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RESEARCH

Recent observations of humps and superhumps and an estimation of outburst parameters of the AM CVn star CR Boo

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Abstract
We present our observational results of AM CVn star CR Boo in the UBVR bands. Our observational campaign includes data obtained over 5 nights with the National Astronomical Observatory Rozhen, Belogradchik, and the AS Vidojevica telescopes. During the whole time of our observations the brightness of the system varied between 13.95 – 17.23 in the B band. We report the appearance of humps during the period of quiescence and superhumps during the active state of the object, (where the latter are detected on two nights). We obtain the superhumps periodicity for two nights, $P_{sh} \approx 24.76 - 24.92$ min. The color during maximum brightness is estimated as $-0.107 < (B-V)_0 < 0.257$ and the corresponding temperature is in the range as $7700\ [\mathrm{K}] < T(B-V)_0 < 11\ 700\ [\mathrm{K}]$. We found that CR Boo varies from bluer to redder in the nights with outbursts activity. The star becomes bluer during the times of superhumps.

Keywords Stars: binaries · White dwarfs · Stars: individual: CR Boo

1 Introduction

AM CVn stars are short-period binary stars in which a white dwarf accretes helium-rich material from a low-mass donor star. Their orbital periods ranges between 5–65 minutes (Podsiadlowski et al. 2003; Solheim 2010). The AM CVn stars are rare and unusual objects. Their study can give us information about the properties of the accretion flow and the compact objects themselves. By their short orbital periods and variations in photometry and spectroscopy, the AM CVn stars could also be classified as interacting binary white dwarfs or Double White Dwarf binaries (DWDs). Their main feature is that both binary components are degenerated dwarfs, the white dwarf accretes from another white-dwarf companion (Nelemans et al. 2001; Paczyñski 1967; Faulkner et al. 1972).

The formation of AM CVn stars currently follows two known models. The first model (Tutukov and Yungelson 1979; Nather et al. 1981) is valid after common envelope phases, then the configuration consists of two degenerate dwarfs in a formation of a close binary star (Paczyñski 1976; Iben and Tutukov 1984; Webbink 1984). The second model describes the detached system with a semidegenerate helium star and a white dwarf companion is formed, after more than two mass-transfer phases. There is also a third, less probable channel of formation (Solheim 2010), when the donor evolves from a low-mass main-sequence star (Podsiadlowski et al. 2003).

The mass transfer between white dwarfs is a defining process in the evolution of AM CVn stars. Its stability or destabilization has a significant effect on the white-dwarf binary configuration (Marsh et al. 2004). When the mass transfer is in progress, while the mass ratio decreases, their orbital separation increases. At a further evolutionary point of the AM CVn objects, the direct accretion (i.e., the matter that inflows directly to the primary star or the accretor star) stops and this leads to the formation of an accretion disc. The mass-transfer rate changes over time, according to the binary orbital separation and also depends on the angular-momentum loss in the system (Marsh et al. 2004; Gokhale et al. 2007).

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According to some theoretical calculations (Tutukov and Fedorova 1989) AM CVn stars could be a subpart of the close binary evolution branch. Thus, they can ensure observational information to investigate the physics of helium-accretion discs (Kato et al. 2000).

It has been possible to detect the AM CVn stars by the existence mainly of helium-emission lines in their spectra, since they are faint objects with an average magnitude of 12–17 (Wood et al. 1987; Provencal et al. 1997; Patterson et al. 1997; Kato et al. 2000).

The AM CVn stars manifest brightness variability usually in the range of 2–4 magnitude at optical wavelengths, detected by the observational analysis (Isogai et al. 2016; Kato et al. 1999, 2000, 2009) or by theoretical models (Tsugawa and Osaki 1997). The outbursts are also reported for the AM CVn objects with orbital periods ranges from 20–50 min (van Roestel et al. 2021).

The AM CVn stars can be categorized by the different phases of their evolution (Warner 1995; Tutukov and Yungelson 1996; Nelemans et al. 2001): When they have short periods, their mass-transfer rates are high and the systems are in a high state. Quiescent systems have longer periods and lower mass-transfer rates.

In this paper, we study the AM CVn star member CR Boo. With our results of an object like CR Boo, we are contributing to improve the knowledge of the star's color index and to enlarge the observational database. We report our observational results of CR Boo in Sects. 3.1 and 3.2 and the detected observational effects are described in Sect. 3.3. In Sect. 4 the color index and the temperature are calculated at the maximum brightness. We discuss the appearance of humps and superhumps, and the variations of the parameters in Sect. 5.

2 Target details

CR Boo was discovered in 1986 by Palomar Green (Green et al. 1986) and cataloged as PG 1346+082. The observations of Wood (Wood et al. (1987)) show brightness variability with amplitude 13.0–18.0 mag in the V band. The spectrum of CR Boo shows broad, shallow He I absorption at the active state and He I emission at the quiescence state (Wood et al. 1987). The average orbital period of CR Boo is determined as $P_{orb} = 0.0170290(6)$ days (Provencal et al. 1997; Isogai et al. 2016), which is about 24.5 min ≈ 1471.3 s. We apply these values of P_{orb} in all calculations in this paper. The masses of two components were estimated to be in ranges of: $M_1 = 0.7 - 1.1\ M\odot$ for the mass of the primary and $M_2 = 0.044 - 0.09\ M\odot$ for the mass of the secondary (Solheim 2010; Roelofs et al. 2007).

CR Boo is an interacting double white-dwarf object, in which the white-dwarf primary accretes from the helium white-dwarf companion (Paczyñski 1967; Faulkner et al. 1972; Kato et al. 2000; Nelemans et al. 2004). By its helium-rich atmosphere, CR Boo is classified as a DB spectral-type object (Sion et al. 1983).

In the classification of Solheim (Solheim 2010), the AM CVn objects are divided into groups by their orbital periods and the disc's properties. Since the orbital period of CR Boo is in a range of $20 < P_{orb} < 40$ min, it can be associated to the 3rd group, with a variable size of the disc, producing outbursts or occasional superoutbursts.

CR Boo is categorized in the group of outburst systems (Kato et al. 2000; Groot et al. 2001) with an amplitude variations in brightness of > 1 mag, lasting from days to months. Two individual states of CR Boo have been observed: a faint state, with normal outbursts usually lasting one to five days (Duffy et al. 2021) and regular super outbursts last for several weeks (Isogai et al. 2016; Kato et al. 2013); and a bright state, with frequent outburst activity, sometimes lasting for months (Kato et al. 2013; Honeycutt et al. 2013). The produced high outbursts during the faint state recur with a frequency in a supercycle of about ≈ 46 days (Kato et al. 1999; Kato and Kunjaya 1995). Such behavior is similar to SU Uma-type dwarf novae – a class of cataclysmic variables (CVs) (Warner 1995).

3 Observations and effects

3.1 Technical details and data reduction

We perform ≈ 20 hours of observations of CR Boo, distributed over 5 nights, during different observational campaigns: 1 July, 2019; 5 July, 2019; 16 April, 2020; 12 February, 2021; 4 February, 2022.[1] We report observational data, obtained with four different telescopes: the 2.0-m telescope of the National Astronomical Observatory (NAO) Rozhen, Bulgaria (hereafter 2 m Roz), the 50/70-cm Schmidt telescope (hereafter Sch) of NAO Rozhen, the 60-cm telescope of the Belogradchik Observatory, Bulgaria and the 1.4-m Astronomical Station Vidojevica (hereafter ASV) telescope, Serbia.

The 2-m telescope with a two-channel focal reductor FoReRo2 and two identical CCD cameras Andor iKON-L was used on the nights of: July 1, 2019 in V band, July 5, 2019 in UVR bands, February 12, 2021 in the B, R bands, February 4, 2022 in the UBVR bands. On the night of July 5, the 50/70-cm Schmidt telescope, equipped with CCD camera FLI PL16803 and the 1.4-m telescope at ASV, equipped with the CCD camera Andor iKON-L were used, both in B and R bands. The observations in the B band were also

[1] Note: Date formats used in this paper: YYYY-MM-DD and DD Month, Year.

Table 1 List of observations of CR Boo in UBVR

Date	Band	Telescope	Exp.time [s]	start / end [UT]	max/min [mag]	Avr [mag]	Error
2019-07-01	V	2 m Roz	60	19:41 / 21:03	16.17 / 16.35	16.26	±0.01
2019-07-05	U	2 m Roz	300	19:50 / 21:19	15.85 / 16.11	15.98	±0.04
	B	50/70 Sch	120	20:15 / 20:30	16.78 / 17.23	17.04	±0.1
	B	Vid	30/60	20:28 / 21:22	16.87 / 17.08	16.98	±0.02
	V	2 m Roz	60	19:42 / 21:22	16.74 / 17.00	16.89	±0.02
	R	Sch	90	20:08 / 21:22	16.51 / 16.93	16.74	±0.1
2020-04-16	B	60 Bel	90	23:58 / 02:05	13.95 / 14.15	14.06	±0.02
2021-02-12	B	2 m Roz	60/50/40	23:55 / 02:03	14.13 / 14.21	14.17	±0.01
	V	2 m Roz	40	02:26 / 02:40	14.08 / 14.14	14.12	±0.005
	R	2-m Roz	20	23:54 / 02:04	14.14 / 14.26	14.22	±0.01
2022-02-04	U	2 m Roz	300	02:40 / 03:56	14.23 / 14.49	14.33	±0.01
	B	2 m Roz	50	23:20 / 02:32	15.24 / 15.49	15.39	±0.01
	V	2 m Roz	60	02:40 / 03:56	14.98 / 15.21	15.08	±0.005
	R	2 m Roz	20	23:20 / 02:32	15.11 / 15.36	15.26	±0.01

obtained with the 60-cm telescope of the Belogradchik Observatory (with CCD camera FLI PL16803), performed on 16 April, 2020 (hereafter 60 Bel).

Data reduction was performed with standard tools for processing of CCD images and aperture photometry. Photometric standards were applied.

Six comparison stars are chosen in the field of CR Boo (see Fig. 8 in the Appendix). Based on the B and V magnitudes published in the APASS9 catalog, the photometry of these comparison stars was performed over all available frames in these bands. Using r' and i' data from APASS9, Rc, and Ic are calculated on the 3 different relations from Fukugita et al. (1996) and in the same way we obtained average magnitudes of comparison stars. The magnitudes in the U band for 3 standard stars are obtained using both the new (B–V) and (V–Rc) and the color indices of normal dwarfs published by Pecaut and Mamajek (2013). The obtained stellar magnitudes of the standard stars are given in the Appendix (Table 4).

The stellar magnitude of CR Boo (in a given band) was obtained by ensemble aperture photometry on all field-visible comparison stars.

3.2 Results from observations

During the time of our observations, the apparent magnitude of CR Boo varies between 14.06 and 17.04 in average, in B.

We see that CR Boo changes its brightness states during the time of our observations. To be more capable to assess the brightness measurements, we put all the observational data for all 5 nights in Fig. 1.

Further, we give the observational data in details, separately for each day. The journal of all observations is shown in Table 1. In (Boneva et al. 2020) we have reported some initial observational results from July 1, 2019 and July 5, 2019. In the current paper, we make more precise observational analysis on these two nights. We also add data in the R band to the observations on July 5. The obtained light curves are presented in Fig. 2 and Fig. 3. It is seen that the star's average brightness in V decreases with 0.7 magnitudes (Fig. 3), in a period of 5 days. The average amplitude variations of the magnitude in these two nights is ≈ 0.23 and the standard deviation varies in the range $0.04 - 0.1$.

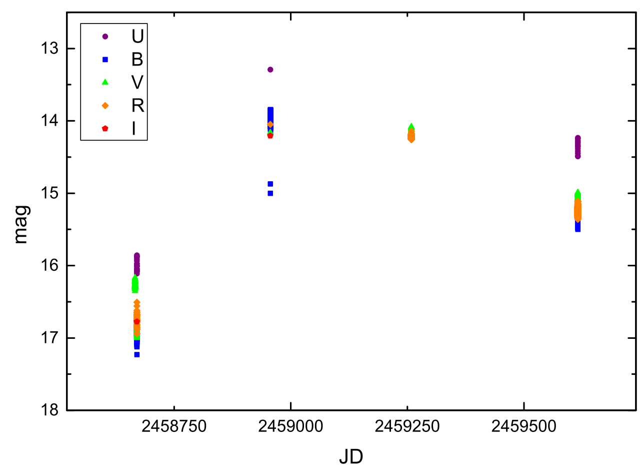

Fig. 1 Light curves of CR Boo for the period of all observations, 2019–2022, in UBVR. The data in the I band was obtained by estimations. The data were received with four different telescopes

On the 3rd night (16 April, 2020), the observable brightness of CR Boo increases with 2–2.5 magnitudes in the B band, compared to the dates in July 2019. The star's magnitude reaches 13.95(±0.02) in B (Table 1), with ≈ 0.15

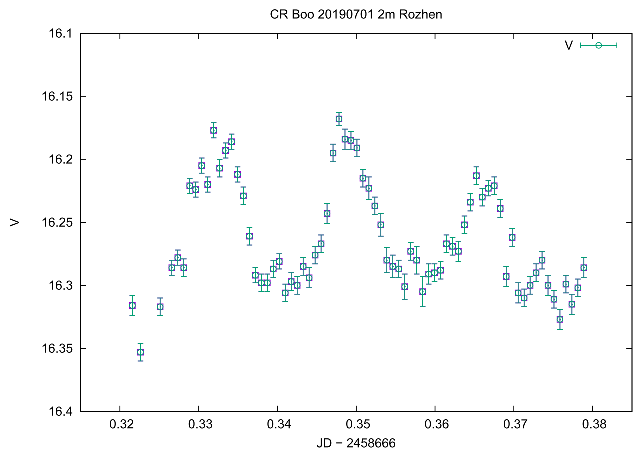

Fig. 2 Light curves of CR Boo: 1 July, 2019 in the V band

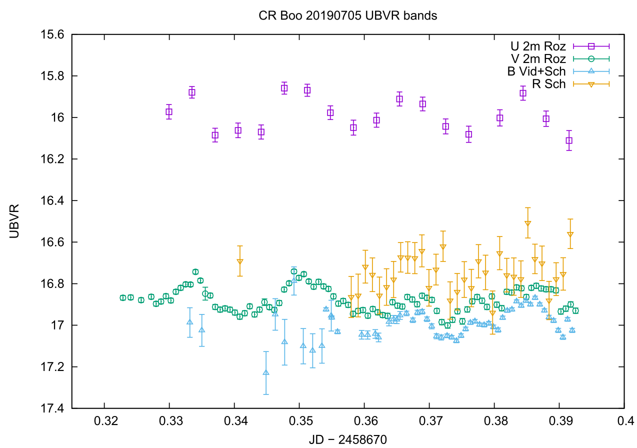

Fig. 3 Light curves of CR Boo: 5 July, 2019 in the UBVR bands. The data are obtained with three different telescopes

amplitude variations and a standard deviation of 0.04. According to the object's details (Sect. 2) and the observable magnitude of CR Boo, we can suggest that on this night the star has been in its outburst state (Fig. 4).

The obtained observational data from 12 February, 2021 show that CR Boo is in its high state, again (Fig. 5) – in comparison to the magnitudes of the nights during the July 2019 campaign. The amplitude variations of the magnitude are in a range: 0.06 – 0.08 and the standard deviation is 0.002 – 0.02.

Our latest observations of CR Boo were performed on 04 February, 2022 (Fig. 6), in UBVR bands. The magnitudes for all bands are given in Table 1. The amplitudes of the variations for all bands are: 0.22 – 0.26 mag and for the corresponding standard deviations we have 0.009 – 0.04. A trend of increase in brightness is seen, more clearly expressed in the U and V bands at the end of the night.

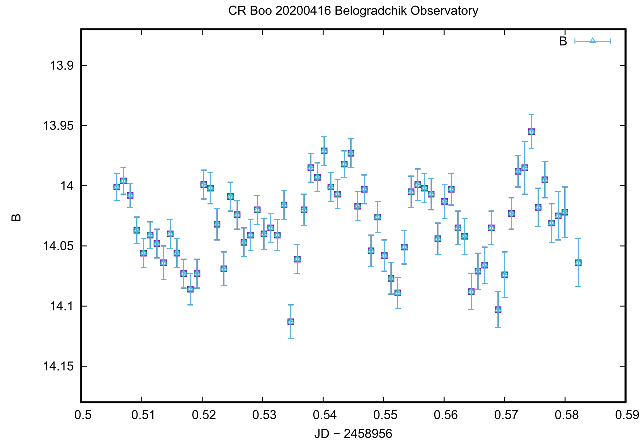

Fig. 4 Light curve of CR Boo: 16 April, 2020, in the B band. The data are obtained with the 60-cm telescope of the Belogradchik Observatory, Bulgaria

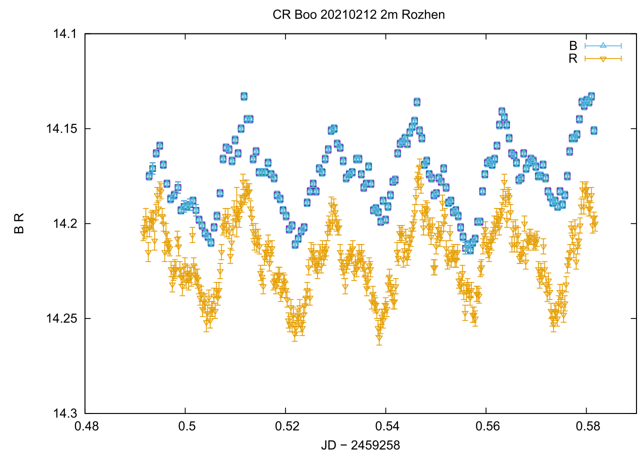

Fig. 5 Light curves of CR Boo: 12 February, 2021 in the BR bands. Superhumps activity is detected in both bands. The data are obtained with the 2-m telescope of NAO Rozhen

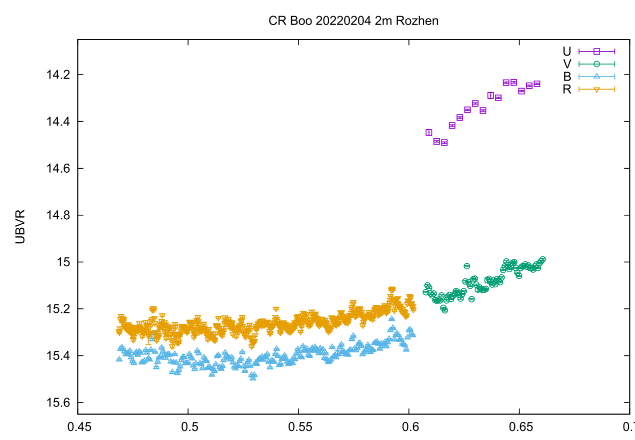

Fig. 6 Light curves of CR Boo: 04 February, 2022 in the UVBR bands. The data are obtained with the 2-m telescope of NAO Rozhen

Table 2 Periodicity of the maximum brightness variations, calculated for each observational night

Parameter Date	P_h [min]	P_{sh} [min]
2019-07-01	23.41 – 24.40 (±0.05)	-
2019-07-05	23.71 – 24.60 (±0.035)	-
2020-04-16	-	24.76 (±0.023)
2021-02-12	-	24.92 (±0.0012)
2022-02-04	4.42 – 10.30 (±0.45)	- -
Ref. values [min]	23.21[a]	(24.79 – 25.44)[b] 24.78[c]

[a](Boneva et al. 2020)
[b](Isogai et al. 2016)
[c](Patterson et al. 1997)

3.3 Observational effects. Humps and superhumps

During the times of our observations, two observational effects are clearly distinguished. They appeared as short-period, low-magnitude brightness variations. The authors recognized them as humps and superhumps (Isogai et al. 2016), (Kato et al. 2000). The humps are observed in the quiescence low state of the cataclysmic variables and AM CVn stars. They appear with a periodicity P_h similar to the binary orbital period. On the other hand, the superhumps' periodicity P_{sh} is a few percent longer than the binary period and they can be observed during the outbursts state of the objects (Warner 1995).

Using the observational data of CR Boo (Sect. 3.2), we obtain the periodicity of the maxima in brightness variations for each observational night. To analyze these periodicities, we apply the PDM (Phase Dispersion Minimization) method by Stellingwerf (1978). We also check our results with additional software packages, such as an OnLine based PGRAM (exoplanetarchive.ipac.caltech.edu) and PerSea (Maciejewski and Niedzielski 2005) based on a fast and statistically optima period search in an uneven sampled observation method by Schwarzenberg-Czerny (Schwarzenberg-Czerny 1996).

The measured period of the amplitude variations on July 1 and July 5 (see Table 2) is approximately the same (with a difference of $\pm 0.07 - 0.2$ min) as the orbital period of 24.5 min.

In the previous section, we defined that on the first two nights the object was in its quiescent state. Following the above terminology, these periodic small-scale amplitude variations in the magnitude of CR Boo could be related to the manifestation of humps, more clearly seen in the U and V bands. The humps are also called orbital humps, since they usually appear regularly with the orbital period.

On the second two nights, 16 April, 2020 and 12 February, 2021, CR Boo is in its outburst state (see Sect. 3.2). The estimated average periodicities of the maximum brightness (see Table 2) on 2020-04-16 and on 2021-02-12 are slightly ($\approx 1.5\%$) higher than the orbital period of the binary. The observed brightness variations then are assumed to be an appearance of superhumps. These values are close to the estimated superhumps periods of CR Boo in the analysis of Patterson et al. (1997) and Isogai et al. (2016).

On the last date, 04 February 2022, the star was in a condition with a rising brightness during the night. In a frame of ≈ 90 minutes its magnitude increased by ≈ 0.26 mag in the U and V bands. It was probably transitioning to an outburst state. Brightness variations with small amplitudes of $0.023 - 0.110$ mag are observed in the B and R bands. These brightness variations have very short periodicity, in the range of $4.42 - 10.30$ min. We found that they look much more like quasiperiodic oscillations in a stage before the star is turning to the higher state.

4 System parameters: color index and temperature

The observations in UBVR filters on July 5, April 16th, February 12th, and February 4 allow us to estimate the color indices of CR Boo. Following the data, we obtain the indices values at average brightness of these four nights.

The dereddened color indices $(B-V)_0$ are obtained using the color excess $E(B-V) = 0.013 \pm 0.006$, calculated on the basis of the field-averaged selective extinction $< Av >= 0.04 \pm 0.02$ (Roelofs et al. 2007), excluding the negative results for the Ref. 3 star for CR Boo and the standard extinction law (Cardelli et al. 1989; Fitzpatrick 1999; Indebetouw et al. 2005).

The observed color index on July 5 is slightly larger than zero or ≈ 0, which shows a tendency for the source to become red at maximum brightness. The usually rare observations for CR Boo in the U band, give negative values of the color index $(U-B)_0$ for both nights: 2019-07-05 and 2022-02-04.

Further, using the dereddened color index $(B-V)_0$, we could calculate the color temperature. The formula of (Ballesteros 2012) is appropriate to apply:

$$T\ [\mathrm{K}] = 4600[\frac{1}{0.92(B-V)_0 + 1.7} + \frac{1}{0.92(B-V)_0 + 0.62}]. \tag{1}$$

Table 3 Color index and color temperature for the four observational dates

Date / Parameter	2019-07-05	2020-04-16	2021-02-12	2022-02-04
$U-B$	-1.09 ± 0.04	-0.772 ± 0.04	-	-1.06 ± 0.04
$(U-B)_0$	-1.097 (± 0.04)	-0.782 (± 0.04)	- -	-1.071 (± 0.05)
$B-V$	0.12 (± 0.02)	-0.094 (± 0.023)	0.054 (± 0.021)	0.27 (± 0.03)
$(B-V)_0$	0.109 (± 0.04)	-0.107 (± 0.03)	0.041 (± 0.02)	0.257 (± 0.04)
$B-R$	0.27 ± 0.03	-	-0.042 ± 0.021	0.13 ± 0.01
$V-R$	0.15 ± 0.05	0.110 ± 0.05	-	-0.15 ± 0.02
$T_{col}(B-V)_0$ [K]	8900 (± 400)	11700 (± 400)	9600 (± 200)	7700 (± 220)

The obtained value for the temperature on July 5th is then: $T(B-V)_0 \approx 8900 \pm 400$ K.

The B–V index on 16 April, 2020 goes from zero to a slightly negative value, which is an indication of a bluer and hotter source of the superhumps events on this night. This results in temperature variations, which reach the value at maximum brightness: $T(B-V)_0 \approx 11700 \pm 400$ K.

The observations during the February 12th, 2021 campaign show that the source of the appeared superhumps is rather redder in relation to the B and U color. Based on the B–V index on the 2021-02-12, the estimation of the average temperature gives a lower value: $T(B-V)_0 \approx 9600 \pm 200$ K, which is in accordance with the reddening of the source.

The lightcurves obtained on February 4, 2022 display the observable trend in brightness. These excursions are typical for CR Boo and were described by Patterson et al. (1997). For that reason, in order to estimate the color indices cited above, we use the average trend values in UBVR bands. The obtained temperature is then:

$$T(B-V)_0 \approx 7700 \pm 220 \text{ K}.$$

The obtained average values of the color indices for each date and the corresponding color temperatures are given in Table 3.

In Fig. 7 we present the color evolution and the temperature gradient through the different states of CR Boo for the time of observations. The figure shows their variations during the humps and superhumps activity (see also Fig. 1).

5 Discussion

AM CVn stars are objects in the final stage of binary-star evolution. They create a medium to study the physical properties of such systems, to obtain more information about the white-dwarf stars and to understand the double white-dwarf evolution, respectively.

5.1 Humps and superhumps production

As we have seen in Sect. 3, the observational results show manifestations of small-scale amplitude semiperiodic variations during the low state of the CR Boo on the first two days of observations (2019-07-01 and 2019-07-05). The similar variations, with a longer period, are observed in the third and fourth nights, when the star is in its outburst state (2020-04-16 and 2021-02-12). Here, we discus the possible sources of their production and their probable positions throughout the accretion disc.

Following the results in Sects. 3.2 and 3.3, our first assumption is that the humps during the dates 2019-07-01 and 2019-07-05 are an exhibition of the orbital humps (Osaki and Meyer 2002). The understanding is that the source of those humps is the periodic appearance of the hot spot, placed in the outer part of the accretion disc. While the CR Boo binary system rotates, the periodical disturbances in the light curve are produced, when the hot spot is at the position facing the direction of observations. This happens in every full rotational cycle and CR Boo is in its quiescence state.

From the geometrical point of view, the orbital inclination of CR Boo, $i = 30°$, (Nasser et al. 2001) could affect the (observable to us) line of sight. In the end, by this configuration a partial effect on the light curve could be detected. This might be the minor disturbances in the brightness, or humps.

It is known that the superhumps during the outburst's activity could be produced by a tidal instability, with an effect of the disc precession (see Hirose and Osaki 1990; Kato and Osaki 2013; Wood et al. 2011; Kato et al. 2017; Warner 1995).

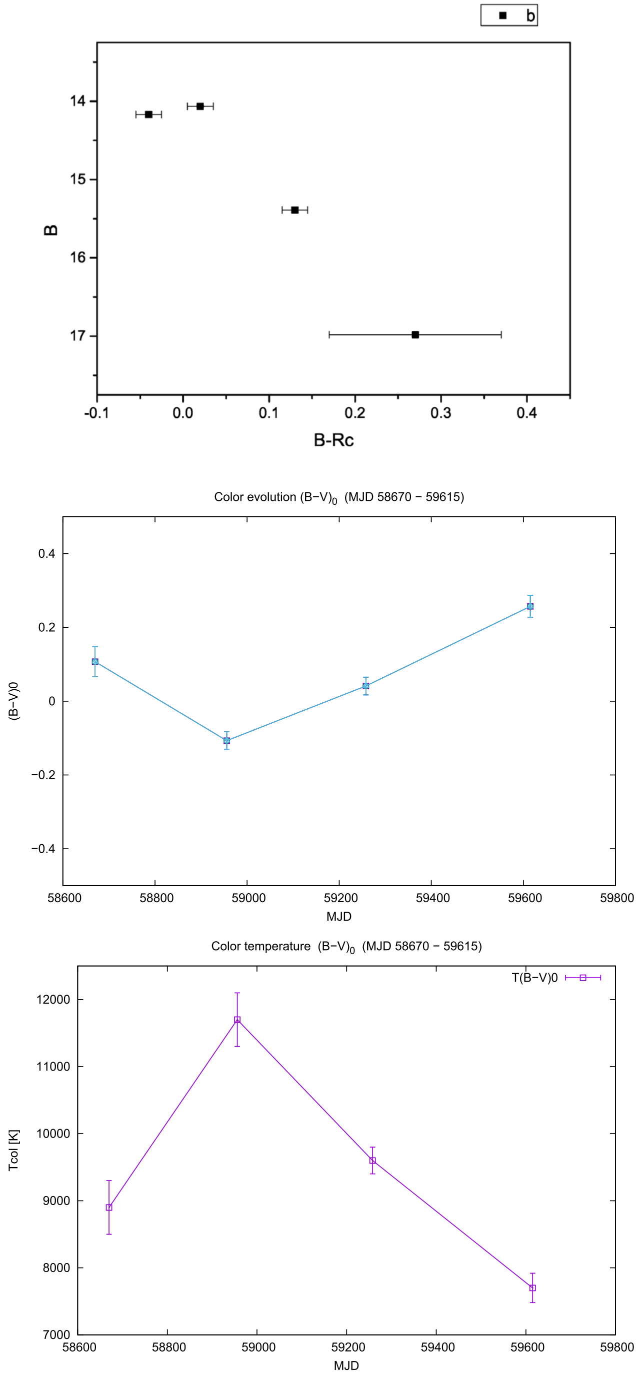

Fig. 7 The color–magnitude diagram B: B-R (upper) presents CR Boo in the outburst state. It is seen that the star becomes bluer and brighter. The color evolution $(B-V)_0$ (middle) and temperature variations (lower) for the period from 2019-07-05 to 2022-02-04, in MJD

The production of superhumps could also be caused by other mechanisms. As a result of interaction, the spiral density wave formation on the outer disc edge could have a significant effect on the light curve and correspondingly on the superhump'production (Simpson and Wood 1998; Kononov et al. 2015). Then, the brightness increases by the energy releases by the density strengthening at the places of spiral-density wave interactions with other disc's shock formations.

As stated above, if a blob exists on the accretion disc surface, its role can be noted here as to its interaction with spiral arms, which leads to the production of short-time oscillations on the light curve.

On the other hand, the tidal wave coming from the secondary star through the Lagrange point L_1 could make the hot-spot parameters (such as its size and density) unstable. This may cause further irregular or fading hump production.

5.2 Variations in parameters

According to the calculated indices (Sect. 4), the color of the star varies from U, B to R, in different states and dates. It becomes ultraviolet and at the same time red (on 2019-07-05), when it is in a low state, with humps activity. When CR Boo is in a low to rising state (on 20220204), with a manifestation of quasiperiodic oscillations, an ultraviolet excess is observed and the star stays redder. We have two different color states of the star, both during the outbursts on two different nights (2020-04-16 and 2021-02-12).

Comparing the results between two of the observational dates (2020-04-16 and 2021-02-12), when the superhumps are observed, it is notable that on the first night (2020-04-16) the object is bluer and its color temperature on this night is a little higher by $\approx 2100 \pm 450$ K than the value of the second night (Table 3). A source of these variations in the temperature in the B band was probably its changed parameters at the later date (2021-02-12), when the star is redder and we have the lower values of temperature.

Many Cataclysmic variables staying in a low brightness state have analogous behavior of their color indices – e.g., MV Lyr (Robinson et al. 1981), KR Aur (Boeva et al. 2006), etc. When they are in a very low state (such as a deep state or a deep minimum), they show a higher temperature and a bluer color, compared to the high state. This could be caused by the appearance in the energy distribution of the white dwarf or the inner hot parts of a weak accretion disk. Comparing CR Boo, by our results, with other AM CVn objects (Rivera Sandoval et al. 2021), we see the star is in contrast to the behavior of binary SDSS 0807 and it is similar to AM CVn SDSS 1411, on the nights of 2019-07-05 and 2020-04-16. On the night of 2021-02-12, CR Boo's color is closely consistent with SDSS 1137 and SDSS 0807. The behavior of our object on 2022-02-04 looks more like SDSS 1411.

In the case of our observations, CR Boo generally becomes redder as its brightness weakens, except on the night of February, 12, 2022. This is probably due to the disc being sufficiently bright, even in the lowest states that we have observed and it is dominating in the system's emission.

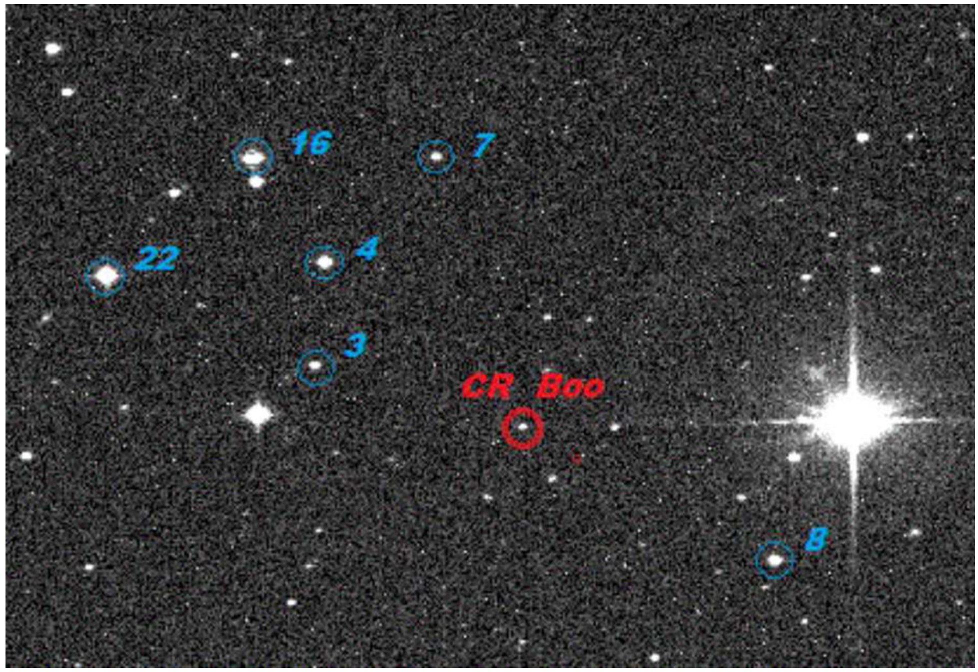

Fig. 8 A chart of comparison stars. The stars are denoted with blue circles and numbers

Table 4 Standard stars photometry (Johnson–Cousins). The stars numbered refer to those in Fig. 8

Star / Band	U	B	V	R	I
(3)	-	16.377 ±0.020	15.545 ±0.010	15.088 ±0.010	14.628 ± 0.05
(4)	16.30 ±0.05	14.959 ±0.030	13.742 ±0.025	12.991 ±0.020	12.373 ± 0.005
(7)	-	16.335 ±0.030	15.758 ±0.010	15.399 ±0.010	15.038 ± 0.05
(8)	-	14.911 ±0.020	14.152 ±0.015	13.762 ±0.030	13.357 ± 0.02
(16)	14.07 ±0.03	13.229 ±0.015	12.259 ±0.015	11.670 ±0.005	11.147 ± 0.01
(22)	12.64 ±0.02	12.621 ±0.015	12.070 ±0.005	11.781 ±0.010	11.472 ± 0.005

The resulting negative value of the color index $U - B < 0$ during our observations is an indication of a hotter radiation zone in the accretion disc around the primary star. The heating parts of the accretion disc could also be responsible for the hump and superhump production.

6 Conclusion

We presented our observational results of AM CVn star CR Boo in the UBVR bands, performed over five nights during different observational campaigns. The data were obtained with the Rozhen National Astronomical Observatory, Belogradchik, and the AS Vidojevica telescopes. The brightness of the system varied between 13.95 − 17.23 in the B band. We confirmed the appearance of humps during the quiescence state and superhumps during the active state in the CR Boo type of objects. The superhumps periodicity is obtained, $P_{sh} \approx 24.76 - 24.92$ min, for the nights, when the object was in its probable outburst state. During the superhumps, the color was $-0.094 < B - V < 0.054$. We calculated the color temperature using the dereddening color indices and it is in the range 9600 [K] $< T(B - V)_0 <$ 11 700 [K]. We observe an increasing temperature during the superhumps observation period, compared to the values of the humps period with an average of 2100 ± 450 K for both nights. The star becomes bluer when it is brighter in times of superhumps. We found that during the two nights with superhump activity, CR Boo has a different behavior: the star became blue on the first night, but it was red on the second night.

Appendix

In Appendix, we present information about the comparison stars, used in the photometric analysis of the recent observations of CR Boo (Sect. 3.1). The chart in Fig. 8 shows the configuration of the stars in the field of CR Boo, where the comparison stars are denoted with numbers and blue circles. The obtained magnitudes of the standard stars are shown in Table 4.

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Author Contribution All authors contributed to the study conception and design. Observations were performed by Svetlana Boeva, Daniela Boneva, Georgi Latev, Yanko Nikolov, and Zorica Cvetković. Material preparation, data collection, and analysis were performed by Svetlana Boeva, Daniela Boneva, Radoslav Zamanov, and Georgi Latev. The text preparation and correction was by Daniela Boneva, Svetlana Boeva, Georgi Latevand, and Wojciech Dimitrov. The first draft of the manuscript was written by Daniela Boneva and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Competing Interests The authors declare that they have no conflicts of interest.

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