No.107 Feb. 2023

ISSN 0917-2211

Variable Star Bulletin

Genuine standstill in the AM CVn star CR Boo

Taichi Kato[1] Yutaka Maeda,[2] Masayuki Moriyama[3]

tkato@kusastro.kyoto-u.ac.jp

[1] Department of Astronomy, Kyoto University, Sakyo-ku, Kyoto 606-8502, Japan
[2] VSOLJ, Kaminishiyamamachi 12-2, Nagasaki, Nagasaki 850-0006, Japan
[3] VSOLJ, 290-383, Ogata-cho, Sasebo, Nagasaki 858-0926, Japan

Received 2023 Feb. 09

Abstract

CR Boo is one of the brightest and most famous AM CVn stars showing dwarf nova-type outbursts. Previous studies showed different modes of outbursts in this object ranging from the one equivalent to a hydrogen-rich ER UMa star or WZ Sge star to a low-amplitude oscillating state. We for the first time identified a bona fide standstill in this object in 2022 and we consider that CR Boo is a helium analog of Z Cam stars in addition to its SU UMa/ER UMa-type classification. The standstill lasted for ∼60 d with variations typically less than 0.2 mag and ended with fading. This standstill was not preceded by a superoutburst and was different from a post-superoutburst phenomenon. The brightness after the standstill was similar to those after superoutbursts and the standstill appears to have acted like a superoutburst in effectively accreting the disk mass. The existence of a standstill in an AM CVn star be a challenge to theories of a helium disk or a degenerate secondary to explain how such a state could be maintained.

CR Boo is one of the brightest and most famous AM CVn stars containing a white dwarf and a mass-transferring helium white dwarf [for a review of AM CVn stars, see e.g., Solheim (2010)]. CR Boo has received much attention since this object exhibits dwarf nova-type outbursts [see e.g., Osaki (1996)] and its behavior can provide observational tests for the disk instability theory in helium disks (Tsugawa and Osaki 1997; Solheim 2010; Kotko et al. 2012). CR Boo has been studied by many authors, starting from the identification of large-amplitude variations with a quasi-period of four to five days by Wood et al. (1987). Subsequent research included Wenzel (1994); Patterson et al. (1997); Provencal et al. (1997); Kato et al. (2000, 2001a); Ramsay et al. (2012); Honeycutt et al. (2013); Kato et al. (2013, 2014); Levitan et al. (2015); Isogai et al. (2016); Duffy et al. (2021); Boneva et al. (2022).

We used the All-Sky Automated Survey for Supernovae (ASAS-SN) Sky Patrol data (Shappee et al. 2014; Kochanek et al. 2017) and the Asteroid Terrestrial-impact Last Alert System (ATLAS: Tonry et al. 2018) forced photometry (Shingles et al. 2021) and our snapshot CCD photometry in addition to observations reported to VSOLJ and VSNET (Kato et al. 2004). Y. M. used a 25-cm RC telescope with a Canon EOS Kiss X3 DSLR camera. M. M. used a 25-cm SCT telescope with an SBIG ST-10XME camera.

In figure 1, we show the light curve of CR Boo in the last four seasons. In the first panel (2018–2019 season), CR Boo showed a regular pattern of supercycles resembling an ER UMa star among hydrogen-rich systems (Kato et al. 2000). This is probably a typical state in this object.

In 2019–2020 (second panel of figure 1), the object initially showed a regular pattern as seen in the preceding season, followed by a phase with low-amplitude (∼1.5 mag) frequent outbursts with increasing cycle length toward the end. Such a pattern is more frequently seen in V803 Cen (sometimes considered as the CR Boo “cousin”): see e.g., Duffy et al. (2021) figure 1, although Duffy et al. (2021) apparently did not pay special attention to this phenomenon and was not seen in CR Boo during the interval discussed by Duffy et al. (2021). Although this state may be similar to oscillating state as observed by Patterson et al. (1997) and “standstill” with low-amplitude (∼0.5–1 mag) variations reported in V803 Cen by Kato et al. (2001b), the amplitudes were apparently larger and the long duration of this state suggests a form of quasi-stable state in helium dwarf novae, which may be a variety of quasi-periodic variations reported in Kato et al. (2001a).

In the third panel (2020–2021) of figure 1, the object showed a relatively regular pattern of outbursts with larger amplitudes (up to 2.0 mag) with cycle lengths of 15–20 d. This pattern corresponds to the second supercycle described in Kato et al. (2001a). In the fourth panel (2021–2022), the object initially showed a pattern similar to the 2020–2021 season. The amplitudes decreased and entered a standstill at around BJD 2459710. The standstill lasted for ∼60 d and faded to 17 mag showing short outbursts. This faint state lasted for ∼20 d.

The details of the standstill in 2022 is shown in figure 2. The object was essentially almost constant within 0.2 mag during the standstill, as best shown by the ASAS-SN g and ATLAS o data. Based on the constancy of the brightness for a long time (∼60 d), we identified this phenomenon to be a true standstill in this system. Such a phenomenon was never reported in this system (Patterson et al. 1997; Honeycutt et al. 2013; Levitan et al. 2015; Duffy et al. 2021), and probably none in other helium dwarf novae (Levitan et al. 2015; Duffy et al. 2021). In figure 1 of Levitan et al. (2015), V803 Cen possibly showed a similar state around JD 2454500–2456700 but only with a small number of measurements. The data by ASAS-3 (Pojmański 2002) and VSNET observations (mainly by Rod Stubbings) of the corresponding interval could not confirm the constancy and we consider that this was unlikely a true standstill.

There was some hint of a standstill-like phenomenon in CR Boo following a superoutburst and subsequent dips (figure 3 in Duffy et al. 2021). The same feature was observed in some superoutbursts of V803 Cen (initial part of V803 Cen shown in figure 1 of Duffy et al. 2021). This feature was first discovered during observing campaigns run by VSNET (PI: K. Isogai) in 2016 and 2017 (the main observers were Berto Monard, Josch Hambsch, Peter Starr and Gordon Myers), see e.g., vsnet-alert 19830[1] and 19855[2]. This feature is similar to damping oscillations seen in some hydrogen-rich WZ Sge-type dwarf novae following a superoutburst: ASASSN-15po (Namekata et al. 2017) and PQ And (Tampo et al. 2021). These phenomena in V803 Cen and hydrogen-rich WZ Sge-type dwarf novae have much shorter (less than ∼10 d) durations and were preceded by a superoutburst, and they are usually considered as a part of the rebrightening phenomenon of WZ Sge stars (see Kato 2015). The 2022 standstill of CR Boo had a much longer duration and was not preceded by a superoutburst and is different from a part of the rebrightening phenomenon. We therefore consider that CR Boo is a helium Z Cam star [for classification of cataclysmic variables, see Warner (1995)]. As in many hydrogen-rich Z Cam stars, the standstill ended with fading. The brightness after the standstill was similar to those after superoutbursts [see also Isogai et al. (2016) for a study of a typical superoutburst]. The standstill in CR Boo may have had an effect similar to a superoutburst on the disk – sweeping out a significant fraction of the mass stored in the disk as in (hydrogen-rich) SU UMa-type superoutbursts (Osaki 1989). Although the presence of superhumps was unfortunately not confirmed during this standstill, they were likely present considering the low mass ratio of this system, and the effective removal of the angular momentum by tidal instability may have worked just as in an SU UMa-type superoutburst.

The existence of a standstill in itself may not be surprising for an object near the thermal stability (Tsugawa and Osaki 1997; Kotko et al. 2012). In hydrogen-rich Z Cam stars, a subtle change in the mass transfer is considered to responsible for standstills (Meyer and Meyer-Hofmeister 1983). Whether this is also the case in helium dwarf novae requires further investigation, and, if it is the case, it would be an interesting question how a degenerate helium white dwarf (without a solar-type magnetic cycle as expected for secondaries in hydrogen-rich Z Cam stars) can produce such a variation in mass transfer. If it is not the case, it would be an interesting question how the disk can produce various states without variation in the mass transfer from the secondary.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 21K03616.

We are grateful to the ATLAS, ASAS-SN and ASAS-3 teams for making their data available to the public. We are also grateful to observers (particularly Masao Funada and Gary Poyner) who provided data of CR Boo in 2018–2022, and observers who contributed to campaigns of V803 Cen (particularly Berto Monard, Josch Hambsch, Peter Starr, Gordon Myers and Rod Stubbings).

This work has made use of data from the Asteroid Terrestrial-impact Last Alert System (ATLAS) project. The Asteroid Terrestrial-impact Last Alert System (ATLAS) project is primarily funded to search for near earth asteroids through NASA grants NN12AR55G, 80NSSC18K0284, and 80NSSC18K1575; byproducts of the NEO

[1]<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/19830>.
[2]<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/19855>.

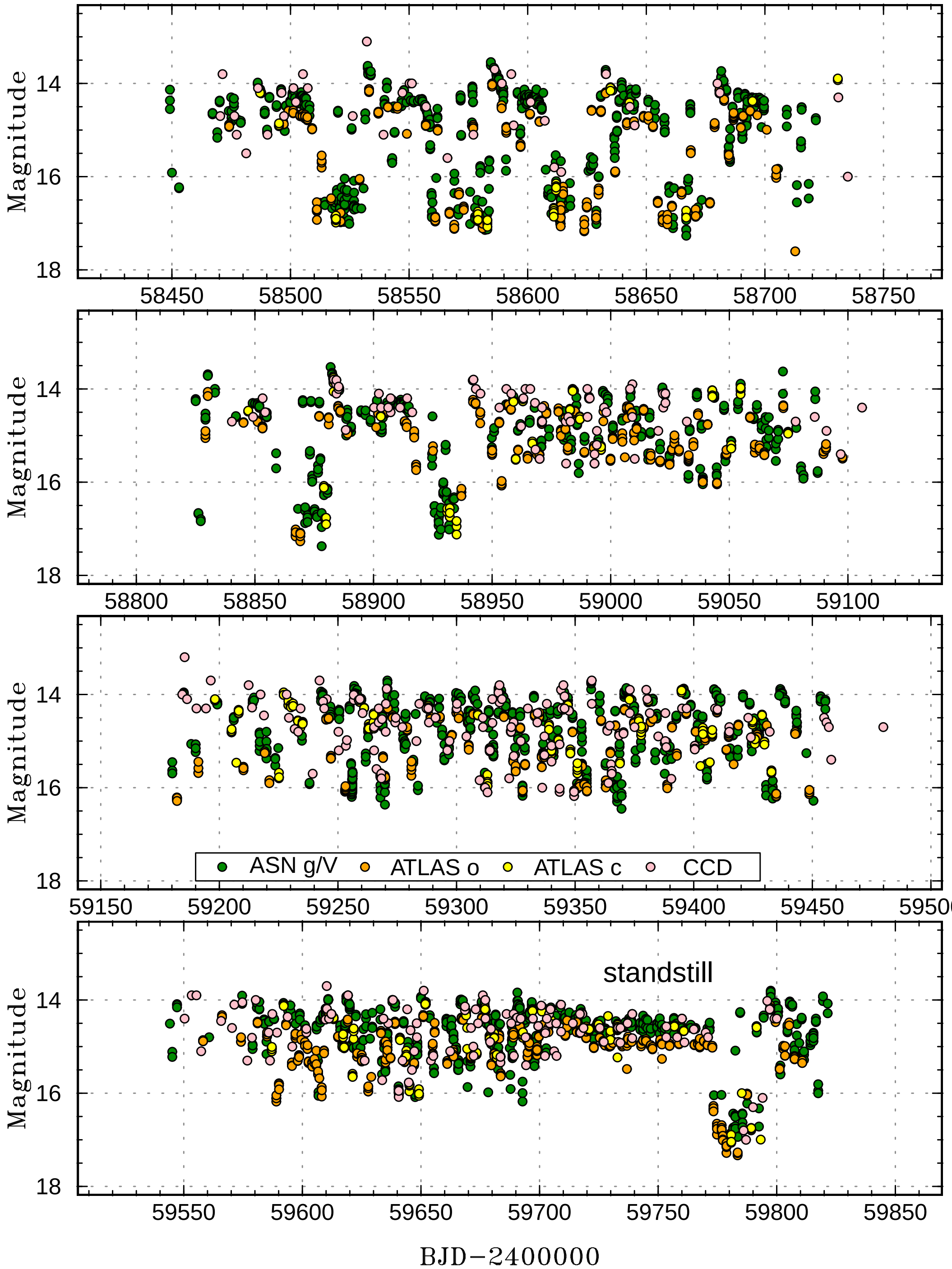

Figure 1: Light curve of CR Boo in 2018–2022. ASAS-SN (ASN) g and (V, only one night in the initial part) were combined together with V observations reported to VSOLJ and VSNET (five observations). The category CCD includes unfileted snapshot CCD observations mainly by Y.M. and M.M. In the first panel (2018–2019 season), CR Boo showed a regular pattern of supercycles resembling an ER UMa star among hydrogen-rich systems (Kato et al. 2000). In the second panel (2019–2020), the object initially showed a regular pattern as seen in the preceding season, followed by a phase with low-amplitude (∼1.5 mag) frequent outbursts with increasing cycle length toward the end. In the third panel (2020–2021), the object showed a relatively regular pattern of outbursts with larger amplitudes (up to 2.0 mag) with cycle lengths of 15–20 d. This pattern corresponds to the second supercycle described in Kato et al. (2001a). In the fourth panel (2021–2022), the object initially showed a pattern similar to the 2020–2021 season. The amplitudes decreased and entered a standstill at around BJD 2459710. The standstill lasted for ∼60 d and faded to 17 mag showing short outbursts. This faint state lasted for ∼20 d.

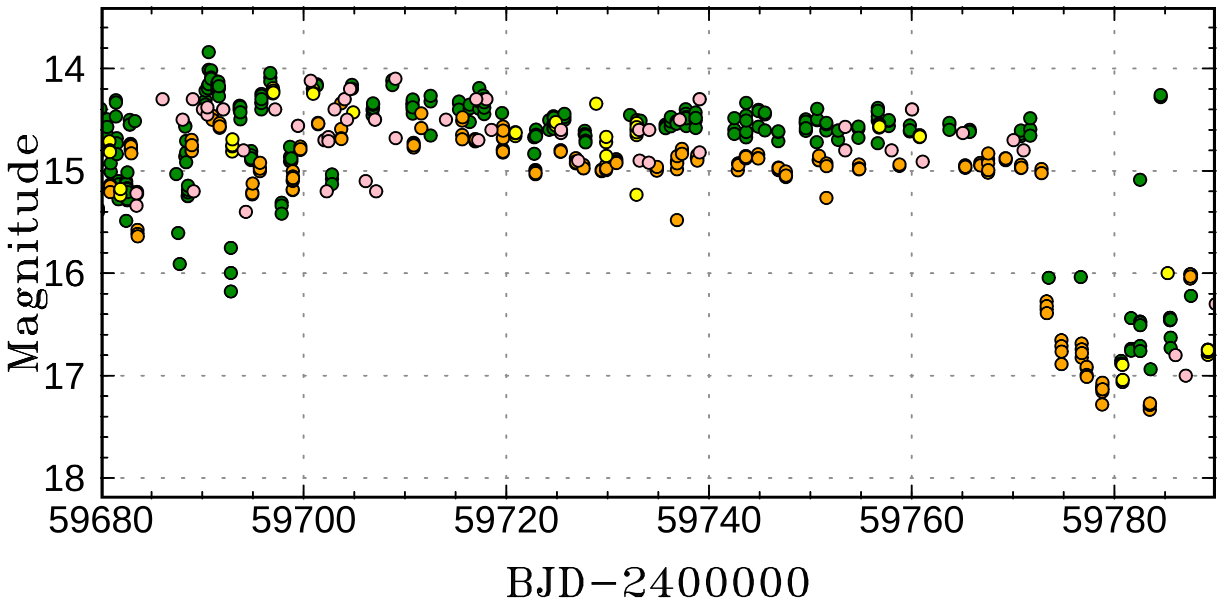

Figure 2: Enlargement of the light curve including the 2022 standstill. The symbols are the same as in figure 1. The object was essentially almost constant within 0.2 mag during the standstill starting from around BJD 2459710, as best shown by the ASAS-SN g and ATLAS o data.

search include images and catalogs from the survey area. This work was partially funded by Kepler/K2 grant J1944/80NSSC19K0112 and HST GO-15889, and STFC grants ST/T000198/1 and ST/S006109/1. The ATLAS science products have been made possible through the contributions of the University of Hawaii Institute for Astronomy, the Queen's University Belfast, the Space Telescope Science Institute, the South African Astronomical Observatory, and The Millennium Institute of Astrophysics (MAS), Chile.

List of objects in this paper

PQ And, CR Boo, Z Cam, V803 Cen, AM CVn, WZ Sge, SU UMa, ER UMa, ASASSN-15po

References

Boneva, D., Zamanov, R., Boeva, S., Latev, G., Nikolov, Y., Cvetković, Z., & Dimitrov, W. (2022) Recent observations of humps and superhumps and an estimation of outburst parameters of the AM CVn star CR Boo. *Ap&SS* **367**, 110

Duffy, C. et al. (2021) Evidence that short-period AM CVn systems are diverse in outburst behaviour. *MNRAS* **502**, 4953

Honeycutt, R. K., Adams, B. R., Turner, G. W., Robertson, J. W., Ost, E. M., & Maxwell, J. E. (2013) Light curve of CR Bootis 1990–2012 from the Indiana long-term monitoring program. *PASP* **125**, 126

Isogai, K. et al. (2016) Superoutburst of CR Bootis: Estimation of mass ratio of a typical AM CVn star by stage A superhumps. *PASJ* **68**, 64

Kato, T. (2015) WZ Sge-type dwarf novae. *PASJ* **67**, 108

Kato, T. et al. (2013) 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. (2014) Survey of period variations of superhumps in SU UMa-type dwarf novae. V: The fifth year (2012–2013). *PASJ* **66**, 30

Kato, T., Nogami, D., Baba, H., Hanson, G., & Poyner, G. (2000) CR Boo: the ‘helium ER UMa star’ with a 46.3-d supercycle. *MNRAS* **315**, 140

Kato, T. et al. (2001a) The second supercycle of the helium ER UMa star, CR Boo. *IBVS* **5120**, 1

Kato, T., Stubbings, R., Monard, B., Pearce, A., & Nelson, P. (2001b) Standstill of the helium ER UMa star, V803 Cen. *IBVS* **5091**, 1

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

Kochanek, C. S. et al. (2017) The All-Sky Automated Survey for Supernovae (ASAS-SN) light curve server v1.0. *PASP* **129**, 104502

Kotko, I., Lasota, J.-P., Dubus, G., & Hameury, J.-M. (2012) Models of AM Canum Venaticorum star outbursts. *A&A* **544**, A13

Levitan, D., Groot, P. J., Prince, T. A., Kulkarni, S. R., Laher, R., Ofek, E. O., Sesar, B., & Surace, J. (2015) Long-term photometric behaviour of outbursting AM CVn systems. *MNRAS* **446**, 391

Meyer, F., & Meyer-Hofmeister, E. (1983) A model for the standstill of the Z Camelopardalis variables. *A&A* **121**, 29

Namekata, K. et al. (2017) Superoutburst of WZ Sge-type dwarf nova below the period minimum: ASASSN-15po. *PASJ* **69**, 2

Osaki, Y. (1989) A model for the superoutburst phenomenon of SU Ursae Majoris stars. *PASJ* **41**, 1005

Osaki, Y. (1996) Dwarf-nova outbursts. *PASP* **108**, 39

Patterson, J. et al. (1997) Superhumps in cataclysmic binaries. XII. CR Bootis, a helium dwarf nova. *PASP* **109**, 1100

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

Provencal, J. L. et al. (1997) Whole Earth Telescope observations of the helium interacting binary PG 1346+082 (CR Bootis). *ApJ* **480**, 383

Ramsay, G., Barclay, T., Steeghs, D., Wheatley, P. J., Hakala, P., Kotko, I., & Rosen, S. (2012) The long-term optical behaviour of helium-accreting AM CVn binaries. *MNRAS* **419**, 2836

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

Shingles, L. et al. (2021) Release of the ATLAS Forced Photometry server for public use. *Transient Name Server AstroNote* **7**, 1

Solheim, J. (2010) AM CVn stars: Status and challenges. *PASP* **122**, 1133

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

Tonry, J. L. et al. (2018) ATLAS: A High-cadence All-sky Survey System. *PASP* **130**, 064505

Tsugawa, M., & Osaki, Y. (1997) Disk instability model for the AM Canum Venaticorum stars. *PASJ* **49**, 75

Warner, B. (1995) Cataclysmic Variable Stars (Cambridge: Cambridge University Press)

Wenzel, W. (1994) Note on the long-term photometric behaviour of the helium white dwarf binary CR Boo. *Mitteil. Veränderl. Sterne* **12**, 180

Wood, M. A., Winget, D. E., Nather, R. E., Hessman, F. V., Liebert, J., Kurtz, D. W., Wesemael, F., & Wegner, G. (1987) The exotic helium variable PG 1346+082. *ApJ* **313**, 757

VSOLJ
c/o Keiichi Saijo National Science Museum, Ueno-Park, Tokyo Japan

Editor Seiichiro Kiyota
e-mail:skiyotax@gmail.com