New Astronomy 47 (2016) 7–15

Contents lists available at ScienceDirect

New Astronomy

journal homepage: www.elsevier.com/locate/newast

The 2015 super-active state of recurrent nova T CrB and the long term evolution after the 1946 outburst☆

Ulisse Munari[a,*], Sergio Dallaporta[b], Giulio Cherini[b]

[a] INAF Astronomical Observatory of Padova, via dell'Osservatorio 8, 36012 Asiago (VI), Italy
[b] ANS Collaboration, c/o Astronomical Observatory, 36012 Asiago (VI), Italy

HIGHLIGHTS

- In 2015 T CrB has entered a phase of unprecedented high activity.
- Similar to what the star underwent in 1938, a few years before its 1946 nova outburst.
- High ionization conditions, [NeV], OIV and a strong HeII in emission.
- Wind of the M3III companion almost fully ionized, enhanced irradiation of its side facing the WD.
- Disappearance of the orbital modulation from B-band lightcurve, now fully dominated by nebular emission.

ARTICLE INFO

Article history:
Received 1 January 2016
Accepted 18 January 2016
Available online 1 February 2016

Keywords:
Novae
Cataclysmic variables
Symbiotic binaries

ABSTRACT

The recurrent nova T CrB has entered in 2015 a phase of unprecedented high activity. To trace something equivalent, it is necessary to go back to 1938, before the last nova eruption in 1946. The 2015 super-active state is characterized by: a large increase in the mean brightness (ΔB=0.72 mag over the underlying secular trend), vanishing of the orbital modulation from the *B*-band lightcurve, and appearance of strong and high ionization emission lines, on top of a nebular continuum that overwhelms at optical wavelengths the absorption spectrum of the M giant. Among the emission lines, HeII 4686 attains a flux in excess of Hγ, the full set of OIII and NIII lines involved in the Bowen fluorescence mechanism are strong and varying in intensity in phase with HeII 4686, and OIV and [NeV] are present. A large increase in the radiation output from the hot source is responsible for a large expansion in the ionized fraction of the M giant wind. The wind is completely ionized in the direction to the observer. A high electron density is supported by the weakness of forbidden lines and by the large amplitude and short time scale of the reprocessing by the nebular material of the highly variable photo-ionization input from the hot source. During the super-active state the nebula is varying to and from ionization-bounded and density-bounded conditions, and the augmented irradiation of the cool giant has changed the spectral type of its side facing the WD from M3III to M2III, i.e. an increase of ~80 K in effective temperature.

1. Introduction

T CrB is one of the few known Galactic recurrent novae (Warner, 1995; Schaefer, 2010), with outbursts recorded in 1866 and 1946. They have been spectacular events, peaking around 2.0 mag (Pettit, 1946), displaying nearly identical lightcurves characterized by an extremely fast rise to maximum and a rapid decline, taking t_2=3.8 days to decline by 2 mag (Paine-Gaposchkin, 1957). The spectroscopic evolution (Sanford, 1946; 1949) was – in modern terms – that of an He/N nova (Williams, 1992), reaching very high ionization conditions as indicated by the presence of strong [FeX] and [FeXIV] coronal lines (Sanford, 1947). Peculiar to T CrB is the presence on both outbursts, of a secondary, fainter and broader maximum ~110 days past the primary maximum, which physical nature is still debated (e.g. Webbink, 1976; Cannizzo and Kenyon, 1992; Selvelli et al., 1992; Ruffert et al., 1993).

The donor star in T CrB is an M3III, filling its Roche lobe (Bailey, 1975; Yudin and Munari, 1993), on a 227.55 day orbit (Kenyon and Garcia, 1986; Fekel et al., 2000) around a WD companion (Selvelli et al., 1992; Belczynski and Mikolajewska, 1998). The presence of a cool giant makes T CrB also a member of the class of symbiotic binaries (Allen, 1984; Kenyon, 1986), similarly to the other symbiotic recurrent novae RS Oph, V745 Sco and V3890 Sgr (Munari, 1997).

☆ Communicated by P.S. Conti.

* Corresponding author. Tel.: +39 424 600033; fax.: +39 424600023.
E-mail address: ulisse.munari@oapd.inaf.it (U. Munari).

http://dx.doi.org/10.1016/j.newast.2016.01.002
1384-1076/

Table 1
Our BVR_CI_C photometric observations of T CrB. The full table is available electronically via CDS, a small portion is shown here for guidance on its form and content.

JD (−2,450,000)	UT date	B	Err	V	Err	R_C	Err	I_C	Err	Id
7277.328	2015 09 11.828	11.058	0.011	9.821	0.004	8.839	0.010	7.447	0.005	11
7283.296	2015 09 17.796	11.188	0.009	9.954	0.008	8.973	0.009	7.566	0.006	11
7284.322	2015 09 18.822	11.103	0.009	9.914	0.012	8.930	0.006	7.533	0.006	36
7286.289	2015 09 20.789	11.029	0.008	9.860	0.009	8.917	0.009	7.536	0.012	11
7287.285	2015 09 21.785	10.931	0.011	9.878	0.011	8.875	0.009	7.593	0.013	11
7291.294	2015 09 25.794	10.809	0.008	9.830	0.011	8.914	0.006	7.585	0.008	36
7300.256	2015 10 04.756	10.763	0.012	9.829	0.010	8.877	0.007	7.579	0.006	36
7301.260	2015 10 05.760	10.802	0.010	9.814	0.007	8.888	0.012	7.624	0.007	11

The brightness in quiescence ($V \sim 10$ mag) and the favourable position on the sky (absence of seasonal gaps in the observability from the northern hemisphere), have fostered continued interest and study of T CrB. In quiescence, typical symbiotic binaries display a rich and high ionization emission line spectrum (comprising [NeV], [CaV], [FeVII], HeII, and Raman scattered OVI), superimposed to the absorption spectrum of the cool giant, with the nebular continuum veiling in the yellow, and overwhelming in the blue, its molecular absorption bands (Allen, 1984; Munari and Zwitter, 2002; Skopal, 2005). As a symbiotic binary, the optical quiescence spectrum of T CrB is atypical in showing very little else than the M3III absorption spectrum. Most of the time, only a weak emission in Hα is noticeable on low resolution spectra (Kenyon, 1986). On rare occasions, a surge in activity causes the optical spectrum of T CrB to show something more typical of symbiotic binaries, e.g. Balmer lines and continuum in emission, and sometimes even the appearance of a weak HeII 4686 in emission (Iijima, 1990; Anupama and Prabhu, 1991).

In this paper we report on the super-active conditions displayed by T CrB during 2015 (in the following SACT-2015 for short), conditions never seen before. SACT-2015 appears to be much stronger, both photometrically and spectroscopically, than previous periods of enhanced activity recorded after the 1946 nova outburst.

2. Observations

BVR_CI_C optical photometry of T CrB is regularly obtained since 2006 with ANS Collaboration telescopes N. 11 and 36, located in Italy in Trieste and Cembra, respectively. The star has been observed on 205 nights, from May 11, 2006 to Dec 20, 2015. The operation of ANS Collaboration telescopes is described in detail by Munari et al. (2012) and Munari and Moretti (2012). The same local photometric sequence, calibrated by Henden and Munari (2006) against Landolt equatorial standards, was used at both telescopes on all observing epochs, ensuring a high consistency of the data. The BVR_CI_C photometry of T CrB is given in Table 1, where the quoted uncertainties are the total error budget, which quadratically combines the measurement error on the variable with the error associated to the transformation from the local to the standard photometric system (as defined by the photometric comparison sequence). All measurements were carried out with aperture photometry, the long focal length of the telescopes and the absence of nearby contaminating stars not requiring to revert to PSF-fitting.

Low resolution spectra of T CrB were obtained with the 1.22 m telescope + B&C spectrograph operated in Asiago by the Department of Physics and Astronomy of the University of Padova. The CCD camera is a ANDOR iDus DU440A with a back-illuminated E2V 42-10 sensor, 2048 × 512 array of 13.5 μm pixels. It is highly efficient in the blue down to the atmospheric cut-off around 3250 Å. The spectral dispersion is 2.31 Ang/pix and the spectral resolution is constant at ∼2.2 pix, with the spectra extending from ∼3300 to ∼8050 Å. The slit width has been kept fixed at 2 arcsec, and the slit always alligned with the parallactic angle for optimal absolute flux calibration.

High resolution spectra were obtained with the Echelle spectrograph mounted on the 1.82 m Asiago telescope. It is equipped with an EEV CCD47-10 CCD, 1024 × 1024 array, 13 μm pixel, covering the interval $\lambda\lambda$ 3600−7300 Å in 30 orders, at a resolving power of 20,000 and without inter-order wavelength gaps.

3. Photometric evolution during 2006–2015

The 2006–2015 BVR_CI_C lightcurves of T CrB from our CCD observations of Table 1 are plotted on the left panel of Fig. 1. The much brighter state of T CrB in 2015 is evident, with increasing revelance toward shorter wavelengths. On the right panel of Fig. 1, the 2006–2014 data (preceeding SACT-2015) are phase plotted against the orbital ephemeris

$$\mathrm{Min}I = 2431933.83 + 227.55 \times E \qquad (1)$$

which gives the epochs of primary minima (passages of the M3III companion at inferior conjunction) for the orbital period derived by Kenyon and Garcia (1986) and Fekel et al. (2000). The resulting phased lightcurve is dominated by the well-known ellipsoidal distortion of the M3III giant, first reported by Bailey (1975) at optical wavelengths and by Yudin and Munari (1993) in the infrared. The over-plotted curves are simple fits to guide the eye, in particular to demonstrate that: (*a*) the amplitude of the ellipsoidal modulation, as given by the fitting curves, is ΔB=0.63, ΔV=0.49, ΔR_C=0.42, and ΔI_C=0.34 mag; (*b*) the secondary minimum (phase 0.5, WD passing at inferior conjunction) is shallower at shorter wavelengths, a fact due to the irradiation of the cool giant by the hot WD companion; and (*c*) the dispersion of points around the fitting curves increases toward shorter wavelengths and is well in excess of the small observational errors (cf Table 1). The reason for that is associated with the erratic behavior of accretion phenomena in the system. In fact, a long record of observations document a large amplitude *flickering* affecting time series observations of T CrB (e.g. Zamanov and Bruch, 1998; Zamanov et al., 2004; Gromadzki et al., 2006; Dobrotka et al., 2010).

The photometric data on T CrB secured during SACT-2015 are not inserted in the right panel of Fig. 1, which only deals with the preceding quiescence. The SACT-2015 data are instead plotted in Fig. 2, against the same ephemeris as used for Fig. 1, from which the polynomial fits are also copied. From Fig. 2 we infer that: (i) the shorter the wavelength, the larger the increase in brightness during SACT-2015: compared with preceding quiescence (as given by the fitting curves in Figs. 1 and 2), the increase is ΔB=0.72, ΔV=0.28, ΔR_C=0.21, and ΔI_C=0.09 mag; (ii) during SACT-2015, the orbital modulation disappears from the B lightcurve, and the depth of secondary minimum (orbital phase 0.5) is reduced in the V and R_C lightcurves; and (iii) contrary to previous high states that did not influence T CrB brightness at longer wavelengths, the effect of SACT-2015 extends well into the far red, with all I_C measurements laying above the polynomial fit to quiescence data. Anticipating