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# The problem of the high mass of the hot component in the recurrent nova T Coronae Borealis solved after 38 years

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**Abstract.** In this paper, we present long-term spectroscopic observations of the recurrent nova (RN) T CrB obtained between the years 1985 and 1996 using 1.02 m and 2.34 m telescopes of the Vainu Bappu Observatory in India and the long-term photoelectric photometry of the object obtained mainly at the Skalnaté Pleso Observatory and at the Hlohovec Observatory in Slovakia. On the basis of our results, we have returned to the re-analysis of the old radial-velocity measurements published by Kraft (1958). The results obtained solve unambiguously the problem of the apparently too high mass of the hot component of T CrB, unacceptable if it has to be a white dwarf (WD), as several independent lines of evidence suggest.

**Key words:** stars: individual: T CrB – novae, cataclysmic variables – white dwarfs

## 1. Introduction

The recurrent nova T CrB has become the first cataclysmic variable (CV) studied spectroscopically when it reached the brightness of 2nd magnitude during its outburst in May 1866. Huggins (1866) then observed the hydrogen emissions superimposed on a weak absorbtion-line spectrum through a visual spectroscope. The object was studied intensively immediately after its second outburst in February 1946 when T CrB became the brightest recurrent nova in history. The photometric observations were published by Pettit (1946) who compared the development of the light curves of both large outbursts of this nova that have been recorded up to now, i.e., in 1866 and 1946.

Sanford (1949) detected for the first time the radial velocity variations resulting from the orbital motion with a period of 230.5 days. The most precise analysis of the radial velocities of both components was presented by Kraft (1958) who determined the orbital elements of the binary system as well as the masses of both components. The radial velocity curve adopted from his paper is displayed in Fig. 1. Kraft's work has played the crucial role in further development of opinions related to T CrB, this involving especially the mass of the hot component derived by him. The re-analysis of Kraft's radial-velocity curve by Paczyński yielded a mass of the hot component still above the Chandrasekhar limit, reaffirming the opinion of the other researchers that the hot component of T CrB is a main-sequence star. A very interesting flare-like increase in the UV colour was announced by Ianna (1964). This brightness increase by one magnitude was fairly rapid and it was followed by a slower irregular decline. After 90 minutes the brightness had dropped to the previous level. A similar light variation with the amplitude of 0.5 mag has previously been recorded by Walker (1957). The ephemeris with a more accurate period of the orbital motion was published by Bailey (1975). Afterwards, further authors (Plavec et al. 1973; Harmanec 1974; Webbink et al. 1987; Kenyon and Garcia 1986) sought for many years the most persuasive reasoning in favour of a model of T CrB with a main-sequence star as the hot component. This trend has only begun to be reversed through the work by Selvelli, Casatella and Gilmozzi who in several papers published the results of their observations of T CrB obtained mainly with the help of IUE satellite. The most important of these papers is Selvelli et al. (1992) in which all the physical properties, behaviour and outburst of T CrB are interpreted in terms of a thermonuclear runaway (TNR) on a massive white dwarf. In spite of this, the problem of the too large mass of the hot component of this recurrent nova remained unsolved, as shown by still discussed alternative triple system model of T CrB (Gilmozzi et al. 1991) with the hot component consisting of a WD and a main-sequence star. In addition, Peel (1990) has pointed out the marginal presence of stellar activity in T CrB in the vicinity of the phase 0.5 on the basis of an UV flare (Ianna 1964) as well as of the visual brightening.

Anupama and Prabhu (1991) have shown that the emission lines in the quiescent spectrum of the T CrB are variable. After removing the slow variation, an orbital-phase-dependent variation becomes apparent in the $H_\alpha$ line. The slow variation indicates secular changes in the accretion disc possibly caused by a variable mass transfer rate. Harrison et al. (1993) have studied the RS Oph/T CrB subclass of recurrent novae on the basis of IR spectroscopic and photometric observations. For T CrB, using the infrared colors, they derived a visual extinction of Av = 0.35 ± 0.05 mag similar to the value Av = 0.47 found from UV

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spectra by Casatella et al. (1982). The red giant in the T CrB system appears to be normal.

The observed K magnitude implies a distance of 1020 pc, the absolute visual magnitude at maximum of the 1946 outburst of T CrB was then Mv = -8.4 and the outburst luminosity L = $1.8\text{x}10^5$ $L_\odot$. T CrB was included in the first systematic survey of the near-infrared ($1-2.5\mu$m) spectra of cataclysmic variables by Ramseyer et al. (1993). Of all the observed systems, T CrB shows the strongest absorption features. The spectrum is consistent with the spectral type of M3 III determined from optical spectra (Adams and Joy 1921). The spectrum of T CrB is more similar to the spectra of giants than supergiants. The small dillution of nonstellar light at 2.2 micron agrees with previous optical and ultraviolet studies, which found that the flux from the accretion disk and hot companion is confined to the UV region (Selvelli et al. 1992). Dobrzycka et al. (1996) studied the short time light variations of T CrB and found that the presence and the characteristics of its flickering activity are apparently not correlated with the system's orbital phase.

Hric et al. (1997) have performed the period analysis of the long-term photoelectric data. They found a 227.355 days period for B and V colours. The more detailed period analysis, including the visual brightness estimates, was published by Leibowitz and Ofek (1997) and Leibowitz, Ofek and Mattei (1997). It was of a considerable assistance for them to be able to use more than 52 000 brightness estimates obtained by the AAVSO members between 1961 and 1996. Quite surprising is the 9 840-day period detected by them, with an amplitude of 0.09 mag. These authors consider that the origin of this variability is not in the M giant of the system. It originates probably in or near the hot component, possibly in an accretion disc around it. The long-term variability may also have originated in a light source that does not take part in the binary revolution, such as a light-emitting outer envelope of the system. Anupama (1997) studied the variations of the emission line strengths and detected the most significant periods of 3 640 days, 906 days and 113,76 days. Further photoelectric observations were published by Zamanov and Zamanova (1997) and Mikolajewski et al. (1997). More recently, Shahbaz et al. (1997) tried to model the light curve in the J band, using a model with a cold spot extending approximately 20°around the libration point between the primary and the secondary. However, they do not explain more closely how such a strong cooling of the convective envelope of the giant (by 750 K from the initial temperature of about 3 500 K) could happen. But the authors started with the incorrect assumption of the mass ratio of the system's components. Their conclusion about the mass of the compact component being 1.9 ± 0.6 $M_\odot$, allegedly still in accord with the mass permitted for a white dwarf, is a little bit peculiar. On the contrary, we think that their value of the mass permits the existence of the main sequence star with a mass overlapping the Chandrasekhar limit. Of more interest is their finding that secondary minima are deeper than the primary ones in all the observed bands, i.e., in I, J, H, K, where the radiation of the cool component is dominant.

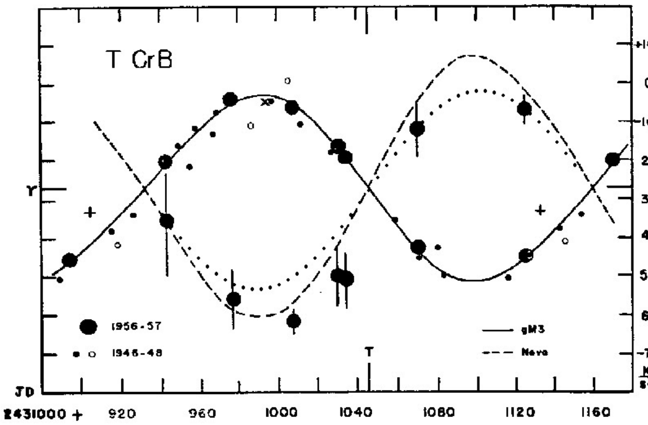

**Fig. 1.** The radial velocity curve adopted from Kraft's paper (1958). Our solution of the orbital elements is depicted schematically by the dotted line.

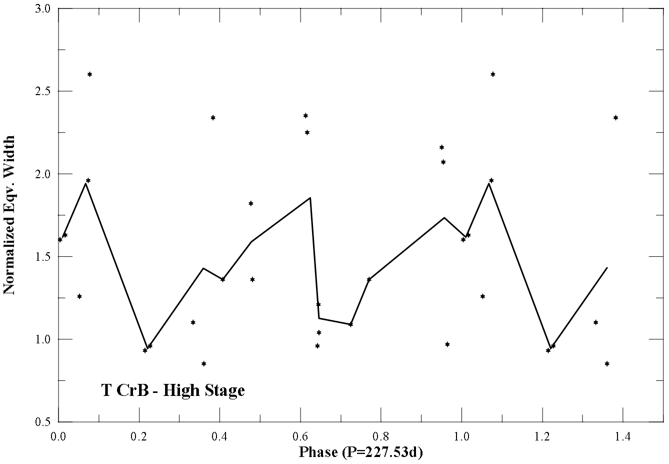

**Fig. 2.** The equivalent widths of the $H_\alpha$ lines in the high stage plotted in the phase diagram. The discrete points represent discrete values, while the solid line represents averaged values (maximally 5 points). Two maxima occurring near 0.5 and 1.0 phases are visible.

## 2. Observations

The spectroscopic observational material consists of long-term monitoring of T CrB between the years 1985 and 1996. The equivalent widths of selected spectral lines ($H_\alpha$, $H_\beta$, He I 5876 and He I 6678) were obtained using the 1.02 m and 2.34 m telescopes of Vainu Bappu Observatory in India. The equivalent widths were measured as follows: the spectra were reduced to a continuum level estimated as a smooth curve through the absorption bandheads. The equivalent widths of an emission line was measured as the area enclosed by the emission profile above the local continuum, which may lie in an absorption band. The equivalent widths are hence the total emission-line fluxes referred to the overall continuum of the star. According to Anupama and Prabhu (1991) 30 % variation in the broadband R flux is much smaller in magnitude compared to the long-term variation of $H_\alpha$ emission-line equivalent width indicating that the latter variation is dominated by intrinsic variations of line flux. It is hence unlikely that the emission enhancement is due

**Table 1.** Photoelectric observations of T Coronae Borealis.

| $\mathrm{JD}_{hel}$ -2 400 000 | U | B | V | R | Obs | $\mathrm{JD}_{hel}$ -2 400 000 | U | B | V | R | Obs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 47969.479 | 12.46 | 11.80 | 10.34 | - | W | 50096.611 | 12.08 | 11.46 | 10.00 | 8.79 | SP |
| 48014.460 | 11.76 | 11.37 | 10.02 | - | W | 50103.651 | 11.50 | 11.35 | 9.99 | 8.80 | SP |
| 48042.412 | 11.77 | 11.35 | 9.96 | - | W | 50104.615 | 12.04 | 11.47 | 10.07 | 8.86 | SP |
| 48088.400 | 11.84 | 11.58 | 10.26 | - | W | 50105.641 | 12.15 | 11.52 | 10.13 | 8.90 | SP |
| 48089.409 | 11.73 | 11.54 | 10.28 | - | W | 50106.632 | 12.02 | 11.53 | 10.17 | 8.95 | SP |
| 48095.408 | 11.50 | 11.50 | 10.28 | - | W | 50114.658 | 11.48 | 11.28 | 10.11 | 8.87 | SP |
| 48100.384 | 11.98 | 11.68 | 10.33 | - | W | 50115.586 | 11.72 | 11.49 | 10.13 | 8.91 | SP |
| 48147.279 | 12.04 | 11.34 | 9.91 | - | W | 50139.574 | 11.15 | 11.31 | 10.25 | 9.07 | SP |
| 48174.228 | 12.14 | 11.46 | 10.07 | - | W | 50140.542 | 11.23 | 11.38 | 10.26 | 9.08 | SP |
| 48177.226 | 12.12 | 11.46 | 10.11 | - | W | 50142.521 | 12.33 | 11.77 | 10.37 | 9.10 | SP |
| 48180.224 | 11.91 | 11.49 | 10.16 | - | W | 50151.551 | 11.86 | 11.65 | 10.30 | 9.07 | SP |
| 48187.212 | 12.38 | 11.62 | 10.23 | - | W | 50152.484 | 11.65 | 11.60 | 10.32 | 9.09 | SP |
| 48332.576 | 12.46 | 11.77 | 10.36 | - | W | 50168.499 | 12.15 | 11.60 | 10.17 | 9.03 | SP |
| 48356.466 | 12.71 | 11.35 | 9.97 | - | B1 | 50240.402 | 11.57 | 11.55 | 10.21 | 9.01 | SP |
| 48359.487 | 12.68 | 11.58 | 10.09 | - | W | 50268.406 | 10.51 | 10.98 | 9.96 | 8.83 | SP |
| 48404.432 | 12.13 | 11.47 | 10.09 | - | W | 50274.437 | 11.12 | 11.19 | 10.01 | 8.84 | SP |
| 48446.452 | 12.40 | 11.67 | 10.25 | - | SP | 50286.364 | 11.40 | 11.24 | 9.97 | 8.79 | SP |
| 48461.406 | 12.25 | 11.54 | 10.05 | - | W | 50422.662 | 11.42 | 11.17 | 9.94 | 8.77 | SP |
| 48504.307 | 12.73 | 11.60 | 10.04 | - | SP | 50429.652 | 10.98 | 10.97 | 9.85 | 8.70 | SP |
| 48647.700 | 12.18 | 11.71 | 10.28 | - | SP | 50439.679 | 11.16 | 11.10 | 9.92 | 8.76 | SP |
| 48666.670 | 12.46 | 11.86 | 10.34 | - | SP | 50457.691 | 11.66 | 11.41 | 10.13 | 8.93 | SP |
| 48681.610 | 12.63 | 11.72 | 10.19 | - | SP | 50464.620 | 11.31 | 11.34 | 10.14 | 8.96 | SP |
| 48691.510 | 12.65 | 11.63 | 10.10 | - | SP | 50517.538 | 11.79 | 11.30 | 9.98 | 8.80 | SP |
| 48748.420 | 12.24 | 11.63 | 10.19 | - | SP | 50520.527 | 11.96 | 11.35 | 9.98 | 8.80 | SP |
| 48829.429 | 12.23 | 11.43 | 9.99 | - | SP | 50520.561 | 12.03 | 11.42 | 9.99 | - | SL |
| 49026.582 | 13.16 | 11.75 | 10.25 | - | SP | 50528.473 | 11.97 | 11.37 | 9.98 | 8.77 | SP |
| 49034.594 | 12.18 | 11.45 | 10.03 | - | SP | 50539.531 | 11.50 | 11.22 | 9.92 | 8.75 | SP |
| 49050.543 | 11.85 | 11.36 | 9.97 | - | SP | 50547.524 | 11.54 | 11.23 | 9.97 | 8.79 | SP |
| 49125.409 | 12.15 | 11.74 | 10.35 | - | SP | 50562.451 | 10.90 | 10.99 | 9.90 | 8.75 | SP |
| 49249.295 | 11.73 | 11.53 | 10.22 | - | SP | 50629.398 | 10.70 | 11.04 | 9.95 | 8.78 | SP |
| 49351.703 | 12.04 | 11.70 | 10.41 | - | SP | 50583.577 | 10.91 | 11.01 | 10.01 | - | HL |
| 49421.586 | - | 11.72 | 10.16 | 8.92 | SP | 50604.438 | 10.13 | 10.80 | 9.92 | - | HL |
| 49477.403 | 13.11 | 11.88 | 10.32 | 9.07 | SP | 50609.488 | 10.53 | 11.02 | 10.05 | - | HL |
| 49518.409 | - | 11.31 | 9.94 | - | K | 50629.487 | 10.12 | 10.98 | 9.85 | - | HL |
| 49519.339 | - | 11.20 | 9.85 | - | K | 50685.376 | 10.64 | 11.14 | 9.99 | - | HL |
| 49521.335 | - | 11.22 | 9.87 | - | K | 50687.385 | 10.75 | 11.15 | 10.03 | - | HL |
| 49523.336 | - | 11.25 | 9.87 | - | K | 50692.340 | 10.55 | 11.08 | 9.94 | - | HL |
| 49524.353 | - | 11.29 | 9.90 | - | K | 50707.353 | 10.95 | 11.40 | 10.20 | - | HL |
| 49537.335 | - | 11.37 | 10.04 | - | K | 50712.328 | 10.98 | 11.24 | 10.08 | - | HL |
| 49540.511 | - | 11.39 | 10.06 | - | K | 50714.328 | 10.80 | 11.15 | 10.07 | - | HL |
| 49890.334 | - | 11.41 | 10.28 | - | K | 50718.331 | 10.85 | 11.24 | 10.11 | - | HL |
| 49891.321 | - | 11.39 | 10.22 | - | K | 50721.332 | - | 11.27 | - | - | HL |
| 49892.336 | - | 11.38 | 10.22 | - | K | 50728.304 | 10.67 | 10.95 | 9.91 | - | HL |
| 50095.611 | 11.91 | 11.42 | 10.00 | 8.80 | SP | 50745.281 | 10.37 | 10.89 | 9.71 | - | HL |

**Obs = observatory :** W - Wroclaw, B1 - Brno, SP - Skalnaté Pleso,
K - Kryonerion, SL - Stará Lesná, HL - Hlohovec

to a decrease in the continuum. The results obtained as well as the style of the reduction of the observational material were presented in detail in the paper by Anupama and Prabhu (1991).

The photometric observational material was obtained in the frame of an international photometric campaign (Hric et al. 1996a and references therein), initiated in 1989, and further in the frame of the Call for the Long Term Photometric Monitoring Campaign of Cataclysmic Variable Stars and Related Objects (Hric et al. 1996b). The majority of the observations in the UBVR system was obtained at the Skalnaté Pleso (SP), Stará Lesná (SL) and Hlohovec (HL) observatories using 0.6-m Cassegrain telescopes and single channel pulse-counting photo-

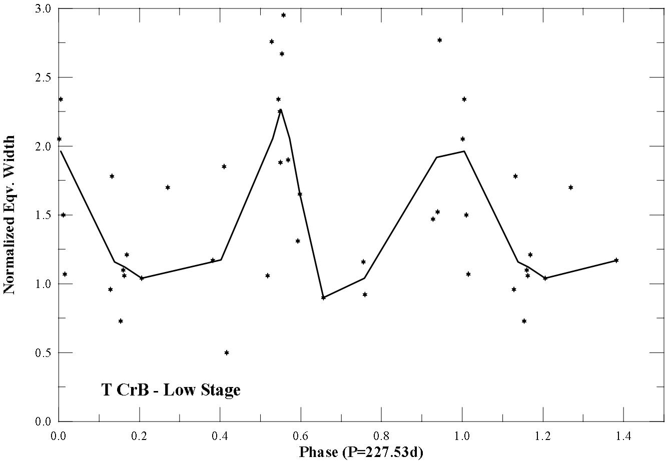

**Fig. 3.** The equivalent widths of the $H_\alpha$ lines in the low stage plotted in the phase diagram. The discrete points represent discrete values, while the solid line represents averaged values (maximally 5 points). Two maxima occurring near 0.5 and 1.0 phases are visible.

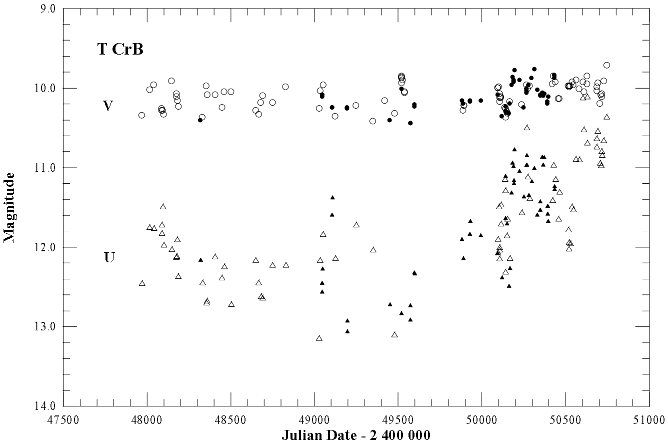

**Fig. 4.** The long-term V and U photometry. The light curve shows very steep increase of the brightness in the U colour.

electric photometers. During the reduction of the observations, the seasonal extinction coefficients and transformation coefficients to the international UBVR system were used. The greatest accuracy of the observations was achieved at the SP, which has resulted from the higher elevation of this mountain observatory (1780 m above the sea level). Our observational material was obtained in 88 nights, covering the interval from March, 1990 to October, 1997. The data are presented in Table 1. In the Figs. 4 - 9 our observations are depicted by open marks and data from literature by filled marks.

## 3. Spectroscopic behaviour

In spite of an intense and extensive (multifrequency) study of the recurrent nova T CrB, the problem of the mass of its hot component remained unsolved. The high mass of the compact component in the binary contradicted the observational facts suggesting the presence of a white dwarf. In order to overcome this contradiction, Gilmozzi et al. (1991) even proposed a triple model for the system, in which the hot component would be a close binary consisting of a white dwarf and a main-sequence star whose sum of masses would correspond to the mass of the hot component determined on the basis of a reanalysis of Kraft's data.

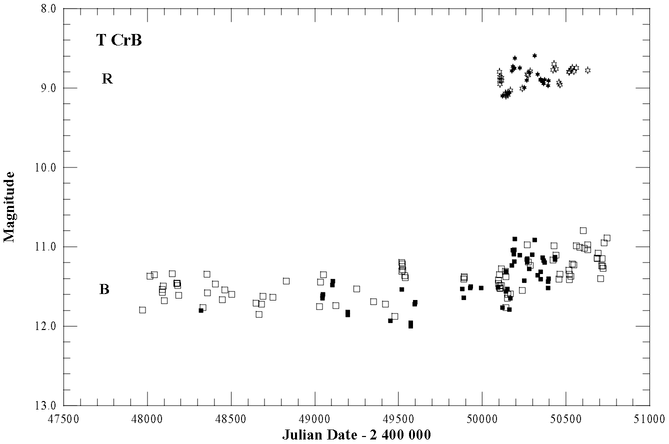

**Fig. 5.** The long-term R and B photometry. An increase of the brightness is slightly visible in the B colour.

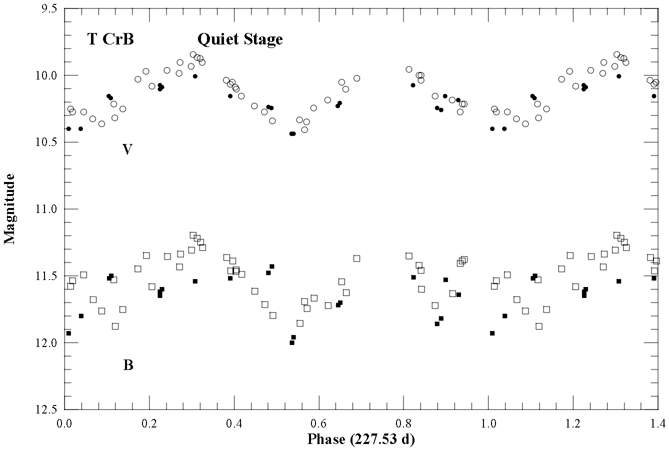

**Fig. 6.** The light variations with the orbital phase in the V and B colours during the quiescence stage.

A new view of this problem has been brought about by the analysis of long-term spectroscopic observations. We have divided spectroscopic data into two subsets according to the continuum level - high stage and low stage data. We have plotted the dependence of our normalized equivalent widths on the orbital phase with the period of 227.53 days (Kenyon and Garcia 1986) and $JD_0$ = 2 435 571.0 from spectroscopy according the data published by Kraft (1958) in Figs. 2 and 3. In our phasing, the red giant is in front at the phase 0. It is apparent from the phase diagram that two maxima at phases 0.5 and 1.0 occur during the orbital cycle, corresponding to the brightness minima in the light curve. The large scatter of data in Figs. 2 and 3 is caused by the fact that data from many cycles are superposed in these phasing diagrams, as well as by the fact that it is not possible to eliminate the influence of the other physical processes which manifest themselves in the binary system studied.

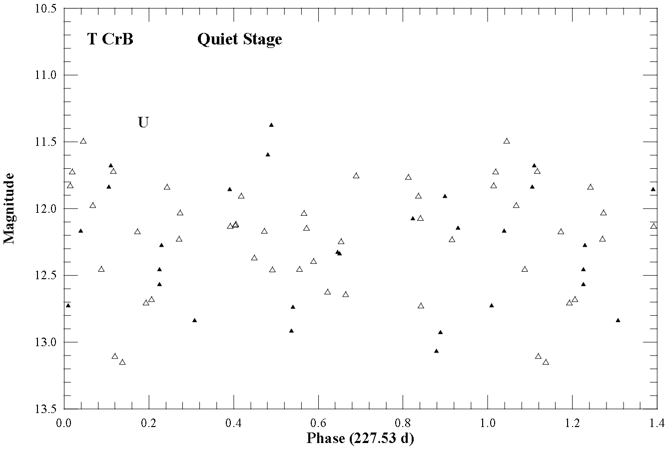

**Fig. 7.** The light variations with the orbital phase in the U colour during the quiescence stage.

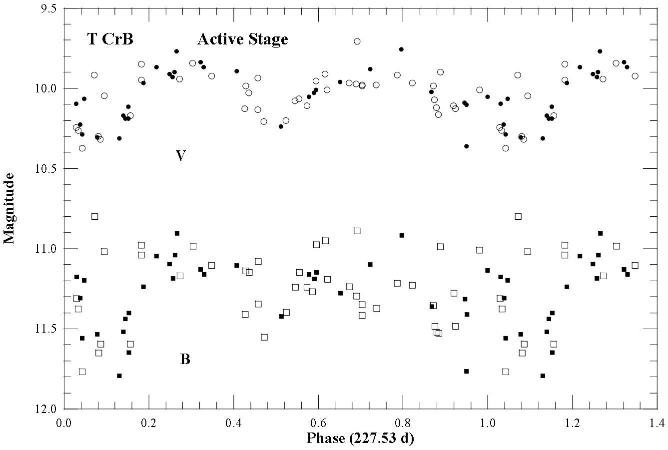

**Fig. 8.** The light variations with the orbital phase in the V and B colours during the active stage.

Such a behaviour can be explained by the presence of two emission-line regions localized in the great volume of space available between the system components. One of these regions can probably be identified with the mass stream flowing out from the red giant through the inner Lagrangian point $L_1$. The second one is located quasi-symmetrically with respect to the line connecting both system components and is fed by that part of matter flowing around the compact component which is not trapped by the accretion disc. Such hydrodynamical processes and a gravitational instability of the emission-line regions indicated in the system of red giant and white dwarf with the accretion disc does not contradict the results of particle trajectories modelling through the numerical integration (Vetešník 1997). It is further apparent from Figs. 2 and 3 that the increase towards the maximum is slower than the decline which could be explained by the eccentric shape of the emission-line regions mentioned above. Of course, the whole process of mass transfer is more complicated because there occurs shock regions formation in the vicinity of the hot component, as it was computed in detail by Bisikalo et al. (1996).

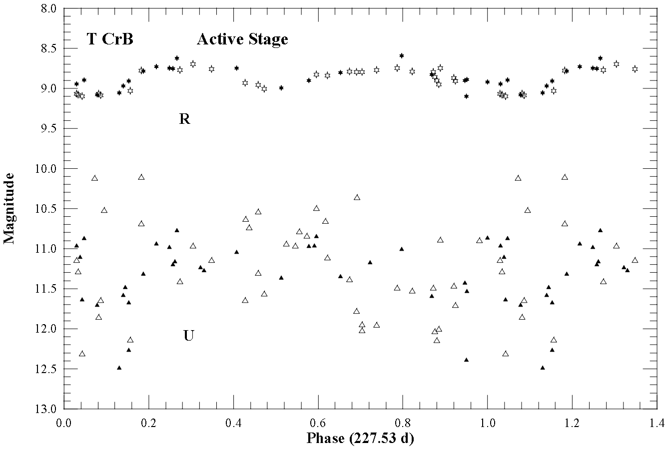

**Fig. 9.** The light variations with the orbital phase in the U and R colours during the active stage.

In such a model of the system, the emission lines will not reflect just the orbital motion of the hot component, because the presence of the mass stream will influence the profiles of the emission lines. The stream of matter manifests itself in the radial-velocity curve in a way similar to the Barr effect (Barr 1908, Struve 1948). For this reason, we have returned to the analysis of the radial-velocity curve (Fig. 1 according to Kraft, 1958) in which it is visible that the negative values of the RV are overestimated mainly before the phase 0.5 when the stream is probably best visible in the emission. The values in the phases of $\approx$ 0.6 and 0.85 are probably minimally affected. In these phases the stream would only produce weak components in the wings of line profiles which would hardly affect the radial velocity of the central parts of line profiles. Although these two values do not suffice to the precise computation of the orbital elements of the hot component, we have tried to use them for the computation of the mass of both components of the binary. For our computations, we have used the program by Kratka (1990) based on the simplex method. This program consists in the optimization method of computation of the spectroscopic orbital elements.

Assuming the inclination of the system to be 68° (see e.g. Kraft 1964, Paczyński 1965, Kenyon and Garcia 1986), we have obtained the masses M$_g = 1.38 M_\odot$ for the giant and M$_{wd} = 1.2 M_\odot$ for the hot component. The higher is the inclination, the lower is the mass of the hot component (for more detailed explanation see Fig. 4 in Kenyon and Garcia 1986). According to our orbital element solution, the lower limit for the inclination of the system is $61\overset{\circ}{.}5$ for which the mass of the white dwarf leads the Chandrasekhar limit. Thus, we can draw an unambiguous conclusion that the mass of the hot component in the system studied does not exceed the Chandrasekhar limit. So there is no obstacle to the adoption of the model of T CrB in which the hot component is a "single" white dwarf, making the triple model unnecessary.

The model of T CrB with the emission-line regions presented by us describes well the behaviour of the equivalent widths of the $H_\alpha$ emissions reaching the maxima at phases around 0.0 and 0.5. Also the observations of the UV fluxes published by Selvelli et al. (1992) are well correlated with this model.

Of course, there is another explanation to be invoked by Figs. 2 and 3 combined with 6, 7 and 8. The variation in the equivalent width of $H_\alpha$ may be simply a reflection of the variation in the continuum. Nevertheless, this was neglected by us as the inapropriate because of the reasons published in the section Observations.

Our preliminary attempt to model the shape of two emission line regions on the basis of spectroscopic behaviour (slow increase to the maximum and steeper decrease of the equivalent widths - see Figs. 2 and 3) gave us the solution of the ellipsoidal shape of these regions. A detailed modelling of that is beyond the scope of this paper.

## 4. Photometric behaviour

In what follows, we shall try to demonstrate that the model of T CrB we are proposing is able to explain also the observed brightness changes of this object. The historical UBVR light curve of T CrB is depicted in Figs. 4 and 5. The regular light variations in B, V and R colours are caused by the ellipsoidal effect of the irradiated red giant. However, it is posssible to deduce from the behaviour of the long-term light curves that at the end of January 1996 there occurred an abrupt brightening of T CrB, most pronounced in the U colour in which the brightness of the object gradually increased by more than 2 magnitudes at the end. The brightness increase in the B colour was less than one magnitude. From this it follows that we can characterize the overall light curve since March 1990 as consisting of two stages. The stage of quasi-quiescence was in January 1996 substituted by an activity stage continuing until the present. For further analysis, we have divided the data into two groups: i. data from the quasi-quiescence stage until JD = 2 450 102 including and ii. data from the activity stage afterwards. From the data files treated that way, the phase diagrams in the individual colours for both the stages were constructed. We used the same parameters of the period and $JD_0$ as in the Sect. 3.

### *4.1. The Quasi-quiescence stage*

The smoothest phase light curve is the one in the V colour (Fig. 6) which reflects the light changes caused by the ellipsoidal effect of the red giant. The amplitude of these light changes is greater than we should expect for the pure effect, the similar comment was made in this respect also by Shahbaz et al. (1997). Here we wish to suggest a possible explanation as follows. In addition to the fact that the matter flowing out from the red giant caused the emission-line regions, there occurs also a scattering of matter into a substantial part of the Roche lobe of the compact white dwarf. The envelope formed in that way contributes also to the ’ellipsoidal’ effect in the light curve.

The phase light curve in the B colour (Fig. 6) displays the larger scatter which can be explained, for example, by the more pronounced flickering activity toward the shorter wavelengths (this is discussed in the Sect. 5.) but also by the other physical processes with effects dependent on the orbital phase (the visibility of the bright spot, etc.). The remarkable effect apparent in the phase diagram in the B colour is a signigficant brightness decrease in the vicinity of phase 0.9, not visible at all in the V colour. Such a behaviour can be explained through the eclipse of some part of the hot component by the emission-line region present in the system.

The light variations in the U colour displayed in the constructed phase diagram (Fig. 7) do not correlate with the behaviour of light curves in the previously mentioned colours, but the general trend suggests that they are in antiphase with respect to light curves in the other colours. Such an anticorrelation is much more pronounced in the active stage (Fig. 9). Such a behaviour can be explained by the Balmer discontinuity within the medium heated to 6 000 - 10 000 K with the simultaneous absorption of light by the ionization of electrons from the second energy level in the hydrogen atoms. In our case, the light source is the hot component and the role of absorbing region is fulfilled by the emission-line regions. The more pronounced anticorrelation in the active stage is probably caused by the increased mass transfer and the larger number of ionized particles within the emission-line region.

### *4.2. The active stage*

On the basis of Figs. 8 and 9, we can generally state that in the activity stage the phase light curves in all colours display a larger scatter which is caused mainly by the superposition of the individual cycles of gradually increasing brightness level.

In the V colour, the ellipsoidal effect is still observed.

In the B colour, the light variations are correlated with those in the V, although the resulting light curve displays larger scatter.

The light variations in the U colour exhibit unambiguous anticorrelation with the light curves in the other three colours.

During the activity stage of T CrB, we managed to obtain also the photometric data in the R colour. Their behaviour markedly correspond to the ellipsoidal effect. Here we need to point out an interesting fact that it is possible to see a significant brightness decrease at around phase 0.9 in all four colours. It is possible to identify such a behaviour with the increase in the mass transfer rate within the system during the activity stage.

On the basis of the analysis of light curves in both stages, we can see an interesting fact that the brightness minimum occurs earlier in the active stage than in the quasi-quiescence stage. In order to determine the value, we have used only secondary minima. We have determined the times of minima in phased data according to parameters (period and $JD_0$) mentioned in Sect. 3, using several methods (parabola fitting, center mass, Kwee Van Worden, sliding, Kordylewski method). The results were virtually the same. On the basis of this analysis, we can state that the secondary minimum occurs $(6.4 \pm 1.1)$ days earlier in the activity stage than in the quasi-quiescence stage. As for the primary minimum, we have obtained a smaller difference which is caused by the larger scatter of data in its vicinity.

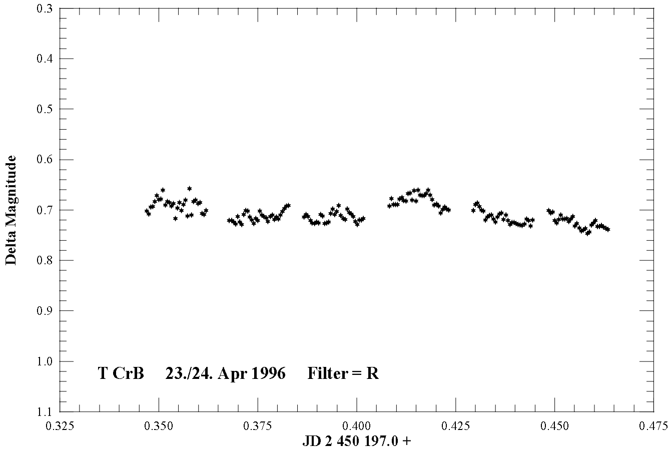

**Fig. 10.** The flickering activity during one night observation in the R filter.

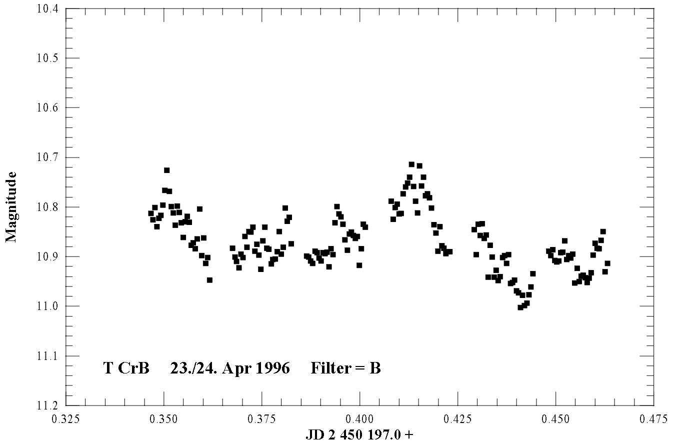

**Fig. 12.** The flickering activity during one night observation in the B filter.

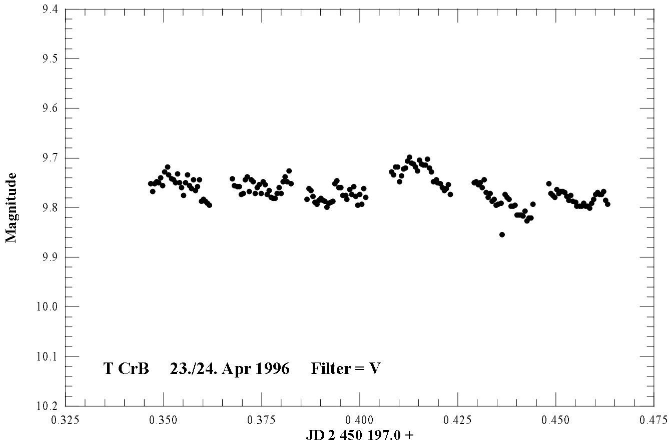

**Fig. 11.** The flickering activity during one night observation in the V filter.

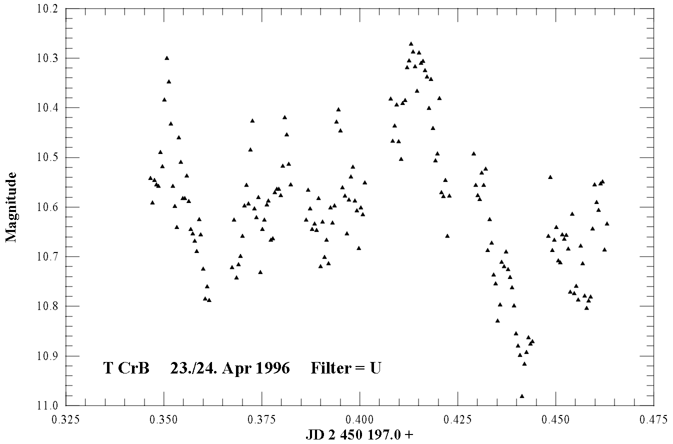

**Fig. 13.** The flickering activity during one night observation in the U filter.

## 5. Flickering activity

We have directed the efforts within our new observational campaign also to the obtaining of longer observational runs. One of the possibilities opened up that way is to study the dependence of the properties of the flickering activity on wavelength or, eventually, on the orbital phase. The preliminary analysis of selected runs showed strong increase in the amplitude of the flickering with the decreasing wavelength. One example of such run, obtained on April 23/24, 1996 at the Skalnaté Pleso Observatory, is displayed subsequently for R, V, B and U colour in Figs. 10, 11, 12 and 13, respectively. The corresponding amplitudes are 75, 150, 300 and 600 millimagnitudes, respectively.

## 6. Summary and discussion

In this paper, we have tried to describe the model of the T CrB system in the light of the most recent observational facts. We interpret the observed maxima of equivalent widths of selected emission lines in the phase diagram by the presence of two emission-line regions within the binary system. The ongoing mass transfer in the system has forced us to reanalyze Kraft's radial velocity curve. We have derived the masses of the components as follows: $M_g = 1.38 \pm 0.2 M_\odot$ and $M_{wd} = 1.2 \pm 0.2 M_\odot$, assuming i = 68°. An anticorrelation of light variations in the U colour with those in the other colours was found. We explain this by the Balmer discontinuity. As for the quasi-quiescence stage, we have detected the brightness decrease in both B and U colours at around the phase 0.9. This was probably caused by the eclipse of some part of the hot component by the emission-line region. We have observed a significant increase in the activity of the system since January 1996. In this activity stage, the secondary minimum occurs earlier than in the quasi-quiescence stage, This is attributable to the increased outflow of matter from the red giant. We have detected an interesting dependence of the properties of the flickering activity on wavelength.

A strikingly similar mass of the hot component was obtained by Belczyński and Mikolajewska (1998), nevertheless we can not agree with their mass ratio (0.6) for the components of the system, because the radial velocity data imply the mass ratio close to 1. We would like to note the following: our model of T Coronae Borealis is based on the spectroscopic observations with the Barr effect included. The semiamplitudes of the radial velocities of both components give us the exact mass ratio. Moreover, our photometric data support this model in many details, while the photometric model of the above mentioned authors uses few free parameters, which can affect the accuracy of the resulting values.

The recurrent nova T CrB represents a unique case of a very wide CV system with a strong mutual interaction between the components. The massive white dwarf accelerates the matter ejected from the cool giant and the part of this matter forms two extended emission-line regions within the volume of the Roche lobe of the hot component. The radial velocities of the emission lines, obtained mainly at phases 0.0 - 0.5, do not reflect just the orbital motion of the hot component and thus it is not possible to deduce its mass solely on the basis of them. Only the measurements obtained outside the phases indicated above can be used for the mass determination. In such a way, we have obtained the mass of the hot component of T CrB *not* exceeding 1.4 $M_{\odot}$. We can conclude unambiguously that the problem of the too high mass of the hot component of this CV, unacceptbale for several basic reasons, is finally, after 38 years, solved.

The method of the mass determination of the accreting component of the system presented above is generalizable to all the binary systems in which the observed values of the radial velocities are influenced by the stream of matter for which there is a sufficient number of RV measurements in the appropriate phases of the orbital cycle. It is probable that there are many binary systems in which the component masses are, in fact, overestimated due to such an influence.

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