The Astrophysical Journal Letters, 902:L14 (3pp), 2020 October 10 https://doi.org/10.3847/2041-8213/abbb2c


# Increasing Activity in T CrB Suggests Nova Eruption Is Impending

Gerardo J. M. Luna[1,2,3], J. L. Sokoloski[4,5], Koji Mukai[6,7], and N. Paul M. Kuin[8]
[1] CONICET-Universidad de Buenos Aires, Instituto de Astronomía y Fısica del Espacio (IAFE), Av. Inte. Güiraldes 2620, C1428ZAA, Buenos Aires, Argentina; gjmluna@iafe.uba.ar
[2] Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Buenos Aires, Argentina
[3] Universidad Nacional de Hurlingham, Av. Gdor. Vergara 2222, Villa Tesei, Buenos Aires, Argentina
[4] Columbia Astrophysics Lab 550 West 120th Street, 1027 Pupin Hall, MC 5247 Columbia University, New York, NY 10027, USA
[5] LSST Corporation, 933 North Cherry Avenue, Tucson, AZ 85721, USA
[6] CRESST and X-ray Astrophysics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[7] Department of Physics, University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA
[8] Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, Surrey RH5 6NT, UK
*Received 2020 August 10; revised 2020 September 21; accepted 2020 September 23; published 2020 October 8*

## Abstract

Estimates of the accretion rate in symbiotic recurrent novae (RNe) often fall short of theoretical expectations by orders of magnitude. This apparent discrepancy can be resolved if the accumulation of mass by the white dwarf (WD) is highly sporadic, and most observations are performed during low states. Here we use a re-analysis of archival data from the Digital Access to a Sky Century @Harvard survey to argue that the most recent nova eruption in symbiotic RN T CrB, in 1946, occurred during—and was therefore triggered by—a transient accretion high state. Based on similarities in the optical light curve around 1946 and the time of the prior eruption, in 1866, we suggest that the WD in T CrB accumulates most of the fuel needed to ignite the thermonuclear runaways (TNRs) during accretion high states. A natural origin for such states is dwarf-nova like accretion-disk instabilities, which are expected in the presumably large disks in symbiotic binaries. The timing of the TNRs in symbiotic RNe could thus be set by the stability properties of their accretion disks. T CrB is in the midst of an accretion high state like the ones we posit led to the past two nova eruptions. Combined with the approach of the time at which a TNR would be expected based on the 80 yr interval between the prior two novae (2026 ± 3), the current accretion high state increases the likelihood of a TNR occurring in T CrB in the next few years.

*Unified Astronomy Thesaurus concepts:* Recurrent novae (1366); Symbiotic binary stars (1674); Accretion (14)

## 1. Introduction

T Coronae Borealis (T CrB) is the nearest symbiotic recurrent nova (RN); a binary system in which a white dwarf (WD) accretes from its red giant companion through a disk. Twice in the last two centuries, the accreted material ignited on the surface of the WD via runaway thermonuclear fusion reactions and produced a nova eruption. In T CrB, outbursts were recorded in 1866 and 1946, suggesting a recurrence time of ∼80 yr. The distance as determined from Gaia data is $806^{+33}_{-31}$ pc (Bailer-Jones et al. 2018). As in the other symbiotic RNe RS Oph, V745 Sco, and V3890 Sgr, the WD mass is required to be well above 1 $M_{\odot}$ to generate repeated nova eruptions in less than a century, and so T CrB is a candidate supernova Ia progenitor (e.g., Shahbaz et al. 1997; Fekel et al. 2000). Being the nearest known RN, we expect the next eruption of T CrB—predicted to happen between 2023.6 ± 1 (Schaefer 2019) and approximately 2026—to shine strongly from $\gamma$-rays to radio wavelengths, providing detailed information about the mass, structure, energetics, and perhaps driving mechanism of the outflow.

The nova recurrence time is inversely related to the WD mass and the accretion rate. In the case of a system with the parameters of T CrB, $M_{\rm WD}$ of 1.2–1.37 $M_{\odot}$ (Belczynski & Mikolajewska 1998; Stanishev et al. 2004) and recurrence time of about 80 yr, theoretical models by Prialnik & Kovetz (1995) predict that an accumulated mass of $10^{-6}$ $M_{\odot}$ will be needed for a thermonuclear runaway (TNR). Over 80 yr that implies an average accretion rate of between $10^{-8}$ $M_{\odot}$ yr$^{-1}$ and $10^{-7}$ $M_{\odot}$ yr$^{-1}$.

But measuring the accretion rate in symbiotic binaries is a difficult task. Although in cataclysmic variables the optical brightness can be used as a proxy for the accretion rate, in symbiotic stars, where the contribution to the optical broadband light of the nebulae and the red giant are not negligible, optical photometry does not provide an actual measurement of the accretion rate.

In the case of T CrB, Selvelli et al. (1992) and Stanishev et al. (2004) estimated the rate of accretion onto the WD ($\dot{M}_{\rm WD}$) from spectra obtained with the International Ultraviolet Explorer satellite between 1978 until 1990. Including periods of both high and low ultraviolet (UV) flux between 1978 and 1990, they found an average accretion rate of $9.6 \times 10^{-9}$ $(d/806\,{\rm pc})^2$ $M_{\odot}$ yr$^{-1}$. By modeling the spectral energy distribution in the UV region, Stanishev et al. (2004) obtained a high-state accretion rate (from 1980 to 1988) of $1.1 \times 10^{-8}$ $(d/806\,{\rm pc})^2$ $M_{\odot}$ yr$^{-1}$ and a low-state accretion rate (from 1978 to 1980 and 1988 to 1990) of $1.5 \times 10^{-9}$ $(d/806\,{\rm pc})^2$ $M_{\odot}$ yr$^{-1}$. It should be noted that the high state identified by Stanishev et al. (2004) did not reach *B*-magnitudes as bright as the ones discussed here (see Section 3).

Additional constraints on $\dot{M}$ onto the WD in T CrB come from the fact that the boundary layer is typically optically thin, making it a hard X-ray source in quiescence, with the strength of the hard X-ray emission directly related to $\dot{M}$ (Luna et al. 2008; Kennea et al. 2009). To date, this is a unique feature among all known symbiotic RNe. Suzaku observations in 2006 allowed us to measure $\dot{M}_q = 0.7 \times 10^{-9}$ $(d/806\,{\rm pc})^2$ $M_{\odot}$ yr$^{-1}$ (Luna et al. 2019), where $\dot{M}_q$ is the accretion rate measured between nova eruptions. Clearly both UV and X-ray

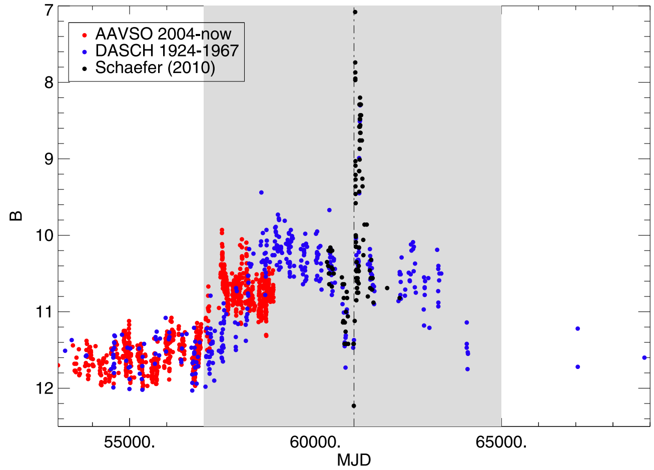


**Figure 1.** DASCH $B$-magnitude light curve (blue dots) and $B$-magnitude data (black dots) from Table 12 in Schaefer (2010), covering the 1924 to 1967 period, which includes the pre- and post-eruption activity and AAVSO $B$-magnitude light curve covering the 2004-now "super-active" state (red dots). The DASCH and Schaefer (2010) light curves were shifted by +80 yr (see Section 4). Vertical dashed line marks the 1946.1 eruption shifted by +80 yr. The match of the initial rise between the current and previous brightening is remarkable. The shaded area shows the pre and post-eruption periods during which T CrB was in a high accretion rate state (see Section 4).

measurements indicate that $\dot{M}_q$ was low since 1979 until 2006 when compared with the predicted average accretion rate necessary to trigger a nova outburst every 80 yr.

## 2. Observations

We base the findings described below on publicly available data from two archives—the Digital Access to a Sky Century @Harvard (DASCH; Grindlay et al. 2009) project to digitize the Harvard Astronomical Photographic Plate collection, which provides a photometric database with a baseline of about 100 yr; and $B$-band observations from the archive of the American Association of Variable Star Observers (AAVSO). Details about the DASCH photometric pipeline can be found in Tang et al. (2013). The DASCH database contains unflagged observations of T CrB from 1901 April through 1989 May with non-uniform sampling.

## 3. Results

### 3.1. Optical High State Leading up to the 1946 Nova Eruption

By querying the DASCH and searching for photometric observations of T CrB previous to the 1946 eruption, we found clear evidence in the $B$-band light curve for an optical bright state that started in 1938 and lasted about 7 yr, until about 1945, about one year before the nova eruption, and then continued after the nova event. Figure 1 shows the DASCH light curve (blue dots). This light curve confirms the phenomenon mentioned in an abstract by Schaefer (2014), who described finding such a high state associated with both the 1866 and 1946 nova eruptions. However, the DASCH data revealed that the high state, which continued after the eruption for several years, had been missed in the previous studies. The visual AAVSO data suggested that a minor precursor event occurred before each eruption that lasted approximately 1 yr. But our examination of the AAVSO light curve revealed that its coverage around the time of the two novae was too sparse to reveal the full high state that is evident in the DASCH data. The DASCH light curve also shows that after ~7 yr of "super-active" state, T CrB faded and almost reached the pre-"super-active" brightness for about 1 yr, after which time the nova eruption occurred.

### 3.2. Similarity to the Current High State

An ongoing optical brightening event that started in early 2014 is extremely similar to the 1938–1945 high state, and the current high state is driven by an increase in $\dot{M}_{\rm WD}$. The current optical bright state reached its maximum ($B \sim 10$) in 2016 April and has continued since then at an average brightness of $B \sim 10.5$ (referred to as a "super-active" state by Munari et al. 2016). An XMM-Newton observation in 2017 January allowed us to detect a soft X-ray component from the boundary layer, which had become mostly optically thick, and to measure the accretion rate of above $6.6 \times 10^{-8}$ $(d/806\ {\rm pc})^2$ $M_\odot$ yr$^{-1}$ (Luna et al. 2018). In 2018 March, another XMM-Newton observation showed that $\dot{M}$ might have decreased to about $6 \times 10^{-9}$ $(d/806\ {\rm pc})^2$ $M_\odot$ yr$^{-1}$ (Zhekov & Tomov 2019), although a fit to the 2018 XMM-Newton spectrum using an alternative model with higher absorbing column suggests the $\dot{M}$ could also have remained high. In Figure 1, we show the DASCH light curve, shifted by +80 yr and superimposed upon the AAVSO $B$-magnitude light curve from the current "super-active" state. The correspondence between the shape of the initial rise of both events is remarkable. Based on the similar optical behavior in 1938 and 2014, and the fact that both brightenings took place several years before expected nova events, it is likely that previous to the 1946 eruption, the accretion increased to the $10^{-8}$ $M_\odot$ yr$^{-1}$ level as it did in 2014.

## 4. Discussion

The historical light curves show that T CrB experiences two active states between nova eruptions: one is the so-called "super-active" state (Munari et al. 2016), which occurs between ~8 and ~1 yr *before* the nova eruption and another one, less noticeable, which starts about 200 days *after* the nova eruption and lasts for about 8 yr. Although previously noted in an abstract by Schaefer (2014), to our knowledge, the DASCH data show this clearly for the first time.

We propose that both high states play a significant role in the further development toward the nova eruption. Outside these states, the quiescent accretion rate typically seems to be about $10^{-9}$ $M_\odot$ yr$^{-1}$; at this level it would not be possible to reach the required ignition mass of a few $10^{-6}$ $M_\odot$ in approximately 80 yr. If the accretion rate during the high states is about $5 \times 10^{-9}$ $M_\odot$ yr$^{-1}$ to $5 \times 10^{-8}$ $M_\odot$ yr$^{-1}$, then an order of magnitude estimation yields that about $10^{-6}$ $M_\odot$ could be accreted onto the WD in 20 yr, providing a large fraction of the ignition mass. We emphasize, however, that the nature of the post-eruption high state is unknown, and thus its connection to a period of increased accretion rate is only speculative.

By comparing both "super-active" states, we see that the current state reached the peak earlier than expected if the recurrence time is exactly 80 yr (we note, however, that most RNe do not recur precisely periodically; Schaefer 2010). Moreover, the plateau of the current "super-active" state is about half a magnitude fainter than the 1938–1945 state, and thus the fading to the quiescent, pre-eruption state, could have already started. Although the AAVSO light curve does not show a significant decline in the optical brightness, both X-ray softness ratio and H$\alpha$ flux indicate a secular decline in the accretion rate since 2016 (G. J. M. Luna et al. 2020, in preparation). We predict that T CrB is within 3–6 yr of its next TNR.

In cataclysmic variables, a single-disk instability dwarf-nova outburst cannot cause the WD to accumulate enough mass to significantly fuel a nova eruption. For example, Cannizzo (1993) modeled the disk instability outburst in SS Cyg and found that about $6 \times 10^{-10}$ $M_{\odot}$ yr$^{-1}$ is stored in the disk during quiescence, which is then all or partially dumped into the WD during a long-lasting (about 50 days long) outburst. The aforementioned theoretical models by Prialnik & Kovetz (1995) show that the ignition mass for a nova eruption in a 1.1 $M_{\odot}$ WD (as in SS Cyg) is on average $10^{-6}$ $M_{\odot}$. On the other hand, in symbiotics, where a large and unstable accretion disk can store a significant amount of mass (about $10^{-6}$ $M_{\odot}$; Wynn 2008), the WD has the potential to assemble enough mass after a disk instability to trigger a nova eruption.

Our results thus suggest a scenario in which the WDs in symbiotic recurrent novae accumulate most of the ignition mass during sporadic high states. Hints of such episodes were already noticed by Nelson et al. (2011) in their analysis of quiescent X-ray data of the symbiotic RN RS Oph. Because of their faintness when not experiencing nova eruptions, the data on the other symbiotic recurrent novae (V3890 Sgr, V745 Sco, and perhaps V2487 Oph) are too scarce for us to place constraints on low-amplitude high states like the one for T CrB we report here. With the ignition mass on the WDs in symbiotic RNe most likely to be reached during an accretion high state, states such as the one that T CrB is currently in then become indicators of an impending nova eruption.

We acknowledge with thanks the variable star observations from the AAVSO International Database contributed by observers worldwide and used in this research. The DASCH project at Harvard is grateful for partial support from NSF grants AST-0407380, AST-0909073, and AST-1313370. G.J. M.L. is a member of the CIC-CONICET (Argentina) and acknowledge support from grants ANPCYT-PICT 0901/2017 and CONICET-NSF International Cooperation Grant 2016. N. P.M.K. acknowledges support from the UK Space Agency. J.L. S. acknowledges support from NSF award AST-1616646.

## ORCID iDs

Gerardo J. M. Luna https://orcid.org/0000-0002-2647-4373
J. L. Sokoloski https://orcid.org/0000-0003-2835-0304
Koji Mukai https://orcid.org/0000-0002-8286-8094
N. Paul M. Kuin https://orcid.org/0000-0003-4650-4186

## References

Bailer-Jones, C. A. L., Rybizki, J., Fouesneau, M., Mantelet, G., & Andrae, R. 2018, AJ, 156, 58
Belczynski, K., & Mikolajewska, J. 1998, MNRAS, 296, 77
Cannizzo, J. K. 1993, ApJ, 419, 318
Fekel, F. C., Joyce, R. R., Hinkle, K. H., & Skrutskie, M. F. 2000, AJ, 119, 1375
Grindlay, J., Tang, S., Simcoe, R., et al. 2009, in ASP Conf. Ser. 410, DASCH to Measure (and preserve) the Harvard Plates: Opening the 100 year Time Domain Astronomy Window, ed. W. Osborn & L. Robbins (San Francisco, CA: ASP), 101
Kennea, J. A., Mukai, K., Sokoloski, J. L., et al. 2009, ApJ, 701, 1992
Luna, G. J. M., Mukai, K., Sokoloski, J. L., et al. 2018, A&A, 619, A61
Luna, G. J. M., Nelson, T., Mukai, K., & Sokoloski, J. L. 2019, ApJ, 880, 94
Luna, G. J. M., Sokoloski, J. L., & Mukai, K. 2008, in ASP Conf. Ser. 401, RS Ophiuchi (2006) and the Recurrent Nova Phenomenon, ed. A. Evans et al. (San Francisco, CA: ASP), 342
Munari, U., Dallaporta, S., & Cherini, G. 2016, NewA, 47, 7
Nelson, T., Mukai, K., Orio, M., Luna, G. J. M., & Sokoloski, J. L. 2011, ApJ, 737, 7
Prialnik, D., & Kovetz, A. 1995, ApJ, 445, 789
Schaefer, B. E. 2010, ApJS, 187, 275
Schaefer, B. E. 2014, AAS Meeting, 223, 209.01
Schaefer, B. E. 2019, AAS Meeting, 51, 122.07
Selvelli, P. L., Cassatella, A., & Gilmozzi, R. 1992, ApJ, 393, 289
Shahbaz, T., Somers, M., Yudin, B., & Naylor, T. 1997, MNRAS, 288, 1027
Stanishev, V., Zamanov, R., Tomov, N., & Marziani, P. 2004, A&A, 415, 609
Tang, S., Grindlay, J., Los, E., & Servillat, M. 2013, PASP, 125, 857
Wynn, G. 2008, in ASP Conf. Ser. 401, RS Ophiuchi (2006) and the Recurrent Nova Phenomenon, ed. A. Evans et al. (San Francisco, CA: ASP), 73
Zhekov, S. A., & Tomov, T. V. 2019, MNRAS, 489, 2930