Hβ emission line of the recurrent nova T CrB

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(Submitted on 27 August 2024; Accepted on 3 November 2024)

Abstract. We present observations of the Hβ emission line of the recurrent nova T CrB, conducted over four nights between August 2023 and July 2024 using the 2.0m RCC telescope at the Rozhen National Astronomical Observatory. By subtracting the red giant contribution from each spectrum, we isolate the double-peaked Hβ emission associated with the accretion disc. We measure the peak separation, which varies between 131 and 179 km s^{-1}. From this, we estimate the average size of the Hβ-emitting region within the disc to be $R_\beta = 45 \pm 11$ $R_\odot$, corresponding to approximately 55% of the white dwarf's Roche lobe. Comparing with the Hα emission, we find that the Hβ emission originates from a region around the white dwarf that is about half the size of the Hα-emitting disc.

Key words: Stars: binaries: symbiotic – accretion, accretion discs – novae, cataclysmic variables – stars: individual: T CrB

1 Introduction

T CrB (HD 143454, NOVA CrB 1946, NOVA CrB 1866) is a notable recurrent nova having recorded eruptions in 1946, 1866, 1787, and possibly even in 1217 (Schaefer 2023a). A new outburst can be expected in the next months (Luna et al. 2020; Schaefer 2023b), which could potentially make T CrB as bright as Polaris.

T CrB consists of a red giant of M4III spectral type (Kenyon & Fernandez-Castro 1987; Muerset & Schmid 1999) as a mass donor and a 1.37 $M_\odot$ white dwarf (Stanishev et al. 2004). The orbital period of the system is 227.5687 d (Fekel et al. 2000). The ellipsoidally shaped red giant fills the Roche lobe and transfers material through the Lagrangian point L_1 at a rate $0.2 - 4 \times 10^{-8}\,M_\odot\,yr^{-1}$ (Selvelli et al. 1992; Zamanov et al. 2023). Since the mass of the white dwarf is close to the Chandrasekhar limit, T CrB is considered candidate progenitor for a Type Ia supernova (e.g. Shahbaz et al. 1997).

In our previous paper (Zamanov et al. 2024) we analysed observations of the Hα emission and estimated the accretion disc radius. In this work, we analyse the Hβ emission of T CrB, using an analogous technique.

2 Observations

Here we present four spectra of the Hβ emission line of T CrB secured with the ESpeRo Echelle spectrograph (Bonev et al. 2017) on the 2.0 m RCC telescope in the Rozhen National Astronomical Observatory, Bulgaria. We measure the equivalent width of the Hβ line in each spectrum. The typical error is around 5%. We then subtract the spectrum of HD134807, which is the red giant used in Stanishev et al. (2004) and Zamanov et al. (2024). The contribution of the red giant to the observed spectra is different for each observation. We apply an empirical method to estimate the contribution of the red giant by scaling the spectrum with a factor from 5 to 100 % with a step of 1 %. Then we tentatively subtract and measure the standard deviation in the continuum for wavelengths from 4843 to 4854 Å. A graph of the standard deviation as a function of the red giant contribution is shown in Fig. 1c. We find the minimum and scale the red giant's spectrum with the corresponding value. An example of the red giant subtraction is presented in Fig. 1a. The double-peaked nature of the line is apparent before subtraction, however, the subtraction enhances its clarity, allowing for a more accurate measurement of the peak separation.

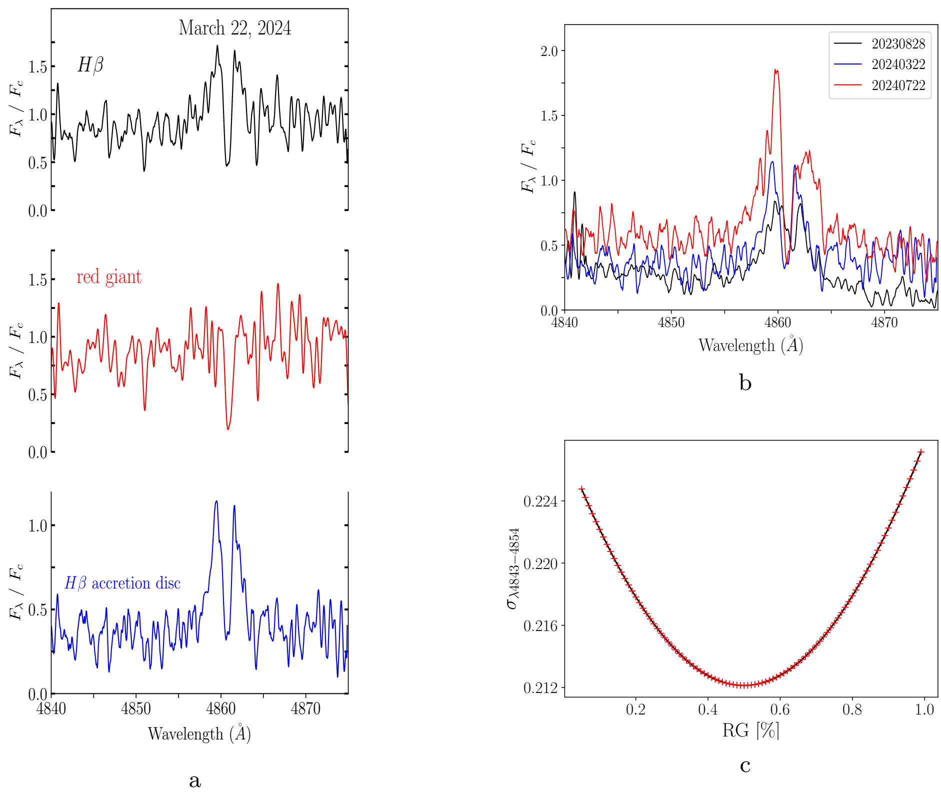

Fig. 1: **(a)** Hβ emission line of T CrB observed on March 22, 2024 (black). Red giant spectrum (red). Hβ line with subtracted red giant contribution (blue). **(b)** Variability of the observed Hβ line of T CrB. **(c)** Standard deviation of the continuum between 4843 and 4854 Å, after subtraction of the red giant with different contribution from 5 to 100 %.

3 Results and discussion

The variability of the Hβ emission line of T CrB is presented in Fig. 1a. Three of the spectra are plotted after the subtraction of the red giant's contribution. Double-peaked Hβ emission coming from the hot component is clearly visible.

In Table 1 are given date of observation, orbital phase calculated from ephemeris $T_0 = 2447918.62 + 227.5687E$ (Fekel et al. 2000), exposure time of the spectra in minutes, equivalent width (EW) of the Hβ line in Å, contribution of the red giant (RG), distance between the peaks (Δv_b) in $\mathrm{km\,s^{-1}}$ and the size of the Hβ emitting disc. The typical error of measurement of EW is ± 5 %, of Δv_b is ± 6 $\mathrm{km\,s^{-1}}$ and of R_β is ± 5 $\mathrm{R}_\odot$.

3.1 Disc size

The subtraction of the red giant's contribution reveals double-peaked profile of the Hβ emission line of the hot component (see Fig. 1). This suggests that the Hβ emission originates from an accretion disc (e.g. Horne & Marsh 1986). We assume this disc to be Keplerian and rotating around the white dwarf. For Hβ emission line originating from a Keplerian disc, the peak separation (Δv_b) can be used as an indicator of the radius of the Hβ-emitting disc (R_β) (Huang 1972):

$$\Delta v_b = 2\ \sin i\ \sqrt{GM_{wd}/R_\beta}\ , \qquad (1)$$

where G is the gravitational constant, M_{wd} is the mass of the white dwarf and i is the inclination angle of the disc axis to the line of sight. We adopt $M_{wd} = 1.37 \pm 0.13 M_\odot$ and $i = 67.5^\circ$ (Stanishev et al. 2004).

3.2 Hβ emitting disc

For our August 2023 – July 2024 observations (see Table 1), we measure $132 \leq \Delta v_b \leq 179\ \mathrm{km\,s^{-1}}$, with average value $\Delta v_b = 146 \pm 22\ \mathrm{km\,s^{-1}}$.

From Eq. 1 we estimate the size of the Hβ emitting disc as $29 \leq R_\beta \leq 54\ R_\odot$, with average value $R_\beta = 45 \pm 11\ R_\odot$.

Table 1: Observations of the Hβ emission line of T CrB.

Date	Phase	Exp-Time [min]	EW (Hβ) [Å]	RG [%]	Δv_b [$\mathrm{km\,s^{-1}}$]	R_β $\mathrm{R}_\odot$
2023-08-28 19:11	0.903	15	1.7 ± 0.2	85	131.5 ± 4	53.9 ± 5
2023-08-29 18:37	0.908	15	1.5 ± 0.1	62	132.1 ± 5	53.4 ± 6
2024-03-22 23:21	0.814	20	1.8 ± 0.1	58	141.9 ± 7	46.2 ± 5
2024-07-22 22:01	0.350	60	3.8 ± 0.2	50	179.0 ± 7	29.1 ± 3

3.3 Roche lobe size

With the parameters of the binary, the separation between the components of T CrB is $a = 212.6\ R_\odot$ and the inner Lagrangian point, L_1 is positioned at 111 $R_\odot$ away from the white dwarf (Zamanov et al. 2024). The Roche lobe radius of the accreting star can be determined using the formula (Eggleton 1983):

$$r_{Roche}/a = (0.49q^{2/3})/[0.6q^{2/3} + \ln(1 + q^{1/3})], \qquad (2)$$

where $q = M_1/M_2$ is the mass ratio. Using this formula and mass ratio $q = 1.22$, we estimate $r_{Roche}/a = 0.396$ and Roche lobe radius of the white dwarf 84.3 $R_\odot$, which means that the average size of the Hβ-emitting disc in August 2023 – July 2024 is approximately 55 % of the size of the Roche lobe of the white dwarf.

3.4 Comparison with Hα disc

The double-peaked Hα line exhibits average peak separation $\Delta v_a = 102\,\mathrm{km\,s^{-1}}$ in the period July 2023 – January 2024 (Zamanov et al. 2024), 1.4 times smaller than the Hβ average peak separation, measured in the current work. The corresponding average size of the Hα emitting disc is $R_\alpha = 89 \pm 19\ R_\odot$. According to our results in Sect. 3.2, the size of the Hβ disc is 2 times smaller than the Hα disc. These results suggest that the Hβ emission that we observed, originates from a more compact region around the white dwarf compared to the Hα. This is similar to what is observed in circumstellar discs of Be stars where Hβ shows 1.8 times larger peak separation than Hα (Hanuschik, Kozok, & Kaiser 1988).

4 Conclusions

We report spectroscopic observations of the Hβ emission line of the recurrent nova T CrB obtained in the period from August 2023 to July 2024. We subtract the contribution of the red giant and isolate double-peaked Hβ emission coming from the accretion disc around the white dwarf. We measure the distance between the peaks in the range $132 < \Delta v_b < 179\ \mathrm{km\,s^{-1}}$ and estimate the average size of the Hβ emission disc $R_\beta = 45 \pm 11\ R_\odot$. It is 0.5 of the R_α and 0.55 of the Roche lobe radius. Thus we suggest that Hβ emission line arises from a region in the accretion disc that is closer to the white dwarf than the Hα-emitting region.

Acknowledgements: We acknowledge Ministry of Education and Science of Bulgaria (Bulgarian National Roadmap for Research Infrastructure) and Bulgarian National Science Fund ("Spectral and spectropolarimetric study of interacting binary stars").

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