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# Red Giant Component of the Recurrent Nova T Coronae Borealis

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ABSTRACT

We performed simultaneous *V*-band photometry and spectroscopic observations of the recurrent nova T CrB and estimate the *V*-band magnitude of the red giant. We find for the red giant of T CrB apparent and absolute *V*-band magnitudes $m_V = 10.17 \pm 0.06$ and $M_V = +0.14 \pm 0.08$, respectively. At the maximum of the ellipsoidal variation when these values are obtained, its absolute *V*-band magnitude is similar but fainter than the typical M4/5III giants. The data will be available on Zenodo.

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

## 1. Introduction

T Coronae Borealis (HD 143454, NOVA CrB 1946, NOVA CrB 1866) is a famous recurrent nova having recorded eruptions in 1946, 1866, 1787 (Schaefer 2023a), when the star peaked at $\approx 1.7$ mag as observed by A.S. Kamenchuk, M. Woodman and N.F.H. Knight (see Kukarkin 1946, Shears 2024a). The recurrence time of the outbursts is of about 80 yr, and a new eruption is thought likely to occur in the next months (Luna *et al.* 2020, Schaefer 2023b, Shears 2024b).

At quiescence T CrB shows (1) an optical spectrum with M-type absorption features with the additional HI, HeI, HeII, and [OIII] emission lines (Kenyon 1986, Iijima 1990, Munari *et al.* 2016) and (2) behavior of a dwarf nova with an extremely long orbital period (Iłkiewicz *et al.* 2023). The binary consists of a M4III red giant (Kenyon and Fernandez-Castro 1987, Mürset and Schmid 1999) and a massive 1.2–1.4 $M_\odot$ white dwarf (Belczynski and Mikolajewska 1998, Stanishev *et al.* 2004). The orbital period of the system is 227.5687 d (Fekel *et al.* 2000).

Here we report simultaneous *V*-band photometry and spectroscopic observations, performed with aim of estimating the *V*-band magnitude of the red giant.

## 2. Observations

During the night of 22/23 August 2024, T CrB was observed simultaneously with the 2.0 m Rozhen and with the 40 cm Shumen telescopes. Optical spectra of T CrB and of four red giants were secured with the ESpeRo Echelle spectrograph (Bonev *et al.* 2017) on the 2.0 m RCC telescope in the Rozhen National Astronomical Observatory, Bulgaria. The spectrograph covers the range between 3900 – 9000 Å with a resolution reaching 45 000 around the H$\alpha$ line. The useful spectral range for T CrB is from 4600 Å to 6800 Å. Simultaneously with the spectral observations, T CrB was monitored in *UBV*-bands with the 40 cm telescope of the Shumen University "Episkop Konstantin Preslavsk" (Kjurkchieva *et al.* 2020). The spectra and the photometry were processed with IRAF. For the photometry, comparison stars from the list of Henden and Munari (2006) were used.

The photometric observations are presented in Table 1. In this table are given UT, number of the data points, minimum, maximum and average magnitude, standard deviation and the typical observational error. The spectroscopic observations are summarized in Table 2. This table lists object, its spectral type, UT of the start of the exposure, exposure time in minutes, signal-to-noise ratio at 5500 Å. Mürset and Schmid (1999) classified the cool component of T CrB as M4.5III. From the Yale Bright Star Catalog (Hoffleit and Warren 1995) we selected four red giants of similar spectral type and observed them with the same setup in the same night. Their spectral classifications from the 14th General Catalogue of MK Spectral Classification (Buscombe and Foster 1999) and the Extended Hipparcos Compilation (Anderson and Francis 2012) are similar:

NV Peg is classified as M4.5III-IIIa (Hoffleit and Warren 1995), M4.5IIIA (Buscombe and Foster 1999), and M4.5IIIa (Anderson and Francis 2012)

XZ Psc – M5III (Hoffleit and Warren 1995), M4.6III (Buscombe and Foster 1999), M3/4 III (Anderson and Francis 2012)

71 Peg – M5IIIa (Hoffleit and Warren 1995), M4.7IIIA (Buscombe and Foster 1999), and M4III (Anderson and Francis 2012)

57 Psc – M4IIIa (Hoffleit and Warren 1995), M4IIIA (Buscombe and Foster 1999), and M4III (Anderson and Francis 2012).

Table 1

Photometric observations of T CrB

| date yyyy–mm–dd | UT start-end hh:mm–hh:mm | | $N_{pts}$ | min [mag] | max [mag] | average [mag] | stdev [mag] | merr [mag] |
|---|---|---|---|---|---|---|---|---|
| 2024–08–22 | 20:03–21:28 | *U* | 23x120s | 11.452 | 11.899 | 11.558 | 0.109 | 0.060 |
| 2024–08–22 | 20:05–21:29 | *B* | 22x40s | 11.146 | 11.229 | 11.186 | 0.021 | 0.008 |
| 2024–08–22 | 20:05–21:30 | *V* | 22x15s | 9.916 | 9.974 | 9.950 | 0.019 | 0.004 |

Table 2

Spectral observations of T CrB and comparison red giants

| object | Spec. | date yyyy-mm-dd | UT start hh:mm | exp-time [min] | S/N | |
|---|---|---|---|---|---|---|
| T CrB | M4.5III+WD | 2024-08-22 | 20:12 | 10 | 17 | spec.1 |
| | | 2024-08-22 | 20:23 | 60 | 35 | spec.2 |
| NV Peg | M4.5III | 2024-08-22 | 21:31 | 15 | 128 | |
| | | 2024-08-22 | 21:47 | 15 | 127 | |
| XZ Psc | M5III | 2024-08-23 | 00:10 | 15 | 107 | |
| | | 2024-08-23 | 00:26 | 15 | 111 | |
| | | 2024-08-23 | 00:42 | 5 | 64 | |
| 71 Peg | M5III | 2024-08-23 | 00:52 | 5 | 68 | |
| | | 2024-08-23 | 00:58 | 15 | 117 | |
| | | 2024-08-23 | 01:14 | 15 | 118 | |
| 57 Psc | M4III | 2024-08-23 | 02:10 | 15 | 120 | |
| | | 2024-08-23 | 02:04 | 5 | 71 | |

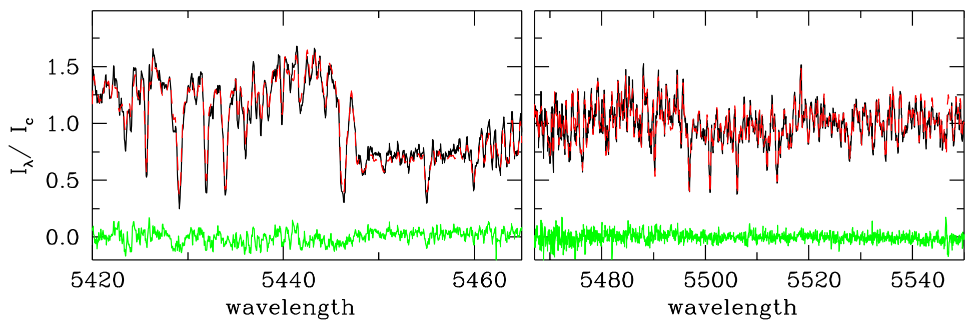


Fig. 1. T CrB (black solid line), the fit (red dashed line), and the residuals (green). *Left panel*: 71 Peg is used (83% contribution of the giant). *Right panel*: 57 Psc is used (88% contribution of the giant).

## 3. Contribution of the Red Giant

The photometric $V$-band has effective wavelength 5445.43 Å and central wavelength 5512.10 Å (*e.g.*, Rodrigo and Solano 2020). We selected two regions on our spectra around these wavelengths to calculate the contribution of the red giant. We used the following procedure:

1. we normalize the spectra to the average value (the local continuum)
2. we multiply the spectrum of the red giant with a factor from 0.05 to 1.00 with a step of 0.01
3. we subtract the red giant contribution from the spectra of T CrB
4. we find the value of the scaling factor that produces the minimum of the standard deviation of the residuals.

This minimum represents the (fractional) contribution of the red giant. This is done for 5420–5460 Å and range 5480–5530 Å, for the two spectra of T CrB, as well as for each of the four red giants listed in Table 2. The results are summarized in Table 3.

Table 3

Contribution of the red giant of T CrB

| | red giant | 5420–5460 Å | 5480–5530 Å |
|---|---|---|---|
| T CrB spec.1 | NV Peg | $0.85 \pm 0.02$ | – |
| T CrB spec.2 | NV Peg | $0.89 \pm 0.01$ | – |
| T CrB spec.1 | XZ Psc | $0.76 \pm 0.02$ | $0.77 \pm 0.03$ |
| T CrB spec.2 | XZ Psc | $0.80 \pm 0.01$ | $0.78 \pm 0.02$ |
| T CrB spec.1 | 71 Peg | $0.78 \pm 0.02$ | $0.76 \pm 0.03$ |
| T CrB spec.2 | 71 Peg | $0.81 \pm 0.01$ | $0.83 \pm 0.02$ |
| T CrB spec.1 | 57 Psc | $0.87 \pm 0.02$ | $0.79 \pm 0.03$ |
| T CrB spec.2 | 57 Psc | $0.90 \pm 0.01$ | $0.86 \pm 0.02$ |

We estimated for the first spectrum contribution of the red giant $0.82 \pm 0.05$ to the wavelength range 5420–5460 Å and $0.77 \pm 0.02$ to the 5480–5550 Å. For the second spectrum the contribution of the red giant is $0.85 \pm 0.05$ and $0.84 \pm 0.05$, respectively. Using the simultaneous $V$-band photometry: (1) for the first spectrum we estimate an average $V$-band band magnitude of T CrB $9.953 \pm 0.015$, contribution of the red giant $80\% \pm 4\%$, and apparent magnitude of the red giant $m_V = 10.20 \pm 0.07$, (2) for the second spectrum – average $V$-band magnitude of

T CrB $9.950 \pm 0.014$, contribution of the red giant $84\% \pm 5\%$, and apparent magnitude of the red giant $m_V = 10.14 \pm 0.06$. The overall result from the two spectra is $m_V = 10.17 \pm 0.06$ mag.

We adopt a distance to T CrB of $d = 914$ pc (Schaefer 2022), which is similar to the value $d = 890$ pc (Bailer-Jones *et al.* 2021) based on the Gaia EDR3 (Gaia Collaboration 2021). We also adopt interstellar extinction $E_{B-V} = 0.07$ mag (Nikolov 2022). This value is consistent with the Galactic dust reddening maps by Schlegel *et al.* (1998) and Schlafly and Finkbeiner (2011), which give an upper limit $E_{B-V} \leq 0.071$ mag (calculated with the NASA/NED extinction calculator). Using $M_V = m_V - 3.1E_{B-V} - 2.5\log[(\mathrm{d}/10)^2]$ mag, we estimate the absolute *V*-band magnitude of the red giant of T CrB as $M_V = +0.14 \pm 0.08$. This value refers to our 22 August 2024 observations, which are on orbital phase 0.49 (calculated with the ephemeris $P_{\mathrm{orb}} = 227.5687$ d, $\mathrm{JD}_0 = 2447918.62$ by Fekel *et al.* 2000).

## 4. Discussion

In the recurrent nova T CrB the red giant is ellipsoidally shaped. The ellipsoidal variability was first demonstrated by Bailey (1975). Later, Lines *et al.* (1988) analyzed the ellipticity effect at *UBVRI* bands and Yudin and Munari (1993) – in J band. The red giant is stable - its *V*-band light curve has not changed in its main features over two decades (Zamanov *et al.* 2004). The stability of the red giant is better defined in the IR observations (Yudin and Munari 1993, Shahbaz *et al.* 1997), where an upper limit of variability $\Delta J < 0.02$ has been constrained. The red giant fills its Roche lobe and transfers material via the Lagrangian point $L_1$ at a rate $\approx 10^{-8}$ $M_\odot$/yr (Selvelli *et al.* 1992, Zamanov *et al.* 2023).

We find $M_V = +0.14 \pm 0.08$ mag on orbital phase 0.49, close to the maximum of the ellipsoidal variation. The amplitude of the ellipsoidal variation is 0.4 mag, and at the minimum it would be $M_V \approx +0.55$ mag. Based on previous estimations the value of the absolute magnitude of M4III giant would be an $M_V = -0.6$ and for an M5III star $M_V = -0.1$ (*e.g.*, Table 2 in Straizys and Kuriliene 1981). It is worth noting that other studies give slightly brighter values:

$M_V{=}-0.94$ mag for M4III, $M_V{=}-0.69$ mag for M5III (Thé *et al.* 1990)

$M_V{=}-0.5$ mag for M4III, $M_V{=}-0.3$ mag for M5III (Schmidt-Kaler 1982)

$M_V{=}-1.0$ mag for M4III, $M_V{=}-0.7$ mag for M5III (Mikami and Heck 1982).

Our result has a lower value than in the literature so far for such giants. Kenyon and Fernandez-Castro (1987) on the basis of TiO, VO and NaI infrared doublet classified the cool component of T CrB as M$4.1 \pm 0.3$III. Mürset and Schmid (1999) using TiO band head $\lambda$8432 (see their Table 3) find M4.5III–M5III. Our results indicate that even at the maximum of the ellipsoidal variations, its absolute *V*-band magnitude is fainter than that of an average M4III–M5III giant. This is probably a result of the evolution of the binary system (*e.g.*, Chen *et al.* 2010), that produced a red giant with a smaller radius and/or lower mass compared to the average value of a giant of the same spectral class – a result of the mass loss towards the compact object and that the red giant is confined (restricted) by the Roche lobe.

The estimated magnitudes of the red giant could be useful:

1. for disentangling the composite spectrum of the system (*e.g.*, Skopal 2005) before, during and after the nova outburst
2. to model the ellipsoidal variability (*e.g.*, Belczynski and Mikolajewska 1998)
3. to study possible changes in the red giant – its atmosphere is expected to be ionized by the nova explosion (*e.g.*, Page *et al.* 2020)
4. the irradiation by the cooling white dwarf during the secondary maximum (Munari 2023).

## 5. Conclusions

We performed simultaneous spectral (2.0 m Rozhen telescope) and photometric (40 cm Shumen telescope) observations of the recurrent nova T CrB on 22 August 2024. Using spectra of red giants of M4III-M5III spectral types obtained in the same night, we estimate for the red giant of T CrB apparent and absolute $V$-band magnitudes $m_V = 10.17 \pm 0.06$ and $M_V = +0.14 \pm 0.08$, respectively.

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