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Modeling of a transient, high accretion state of the recurrent nova T CrB as a enhanced mass transfer event

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Abstract. T Coronae Borealis is the nearest symbiotic recurrent nova. Twice in the last two centuries, in 1866 and 1946, the accreted material ignited on the surface of the white dwarf via runaway thermonuclear fusion reactions and produced a nova eruption. The most recent nova eruption occurred during a transient high-accretion state. A natural origin of such state is a dwarf nova like outburst, where a possible explanation is an instability in the mass transfer rate of the donor star (MTIM) during the transient. We simulate the response of an accretion disc to pulses of enhanced mass transfer, in the context of the MTIM, to model the optical light curve of T CrB. The observed brightening can be satisfactorily reproduced by models with a viscosity parameter $\alpha > 1$ and a pulse of width $\Delta t \sim 1.0 \times 10^8$ s (~ 3.2 yr).

Resumo. T Coronae Borealis é a nova recorrente simbiótica mais próxima. Duas vezes nos últimos dois séculos, em 1866 e 1946, o material acrescido inflamou-se na superfície da anã branca através de reações de fusão termonuclear descontroladas e produziu uma erupção de nova. A erupção de nova mais recente ocorreu durante um estado de alto acréscimo transiente. Uma origem natural de tais estados são erupções do tipo nova-anã, onde uma possível explicação é uma instabilidade na taxa de transferência de massa da estrela doadora (MTIM) durante o transiente. Simulamos a resposta de um disco de acréscimo a eventos de transferência de massa aumentada, no contexto do MTIM, para modelar a curva de luz óptica de T CrB. O brilho observado pode ser reproduzido satisfatoriamente por modelos com parâmetro de viscosidade $\alpha > 1$ e um pulso de largura $\Delta t \sim 1.0 \times 10^8$ s (~ 3.2 anos).

Keywords. Accretion, accretion discs – novae, cataclysmic variables – Methods: numerical

1. Introduction

T Coronae Borealis (T CrB) is the nearest symbiotic recurrent nova. The system contains a M4.5 III giant (RG, Mürset & Schmid 1999), which fills its Roche lobe and transfers mass toward a white dwarf (WD). Twice in the last two centuries, in 1866 and 1946, the accreted material ignited on the surface of the white dwarf via runaway thermonuclear fusion reactions and produced a nova eruption. With a recurrence time of ~ 80 yr, the next eruption of T CrB is predicted to happen between 2023.6 (Schaefer 2019) and approximately 2026.

2. Observations

The dataset used in this work is derived from Luna et al. (2020) and comes from 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 BV-band observations from the archive of the American Association of Variable Star Observers (AAVSO). In Fig. 1 the DASCH (black crosses) and AAVSO (red crosses) light curves are shown. The DASCH data are from the nova event that occurred in 1946, while the AAVSO data are from the current event and were shifted by −78 years to match the 1946 event.

In our analysis, we used the current event data (AAVSO), which cover the transient event to the nova eruption. Therefore, a median filter with a width of 51 points was applied to the AAVSO dataset (blue points with error bars). It is worth highlighting that there is the possibility that the entire period of high accretion before and after the nova eruption is a single transient

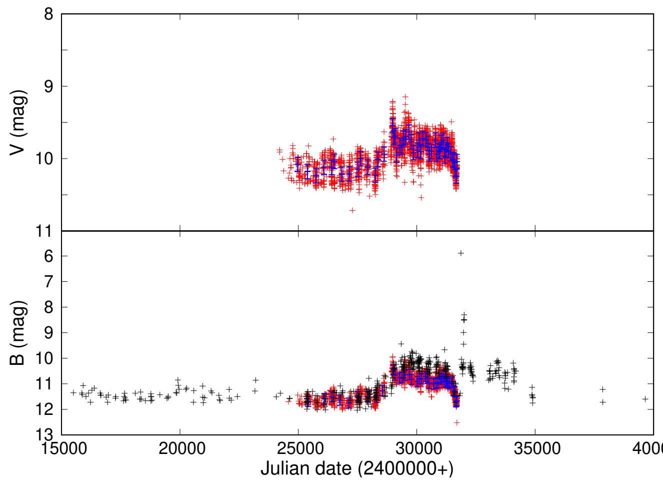

Figure 1. Light curves of T CrB. *Top panel:* the red crosses are the AAVSO V-magnitudes. *Bottom panel:* the black and red crosses are the DASCH and AAVSO B-magnitudes, respectively. In both panels, for better comparison, we shifted the AAVSO data by -78 yr. The blue dots with error bars are the result of a 51-point median filter on the AAVSO data.

and that the decrease in brightness prior to the eruption is caused by another phenomenon, but this will not be studied in this work.

3. Model and results

The nova eruption in 1946, occurred during (or at the end) a transient accretion high state (see Fig. 1). A natural origin of

Table 1. The binary parameters of T CrB used in our simulations.

Parameters	Model I	Model II
Orbital period	5461.65 h (Fekel et al. 2000)	
M_{WD}	$1.37\,M_\odot$ (Stanishev et al. 2004)	$1.25\,M_\odot$ (assumed)
R_{WD}	$0.003\,R_\odot$	$0.005\,R_\odot$
Inclination (i)	67° (Stanishev et al. 2004)	60° (assumed)
Mass ratio (q)	0.82 (Stanishev et al. 2004)	0.57 ((Fekel et al. 2000) w/ $i = 60°$)
Binary separation (a)	$211.5\,R_\odot$	$195.3\,R_\odot$
Radius to the inner Lagrangian point (R_{L_1})	$110.0\,R_\odot$	$108.6\,R_\odot$
μ	0.615 (solar abundance of fully ionized gases)	
Distance	916 pc (Gaia Collaboration et al. 2023)	
B_{RG}	11.779 mag (Iłkiewicz, Mikołajewska, & Stoyanov 2023)	
V_{RG}	10.029 mag (Iłkiewicz, Mikołajewska, & Stoyanov 2023)	
$\dot{M}_2$ in quiescence ($\dot{M}_2^i$)	$9.5 \times 10^{-9}\,M_\odot$/yr	$7.1 \times 10^{-9}\,M_\odot$/yr
$\dot{M}_2$ during pulse maximum ($\dot{M}_2^p$)	$2.4 \times 10^{-7}\,M_\odot$/yr	$1.7 \times 10^{-7}\,M_\odot$/yr
Viscosity parameter (α)	5.0	
Pulse duration (Δt_p)	1.0×10^8 s	

such states is a dwarf nova like outburst, where a possible explanation is an instability in the mass transfer rate of the donor star (MTIM, Bath 1972, 1975; Bath & Pringle 1981) during the transient. To do this, the disc has to respond quickly to the enhanced mass pulse with a high viscosity.

We applied to simulations of the response of accretion discs to pulses of enhanced mass transfer (Schlindwein 2021; Schlindwein & Baptista 2024), in the context of the MTIM, to model the light curve of the T CrB accretion disc. We adopt a pulse of enhanced mass with the shape described by Eq. 1, where t_p and Δt_p are the pulse mid-time and its full width at half maximum, and that the disc emits locally as a blackbody.

$$\dot{M}_2 = \dot{M}_2^i + (\dot{M}_2^p - \dot{M}_2^i)\exp\left[-\frac{1}{2}\left(\frac{t - t_p}{\Delta t_p/\sqrt{2\ln 2}}\right)^4\right] \quad (1)$$

Considering that the binary parameters of T CrB are not very well defined due to the lack of knowledge of the inclination of the system, we adopted two configurations in the simulations performed. In Table 1, the parameters of these configurations are listed as models I and II.

In Fig. 2, the light curves resulting from the simulations in the passbands B and V for the parameters of models I and II are shown. These light curves are the sum of the brightness of the simulated accretion disc and the estimated constant contribution of the RG. As the RG is an important light source in the system, a good estimate of its magnitudes and variations becomes important for modeling.

4. Conclusions and perspectives

T CrB observed brightness variations can be satisfactorily reproduced by models with the viscosity parameter $\alpha > 1$ and a pulse of width $\Delta t_p \sim 1.0 \times 10^8$ s (~ 3.2 yr). The $\dot{M}_2$ values used in the models are close to those determined by Luna et al. (2018) from the X-ray emission of the boundary layer ($\sim 2 \times 10^{-9}\,M_\odot$/yr and $\sim 6 \times 10^{-8}\,M_\odot$/yr, respectively for the quiescence and high state estimates).

The match between our model light curve and the data may clearly be improved. Something that can be implemented is modeling the contribution of other light sources in the system, such as the RG. We can also perform a χ^2 test similar to that performed for the dwarf nova EX Draconis (Schlindwein 2021; Schlindwein & Baptista 2024) to determine the best-fit model set of parameters to describe the brightness variations of T CrB.

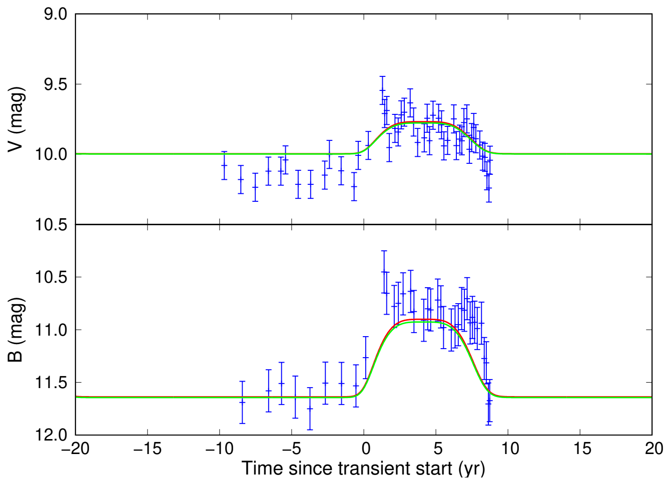

Figure 2. Simulation results with model I (red curve) and II (green curve) parameters. The points with error bars are the same as in Fig. 1.

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