BC Cassiopeiae: First Detection of IW And-Type Phenomenon Among Post-Eruption Novae

Taichi Kato,¹ Naoto Kojiguchi¹

¹ Department of Astronomy, Kyoto University, Kyoto 606-8502, Japan

E-mail: *tkato@kusastro.kyoto-u.ac.jp

Received 2010; Accepted 2010

Abstract

IW And-type dwarf novae are recently recognized group of cataclysmic variables which are characterized by a sequence of brightening from a standstill-like phase with damping oscillations often followed by a deep dip. We found that the supposed classical nova BC Cas which erupted in 1929 experienced a state of an IW And-type dwarf nova in 2018, 89 yr after the eruption. This finding suggests that high mass-transfer rate following the nova eruption is associated with the IW And-type phenomenon. The mass of the white dwarf inferred from the decline rate of the nova is considerably higher than the average mass of the white dwarfs in cataclysmic variables and the massive white dwarfs may be responsible for the manifestation of the IW And-type phenomenon.

Key words: accretion, accretion disks — stars: novae, cataclysmic variables — stars: dwarf novae — stars: individual (BC Cassiopeiae)

1 Introduction

Cataclysmic variables (CVs) are composed of a white dwarf and a mass-transferring secondary. The transferred matter forms an accretion disk around the white dwarf, and in some cases, the accreted matter on the surface of the white dwarf causes thermonuclear runaway, which is observed as a nova. Dwarf novae (DNe) are a class of CVs, which show outbursts resulting from instabilities in the accretion disk [for general information of CVs, novae and DNe see e.g. Warner (1995)].

One of the long-standing questions about the relation between novae and DNe is whether novae between eruptions become detached systems (and hence not observed as CVs) or become DNe. This possibility was highlighted by Patterson (1984) after a comparison of the space densities of novae and known CVs, and Patterson (1984) suggested that there are “dead” novae ~100 times of CVs. Shara et al. (1986) extended this discussion and suggested the “hibernation” scenario by assuming that the mass-transfer stops following angular momentum loss during a nova eruption resulting in the binary to be detached.

The relationship between novae and DNe have only recently directly confirmed by observations: discoveries of remnant nova shells around the DNe Z Cam (Shara et al. 2007) and AT Cnc (Shara et al. 2012), DN in AD 483 nova shell Te 11 (Miszalski et al. 2016), DN state before a nova eruption (Mróz et al. 2016) and DN in AD 1437 nova shell (Shara et al. 2017).

Quite recently, a nova eruption was recorded from the previously known DN V392 Per by Y. Nakamura in 2018¹. These observations indicate that at least some novae erupt from DNe and some very old (≥1000 yr old) novae become DNe.

In this paper, we report on the discovery of the DN state of a recently recognized type with unusual characteristics in the supposed classical nova BC Cas which erupted in 1929.

¹ <http://www.cbat.eps.harvard.edu/unconf/followups/J04432130+4721280.html>.
2 BC Cassiopeiae

BC Cas was originally discovered as a long-period variable by Beljawsky (1931) on 1929 Simeis plates. Duerbeck (1984a) studied Harvard plates and presented a light curve. The maximum brightness was 10.7 mag (photographic) on 1929 August 1. The object was not detected 14 d before. Since the outburst amplitude was small and since an old “nova” (HVVir, 1929) similarly recognized by the same author (Duerbeck 1984b) turned out to be a large-amplitude DN (Leibowitz et al. 1994; Kato et al. 2001), BC Cas was suspected to be a candidate large-amplitude DN and a search for a further outburst was conducted [see a remark in Kato et al. (2001)]. This situation continued until Ringwald et al. (1996) published a spectrum. The spectrum showed relatively weak Hα emission and a red continuum, which preferred a modified α model spectrum. The spectrum showed relatively weak Hα emission and a red continuum, which preferred a modified α model spectrum. Since an old “nova” (HV Vir, 1929) similarly recognized by the same author (Duerbeck 1984b) turned out to be a large-amplitude DN (Leibowitz et al. 1994; Kato et al. 2001), BC Cas was suspected to be a candidate large-amplitude DN and a search for a further outburst was conducted [see a remark in Kato et al. (2001)]. This situation continued until Ringwald et al. (1996) published a spectrum. The spectrum showed relatively weak Hα emission and a red continuum, which preferred a modified α model spectrum.

4 Discussion

4.1 Post-eruption BC Cas as an IW And-type dwarf nova

The features of the light curve of BC Cas 89-yr after the (most likely) nova eruption in 1929 described in section 3 very well match the characteristics of IW And-type DNe [see Kato (2019) and references therein], which have been a recently recognized type of DNe. The IW And-type DNe show outbursts starting from (quasi-)standstills and these outbursts are often followed by dips and damping oscillations. These DNe exhibit such outbursts only a fraction of time and such a state is referred to as IW And-type state or phenomenon. The most remarkable feature is that this sequence is often semi-periodically repeated. The semi-regular occurrence of this cycle suggests a yet unidentified type of limit-cycle oscillation (Kato 2019).

BC Cas is the first (supposed) classical nova that experienced the IW And-type state.

The origin of the unusual variations of IW And-type DNe is still poorly known. Szkody et al. (2013) suggested periodic increase of the mass-transfer from the secondary. Kimura et al. (2020b) suggested that the tilted accretion disk could cause a limit-cycle oscillation similar to IW And DNe. The tilted disk, however, has proven not to be a universal explanation for IW And stars by the lack of negative superhumps, a signature of a tilted disk, in many IW And stars [e.g. IM Eri Kato et al. (2020)]. Most recently, a detailed analysis of the Kepler data of KIC 9406652, an IW And DN with prominent negative superhumps, by Kimura et al. (2020a) indicated that neither models of Szkody et al. (2013) and Kimura et al. (2020b) could explain the variation of the disk radius. The cause of the unusual pattern of variation of IW And DNe still remains a mystery.

4.2 Implications on IW And-type dwarf novae

In the hibernation scenario of classical novae, the gradual reduction of the mass-transfer rate $\dot{M}$ from the secondary Shara et al. (1986) enables the accretion disks in post-novae to become thermally unstable to cause DN outbursts. BC Cas showed the IW And-type phenomenon 89 yr after the supposed nova eruption, which is one of the shortest among classical novae to exhibit DN activity (no other classical novae showed this phenomenon in the ZTF data, and the case of BC Cas should be rare). The condition, such as $\dot{M}$, enabling the IW And-type phenomenon is still unknown. Considering that BC Cas showed this phenomenon during the cooling phase after

---

2 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].

3 These objects are also called “anomalous” Z Cam stars (Szkody et al. 2013).
the nova eruption, it is likely that the IW And-type phenomenon in this object was achieved in high-$M$ condition probably close to the border of thermal instability of the accretion disk [see e.g. Warner (1995)]. Whether this is applicable to all IW And-type DNe requires further study in other systems.

According to Duerbeck (1984a), BC Cas was a moderately fast nova with $t_3$ (time required to fade by 3 mag) of 50–75 d. This translates to $t_2$ of 29–44 d using the formula in Hachisu and Kato (2006). It is widely accepted that nova eruptions occurring on heavier white dwarfs have shorter $t_2$ or $t_3$ [see e.g. Hachisu and Kato (2006)]. Using the model grid in Shara et al. (2018), the mass of the white dwarf in BC Cas is expected to be 1.02–1.09$M_\odot$. Zorotovic et al. (2011) obtained an average mass of 0.82(3)$M_\odot$ for white dwarfs in CVs with an intrinsic scatter of white dwarf masses of 0.15$M_\odot$. A more recent study of eclipsing CVs yielded a consistent result (McAllister et al. 2019). The inferred mass of the white dwarf in BC Cas is more than 1r larger than the average white dwarf mass in CVs and it may be that the IW And-type phenomenon associated with the high mass of the white dwarf. This might explain why the IW And-type phenomenon is seen only in limited number of DNe, and why the same object repeatedly shows this phenomenon while others never showed it. Since no reliable estimates of white dwarf masses are available in IW And-type DNe, more effort should be paid to determine orbital parameters of these objects.

Acknowledgments

Based on observations obtained with the Samuel Oschin 48-inch Telescope at the Palomar Observatory as part of the Zwicky Transient Facility project. ZTF is supported by the National Science Foundation under Grant No. AST-1440341 and a collaboration including Caltech, IPAC, the Weizmann Institute for Science, the Oskar Klein Center at Stockholm University, the University of Maryland, the University of Washington, Deutsches Elektronen-Synchrotron and Humboldt University, Los Alamos National Laboratories, the TANGO Consortium of Taiwan, the University of Wisconsin at Milwaukee, and Lawrence Berkeley National Laboratories. Operations are conducted by COO, IPAC, and UW.

The ztfquery code was funded by the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (grant agreement n°759194 – USNAC, PI: Rigault).

Supporting information

Additional supporting information can be found in the online version of this article. Supplementary data is available at PASJ Journal online.

References

Beljawsky, S. 1931, Astron. Nachr., 243, 115
Duerbeck, H. W. 1984a, IBVS, 2490
Duerbeck, H. W. 1984b, IBVS, 2502
Gaia Collaboration, et al. 2018, A&A, 616, A1
Hachisu, I., & Kato, M. 2006, ApJS, 167, 59
Kato, T. 2019, PASJ, 71, 20
Kato, T., Sekine, Y., & Hirata, R. 2001, PASJ, 53, 1191
Kato, T., et al. 2020, PASJ, 72, 11
Kimura, M., Osaki, Y., & Kato, T. 2020a, PASJ, in press
(arXiv:2008.11328)
Kimura, M., Osaki, Y., Kato, T., & Mineshige, S. 2020b, PASJ, 72, 22
Leibowitz, E. M., Mendelson, H., Bruch, A., Duerbeck, H. W.,
Seitter, W. C., & Richter, G. A. 1994, ApJ, 421, 771
Masci, F.-J., et al. 2019, PASP, 131, 018003
McAllister, M., et al. 2019, MNRAS, 486, 5535
Miszalski, B., et al. 2016, MNRAS, 456, 633
Mróz, P., et al. 2016, Nature, 537, 649
Patterson, J. 1984, ApJS, 54, 443
Ringwald, F. A., Naylor, T., & Mukai, K. 1996, MNRAS, 281, 192
Schaefer, B. E. 2018, MNRAS, 481, 3033
Shara, M. M., et al. 2017, Nature, 548, 558
Shara, M. M., Livio, M., Moffat, A. F. J., & Orio, M. 1986, ApJ, 311, 163
Shara, M. M., et al. 2007, Nature, 446, 159
Shara, M. M., Mizusawa, T., Wehinger, P., Zurek, D., Martin, C. D.,
Neill, J. D., Forster, K., & Seibert, M. 2012, ApJ, 758, 121
Shara, M. M., Prialnik, D., Hillman, Y., & Kovetz, A. 2018, ApJ, 860, 110
Szkody, P., et al. 2013, PASP, 125, 1421
Warner, B. 1995, Cataclysmic Variable Stars (Cambridge University Press)
Zorotovic, M., Schreiber, M. R., & Gänsicke, B. T. 2011, A&A, 536, A42