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Pre-Outburst Signal in the Light Curves of the Recurrent Novae RS Oph and T CrB

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Abstract. Pre-outburst signal (a decrease of the optical brightness) just before the outburst is clearly detected in the observations of the T CrB obtained before and during the 1946 outburst. A similar decrease is also visible in the light curve of RS Oph during the 2021 outburst. We suppose that this is due to formation of a thick, dense envelope around the white dwarf, and we estimate its size (1000–2000 km), mass ($5 \times 10^{-8} - 6 \times 10^{-7}$ M$_\odot$) and average density (5–16 g cm^{-3}).

KEY WORDS: stars (novae cataclysmic variables), stars individual (RS Oph, TCrB).

1 Introduction

The Recurrent Novae (RNe) are classical novae that repeat their outbursts. RNe are ordinary novae systems for which the recurrence time scale happens to be from a decade to a century. They are binary stars where matter accretes from a donor star onto the surface of a white dwarf (WD), where the accumulated material will start a thermonuclear explosion that makes the nova eruption (e.g. [1,2]). The two RNe discussed here (T CrB and RS Oph) belong to the group of the RNe with red giant companions and with orbital periods of about one year, $P_{\rm orb} = 227.6$ d for T CrB [3] and $P_{\rm orb} = 453.6$ d for RS Oph [4]. T CrB and RS Oph are also classified as symbiotic stars, because the mass donor is a red giant. This type of nova is also referred to as a symbiotic recurrent nova (e.g. [5,6]).

In both stars a decrease of the B band brightness is observed a month before the nova outburst. In this work, we propose a hypothesis explaining this drop of optical brightness.

2 Pre-Outburst Signal – RS Oph and T CrB

Adamakis et al. [7] find a signal via wavelet analysis that can be used to predict a nova outburst. A drop in the B band magnitude (decrease of the B band brightness with $\sim$ 1 magnitude) just before the outburst is clearly detected in the photographic observations of the T CrB obtained before and during the 1946 outburst [8]. A similar decrease (however with smaller amplitude) is visible in the light curve of RS Oph (Figure 1). Decrease of the mass accretion rate is the usual explanation for the brightness decrease of any accreting source and for T CrB in particular (e.g. [9, 10]). Here, we propose a different hypothesis, that the preoutburst decrease of the brightness is due to formation of a dense envelope around the white dwarf.

The accretion luminosity of an accreting white dwarf is:

$$L_{\rm acc} = G \frac{M_{\rm wd} \dot{M}_a}{R_{wd}} \, , \qquad (1)$$

where G is the gravitational constant, $M_{\rm wd}$ is the mass of the white dwarf, $R_{\rm wd}$ is its radius, $\dot{M}_a$ is the mass accretion rate. Our hypothesis is that a heavy (dense) envelope forms around the white dwarf. This dense envelope will later produce

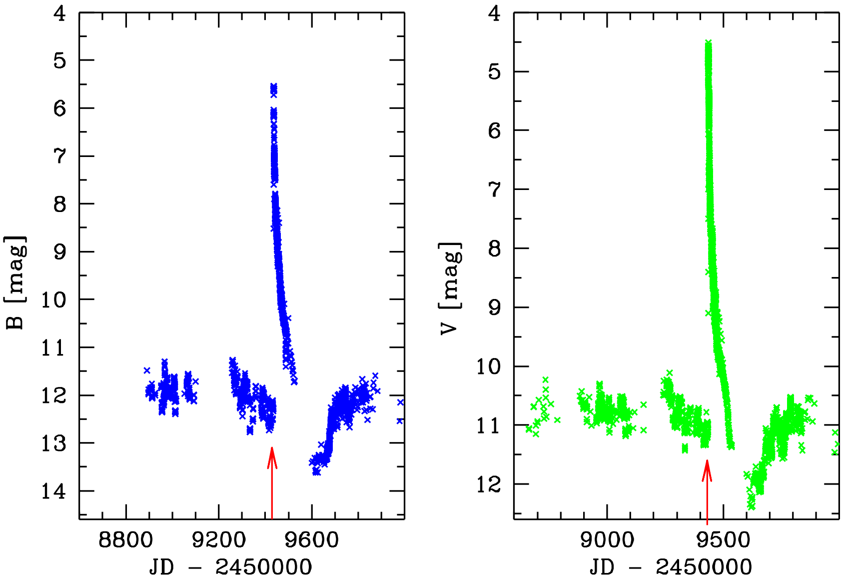

Figure 1. AAVSO light curve of the recurrent nova RS Oph around the 2021 outburst. A drop of the brightness before the 2021 outburst is visible in B as well as in V band. The decrease of the brightness is with $\sim$ 0.5 mag and is indicated with red arrows.

TNR and nova outburst. The envelope is impenetrable for the accreting matter and the L_{acc} decreases:

$$L_{\text{acc}} = G\frac{M_{\text{wd}}\dot{M}_a}{R_{\text{wd}} + \Delta R_{\text{env}}} \, , \tag{2}$$

where ΔR_{env} is the size (thickness) of the envelope.

A sketch representing accreting white dwarf is drawn in Figure 2. For most time of the outburst cycle the envelope is thin and the inner edge of the accretion disc reaches the surface of the white dwarf (Figure 2a). About 30-50 days before the outburst the envelope becomes thick and dense. The inner edge of the accretion disc is not able to go down to the surface of the white dwarf. The brightness decreases (Eq. 2, Figure 2b). When the pressure exceeds the critical value, the white dwarf explodes as a nova (Figure 2c).

RS Oph: The mass of the white dwarf in RS Oph is estimated $M_{\text{wd}} = 1.35 \pm 0.01$ M$_\odot$ on the basis of the supersoft X-ray flux [11]. The mass-radius relation for WDs gives $R_{\text{wd}} = 2296$ km, using the Eggleton's formula as given in [12]. The ignition mass, M_{ign}, can be estimated from

$$P_{\text{crit}} = G\frac{M_{\text{wd}}M_{\text{ign}}}{4\pi R^4_{\text{wd}}}, \tag{3}$$

where P_{crit} is the critical pressure for ignition, which is $\approx 10^{19}$ dyne cm^{-2} [13]. We estimate $M_{\text{ign}} = 9.7 \times 10^{-7}$ M$_\odot$, and average mass accretion rate $\dot{M}_a = 4.8 \times 10^{-8}$ M$_\odot$ yr^{-1}, for a 20 years interval between the nova outbursts. Following Eq. 2, for the B band brightness and L_{acc} to decrease by factor of 1.5, we estimate $\Delta R_{\text{env}} \approx 1150$ km. This corresponds to an average density in the envelope 16.2 g cm^{-3}.

T CrB: The mass of the white dwarf in T CrB is estimated $M_{\text{wd}} = 1.37$ M$_\odot$ on the basis of the radial velocities of the Hα emission line [14]. The mass-radius relation for WDs gives $R_{\text{wd}} = 2018$ km. In the same way as above, we calculate $M_{\text{ign}} = 5.7 \times 10^{-7}$ M$_\odot$, and average mass accretion rate $\dot{M}_a = 7 \times 10^{-9}$ M$_\odot$ yr^{-1}, for a 80 years interval between the nova outbursts. Following Eq. 2, for the L_{acc} and B band magnitude to decrease by factor of 2, we estimate $\Delta R_{\text{env}} \approx 2000$ km. This corresponds to an average density in the envelope 4.8 g cm^{-3}, which is 4 times denser than the water (and slightly denser than the granite and aluminum).

Bruch & Duschl [15] determined limits for the geometrical size of the boundary layer between the white dwarf and the accretion disc (T CrB and RS Oph are also included in their study) and found typical values of $\gtrsim 2$ white dwarf radii. Our results indicate that the envelope is probably inside the boundary layer. It is worth noting, that Ilkiewicz et al. [10] proposed that the super-active stage of T CrB in the period 2015 – 2023 is due to an activity similar to disc instability of the dwarf novae. The disc instability can be the reason for the density enhancement of the envelope.

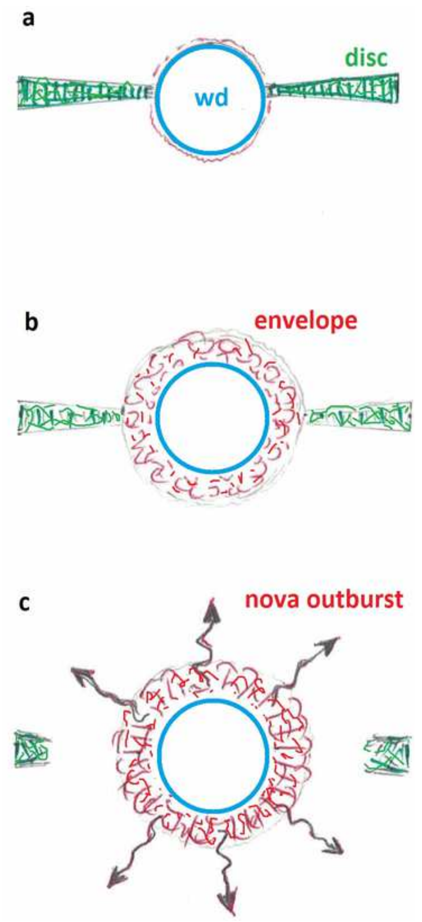

Figure 2. A sketch representing accreting white dwarf: **a)** the inner edge of the accretion disc reaches the surface of the white dwarf; **b)** a dense envelope forms and the inner edge of the accretion disc is not able to go down to the surface of the white dwarf; **c)** the mass of the envelope exceeds the critical value and produces a nova outburst.

3 Conclusions

We suppose that the decrease of the optical brightness before the nova outburst detected in the observations of the recurrent novae T CrB and RS Oph is a result of formation of a thick, dense envelope around the white dwarf. We estimate for this dense envelope size (1000–2000 km), mass $(5 \times 10^{-8} - 6 \times 10^{-7}\ \mathrm{M}_\odot)$ and density (5–16 $\mathrm{g\,cm^{-3}}$). The next outburst of T CrB is expected soon and multifrequency observations can be valuable to understand the structure of the envelope.

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