**S E S 2 0 2 3**
*Nineteenth International Scientific Conference*
SPACE, ECOLOGY, SAFETY
*24 – 26 October 2023, Sofia, Bulgaria*

# SHORT- AND LONG- LASTING OUTBURSTS AND MASS TRANSFER PROPERTIES OF THREE AM CVn STARS

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***Keywords:*** *Stars: Binary stars; Stars: cataclysmic variables; Stars: AM CVn; Accretion*

***Abstract:*** *We present a two years variability in brightness of three AM CVn stars: CR Boo (Bootes), V 803 Cen (Centaurus) and KL Dra (Draconis). We use observational data both from the AAVSO (American Association of Variable Star Observers) and the 2m telescope of the National Astronomical Observatory (NAO) Rozhen. Results show similar behavior in brightness variability, outbursts and the transition from low to high state of the objects CR Boo and V 803 Cen.*

*Base on the objects parameters, we estimate the mass transfer rate during the outbursts states. We compare the mass transfer properties of the three AM CVn stars.*

# КРАТКОТРАЙНИ И ДЪЛГОВРЕМЕННИ ИЗБУХВАНИЯ И СВОЙСТВА НА ТРАНСФЕРА НА МАСА ПРИ ТРИ ЗВЕЗДНИ СИСТЕМИ ОТ ТИП AM CVn

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***Ключови думи:*** *Звезди: Двойни звезди; Звезди: AM CVn; Акреция*

***Резюме:*** *Представяме двугодишна променливост в яркостта на три AM CVn звезди: CR Boo (Bootis), V 803 Cen (Centauri) и KL Dra (Draco). Използваме данни от наблюдения както от AAVSO (Американската асоциация на наблюдателите на променливи звезди), така и от 2-метровия телескоп на Националната астрономическа обсерватория (NAO) Рожен. Резултатите показват подобно поведение в променливостта на блясъка, избухванията и прехода от ниско към високо състояние при CR Boo и V 803 Cen.*

*Въз основа на параметрите на обектите, ние оценяваме темпа на пренос на маса по време на избухванията. Направено е сравнение на свойствата на пренос на маса на трите AM CVn звезди.*

## Introduction

The study of AM CVn objects is important, since they are rare and unusual objects. They are subclass of cataclysmic variables (CV) stars [30]. AM CVns are binary stars in which a white dwarf primary component accretes from a secondary helium – rich white dwarf component. As the interaction between the white dwarf companions is observed, they could be attached to the group of Double White Dwarf binaries (DWDs) [4, 19, 21]. The both components are fully- or semi-degenerate white dwarfs. Their orbital periods are very short and range in the interval of 5 – 65 min.

The AM CVn stars manifest outbursts with brightness variability in the range of 2–4 magnitude at optical wavelengths, detected by the observational analysis [9, 13].

Individual brightening states of some AM CVn stars have been distinguished: a faint state, with normal outbursts for one to five days [2]; regular super outbursts for several weeks [9, 13]; and a longer state, lasting for months, but with a frequent outburst activity [8, 13].

Some of the outbursts in AM CVns could be produced by the mass-transfer enhancement [25]. The mass transfer between the two components of AM CVn stars plays an important role in their evolutionary path. The mass transfer rate depends on the angular momentum loss in the system. During the mass transfer process, its value changes over time and is in a relation to the binary orbital separation variations and mass ratio [5, 16]. The mass-transfer rate is increasing, while the separation is narrowing for shorter orbital periods.

For the purpose of this paper, three of the short-orbital's period AM CVn objects are selected, CR Boo, V 803 Cen and KL Dra. They show characteristics as ordinary AM CVns.

CR Boo was discovered in 1986 by Palomar Green [6] and catalogued as PG 1346+082. The first observations of Wood et al. (1987) [31] showed a brightness variability in the range of 13.0 - 18.0 magnitude in the V band. The average orbital period of CR Boo is estimated as ~1471.3s (or ~24.5 min) [9, 23]. The system displays spectroscopic variations broad, shallow HeI absorption lines at its maximum, and a weak emission lines in HeI 4471 at minimum light [31].

Masses of the two components of CR Boo were estimated to be in the ranges: $M_1$ = 0.7–1.1 $M_\odot$ for the mass of the primary star and $M_2$ = 0.044–0.09 for the mass of the secondary star [26, 29]. For the mass ratio the range is q = 0.04-0.13 [22, 26]. CR Boo is classified as DB spectral type [27], related to its helium rich atmosphere. Since the orbital period of CR Boo is in a range of 20 < Porb < 40 min, it can be associated in the group with a variable size of disc, producing outbursts or occasional super-outbursts [29].

V803 Centauri was discovered by Elvius (1975) [3]. V 803 Cen is also a member of a special subset of mass transferring binary systems with a short orbital period of 1596.4 – 1611s (or 26.6 min).

Its two component's masses are $M_1$ = 0.8 - 1.2 $M_\odot$ and $M_2$ = 0.06 – 0.11 $M_\odot$ [26, 29]. Then, the mass ratio takes the values: 0.075 – 0.091. The responsibility for these variations is usually taken by the superhumps, during the outbursts of the star (). Its brightness as a magnitude variability is observed in a wide range: 13.2-17.4. At the outburst states, the spectrum of V 803 Cen shows broad, shallow He I absorption. At the Quiescence state – He I emission [20. Its Mass accretion rate is $\dot{M}_2$ = (3±1) x $10^{-9}$ $M_\odot$ $yr^{-1}$ [18].

KL Dra is a helium dwarf nova system, similar to CR Boo [22, 23, 31]. The orbital period of KL Dra is 25 min. The object's magnitude is observed to be in the range of 16.8 – 20 in the V band [9]. The estimated mass ratio of the object is q ≈ 0.075 [32]. They obtain for the mass of the components, $M_2$ = 0.057 $M_\odot$ and $M_1$ = 0.76 $M_\odot$. The value derived for the KL Dra mass transfer rate yields $\dot{M}_2$ = 5.1 x $10^{-10}$ $M_\odot y^{-1}$ [32]. Superhumps are observed and reported for both of the stars, CR Boo [1] and KL Dra [32].

In this paper, we follow the light curves of those three objects, obtained from data of NAO Rozhen and AAVSO (Section 2). In Section 3 we compare the mass transfer rates and explain the properties of their mechanisms.

**Observational periods and outbursts states**

Among AM CVn stars, CR Boo and V803 Cen have the best observational behavior, since they exhibit large-scale amplitude variations in brightness, from days to months. Their origins are still not well understood.

By the high - speed photometry [30], results of CR Boo and V 803 Cen show that the transition between the high and low states happens with significant changes in the objects behavior.

AM CVn stars are blue objects, but they have unusual behavior at some observational periods. As an example, CR Boo became redder during the superhumps in 2021 [1]. CR Boo has amplitude variations in brightness of > 1 mag. and it is categorized in the group of outburst systems [7, 13]. The brightness events could lasting from days to months. The high outbursts during the faint state are produced with a recuring frequency in a super-cycle of about ≈ 46 days [11, 12].

Here, we present light curves of CR Boo, V 803 Cen and KL Dra. For CR Boo we apply combined data, obtained with the 2m telescope of NAO Rozhen and AAVSO. Since V 803 Cen is visible at the southern hemisphere, we apply the observational data from online sources, as AAVSO.

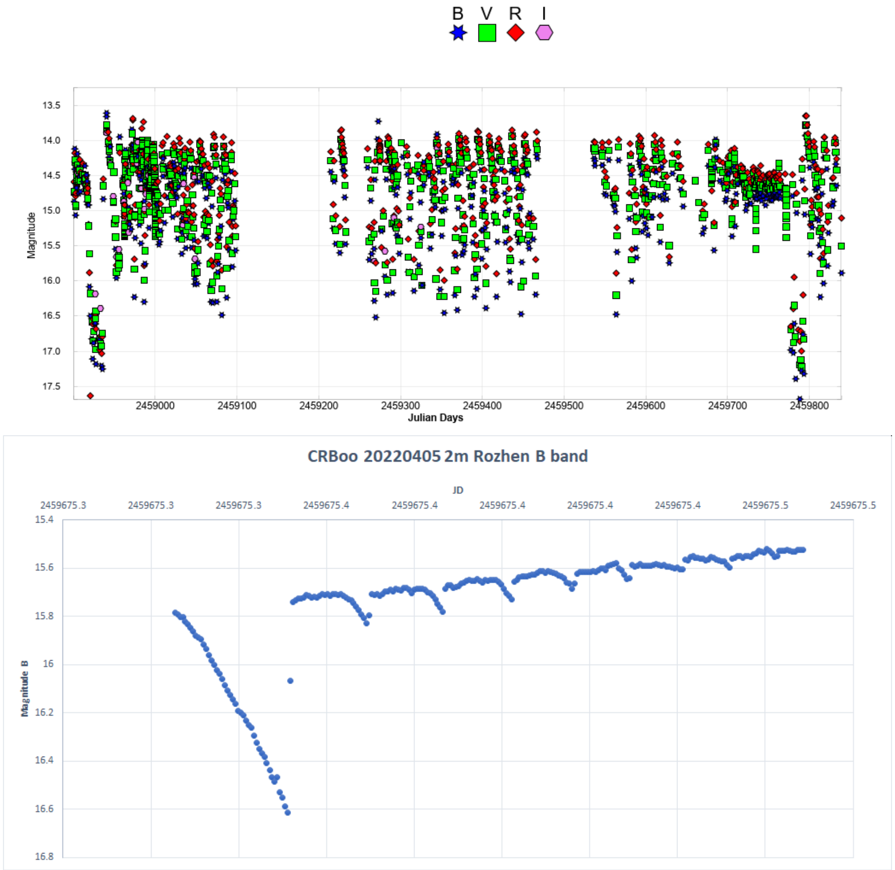


Fig. 1. Light curves of CR Boo in UBVRI bands. The data for the observational period of 2 years (2020/02/20 to 2022/11/16) are taken from AAVSO (up). The shorter period's data during the high state of the object are obtained with 2m telescope at NAO Rozhen (down).

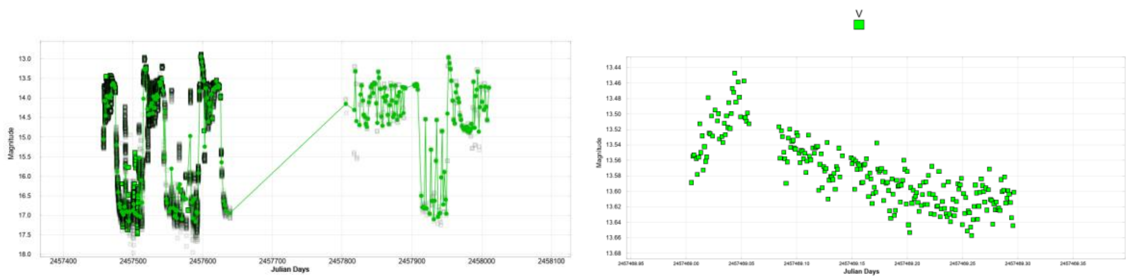


Fig. 2. Light curves of V 803 Cen. The magnitude of the star is in V band and the observational times are in JD (Julian dates). The data are taken from AAVSO: for the observational period of 2 years (2015 – 2017) (left). The brightness variation during high state is seen, for the shorter period during March 2016.

The above light curves show the alternate periods from low to high states and well seen outbursts activity with different durations. This observational behavior is identical for both objects. Unfortunately, we could not apply any observational data of the third object KL Dra. In the paper of Ramsay et al. 2020 [24], KL Dra was revealed as a frequently outbursts system with a recurring time of ≈60 days.

### Mass-transfer properties

The study and knowing of the mass transfer process could give an useful information of the interior of the donor and its evolution, as well as of the resulting properties of interacting area between the mass inflow and the primary star accretion zone [29].

In this Section, we give an estimation of the mass transfer rate of CR Boo, V803 Cen and KL Dra. In this aim, we use the average values of the systems parameters given in the literature (Table 1). The orbital separation ***a*** is obtained in the current paper by applying the Kepler's 3-rd law.

Table 1. The system parameters of CR Boo, V803 Cen and KL Dra, as follows: $M_1$ - mass of the primary star; $M_2$ - mass of the secondary star; q - mass ratio; P - orbital period; a - the orbital separation between the components. Here [tp] means "this paper".

| **Parameters<br>------------<br>Object** | **$M_1$<br>[$M_\odot$]** | **$M_2$<br>[$M_\odot$]** | **q** | **Porb<br>[min]** | **a<br>[$R_\odot$]** |
|---|---|---|---|---|---|
| **CR Boo** | 0.80<br>[26] | 0.07<br>[26] | 0.087 | 24.5 [9] | 0.266<br>[tp] |
| **V 803 Cen** | 0.95<br>[29] | 0.08<br>[29] | 0.085 | 26.6<br>[23] | 0.167<br>[tp] |
| **KL Dra** | 0.76<br>[32] | 0.057<br>[32] | 0.075 | 25<br>[31] | 0.149<br>[tp] |

When binaries have sufficiently short orbital periods, as our objects have, the angular momentum loss is efficient through the gravitational wave emission [4, 21]. Therefore, the rate of angular momentum loss of a binary system is given by the equation of Landau and Lifshitz [15]:

$$(1)\quad \left(\frac{\dot{J}}{J}\right)_{GWR} = \frac{-32}{5}\frac{G^3}{c^5}\frac{M_1M_2(M_1+M_2)}{a^4}$$

Where $(\dot{J}/J)_{GWR}$ expresses the relation of this rate to the orbital angular momentum. This term is further used in the equation for the mass transfer rate by Paczyñski [21]:

$$(2)\quad \left(\frac{\dot{M}_2}{M_2}\right) = \left(\frac{\dot{J}}{J}\right)_{GWR} \times \left[\frac{\zeta(M_2)}{2} + \frac{5}{6} - \frac{M_2}{M_1}\right]^{-1}$$

Here, $\zeta = dlnR_2/dlnM_2$. Our calculations of this term give the values: ζ = - 0.19, - 0.33;

In order to calculate the mass-transfer rate $\dot{M}_2$, we first apply the parameters for the three objects (masses and orbital separation from Table 1) into the Eq.1. This gives the angular momentum loss in a relation to the orbital angular momentum.

Then, we put these terms into Eq.2 to calculate the mass transfer rates $\dot{M}_2$ with respect to the mass of the secondary $M_2$. Finally, using the value of $M_2$ we determine the absolute values of the mass transfer rate. The obtained values are as follows:

- for CR Boo, $\dot{M}_2 = 1.41(\pm 0.5) \times 10^{-9} M_\odot\ y^{-1}$ ;
- for V 803 Cen it is: $\dot{M}_2 = 2.53(\pm 0.2) \times 10^{-9} M_\odot\ y^{-1}$;
- for KL Dra: $\dot{M}_2 = 4.76(\pm 0.1) \times 10^{-9} M_\odot\ y^{-1}$.

We see that the mass transfer rates of these studied binaries are similar, except for the KL Dra, where the estimated value is lower. The obtained from us values differ from the mass transfer rates in the literature, pointed in the Introduction for each of the objects. The reason of this could be the applied models and equations. They are also similar to the mass transfer rate, comparing to those found for some AM CVn class objects by [17, 27, 28], which is in order of $\sim 0.4 - 1.2 \times 10^{-9}$ to even $5 \times 10^{-10} M_\odot yr^{-1}$.

We suggest a simple explanation of the processes. During the mass-transfer process, in a time period of our observations $t_1 ... t_n$, the mass of the secondary component $M_{2t1}$ started to decrease over time, due to the increasing mass-transfer rate. At the final time of observations $t_n$ it takes the value $M_{2tn}$. In the same time, the orbital separation ***a*** also changes over time $a_{1t1} ... a_{ntn}$, as it could increase or decrease depends on the mass transfer rate and mass ratio. After these suggestions, we have: $a_{1t1} \leq\geq a_{ntn}$.

## Discussion and Conclusion

AM CVn stars are objects in a final stage of binary stars evolution. As their characteristics, they create a medium to study the physical properties of such systems to understand and to obtain more information about the white dwarf stars and double white dwarfs' evolution respectively.

We presented the light curves of three AM CVn stars - CR Boo, V803 Cen and KL Dra. Their light curves show short- and long- brightness variability that manifests periodically outbursts in a frame of two years. CR Boo and V 803 Cen demonstrated similar behavior. We used observational data both from AAVSO (American Association of Variable Star Observers) and our own observations, obtained with the 2m telescope of the National Astronomical Observatory (NAO) Rozhen.

Employing the equation of mass transfer for the gravitational wave emission, we obtained the values of mass-transfer rate for each of the three objects. The less massive object has the smallest value of the mass transfer rate. As dwarf nova objects V803 Cen and CR Boo give signs of an intermediate region of instability in the disc formation.

**Acknowledgements:** We acknowledge with thanks the variable star observations from the AAVSO International Database contributed by observers worldwide and used in this research.

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