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MGAB-V240: 23-min AM CVn star showing both 12-d supercycle and standstills

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Abstract

Using Zwicky Transient Facility (ZTF) data, I noticed that MGAB-V240 = PS1-3PI J185529.82+323017.8 showed two different states: regularly outbursting state with a cycle length of 12 d and standstills. I found that the regularly outbursting state was in fact a sequence of superoutburst and intervening normal outbursts comprising a 12-d supercycle. During one of the superoutbursts, superhumps with a period of 0.015824(9) d (=22.79 min) were detected in the ZTF time-resolved data. This period and behavior have confirmed that MGAB-V240 is an AM CVn-type object with the shortest known supercycle and the second known AM CVn star showing genuine standstills. The standstills in this system were interrupted by short drops and the system often brightened after these drops. This phenomenon can be explained by the accumulation of the transferred matter in the outer part of the disk during the drops. This phenomenon favors a constant mass-transfer from the secondary combined with the difficulty in maintaining the hot state in a helium disk rather than a temporary decrease of the mass-transfer rate as the cause of these drops. MGAB-V240 should be close to the border of the thermal instability of a helium disk, and the observed superhump period agrees very well with the activity sequence expected by the disk instability theory and the evolutionary sequence of AM CVn stars.

MGAB-V240 was discovered as a faint SS Cyg-type dwarf nova with frequent outbursts.[1] The object had also been selected as a candidate RR Lyr star (PS1-3PI J185529.82+323017.8, Sesar et al. 2017).[2] I used Zwicky Transient Facility (ZTF: Masci et al. 2019)[3] data and found that this object showed standstills in 2020 and 2022. The long-term light curves containing a regularly outbursting part (2018–2019) and a state with standstills and outbursts (2020–2022) are shown in figures 1 and 2, respectively. A naïve look at these figures would simply re-classify the object as an Z Cam star [for cataclysmic variables and their subclasses, see e.g., Warner (1995)]. I, however, noticed that the object showed sudden drops during the 2022 standstill (figure 3), which is unusual for a Z Cam-type dwarf nova (vsnet-chat 9317).[4] One or two drops were also recorded during the 2020 standstill. The fading rates of these sudden drops were sometimes close to 2 mag d^{-1}, whose large value is one of the signatures of AM CVn-type outbursts (Kato and Kojiguchi 2021) [for a review of AM CVn stars, see e.g., Solheim (2010)].

Upon a closer look at the ZTF light curve of the regularly outbursting part, I found short outbursts between long outbursts (figure 4). This is a clear indication of an SU UMa-type supercycle (long outbursts and short outbursts between them). Superhumps with a period of 0.015824(9) d were indeed detected from the ZTF time-resolved data during one of long outbursts (figure 5). The error of the period was estimated by the methods of Fernie (1989) and Kato et al. (2010). The overall light curve of the 2018–2019 season resembles that of ASASSN-14cc (Kato et al. 2015). Kato et al. (2015) detected a supercycle of 21–33 d together with superhumps with period of 0.01560–0.01562 d by a network of ground-based small telescopes aiming at ASASSN-14cc under a VSNET

[1] <https://www.aavso.org/vsx/index.php?view=detail.top&oid=702830>.

[2] Although the name PS1-3PI J185529.82+323017.8 would be adequate considering the priority in discovery, I use MGAB-V240 in this paper because of its brevity.

[3] The 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>.

[4] <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-chat/9317>.

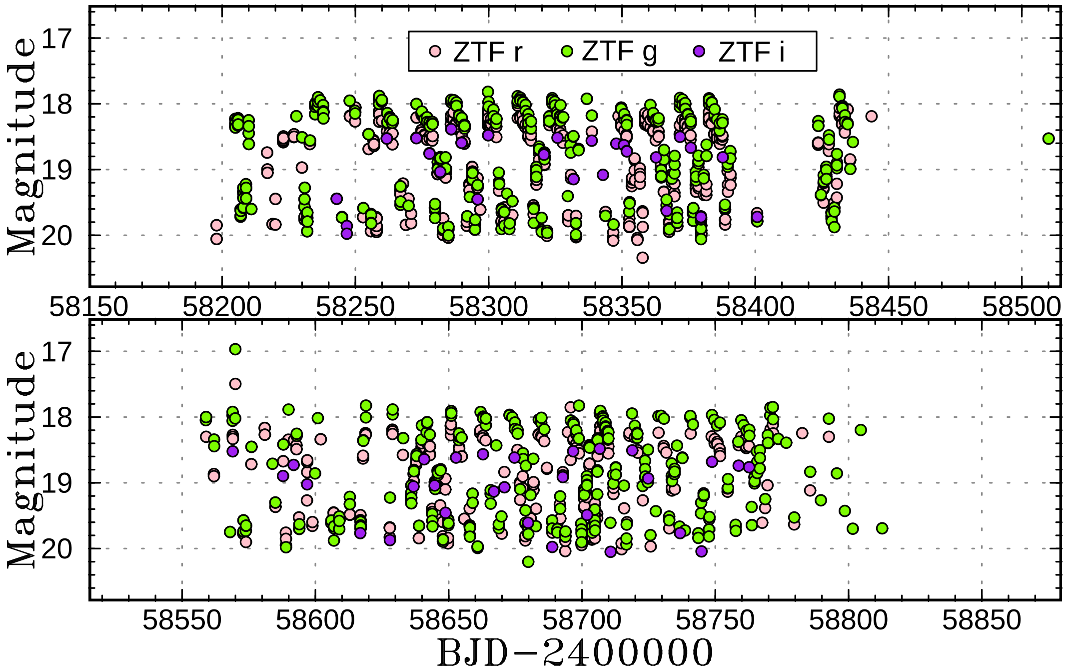

Figure 1: Light curve of MGAB-V240 in 2018–2019. The object showed a regular pattern of outbursts recurring with a period of ∼12 d. They turned out to be superoutbursts, not SS Cyg-type outbursts (see text).

(Kato et al. 2004) campaign. This period was confirmed by TESS photometry (Pichardo Marcano et al. 2021). Kato et al. (2015) suggested that ASASSN-14cc showed a supercycle similar to the hydrogen-rich system RZ LMi. RZ LMi typically has a supercycle of 19 d (Robertson et al. 1995; Nogami et al. 1995; Olech et al. 2008), but showed a short standstill in 2016 (Kato et al. 2016). Such a short supercycle could not be naturally reproduced (Osaki 1995a,b) by the thermal-tidal instability model (Osaki 1989, 1996), which successfully explained the supercycles of most SU UMa stars. Osaki (1995b) explained the short supercycle by artificially quenching the superoutburst when the accretion disk is still large. This treatment led to an idea of decoupling between the thermal and tidal instabilities (Hellier 2001).

The present observations of MGAB-V240 make this object as a perfect helium analog (although no spectrum has been obtained, the short superhump period is an unambiguous signature of an AM CVn-type object) of the hydrogen-rich RZ LMi: a short-period supercycle and standstills. True standstills in AM CVn stars have been very rare and this object becomes the second well-established example after CR Boo (Kato et al. 2023). The suggested type is SU UMa(ER UMa)+Z Cam+AM CVn.

In AM CVn stars, an RZ LMi-like short supercycle would be more easily achieved than in hydrogen-rich systems for two reasons: (1) Helium disks require a higher temperature to maintain the hot state and a cooling wave starts more easily than in hydrogen-rich systems. (2) AM CVn stars have (usually) lower mass ratios than in hydrogen-rich systems, which would make decoupling between the thermal and tidal instabilities easier to happen [For the disk-instability model of AM CVn stars, see Tsugawa and Osaki (1997); Solheim (2010); Kotko et al. (2012)]. Drops from standstills may be caused by the difficulty (relative to hydrogen-rich systems) in maintaining the hot state. In contrast to most (hydrogen-rich) Z Cam stars, these drops were often followed by short brightening (after the initial three drops in figure 4). This phenomenon can be interpreted as follows: The mass transfer from the secondary and the mass accretion to the primary are balanced during the standstill. Once a cooling wave starts, the mass accretion to the primary decreases and the mass accumulates (if the mass-transfer rate is constant) during these drops in the outer part of the disk, and this extra mass causes brightening when the disk becomes hot again. The phenomenon observed in standstills of MGAB-V240 excludes the possibility of a temporary decrease of the mass-transfer rate as the cause of the drops; rather the constant mass-transfer rate is favored to explain brightening after the drops.

The superhump period of 0.015824 d, which is usually ∼1% longer than the orbital period ($P_{\rm orb}$) in AM CVn stars, in MGAB-V240 is between the thermally unstable dwarf nova-type CR Boo ($P_{\rm orb}$=0.017029 d: Provencal

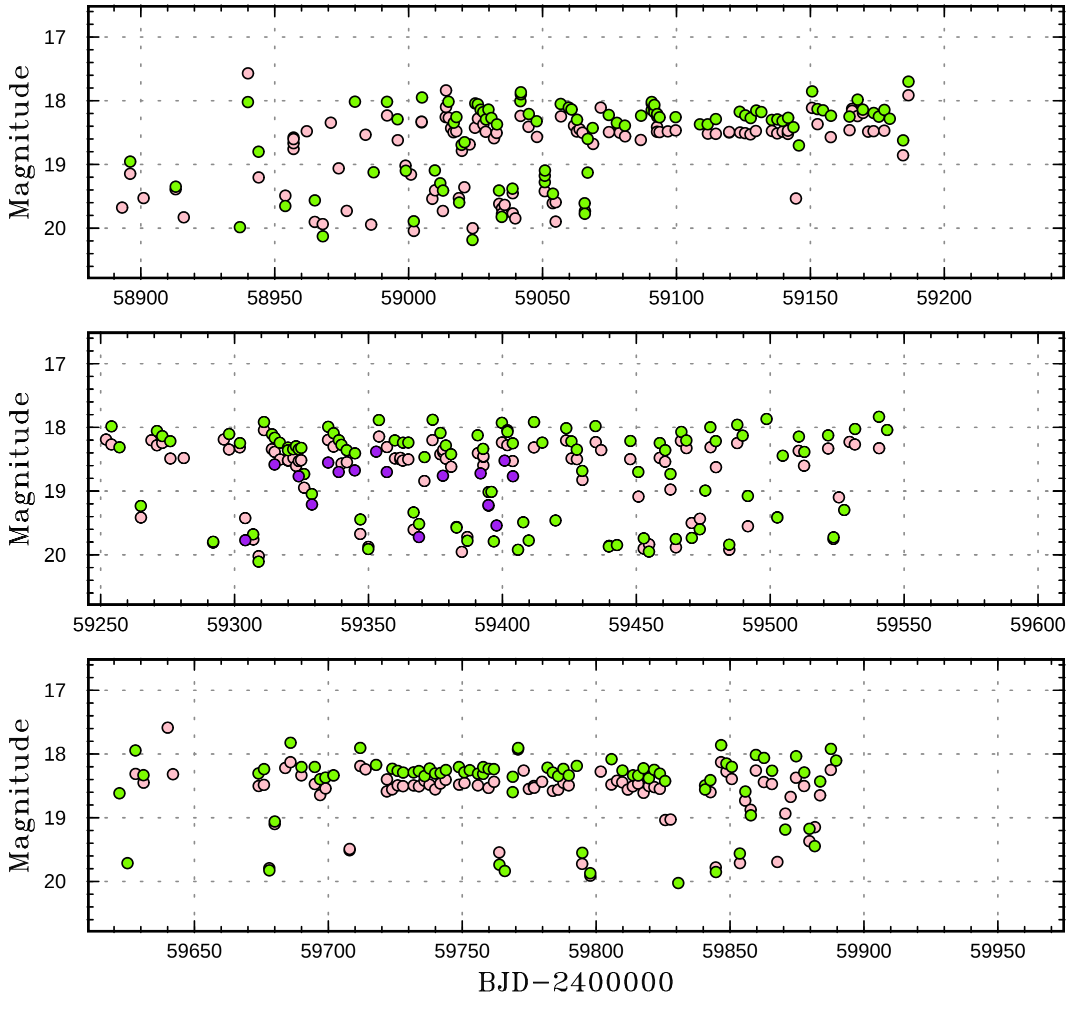

Figure 2: Light curve of MGAB-V240 in 2020–2022. The symbols are the same as in figure 1. Standstills were present in addition to outbursts.

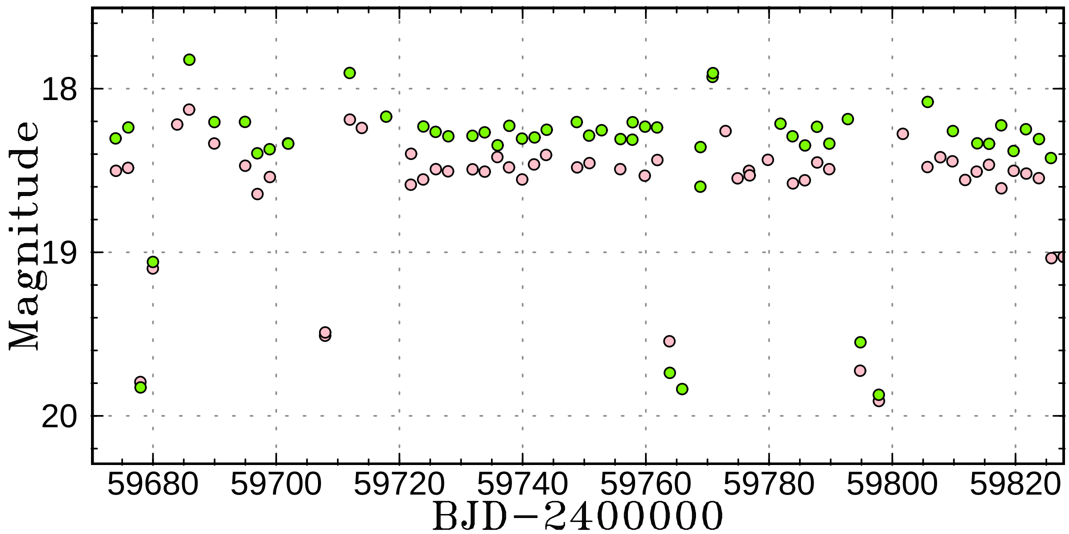

Figure 3: Enlargement of the 2022 standstill of MGAB-V240. The symbols are the same as in figure 1. Sudden drops from the standstill were recorded. The object usually brightened after these drops.

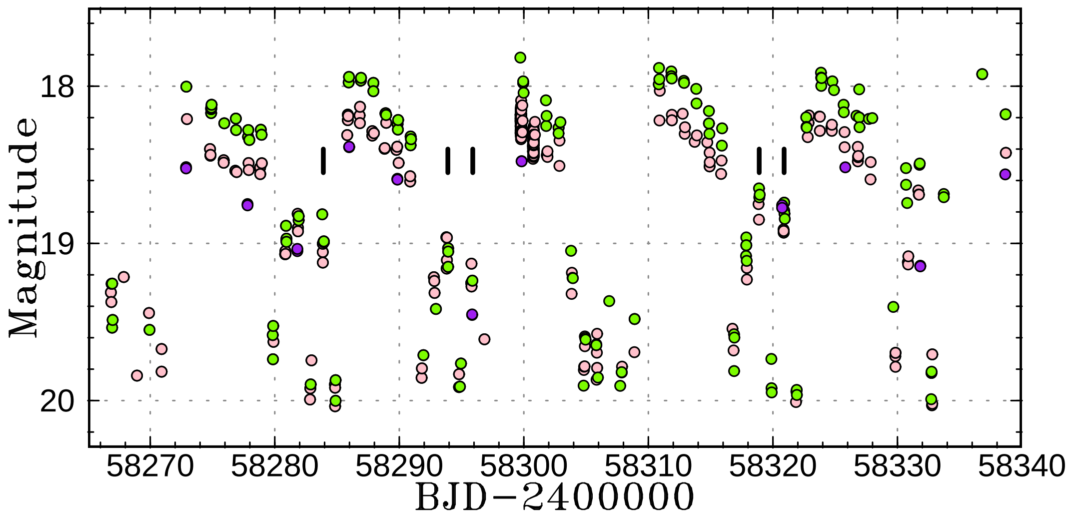

Figure 4: Enlargement of the 2018 outbursts of MGAB-V240. The symbols are the same as in figure 1. In addition to relatively regular long outbursts, short outbursts (with tick marks) were also present. Some outbursts between the long ones apparently had durations more than 1 d and they were not marked by the ticks.

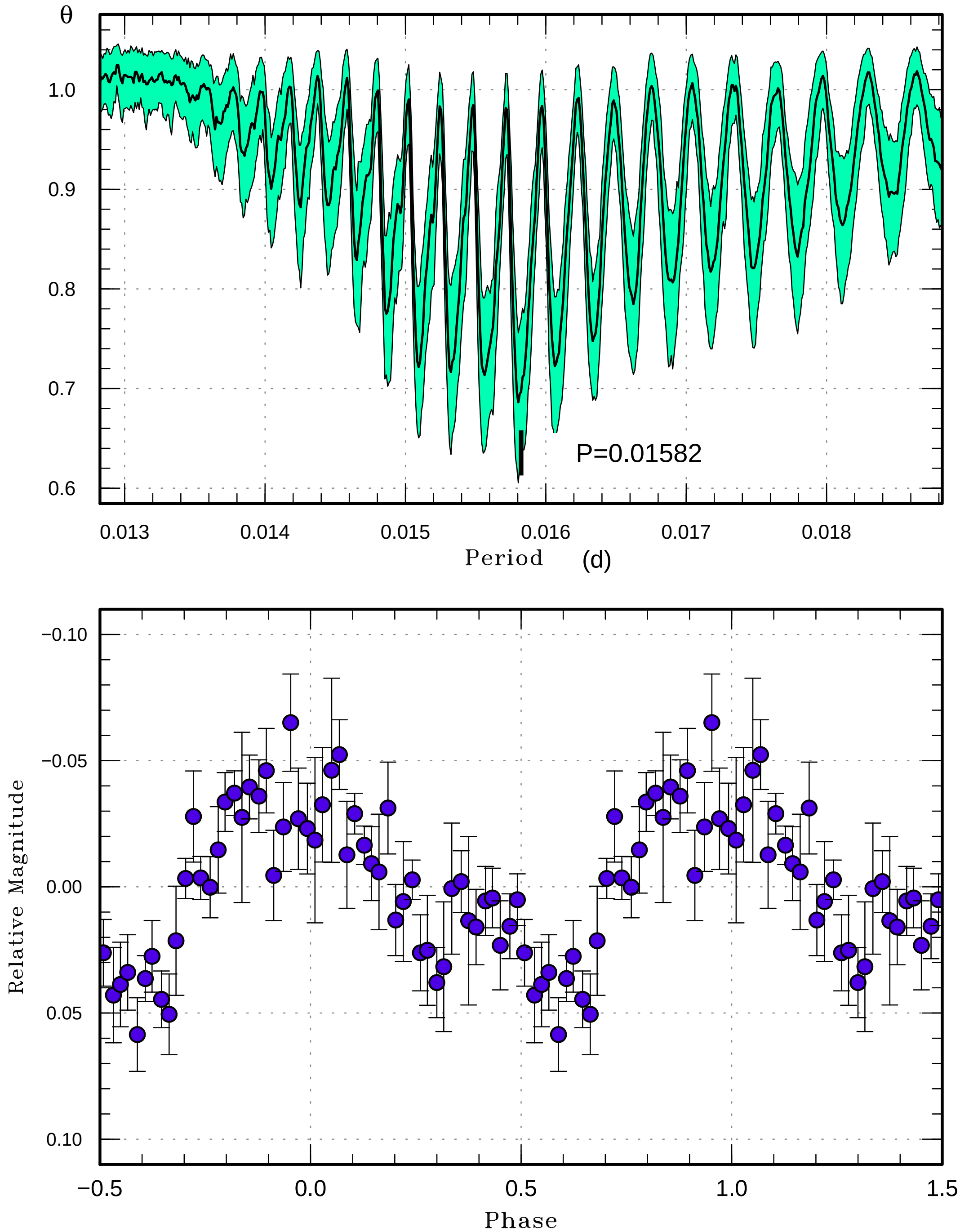

Figure 5: Superhumps on 2018 June 30–July 1 recorded by ZTF time-resolved photometry. (Upper): PDM analysis. The bootstrap result using randomly contain 50% of observations is shown as a form of 90% confidence intervals in the resultant θ statistics. (Lower): Phase plot.

et al. 1997) and the thermally stable novalike-type HP Lib ($P_{\rm orb}$=0.012763 d: Patterson et al. 2002; Roelofs et al. 2007) among AM CVn stars and follows the activity sequence expected by the disk instability theory and the evolutionary sequence of AM CVn stars (Tsugawa and Osaki 1997; Kotko et al. 2012).

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List of objects in this paper

CR Boo, Z Cam, AM CVn, SS Cyg, HP Lib, RZ LMi, SU UMa, ER UMa, ASASSN-14cc, MGAB-V240, PS1-3PI J185529.82+323017.8

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