

© 2020. The American Astronomical Society. All rights reserved. Access to this work was provided by the University of Maryland, Baltimore County (UMBC) ScholarWorks@UMBC digital repository on the Maryland Shared Open Access (MD-SOAR) platform.

Please provide feedback Please support the ScholarWorks@UMBC repository by emailing scholarworks-group@umbc.edu and telling us what having access to this work means to you and why it's important to you. Thank you.

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. KUIN⁸

¹CONICET-Universidad de Buenos Aires, Instituto de Astronomia y Fisica del Espacio (IAFE), Av. Inte. Giraldes 2620, C1428ZAA, Buenos Aires, Argentina

²Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Buenos Aires, Argentina.

³Universidad Nacional de Hurlingham, Av. Gdor. Vergara 2222, Villa Tesei, Buenos Aires, Argentina.

⁴Columbia Astrophysics Lab 550 W120th St., 1027 Pupin Hall, MC 5247 Columbia University, New York, New York 10027, USA

⁵LSST Corporation, 933 North Cherry Ave, Tucson, AZ 85721.

⁶CRESST and X-ray Astrophysics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

⁷Department of Physics, University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA

⁸Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, Surrey RH5 6NT, UK

(Received; Revised; Accepted September 28, 2020)

Submitted to ApJ

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 reanalysis of archival data from the Digital Access to a Sky Century @Harvard (DASCH) 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-year 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.

Keywords: binaries: symbiotic — accretion, accretion disks — stars: individual: T CrB

1. INTRODUCTION

T Coronae Borealis (T CrB) is the nearest symbiotic recurrent nova; 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 years. The

distance as determined from *Gaia* data is 806_{-31}^{+33} pc (Bailer-Jones et al. 2018). As in the other symbiotic recurrent novae 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., Fekel et al. 2000; Shahbaz et al. 1997). Being the nearest known recurrent nova, we expect the next eruption of T CrB – predicted to happen between 2023.6 ± 1 (Schaefer 2019) and approximately 2026 – to shine strongly from γ -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 white dwarf mass and the accretion rate. In the case of a system with the parameters of T CrB, M_{WD} of 1.2 – 1.37 M_{\odot} (Belczynski & Mikolajewska 1998; Stanishev et al. 2004) and recurrence time of about 80 years, theoretical models by Prialnik & Kovetz (1995) predict that an accumulated mass of $10^{-6} M_{\odot}$ will be needed for a TNR. Over 80 years that implies an average accretion rate of between $10^{-8} M_{\odot} \text{ yr}^{-1}$ and $10^{-7} M_{\odot} \text{ yr}^{-1}$.

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}_{WD}) from spectra obtained with the IUE (International Ultraviolet Explorer) satellite between 1978 until 1990. Including periods of both high and low UV flux between 1978 and 1990, they found an average accretion rate of $9.6 \times 10^{-9} (d/806pc)^2 M_{\odot} \text{ yr}^{-1}$. By modeling the SED in the UV region, Stanishev et al. (2004) obtained a high-state accretion rate (from 1980 to 1988) of $1.1 \times 10^{-8} (d/806pc)^2 M_{\odot} \text{ yr}^{-1}$ and a low-state accretion rate (from 1978 to 1980 and 1988-1990) of $1.5 \times 10^{-9} (d/806pc)^2 M_{\odot} \text{ yr}^{-1}$. 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 Sect. 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 recurrent novae. *Suzaku* observations in 2006 allowed us to measure $\dot{M}_q = 0.7 \times 10^{-9} (d/806pc)^2 M_{\odot} \text{ yr}^{-1}$ (Luna et al. 2019), where \dot{M}_q is the accretion rate measured between nova eruptions. Clearly both UV and X-ray 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 years.

2. OBSERVATIONS.

We base the findings described below on publicly available data from two archives – the DASCH (Digital Access to a Sky Century @Harvard; Grindlay et al. 2009)

project to digitize the Harvard Astronomical Photographic Plate collection, which provides a photometric database with a baseline of about 100 years; and V- 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 April 1901 through May 1989 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 years, 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 (2014a), 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 one year. 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 years of “super-active” state, T CrB faded and almost reached the pre-“super-active” brightness for about one year, after which time the nova eruption occurred.

3.2. Similarity to the current high state

An on-going 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}_{WD} . The current optical bright state reached its maximum (B \sim 10) in April 2016 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 January 2017 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 $6.6 \times 10^{-8} (d/806pc)^2 M_{\odot} \text{ yr}^{-1}$ (Luna et al. 2018). In March 2018, another *XMM-Newton* observation showed that \dot{M} might have decreased to about $6 \times 10^{-9} (d/806pc)^2 M_{\odot} \text{ yr}^{-1}$

(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 years 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 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 $10^{-8} M_{\odot} \text{ yr}^{-1}$ level as it did in 2014.

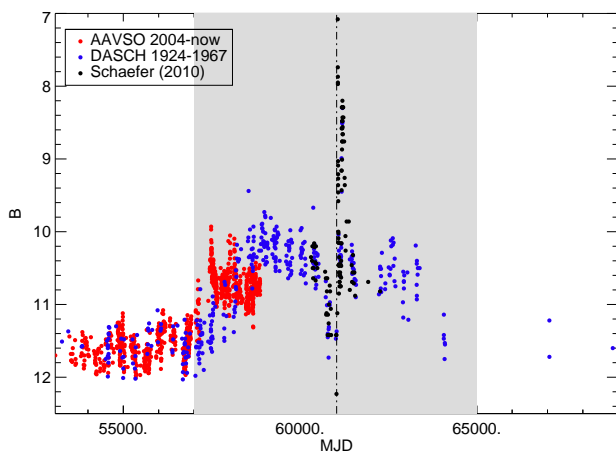


Figure 1. DASCH B-magnitude light curve (blue dots) and B-magnitude data (black dots) from Table 12 in Schaefer (2010), covering the 1924 to 1967 period, which includes the pre and post-eruption activity and AAVSO B-magnitude light curve covering the 2004-now “super-active” state (red dots). The DASCH and Schaefer (2010) light curves were shifted by 80 years (see Sect. 4). Vertical dashed line marks the 1946.1 eruption shifted by +80 years. 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).

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 year *before* the nova eruption and another one, less noticeable, which starts about 200 days *after* the nova eruption and lasts for about 8 years. Although previously noted in an abstract

by Schaefer (2014b), 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 $10^{-9} M_{\odot} \text{ yr}^{-1}$; at this level it would not be possible to reach the required ignition mass of a few $10^{-6} M_{\odot}$ in approximately 80 years. If the accretion rate during the high states is about $5 \times 10^{-9} M_{\odot} \text{ yr}^{-1}$ to $5 \times 10^{-8} M_{\odot} \text{ yr}^{-1}$, then an order of magnitude estimation yields that about $10^{-6} M_{\odot}$ could be accreted onto the WD in 20 years, 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 years (we note however that most recurrent novae 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 (Luna et al., *in prep.*). We predict that T CrB is within 3-6 years of its next thermonuclear runaway.

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 $6 \times 10^{-10} M_{\odot} \text{ yr}^{-1}$ 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 recurrent nova 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 recurrent novae 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.

ACKNOWLEDGMENTS

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. GJML is a member of the CIC-CONICET (Argentina) and acknowledge support from grants ANPCYT-PICT 0901/2017 and CONICET-NSF International Cooperation Grant 2016. NPMK acknowledges support from the UK Space Agency. JLS acknowledges support from NSF award AST-1616646.

REFERENCES

- Bailer-Jones, C. A. L., Rybizki, J., Fouesneau, M., Mantelet, G., & Andrae, R. 2018, *AJ*, 156, 58, doi: [10.3847/1538-3881/aacb21](https://doi.org/10.3847/1538-3881/aacb21)
- Belczynski, K., & Mikolajewska, J. 1998, *MNRAS*, 296, 77, doi: [10.1046/j.1365-8711.1998.01301.x](https://doi.org/10.1046/j.1365-8711.1998.01301.x)
- Cannizzo, J. K. 1993, *ApJ*, 419, 318, doi: [10.1086/173486](https://doi.org/10.1086/173486)
- Fekel, F. C., Joyce, R. R., Hinkle, K. H., & Skrutskie, M. F. 2000, *AJ*, 119, 1375, doi: [10.1086/301260](https://doi.org/10.1086/301260)
- Grindlay, J., Tang, S., Simcoe, R., et al. 2009, *Astronomical Society of the Pacific Conference Series*, Vol. 410, *DASCH to Measure (and preserve) the Harvard Plates: Opening the 100-year Time Domain Astronomy Window*, ed. W. Osborn & L. Robbins, 101
- Kennea, J. A., Mukai, K., Sokoloski, J. L., et al. 2009, *ApJ*, 701, 1992, doi: [10.1088/0004-637X/701/2/1992](https://doi.org/10.1088/0004-637X/701/2/1992)
- Luna, G. J. M., Nelson, T., Mukai, K., & Sokoloski, J. L. 2019, *ApJ*, 880, 94, doi: [10.3847/1538-4357/ab2884](https://doi.org/10.3847/1538-4357/ab2884)
- Luna, G. J. M., Sokoloski, J. L., & Mukai, K. 2008, in *Astronomical Society of the Pacific Conference Series*, Vol. 401, *RS Ophiuchi (2006) and the Recurrent Nova Phenomenon*, ed. A. Evans, M. F. Bode, T. J. O'Brien, & M. J. Darnley, 342. <https://arxiv.org/abs/0711.0725>
- Luna, G. J. M., Mukai, K., Sokoloski, J. L., et al. 2018, *A&A*, 619, A61, doi: [10.1051/0004-6361/201833747](https://doi.org/10.1051/0004-6361/201833747)
- Munari, U., Dallaporta, S., & Cherini, G. 2016, *NewA*, 47, 7, doi: [10.1016/j.newast.2016.01.002](https://doi.org/10.1016/j.newast.2016.01.002)
- Nelson, T., Mukai, K., Orio, M., Luna, G. J. M., & Sokoloski, J. L. 2011, *ApJ*, 737, 7, doi: [10.1088/0004-637X/737/1/7](https://doi.org/10.1088/0004-637X/737/1/7)
- Prialnik, D., & Kovetz, A. 1995, *ApJ*, 445, 789, doi: [10.1086/175741](https://doi.org/10.1086/175741)
- Schaefer, B. E. 2010, *ApJS*, 187, 275, doi: [10.1088/0067-0049/187/2/275](https://doi.org/10.1088/0067-0049/187/2/275)
- Schaefer, B. E. 2014a, in *American Astronomical Society Meeting Abstracts*, Vol. 223, *American Astronomical Society Meeting Abstracts #223*, 209.01
- Schaefer, B. E. 2014b, in *American Astronomical Society Meeting Abstracts*, Vol. 223, *American Astronomical Society Meeting Abstracts #223*, 209.01
- Schaefer, B. E. 2019, in *American Astronomical Society Meeting Abstracts*, Vol. 51, *American Astronomical Society Meeting Abstracts #234*, 122.07
- Selvelli, P. L., Cassatella, A., & Gilmozzi, R. 1992, *ApJ*, 393, 289, doi: [10.1086/171506](https://doi.org/10.1086/171506)
- Shahbaz, T., Somers, M., Yudin, B., & Naylor, T. 1997, *MNRAS*, 288, 1027, doi: [10.1093/mnras/288.4.1027](https://doi.org/10.1093/mnras/288.4.1027)
- Stanishev, V., Zamanov, R., Tomov, N., & Marziani, P. 2004, *A&A*, 415, 609, doi: [10.1051/0004-6361:20034623](https://doi.org/10.1051/0004-6361:20034623)

Tang, S., Grindlay, J., Los, E., & Servillat, M. 2013, PASP, 125, 857, doi: [10.1086/671760](https://doi.org/10.1086/671760)

Wynn, G. 2008, in *Astronomical Society of the Pacific Conference Series*, Vol. 401, RS Ophiuchi (2006) and the Recurrent Nova Phenomenon, ed. A. Evans, M. F. Bode, T. J. O'Brien, & M. J. Darnley, 73

Zhekov, S. A., & Tomov, T. V. 2019, MNRAS, 489, 2930, doi: [10.1093/mnras/stz2329](https://doi.org/10.1093/mnras/stz2329)