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The 2022 active state of the AM CVn star NSV 1440

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Abstract

We found an active state lasting for ~200 d in the AM CVn star NSV 1440 in 2022. During this state, the object reached a magnitude of 16.5, 2.0–2.5 mag above quiescence, and showed a number of superposed normal outbursts. Such an active state was probably brought either by an enhanced mass-transfer from the secondary or increased quiescent viscosity of the accretion disk. These possibilities are expected to be distinguished by an observation of the interval to the next superoutburst. We also found that the brightness and the course toward the end of the event were similar to the post-superoutburst fading tail in 2021. The mechanism producing the 2022 active state and post-superoutburst fading tails in AM CVn stars may be the same, and the present finding is expected to clarify the nature of these still poorly understood fading tails in AM CVn stars, and potentially of the corresponding phenomenon in hydrogen-rich WZ Sge stars. We also note that the faint, long "superoutbursts" in long-period AM CVn stars claimed in the past were not true outbursts powered by disk instability, but were more likely phenomena similar to the 2022 active state in NSV 1440.

NSV 1440 was discovered as a variable star (BV 1025) with a photographic range of 12.6 to fainter than 15.0 (Knigge and Bauernfeind 1967). The variability of this object was not studied further and was listed as a suspected variable in Kukarkin et al. (1982). In 2015, the All-Sky Automated Survey for Supernovae (ASAS-SN, Shappee et al. 2014) detected the transient ASASSN-15sz (K. Stanek, vsnet-alert 19288)[1], which was soon identified with NSV 1440 (D. Denisenko, vsnet-alert 19289)[2]. Subsequent time-resolved photometry immediately detected short-period variations (vsnet-alert 19291[3] and vsnet-alert 19293[4]), followed by rapid fading (vsnet-alert 19298)[5]. These variations were soon identified as early superhumps and ordinary superhumps [see e.g., Kato (2015) for the nomenclature of superhumps in WZ Sge stars], and the object was suggested to be the first AM CVn star showing both early and ordinary superhumps (vsnet-alert 19304)[6]. This object showed multiple rebrightenings (starting with the one reported in vsnet-alert 19328)[7], which has been now identified as one of the characteristic features of AM CVn-type superoutbursts (see e.g., Kato and Kojiguchi 2021). Another very similar superoutburst with multiple rebrightenings occurred in 2017 and Isogai et al. (2019) reported on these two superoutbursts. Isogai et al. (2019) measured the periods of early and ordinary superhumps to be 0.0252329(49) d and 0.025679(20) d, respectively. The former is expected to be very close to the orbital period ($P_{\rm orb}$). Isogai et al. (2019) determined a mass ratio of q=0.045(2).

Not much work was done since Isogai et al. (2019) for this object, one of the reasons probably being the object near the south celestial pole, which is inaccessible from northern observers. Although Pichardo Marcano et al.

[1] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/19288>.
[2] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/19289>.
[3] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/19291>.
[4] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/19293>.
[5] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/19298>.
[6] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/19304>.
[7] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/19328>.

Table 1: Superoutbursts in NSV 1440.

Year	Month	Day	BJD	Peak magnitude	Interval (d)
2015	November	21	2457350	V=12.9	–
2017	August	21	2457987	$m_{\rm vis}$=13.0	637
2019	February	16	2458531	$m_{\rm vis}$=13.0	544
2021	August	30	2459457	$m_{\rm vis}$=12.9	926

(2021) referred to the presence of Transiting Exoplanet Survey Satellite (TESS) (Ricker et al. 2015)[8] observations of this object, nothing particular was discussed. This is understandable, since (currently) public TESS data only recorded quiescent parts and we could not detect a periodic signal corresponding to $P_{\rm orb}$.

One of the authors (RS) noticed a number of short outbursts in 2022 by visual observations. Using ASAS-SN observations and Asteroid Terrestrial-impact Last Alert System (ATLAS: Tonry et al. 2018) forced photometry (Shingles et al. 2021), we found that this object was indeed brighter its ordinary quiescence [BP=18.44 and RP=18.42 according to Gaia Collaboration et al. (2022)] and the even reached g=16.5 between these outbursts.

The long-term light curves are shown in figures 1 and 2. Only positive detections are shown and all other ASAS-SN observations were upper limits. Although there are segments with only a few points, a missed long outburst is excluded from these ASAS-SN upper-limit observations. Since the end of 2021, ATLAS observations became available and the variation of the quiescent level and occurrence of short outbursts are clearly shown in the third and fourth panels of figure 2. An enlargement of the 2022 active state is shown in figure 3. We must note, however, isolated ASAS-SN points near quiescence of these figures should be regarded as upper limits rather than real values since they were incidentally positively detected among other upper-limit observations due to random errors. A phenomenon similar to the 2022 active state was not present at least between 2015 and 2021 based on observations by the ASAS-SN and RS.

Superoutbursts shown in these figures are summarized in table 1. The dates are given for optical peaks. The 2019 superoutburst was preceded by a precursor outburst. All these outbursts had a short initial segment (4–6 d) followed by complex rebrightenings (both long and short ones depending on the superoutburst) and a fading tail (see Kato and Kojiguchi 2021), which is commonly seen after AM CVn-type superoutbursts. Among these superoutbursts, the 2021 one appears to have been the most powerful one in that it had the longest duration (6 d) of the initial segment. This is probably a consequence of the long quiescent interval before this superoutburst. A larger mass should have been accumulated in the disk before this superoutburst.

After this 2021 superoutburst, the quiescent level strongly varied, associated by frequent occurrence of short outbursts as initially reported by RS. There are two possibilities for this phenomenon (and possibly a combination of them):

- The mass transfer-rate ($\dot{M}_{\rm tr}$) varied and outbursts occurred frequently when $\dot{M}_{\rm tr}$ was high.
- The quiescent viscosity varied and outbursts occurred frequently when the viscosity was high, if there was sufficient mass in the disk.

Both possibilities appear to naturally explain the observed phenomenon. AM CVn can have variable $\dot{M}$ as in the recent example of a standstill in CR Boo (Kato et al. 2023) and the variation in $\dot{M}_{\rm tr}$ could to be a viable explanation. The variation in the quiescent viscosity also appears to be promising, and has been proposed to explain post-superoutburst rebrightenings in hydrogen-rich systems (WZ Sge stars) (Osaki et al. 2001; Meyer and Meyer-Hofmeister 2015). The same explanation would apply to a helium disk, and since the helium disk requires a higher temperature to partially ionize (Tsugawa and Osaki 1997; Kotko et al. 2012), a small change in the quiescent viscosity would produce a more prominent effect than in hydrogen-rich dwarf novae. These possibilities may be distinguished by observing the next superoutburst. If $\dot{M}_{\rm tr}$ indeed increased, the mass of the disk increased more rapidly than in ordinary quiescence and the next superoutburst is expected to occur earlier than expected or to be a powerful one. If the quiescent viscosity increased and $\dot{M}_{\rm tr}$ remained the same, the mass in the disk should have been drained more quickly than in ordinary quiescence and the next superoutburst is expected to occur later. It is a pity that this object does not show orbital modulations even in TESS data and it was impossible to detect a possible enhancement of the hot spot resulting from increased $\dot{M}_{\rm tr}$.

[8] <https://tess.mit.edu/observations/>. The full light-curve is available at the Mikulski Archive for Space Telescope (MAST, <http://archive.stsci.edu/>).

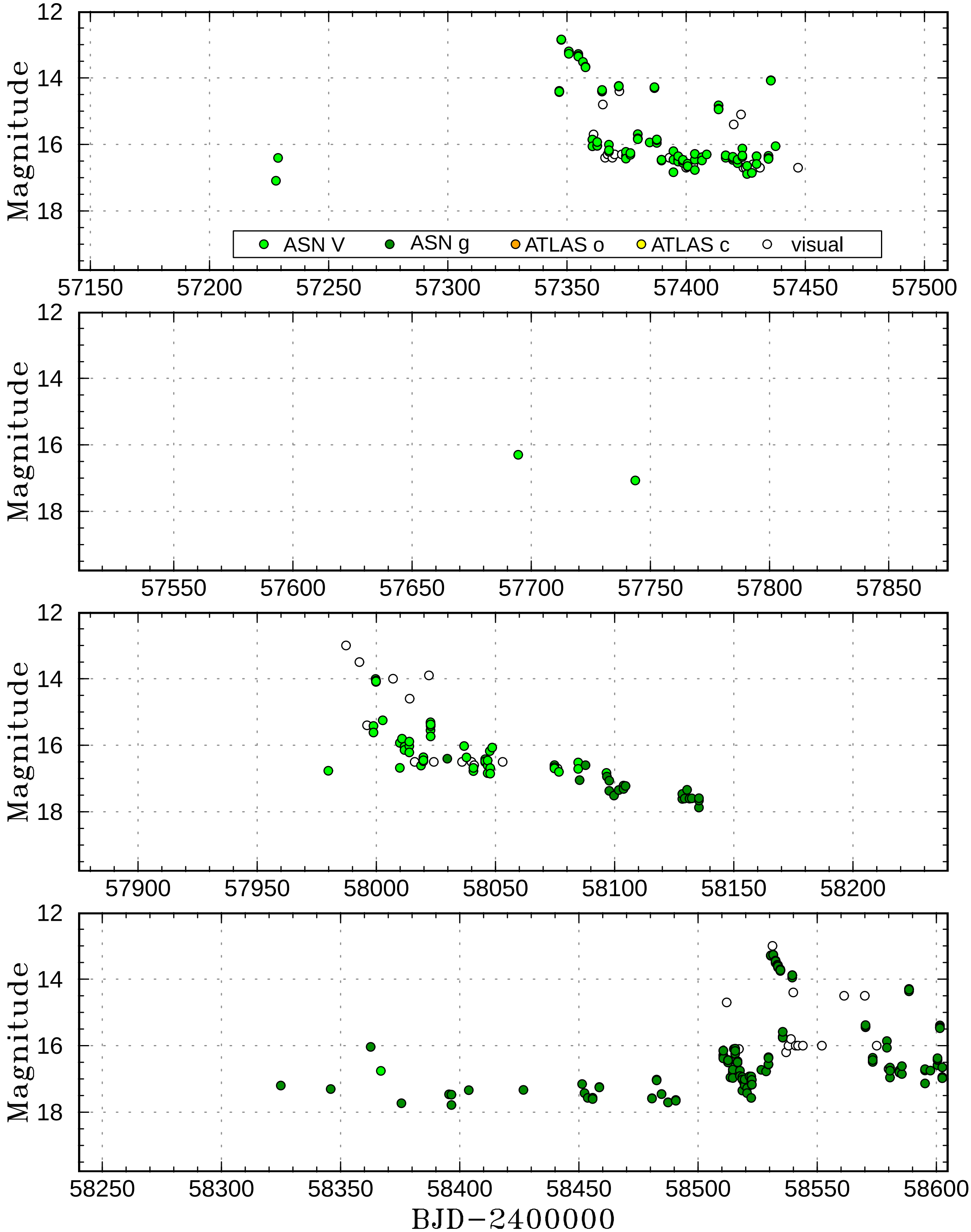

Figure 1: Light curve of NSV 1440 in 2015–2019. ASN and "visual" refer to ASAS-SN observations and visual observations by RS, respectively. Only positive detections are shown and all other ASAS-SN observations were upper limits. No other major outburst was missed.

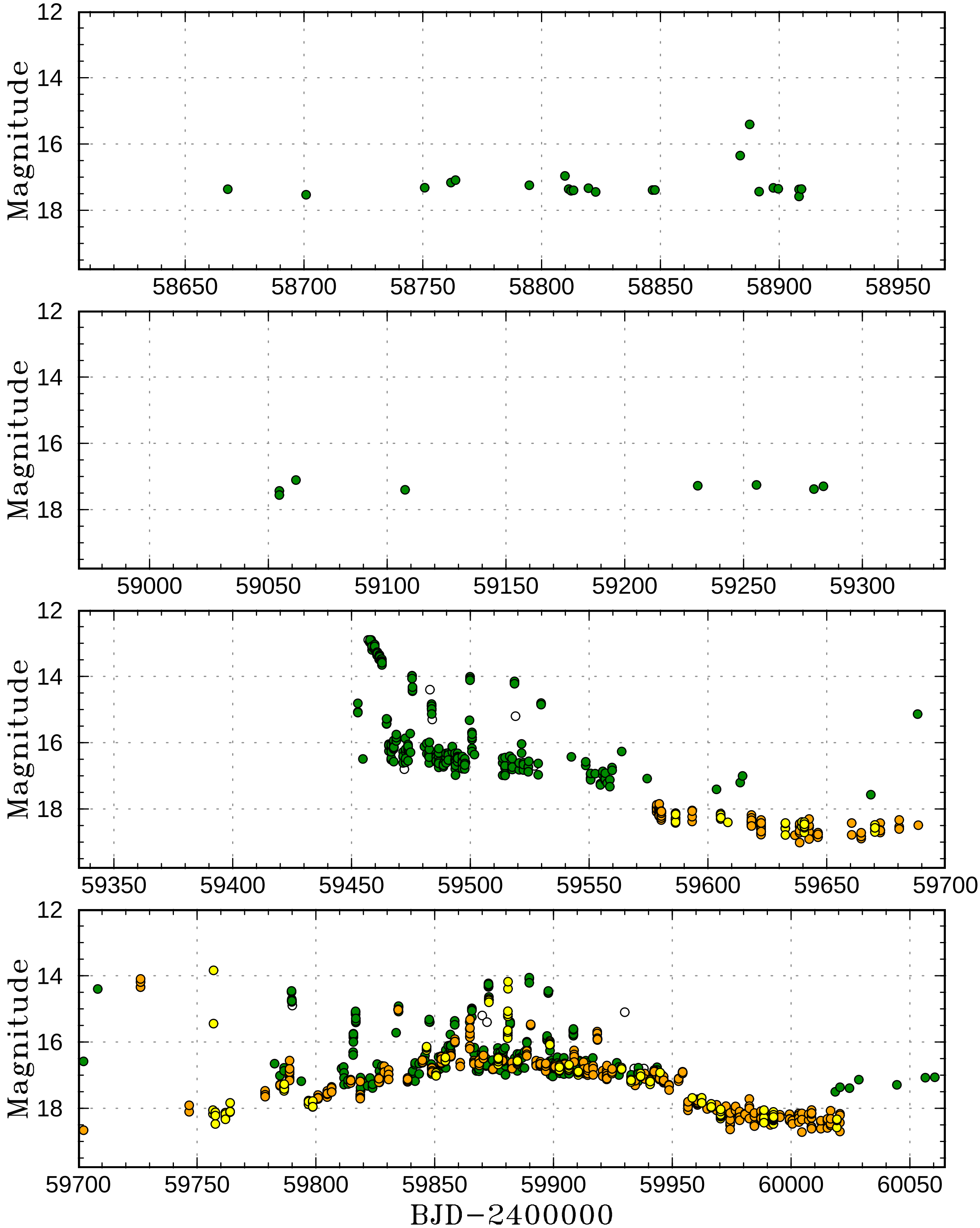

Figure 2: Light curve of NSV 1440 in 2019–2023. The symbols are the same as in figure 1.

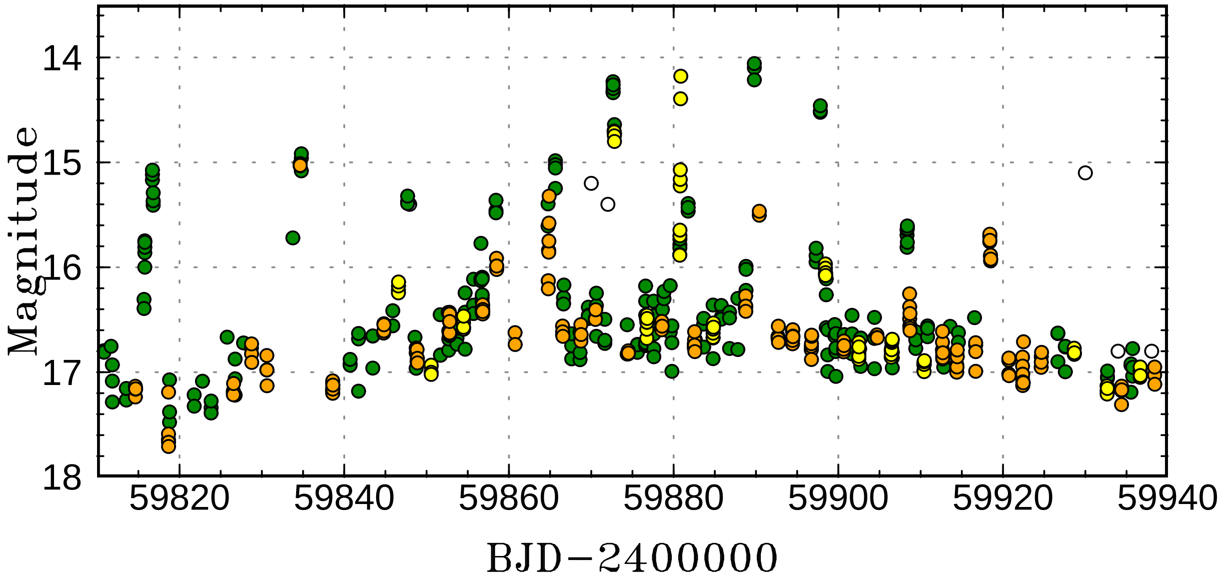

Figure 3: Enlargement of the central part of the 2022 active state in NSV 1440. The symbols are the same as in figure 1.

It may be worth noting that this active state in 2022 was very similar in brightness and duration to the post-superoutburst fading tail of the 2021 superoutburst. The mechanism of fading tails of AM CVn stars is still poorly understood. In hydrogen-rich WZ Sge stars, very long-duration (reaching a few years) fading tails have been considered to arise from the cooling white dwarf (Szkody et al. 1998; Godon et al. 2004; Long et al. 2004; Piro et al. 2005; Godon et al. 2006). This explanation, however, cannot be directly applicable to fading tails of AM CVn-type superoutbursts at least for two reasons: (1) the mass accumulated or accreted in AM CVn-type dwarf novae is much smaller and (2) the fading tail ends abruptly (see the third panel of figure 2), in contrast to smooth fading expected for a cooling white dwarf. The same feature of abrupt fading was also present in the 2022 active phase: a sudden drop was present around BJD 2459955. These features suggest rapid switching between high and low states, either by variable $\dot{M}_{\rm tr}$ or quiescent viscosity. If the mechanism of the 2022 active phase is clarified, it will also help understanding the yet unsolved mechanism of the fading tail and associated rebrightenings in AM CVn stars (see e.g., Kato and Kojiguchi 2021; Rivera Sandoval et al. 2022). This might also provide a clue in understanding the exceptional hydrogen-rich dwarf nova V3101 Cyg with a long-lasting post-superoutburst phase with increased outburst activity (Tampo et al. 2020; Hameury and Lasota 2021).

We should make a comment on long-lasting faint "superoutbursts" claimed in the past. Rivera Sandoval et al. (2020) reported a faint "superoutburst" lasting more than a year in SDSS J080710.33+485259.6 with a photometric period of 53.3(3) min (Kupfer et al. 2019). This "superoutburst" was very unusual in its morphology and the peak brightness (18.2 mag) was only ~2 mag above the quiescence. Rivera Sandoval et al. (2021) reported a similar 0.5–1 mag (according to their paper; the amplitude was 1.5 mag according to the ATLAS data) long-lasting brightening in SDSS J113732.32+405458.3 with $P_{\rm orb}$ of 59.6±2.7 min (Carter et al. 2014). Based on these two "outbursts", Rivera Sandoval et al. (2022) suggested the presence of two types of superoutbursts in long-$P_{\rm orb}$ AM CVn stars. One type has a large amplitude and a short duration, and it follows the tendency expected from the disk-instability model. This type is what we referred to superoutbursts here. The other type with a small amplitude and a long duration appears to be similar to the active state of NSV 1440 in 2022, although short outburst on them were absent in these two objects claimed in the past. The peak M_V of the long "outburst" in SDSS J113732.32+405458.3 was +10.9 using the Gaia parallax (Gaia Collaboration et al. 2022) and the ATLAS data. This value is close to the peak $M_V = +8.9$ in the active state of NSV 1440 in 2022. The long "outburst" in SDSS J113732.32+405458.3 was probably a phenomenon similar to the active state in NSV 1440 rather than a true outburst considering the presence of genuine superoutbursts in NSV 1440 with much larger amplitudes. Although the parallax of SDSS J080710+485259 was not determined well, the peak M_V is expected to be similar to that of SDSS J113732.32+405458.3 considering the similar amplitude. These active states should not be called outbursts or superoutbursts, and they should not be discussed as outbursts in the context of disk instability.

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List of objects in this paper

CR Boo, AM CVn, V3101 Cyg, WZ Sge, NSV 1440, ASASSN-15sz, BV 1025, SDSS J080710.33+485259.6, SDSS J113732.32+405458.3

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