of early superhumps. *PASJ* **64**, 92
- Uthas, H., Knigge, C., Long, K. S., Patterson, J., & Thorstensen, J. (2011) The cataclysmic variable SDSS J1507+52: an eclipsing period bouncer in the Galactic halo. *MNRAS* **414**, L85
- Waagan, E., Linnolt, M., & Pearce, A. (2011) T Pyxidis. *IAU Circ.* **9205**, 1
- Wakamatsu, Y. et al. (2017) ASASSN-16eg: New candidate for a long-period WZ Sge-type dwarf nova. *PASJ* **69**, 89
- Warner, B. (1995) *Cataclysmic Variable Stars* (Cambridge: Cambridge University Press)
- Warner, B. (1987) Absolute magnitudes of cataclysmic variables. *MNRAS* **227**, 23
- Watson, C. L., Henden, A. A., & Price, A. (2006) The International Variable Star Index (VSX). *Society for Astronom. Sciences Ann. Symp.* **25**, 47
- Whitehurst, R. (1988) Numerical simulations of accretion disks. I – Superhumps: A tidal phenomenon of accretion disks. *MNRAS* **232**, 35
- Zharikov, S. V. et al. (2008) Cyclic brightening in the short-period WZ Sge-type cataclysmic variable SDSS J080434.20+510349.2. *A&A* **486**, 505
- Zhirkov, K. et al. (2021) MASTER OT J030227.28+191754.5 – 10 mag outburst detection during an inspect of IceCube-211125A. *Astron. Telegram* **15067**, 1
- Zubareva, A. M., Shugarov, S. Y., & Zharova, A. V. (2018) in A. A. Boyarchuk Memorial Conference, INASAN Science Proceedings, ed. D. V. Bisikalo, & D. S. Wiebe (Moscow: Online at <http://www.inasan.ru/wp-content/uploads/2018/12/Boyarchuk.pdf>) p. 120



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