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SU UMa-type supercycle in the IW And-type dwarf nova BO Cet above the period gap

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Abstract

BO Cet is renowned cataclysmic variable having an orbital period above the period gap (0.139835 d) and showing both features of a Z Cam/IW And star and an SU UMa star. Using the Asteroid Terrestrial-impact Last Alert System (ATLAS) forced photometry and the All-Sky Automated Survey for Supernovae (ASAS-SN) Sky Patrol data, I found that BO Cet underwent a superoutburst in 2022 October–November after a series of short, normal outbursts with increasing amplitudes. This sequence of outbursts (supercycle) is what is seen in many SU UMa stars and this observation strengthened the suggestion that the accumulating mass and angular momentum in the disk during repeated normal outbursts caused a superoutburst even in the unusual system BO Cet. The outburst just preceding the superoutburst bore characteristics of an IW And-type standstill. This phenomenon reinforces the suggestion that the terminal outburst in IW And stars occurs when the disk radius reaches a certain limit. I consider that this outburst was a failed superoutburst, during which the disk reached the radius of the 3:1 resonance but the outburst faded before superhumps developed. In BO Cet with a mass ratio on the borderline of the stability of the 3:1 resonance, there may have been a competition between the effects of tidal truncation and the 3:1 resonance as the disk radius grew and the latter won in the current case. This finding in BO Cet might suggest that IW And-type and SU UMa-type phenomena are more strongly physically related than have been thought.

1 Introduction

Major categories of cataclysmic variables (CVs) include novalike (NL) variables and dwarf novae (DNe). In NL-type variables, the accretion disk is thermally stable due to the high mass-transfer rate from the secondary. In DNe, the disk is thermally unstable and shows outbursts. [For general information of CVs, see e.g., Warner (1995)]. DNe are subdivided (mainly) into SS Cyg stars, Z Cam stars and SU UMa stars. Z Cam stars show standstills (equivalent to NL-type thermally stable states) and SU UMa stars show superoutbursts in addition to ordinary outbursts in SS Cyg stars. During superoutbursts, superhumps with periods a few percent longer than the orbital periods are observed, and they are considered as the defining characteristics of SU UMa stars (see e.g., Osaki 1996). These superhumps are considered to be the result of the 3:1 resonance in the disk (Whitehurst 1988; Hirose and Osaki 1990; Lubow 1991). Only systems with relatively small mass ratios ($q = M_2/M_1$) are considered to hold a large disk reaching the radius of the 3:1 resonance and this is considered to determine whether a certain system can show an SU UMa-type phenomenon. The borderline of q for SU UMa stars is usually considered somewhere between 0.25 (Whitehurst 1988) and 0.33 (Murray et al. 2000).

Recently, some of Z Cam stars are known to show atypical behavior (see also Hameury and Lasota 2014), often characterized by (1) slowly rising standstills, sometimes with damping oscillations, are terminated by brightening, (2) the sequence is often very regular with almost a constant recurrence time and (3) deep dips are sometimes seen following brightening (Kato 2019). These objects are called IW And stars [Note that not all items are always seen in all IW And stars. The item (1) can be considered as the defining characteristic]. There is a suggestion that the IW And-type phenomenon is a manifestation of a limit cycle reflecting the increase of the angular momentum of the disk during a sequence of small outbursts in the outer part of the disk (Kimura et al. 2020a,b). This picture is very similar to SU UMa stars having two types of cycles (outburst cycle and supercycle) (Osaki 1989, 1996) and led to a suggestion that tidal truncation might work in IW And stars just as the 3:1 resonance works in SU UMa stars [subsection 4.1 in Kimura et al. (2020a) and Kato et al. (2021)].

BO Cet is the first object showing both characteristics of SU UMa stars and Z Cam/IW And stars (Kato et al. 2021) [currently two more (but much fainter) objects are known: MGAB-V349 (vsnet-alert 26832)[1] and ZTF J181732.64+101954.5 (vsnet-alert 26776)[2]] and this object is expected to provide a clue in understanding the relation between these two classes of DNe.

2 BO Cet

BO Cet was initially discovered as a NL-type CV by R. Remillard (1992) but no details were published. The CV nature was confirmed by Rodríguez-Gil et al. (2007). The orbital period was initially detected by the members of the Center for Backyard Astrophysics.[3] and was refined by Bruch (2017), placing BO Cet above the period gap, which appeared to be consistent with the NL-type classification.

This object, however, was confirmed to be a dwarf nova by Kato et al. (2021). Using the data by the VSNET Collaboration (Kato et al. 2004), Kato et al. (2021) clarified that the object is an eclipsing object with an orbital period of 0.139835 d. Furthermore, Kato et al. (2021) showed that the object also showed IW And-type standstills. The most unexpected finding by Kato et al. (2021) was that BO Cet showed superhumps during one of its long outburst. Superhumps had a period 7.8% longer than the orbital period leading to an estimation of the mass ratio of q=0.31–0.34. Superhumps during a long outburst defines the SU UMa-type dwarf nova and it was very unusual that an object far above the period gap showed the SU UMa-type phenomenon (but not unprecedented). It was considered that q of BO Cet is very close to the upper limit of q in which the disk can reach the radius of the 3:1 resonance. BO Cet could have accidentally reached this radius, since there had been no such a phenomenon recorded in this object despite past observations for more than 10 years, and this might implicitly suggest such a superoutburst should be rare. This suggestion, however, was disproven only two years later.

3 Observations and Analysis

Using 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), I noticed that BO Cet gradually brightened following a bright outburst in 2022 June. During this brightening phase, small outbursts with increasing amplitudes were recorded (figure 1 lower panel: BJD 2459765–2459850). The object stopped fading and brightened (BJD 2459850–2459861) just like an IW And-type standstill. After reaching a minimum around BJD 2458871, this object underwent a long, bright outburst (figures 1, 2).

During this long outburst, the increasing scatter in the light curve was suggestive of developing superhumps (figure 2). A phase dispersion minimization (PDM; Stellingwerf 1978) analysis indeed detected a strong superhump signal (figure 3). I used the methods of Fernie (1989) and Kato et al. (2010) to determine 1σ errors. The resultant period of 0.1496(6) d is in good agreement with the value 0.15069(3) d obtained during the 2020 superoutburst (Kato et al. 2021). No significant superhump signal was detected after BJD 2459888. This was probably due to the decrease in the amplitude of superhumps and the limited number of observations (10 per day or even less). If a time-resolved photometric campaign had been conducted, the superhump signal may have been detected for a longer time.

[1]<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/26832>.
[2]<http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/26776>.
[3]J. Patterson in 2002, <http://cbastro.org/communications/news/messages/0274.html>.

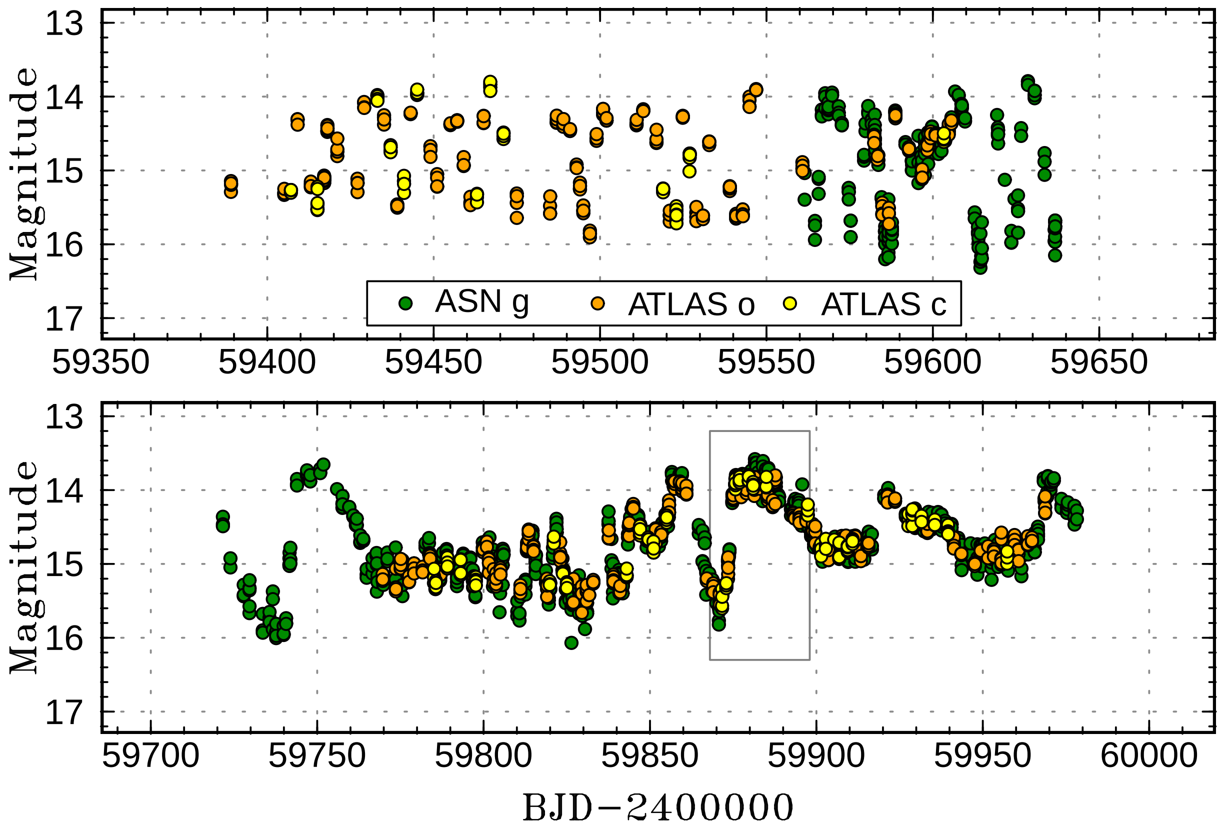

Figure 1: Light curve of BO Cet in 2021–2023. ASAS-SN (ASN) and ATLAS observations are used. In the upper panel, an IW And-type standstill (terminal brightening with sudden fading) was recorded (BJD 2459593–2459610, 2022 January). In the lower panel, an SU UMa-like supercycle was recorded between BJD 2459744 and 2459890: following a long, bright outburst, a sequence of short repeated outbursts with increasing amplitudes led to a long, bright outburst. The long, bright outburst starting on BJD 2459875 was confirmed to be a superoutburst (enlargement of the grey box in figure 2).

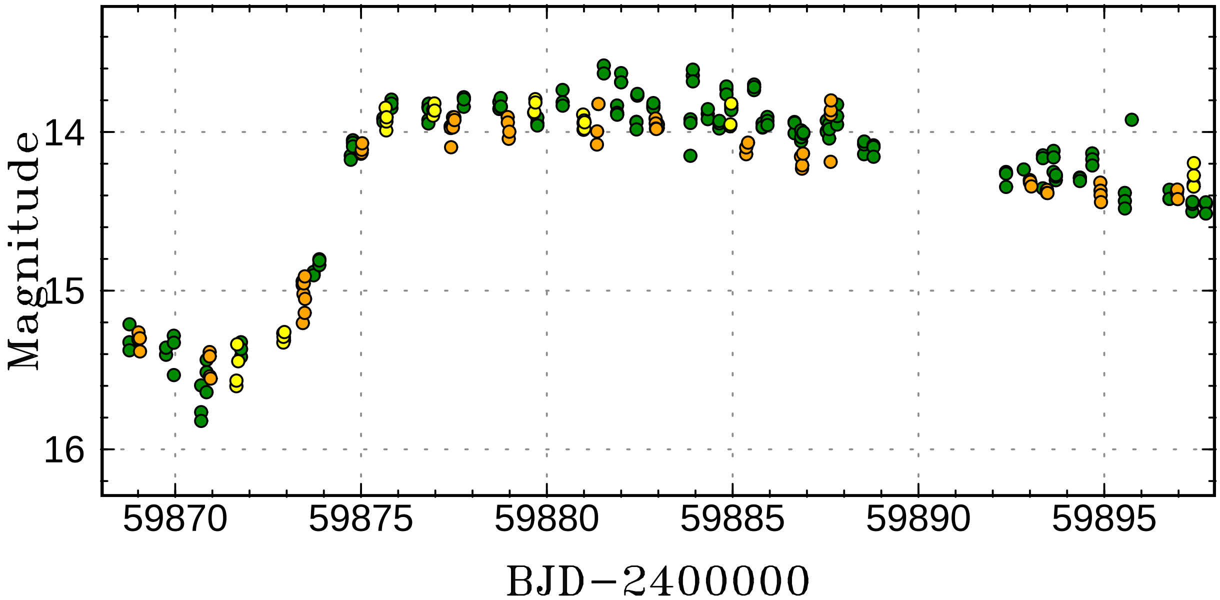

Figure 2: Enlargement of the light curve of the 2022 superoutburst. The symbols are the same as in figure 1. The scatter in the middle part of the light curve indicates superhumps.

4 Discussion

4.1 Supercycle

This observation for the first time detected a typical supercycle for an SU UMa star in BO Cet: repeated short normal outbursts with increasing amplitudes between two long outbursts. The second long outburst was confirmed to be a superoutburst. Although the nature of the first long outburst was unknown due to the lack of observations, it could also have been a superoutburst as seen from the shape similar to the second one. Although the presence of a supercycle is not surprising for an SU UMa star, it was not evident in 2020 when the first superoutburst was detected. This observation strongly supports the idea that the accumulating mass and angular momentum in the disk during repeated normal outbursts caused the disk to expand to the radius of the 3:1 resonance (Osaki 1989, 1996).

4.2 Relation to IW And-type phenomenon

As shown in section 3, the final outburst before the superoutburst had characteristics similar to an IW And-type standstill. This finding supports the interpretation that terminal brightening of an IW And-type standstill occurs when the disk radius reaches a certain upper limit (Kimura et al. 2020a; Kato et al. 2021), possibly the radius of tidal truncation.

The 2022 phenomenon of BO Cet was different from an IW And-type standstill in that it showed increasing amplitudes of dwarf-nova outbursts while damping oscillations are seen in IW And stars. This difference may have been due to the difference in the initial condition when the cycle started following a long outburst: in 2022, the cycle started when the cool region in the disk in BO Cet was larger than in the IW And state (at the start of the cycle, BO Cet was 0.5 mag fainter than average standstills of the same object).

4.3 Failed superoutburst?

As seen in several SU UMa stars (usually with long orbital periods) near the stability border of the 3:1 resonance, an outburst just preceding a superoutburst tends to be long and bright. Such an outburst is possibly a failed superoutburst, in which the duration of the outburst is not long enough for the 3:1 resonance to develop despite that the radius already reaches the radius of the 3:1 resonance. The case in BO Cet in 2022 might be the same. This final outburst also corresponded to IW And-type terminal brightening. In a case in which the radii of the

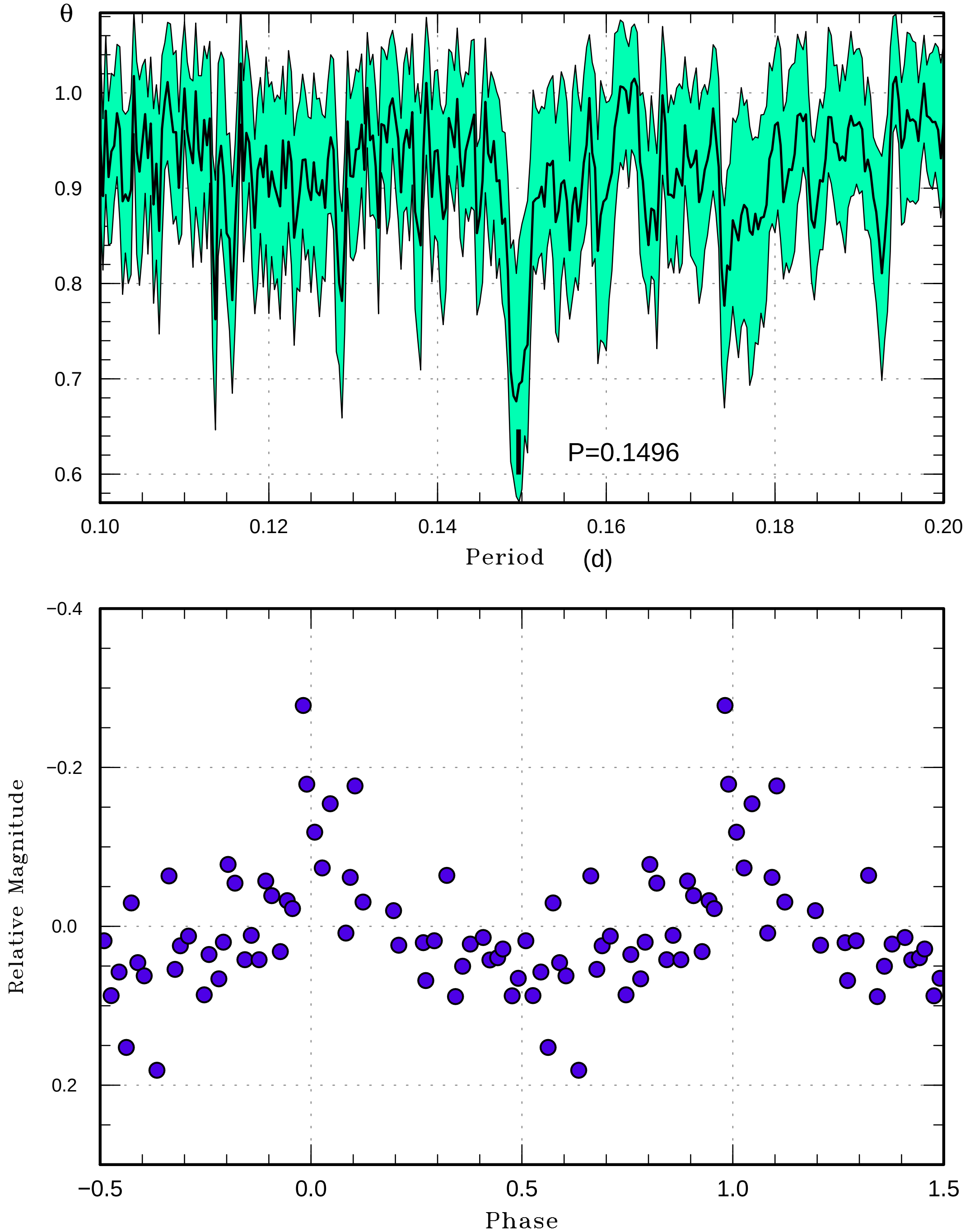

Figure 3: Superhumps of BO Cet in 2022 (interval BJD 2459876.8–2459887.9). (Upper): PDM analysis. The bootstrap result using randomly contain 50% of observations is shown as a form of 90% confidence intervals in the resultant θ statistics. (Lower): Phase plot.

3:1 resonance and tidal truncation are very close, as suggested in BO Cet (Kato et al. 2021), both effects – tidal truncation and the 3:1 resonance might work at the same time. If the 3:1 resonance is strong enough and wins the competition, it may develop and eventually cause a superoutburst. If this fails, the behavior would look like an ordinary IW And phenomenon. Although this is not beyond speculation, further observations and theoretical studies are needed keeping this possibility in mind.

4.4 Suggested observations

This 2022 very unexpected phenomenon was not detected in real time, but was found during an inspection of public archives. This was primarily due to the lack of regular monitoring and reporting of this object to VSOLJ or VSNET despite its brightness (14–15 mag), well withing reach of many amateur instruments. This probably came from the old impression of BO Cet – an NL-type star with little variation and a dull target for nightly monitoring. This star never gained popularity during the history of VSNET: only sporadic observations were reported by observers who are mainly interested in NL-type stars. Please remember that the behavior of BO Cet completely changed after 2019 and it should deserve more regular attention as for other dwarf novae already on visual/CCD observers' menus. Such a change in state in a CV may be a transient one and may not easily be reproduced, just as we have seen in the case of BK Lyn, which had been known as an NL star but showed a transient ER UMa-type state (Kemp et al. 2012; Patterson et al. 2013; Kato et al. 2013, 2014). This ER UMa-type state (probably had lasted for a decade) in BK Lyn ended in 2013 and has not repeated again.

Due to the long orbital period (compared to typical SU UMa stars), occasional observations to search for superhumps may not be very attracting since it requires relatively long time. If your telescope can point the object quickly, several snapshots per night would be helpful since a small number of nightly observations by ATLAS and ASAS-SN detected superhumps, a more organized observations should obtain a better result. More intensive time-resolved photometry sessions will clarify the presence or absence of superhumps during particular outburst – when the object is brighter than 14.0 mag, the result would be promising.

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List of objects in this paper

IW And, Z Cam, BO Cet, SS Cyg, BK Lyn, SU UMa, MGAB-V349, ZTF J181732.64+101954.5

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