

Can dwarf novae produce type Ia supernovae?

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ABSTRACT

Context. Accreting white dwarfs (WDs) are considered some of the most promising progenitor candidates of type Ia supernovae (SNe Ia). Dwarf novae (DNe), a subclass of cataclysmic variables, consist of a CO WD accretor and a low-mass donor star, which can be either a main-sequence (MS) star or a slightly evolved subgiant. Previous studies suggested that, under the thermal–viscous disc instability mechanism, the time-averaged accretion rate in long-period DNe approaches the regime of stable hydrogen burning, potentially allowing WD mass growth towards the Chandrasekhar mass (M_{Ch}). However, whether such periodic accretion can sustain stable H burning and lead to a mass increase in the WD remains uncertain.

Aims. We explore whether high accretion rates on short, periodic timescales can maintain stable H burning on the WD surface and drive its growth towards M_{Ch} .

Methods. We investigated the mass retention efficiency of WDs undergoing intermittent, DN-like accretion using MESA simulations, and explored the dependence on the duty cycle, accretion rate, and initial WD properties.

Results. We find that periodic accretion fails to maintain stable H burning. During quiescent phases, the WD cools and becomes increasingly degenerate, triggering nova outbursts with declining mass retention efficiency, ultimately preventing further WD mass growth. We therefore suggest that DNe are unlikely to be progenitors of SNe Ia.

Key words. stars: dwarf novae – novae, cataclysmic variables – white dwarfs

1. Introduction

Type Ia supernovae (SNe Ia), with typical bolometric luminosities of the order of 10^{43} erg/s, are among the most energetic objects in the Universe. As reliable standard candles, due to their high luminosity and the fact that their light curves can be standardized to yield a uniform peak luminosity, SNe Ia enabled the discovery of the accelerating expansion of the Universe driven by dark energy (Riess et al. 1998; Perlmutter et al. 1999). They are also major contributors to iron enrichment in galaxies, producing approximately two-thirds of the Milky Way’s iron content (Greggio & Renzini 1983; Matteucci & Greggio 1986; Dwek 2016). By injecting kinetic energy and turbulence into the interstellar medium, SNe Ia drive large-scale galactic winds, stimulate star formation, and influence galaxy evolution; understanding this helps us understand galactic dynamics and evolution (e.g. Joung et al. 2009; Strickland & Heckman 2009; Osaki 1974). Additionally, as remnants of binary stellar evolution, they provide valuable insights into mass transfer, accretion processes, and binary system dynamics. Despite their importance, no pre-explosion counterparts have been detected to date, leaving the progenitors of SNe Ia uncertain (Hillebrandt & Niemeyer 2000; Röpke & Hillebrandt 2005; Podsiadlowski et al. 2008; Wang & Han 2012; Maoz & Mannucci 2012; Maoz & Graur 2017).

Two competing progenitor models dominate current debates: the single degenerate (SD) model and the double degenerate (DD) model (e.g. Maoz et al. 2014; Wang 2018a; Liu et al. 2023;

Ruiter & Seitzzahl 2025). The SD model postulates that a white dwarf (WD) accretes material from a non-degenerate companion, which can be either a main-sequence (MS) star or a slightly evolved subgiant (the WD+MS channel), a helium star (the WD+He channel), or a red giant (the WD+RG channel; see e.g. Langer et al. 2000; Han & Podsiadlowski 2004; Wang et al. 2015; Brooks et al. 2016; Wu & Wang 2019; Wong & Schwab 2019; Wu et al. 2020). Stable burning of accreted material gradually increases the WD’s mass towards the Chandrasekhar mass limit ($M_{\text{Ch}} \approx 1.4 M_{\odot}$), eventually producing an SN Ia (Hoyle & Fowler 1960; Whelan & Iben 1973; Nomoto et al. 1984; Branch et al. 1985). The WD explosion with M_{Ch} can reproduce the observed light curves and spectroscopy of most SNe Ia (Leung & Nomoto 2018). The original DD model posits that two WDs merge via gravitational wave radiation, losing orbital angular momentum (AM). If the resulting merged WD exceeds M_{Ch} , a thermonuclear explosion is triggered, producing an SN Ia (Iben & Tutukov 1984; Webbink 1984). However, some studies suggested that such mergers can instead lead to accretion-induced collapse (AIC), resulting in the formation of a neutron star (e.g. Saio & Nomoto 1985, 1998; Timmes et al. 1994; Mochkovitch et al. 1997; Schwab et al. 2016; Wu & Wang 2018; Wang 2018b; Wu & Wang 2019; Liu & Wang 2020; Schwab 2021), while others showed that, when rotation was taken into account, CO WD mergers could still produce SNe Ia (e.g. Yoon et al. 2007). More recent work indicates that SNe Ia in this channel can arise from sub- M_{Ch} configurations. In the violent merger scenario, two comparable mass WDs undergo a dynamical merger that directly triggers carbon detonation (Pakmor et al. 2010, 2011, 2012) and the double

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detonation scenario, where a helium shell detonation initiates a secondary carbon detonation in the core (Fink et al. 2007, 2010; Boos et al. 2021). However, the ignition conditions for a violent merger and the required helium shell properties for double detonation remain uncertain.

In the SD channel, a cataclysmic variable (CV) system consists of a carbon–oxygen (CO) WD accretor and a donor star that fills its Roche lobe and transfers material to the WD. The donor is typically a low-mass MS star or a slightly evolved subgiant. Dwarf novae (DNe) are a subclass of CVs characterized by alternating long quiescent phases and short outbursts (Osaki 1974). According to the thermal–viscous disc instability mechanism (Meyer & Meyer-Hofmeister 1981; King 1997), the accretion disc remains cool and dominated by neutral H, suppressing AM transport. This low-viscosity state causes material to accumulate in the outer disc, corresponding to the quiescent phase. As density increases, gravitational compression heats the disc, ionizing H and increasing the viscosity. The increased viscosity enables the accumulated material in the outer disc to be efficiently transported inwards, eventually accreting onto the WD surface. The rapid accretion then releases gravitational energy, producing an outburst. As the accreted material is depleted, the disc cools and returns to quiescence. This allows mass to build up again in the outer disc, setting the stage for the next instability and thus establishing the recurrent cycle between outburst and quiescence.

Based on the disc instability mechanism, King et al. (2003) proposed an evolutionary pathway for the forming of SNe Ia in which long-period DNe (≥ 2 d) enable a WD to grow in mass and reach M_{Ch} . Although the mass transfer rate from the donor in DNe ($\dot{M}_2$) is typically too low to sustain stable H burning, accretion onto the WD occurs only during the outburst phase. Considering the duty cycle (d) – defined as the ratio of the burst duration (τ_{bur}) to the quiescent phase duration (τ_{qui}), i.e. $d = \tau_{\text{bur}}/\tau_{\text{qui}}$ – the equivalent accretion rate onto the WD ($\dot{M}_{\text{acc}} \sim \dot{M}_2/d$) can reach the stable H-burning regime. Consequently, the WD can stably burn H and retain a substantial fraction of the transferred mass during DN outbursts, allowing it to grow in mass and potentially reach M_{Ch} . Xu & Li (2009) adopted a similar idea, suggesting that in DN systems with $d = 0.003$, a WD undergoing AIC could explain the pulsar GRO J1744-28. Wang et al. (2010) incorporated the disc instability mechanism into their studies to estimate the birthrates and delay-time distributions of SNe Ia (see also Meng & Yang 2010).

However, whether the cumulative effect of multiple short-timescale accretion episodes can sustain long-term stable H burning remains poorly understood. Nomoto et al. (2007) suggested that a H envelope mass of approximately $10^{-5} M_{\odot}$ is required to sustain stable H burning on a $1.0 M_{\odot}$ WD. The timescales of DN outbursts are extremely short, ranging from tens of days to several decades. Therefore, even at high accretion rates, the material accumulated during quiescence may be insufficient to reach the critical mass required for stable H ignition. Furthermore, the WD may cool and become more degenerate during the long quiescent period. If this is the case, once ignition occurs, a thermonuclear runaway can be triggered, leading to a nova explosion rather than steady burning.

The aim of this study is to investigate whether high accretion rates over short, periodic timescales can ignite the accreted material on the WD surface, allowing stable nuclear burning and enabling the WD to grow to M_{Ch} , and thus leading to the formation of a SN Ia. In Sect. 2 we describe the methods used in this study. The numerical results are presented in Sect. 3. A brief discussion and conclusions are provided in Sect. 4.

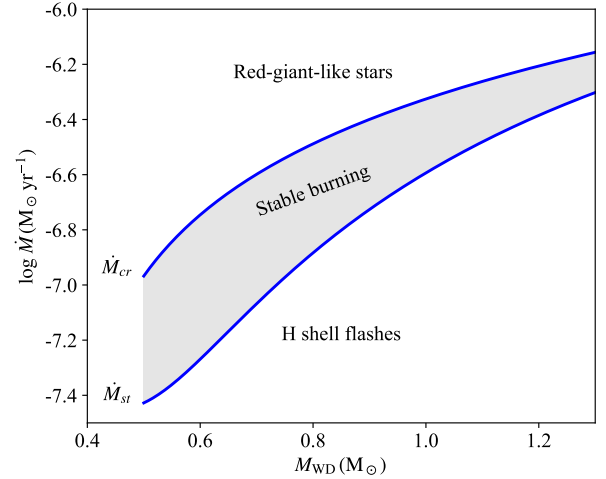


Fig. 1. Stable H-rich burning regime in the $\dot{M}$ – M_{WD} plane. The horizontal axis represents the WD mass and the vertical axis the accretion rate. The upper and lower boundaries are given by Eqs. (1) and (2), following Wang (2018a).

2. Methods

2.1. Mass transfer and accretion-disc instability

The stable burning of accreted H occurs only within a specific range of accretion rates. According to Wang (2018a), the upper and lower limit of stable H burning ($\dot{M}_{\text{cr}}$, $\dot{M}_{\text{st}}$) are as follows:

$$\frac{\dot{M}_{\text{cr}}}{M_{\odot} \text{ yr}^{-1}} = 0.27 \times 10^{-7} \left[\left(\frac{M_{\text{WD}}}{M_{\odot}} \right)^2 + 25.52 \left(\frac{M_{\text{WD}}}{M_{\odot}} \right) - 9.02 \right], \quad (1)$$

$$\frac{\dot{M}_{\text{st}}}{M_{\odot} \text{ yr}^{-1}} = 2.93 \times 10^{-7} \left[- \left(\frac{M_{\text{WD}}}{M_{\odot}} \right)^3 + 4.41 \left(\frac{M_{\text{WD}}}{M_{\odot}} \right)^2 - 3.38 \left(\frac{M_{\text{WD}}}{M_{\odot}} \right) + 0.84 \right]. \quad (2)$$

Figure 1 shows the variation in the stable H-rich burning interval with the WD mass according to Eqs. (1) and (2). When the accretion rate of H-rich material onto the WD ($\dot{M}_{\text{acc}}$) exceeds the critical rate ($\dot{M}_{\text{cr}}$), the continuous accumulation of accreted material leads to the expansion of the outer envelope, and the WD can enter a red-giant-like phase. In contrast, if $\dot{M}_{\text{acc}}$ falls below the lower stability limit $\dot{M}_{\text{st}}$, H burning becomes thermally unstable, giving rise to repeated H shell flashes that manifest as nova eruptions.

Considering that nova eruptions can occur, we included a super-Eddington stellar wind during these phases (see Paxton et al. 2010, 2015, for more details). The Eddington luminosity (L_{Edd}) is expressed as

$$L_{\text{Edd}} = \frac{4\pi G c M}{\kappa}, \quad (3)$$

where G is the gravitational constant, M is the mass of the WD, c is the speed of light, and κ is the Rosseland mean opacity on the surface of the WD.

When the radiative pressure at the surface of the WD becomes sufficiently high (i.e. $L > L_{\text{Edd}}$), material can be ejected from the WD surface in the form of strong stellar winds. The mass-loss rate of the stellar wind ($\dot{M}_{\text{wind}}$) can be estimated using

the empirical relation:

$$\dot{M}_{\text{wind}} = \frac{2\eta_{\text{Edd}} (L_{\text{eff}} - L_{\text{Edd}})}{v_{\text{esc}}^2}, \quad (4)$$

where η_{Edd} represents the super-Eddington factor, and $v_{\text{esc}} = \sqrt{\frac{2GM_{\text{WD}}}{R_{\text{WD}}}}$ denotes the escape velocity, R is the surface radius. The parameter η_{Edd} regulates the efficiency of mass loss due to the wind and takes values between 0 and 1. In our simulations, when the super-Eddington wind is activated, we assume that all energy exceeding the Eddington luminosity is utilized for mass ejection (i.e. $\eta_{\text{Edd}} = 1$).

The disc instability mechanism is the primary theoretical framework for explaining DN outbursts. When the mass transfer rate from the donor star to the WD ($\dot{M}_2$) falls below a critical value ($\dot{M}_{\text{d,cr}}$), the outer edge of the accretion disc enters a cool, low-viscosity state with an effective temperature below the H ionization threshold (~ 6500 K). During the quiescent phase, matter gradually accumulates in the accretion disc, causing the surface density to steadily increase. As the accumulated mass grows, the disc temperature approaches the H ionization threshold. The onset of partial ionization sharply increases the local opacity, suppressing radiative cooling and disrupting the local thermal equilibrium. This triggers a thermal-viscous instability, causing the disc to transition from a cool, low-viscosity state to a hot, high-viscosity state. The material stored in the outer disc is then rapidly transported inwards and accreted onto the WD surface, giving rise to a DN outburst. The critical mass transfer rate ($\dot{M}_{\text{d,cr}}$) is given by (van Paradijs 1996)

$$\dot{M}_{\text{d,cr}} = 4.3 \times 10^{-9} \left(\frac{P_{\text{orb}}}{4 \text{ h}} \right)^{1.7} \text{ M}_{\odot} \text{ yr}^{-1}, \quad (5)$$

where P_{orb} represents the orbital period of the system.

If the mass transfer rate ($\dot{M}_2$) is lower than $\dot{M}_{\text{d,cr}}$, the accretion disc becomes unstable and undergoes periodic transitions between outburst and quiescent states. During the outburst phase, the accumulated material in the disc is rapidly transferred onto the surface of the WD, while during the quiescent phase, matter accumulates in the accretion disc. Due to this instability, the WD accretes material only during outburst phases at a rate of $\dot{M}_{\text{acc}}$; in such a case, $\dot{M}_{\text{acc}} = \frac{\dot{M}_2}{d}$ if $\dot{M}_2 \leq \dot{M}_{\text{d,cr}}$, where d is the duty cycle, defined as ratio of the burst duration to the quiescent phase duration. $\dot{M}_2$ in long-period DNe is typically low ($\sim 10^{-9} \text{ M}_{\odot} \text{ yr}^{-1}$), while d generally satisfies $d \ll 1$, the burst timescale τ_{bur} is of the order of days, whereas the quiescent timescale τ_{qui} is of the order of years. Under these conditions, the equivalent accretion rate ($\dot{M}_{\text{acc}}$) can reach values within the steady H-burning regime (see Fig. 2).

2.2. Stellar evolution code

We employed Modules for Experiments in Stellar Astrophysics (MESA; version, r24.03.01; see Paxton et al. 2010, 2013, 2015, 2018, 2019) to simulate the accretion of H-rich material onto a CO WD periodically. For the chemical composition of the accreted material, we adopted solar abundances ($X = 0.70$, $Y = 0.28$, $Z = 0.02$). We employed the Type 2 opacity table from the OPAL opacity controls to account for the chemical composition variations within the stellar interior (Iglesias & Rogers 1996).

We first constructed the $1 \text{ M}_{\odot}$ CO WD using `make_co_wd`, starting from the $5.9 \text{ M}_{\odot}$ zero-age MS. The star evolved through the MS and post-MS phases until a C/O core formed at the

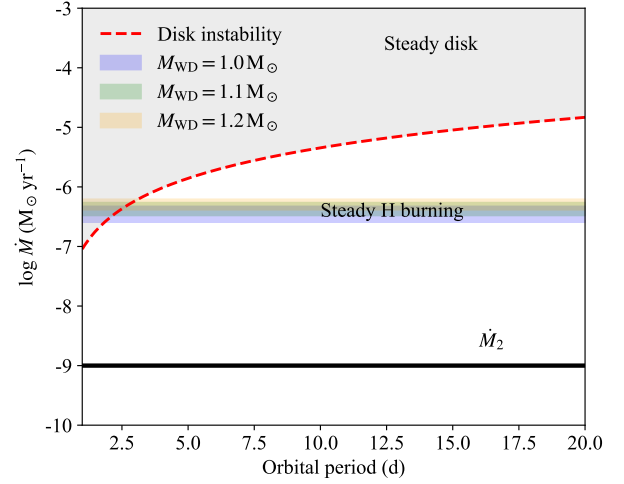


Fig. 2. Disc instability boundary calculated from Eq. (5) (dashed red line). The region above this line corresponds to steady discs. The blue, red, and green rectangular regions indicate the stable H-rich burning zones of WDs with $M_{\text{WD}} = 1.0, 1.1$, and $1.2 \text{ M}_{\odot}$, respectively. The horizontal bar labelled $\dot{M}_2$ denotes the typical mass transfer rates observed in DNe.

centre. During the asymptotic giant branch phase, the H envelope was removed manually, leaving behind a cool CO WD with a luminosity of $1 L_{\odot}$ and an extremely thin H envelope ($\sim 10^{-6} \text{ M}_{\odot}$).

In order to stabilize the H-rich envelope, this CO WD initially accreted at a high and stable accretion rate of $\dot{M}_{\text{acc}} = 2.5 \times 10^{-7} \text{ M}_{\odot} \text{ yr}^{-1}$ for 2000 years. It then alternated between a quiescent state ($\tau_{\text{qui}} = 10\,000$ days) with no mass accretion and an outburst state ($\tau_{\text{out}} = 100$ days) characterized by an equivalent accretion rate of $\dot{M}_{\text{acc}} = 4 \times 10^{-7} \text{ M}_{\odot} \text{ yr}^{-1}$, corresponding to $\dot{M}_2 = 4 \times 10^{-9} \text{ M}_{\odot} \text{ yr}^{-1}$, yielding a duty cycle of $d = 0.01$. This accretion rate lies within the stable H-burning regime defined in Eqs. (1) and (2) and corresponds to a relatively high value within that range. The DN-like accretion is prescribed externally and maintained throughout the entire evolution, including during nova outbursts. Since the timescale of nova outbursts is much shorter than the quiescent phase of the DN cycle, the outburst phase is not affected by the imposed accretion prescription¹.

3. Results

Our simulations show that periodic accretion in DNe cannot sustain stable H burning. Instead, the accumulated material eventually triggers nova eruptions. Figure 3 illustrates the luminosity and mass evolution of a $1 \text{ M}_{\odot}$ CO WD undergoing periodic accretion at a rate of $4 \times 10^{-7} \text{ M}_{\odot} \text{ yr}^{-1}$. After 2000 yr of stable accretion, the system enters a 10 000-day quiescent phase, during which mass accretion ceases entirely. The quiescent period is followed by a 100-day outburst phase, in which material is accreted onto the WD at a rate of $\dot{M}_{\text{acc}} = 4 \times 10^{-7} \text{ M}_{\odot} \text{ yr}^{-1}$. This accretion cycle repeats periodically.

In Fig. 3, the numerous DN outbursts manifest as dense, small-scale luminosity variations that appear as a blurred green band. During these outbursts, the luminosity enhancements are dominated by the release of gravitational potential energy associ-

¹ The complete list of controls is available to the reader as our MESA input files are posted online at <https://doi.org/10.5281/zenodo.19585622>.

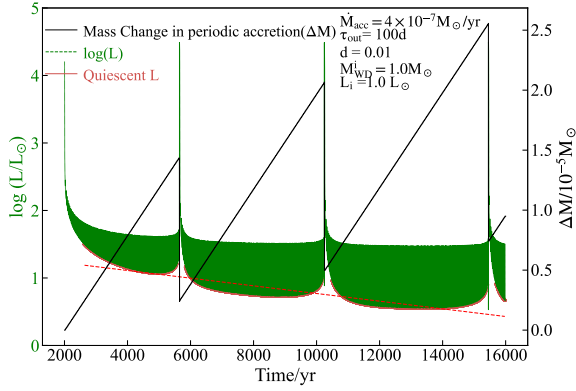


Fig. 3. Evolution of a $1.0 M_{\odot}$ CO WD undergoing periodic accretion. The solid black line traces the WD’s mass variation (ΔM), while the dashed green line shows the evolution of luminosity ($\log L$). Prior to the periodic accretion, the system sustained stable H-rich accretion for 2000 years (not shown). Then, the WD undergoes a periodic accretion phase during which the mass accretion rate is $4 \times 10^{-7} M_{\odot}/\text{yr}$ with a duty cycle of 0.01. The solid red line represents the quiescent state luminosity, while the dashed red line illustrates its declining trend over time.

ated with episodic accretion onto the WD (Townesley & Bildsten 2004; Piro et al. 2005; Townesley & Gänsicke 2009). As mass accumulates in the accreted envelope, the density at the base of the shell gradually increases. At approximately 5600 years, the temperature and density at the shell base reach the critical conditions required for thermonuclear runaway hydrogen burning, leading to a nova eruption. The eruption induces a super-Eddington wind ($\eta_{\text{Edd}} = 1$), expelling a significant fraction of the previously accumulated mass. After the nova explosion, the system resumes its periodic accretion pattern. At this stage, the WD interior is able to lose energy, resulting in a cooler and more degenerate CO core (Yaron et al. 2005). Consequently, a longer period of mass accumulation is required before the second nova explosion. As a result, the second nova ejects a larger amount of material. This evolutionary trend becomes more pronounced in subsequent cycles. Furthermore, the cooling effect leads to a progressive decline in the quiescent luminosity, as illustrated by the dashed red line in Fig. 3.

Figure 4 presents the temperature-density profile at both the onset of H ignition and the peak luminosity of the first nova outburst. In our models, the formation of a convective zone indicates the ignition of H burning. Ignition begins at the base of the shell, and within 200 days, thermal energy is transported to the surface through convective expansion. In Fig. 5, we present the Hertzsprung-Russell diagram for the same system as in Fig. 3. Three nova eruption episodes occur during the periodic accretion phase, each characterized by three distinct stages (annotated by blue arrows in the diagram): (a) The ignited H shell expands, causing a decline in surface temperature (T_{eff}) and luminosity (L) as the radius increases. (b) Efficient energy transport via convection rapidly increases the radiative luminosity. This phase culminates in L exceeding the Eddington luminosity limit (L_{Edd}). (c) L exceeds L_{Edd} , triggering the super-Eddington wind to lose matter. These winds gradually subside as the expanding photosphere reduces radiative driving efficiency, ultimately ceasing when the luminosity returns to sub-Eddington levels, thereby concluding the nova eruption cycle.

Following each nova, the system returns to the periodic accretion mode. During accretion, the addition of H-rich material onto the WD surface compresses the outer layers, releasing

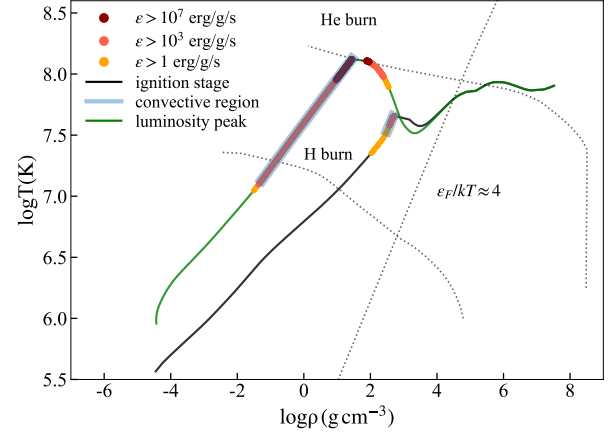


Fig. 4. Density-temperature profiles during the first nova outburst for the system shown in Fig. 3. The solid black line represents the profile at the onset of H ignition, while the solid green line corresponds to the profile at the luminosity peak. Semi-transparent blue indicates convective zones. In the burning zone, the burgundy-to-yellow gradients represent the energy generation rates (high to low). The H- and He-burning boundaries are based on tabulated reference curves provided with MESA and used in its standard plotting routines (Paxton et al. 2010).

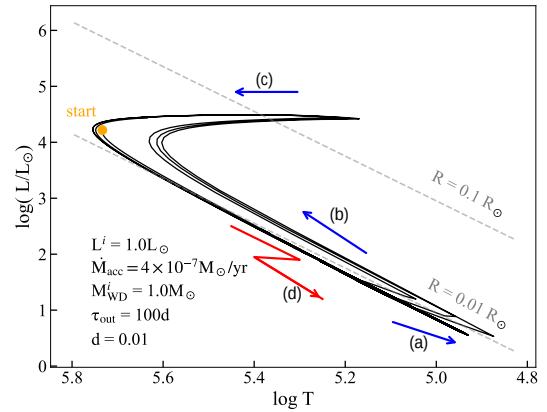


Fig. 5. Hertzsprung-Russell diagram for the system shown in Figs. 3 and 4. The yellow filled circle marks the onset of periodic accretion; the preceding 2000 years of stable accretion are not shown. Blue arrows mark the nova outburst phases, and the red arrow indicates the periodic accretion phase, schematically illustrating the approximate luminosity–temperature variations during this stage.

gravitational potential energy that heats the surface and increases the luminosity (L); conversely, during quiescence, the absence of accretion allows the outer layers to cool, causing L to decline. As a result, the luminosity oscillates within the region indicated by the red arrow in Fig. 5d. During this phase, H-rich material gradually accumulates on the WD surface until it reaches critical ignition conditions, setting the stage for the next nova eruption. Notably, the minimum T_{eff} and L of each nova explosion decrease over time due to the gradual cooling of the CO core.

We investigated how the initial WD temperature, accretion rate, accretion timescale, and quiescent timescale during the DN phase affect the system’s evolution. In our approach, one parameter was varied at a time with the others kept fixed, allowing us to isolate each effect.

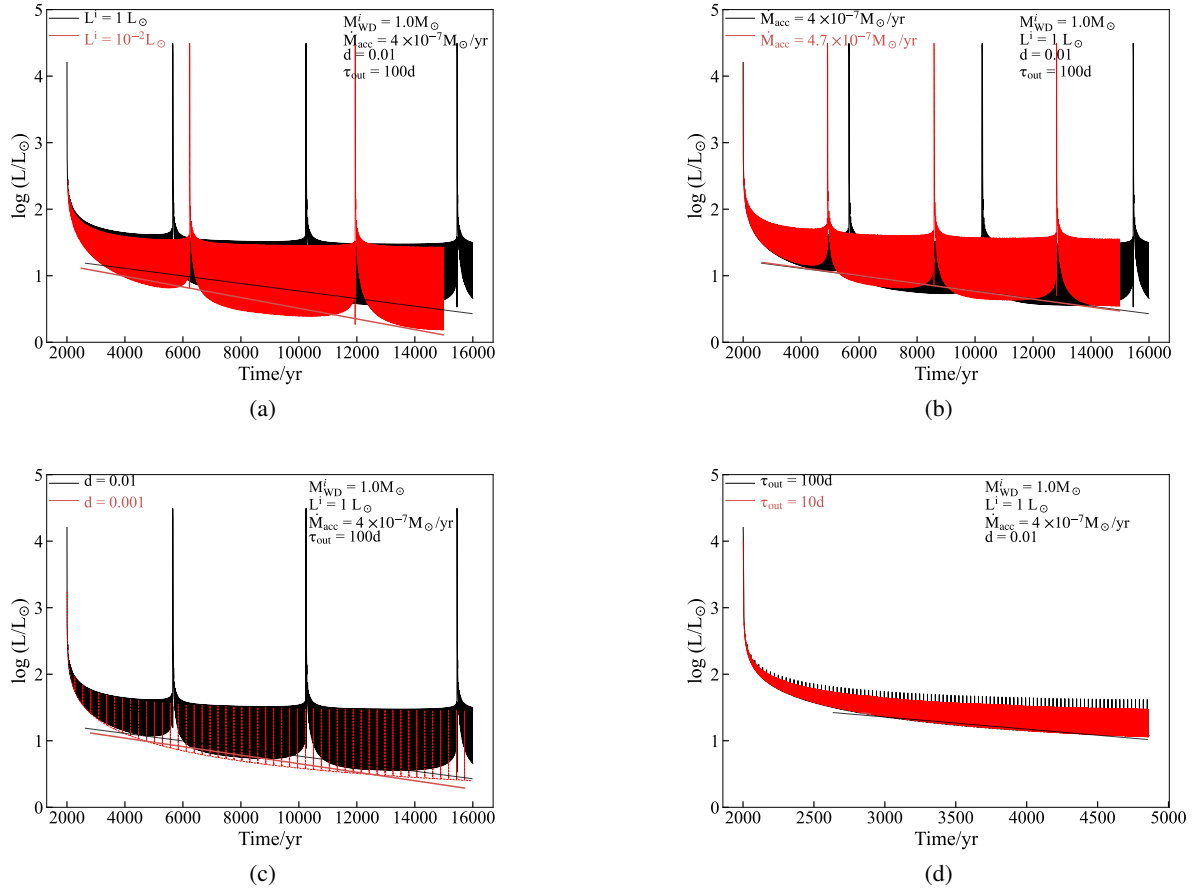


Fig. 6. Combined effects of various parameters on the evolution of a CO WD undergoing periodic accretion. Panel (a): Effect of the initial WD temperature. The black line corresponds to an initial luminosity of $1 L_{\odot}$ and the red line to $10^{-2} L_{\odot}$. Panel (b): Effect of the accretion rate. The black line represents $\dot{M}_{\text{acc}} = 4 \times 10^{-7} M_{\odot} \text{ yr}^{-1}$ and the red line $4.7 \times 10^{-7} M_{\odot} \text{ yr}^{-1}$. Panel (c): Effect of the duty cycle. The black line represents $d = 0.01$ and the red line $d = 0.001$. Panel (d): Effect of the outburst duration. The black line corresponds to $\tau_{\text{out}} = 100 \text{ d}$ and the red line to $\tau_{\text{out}} = 10 \text{ d}$.

To assess the influence of the initial WD temperature, we constructed a CO WD with an initial luminosity of $10^{-2} L_{\odot}$. This corresponds to an initial centre temperature $\log(T_c/\text{K}) \approx 7.2$; for comparison, the standard model has $\log(T_c/\text{K}) \approx 7.9$. All other parameters are kept identical. As illustrated in Fig. 6a, a lower initial WD temperature results in a more rapid decline in quiescent-phase luminosity. This is because the different initial WD temperatures lead to distinct thermal structures at the onset of the periodic accretion phase. During the initial 2000 yr of steady accretion, the cooler WD requires a longer time to trigger the super-Eddington wind, allowing more H-rich material to accumulate and be subsequently ejected. As a result, by the end of this phase, the thermal profiles of the two models differ. At the onset of periodic accretion, although the two models reach a similar peak temperature of $\log(T_{\text{peak}}/\text{K}) \approx 7.9$, this peak occurs at slightly different densities ($\log(\rho/\text{g cm}^{-3}) \approx 4.2$ and 4.1 for the $L = 1 L_{\odot}$ and $10^{-2} L_{\odot}$ cases, respectively). The lower-density burning region in the cooler WD implies a weaker degeneracy and a more efficient thermal response of the envelope, allowing the deposited heat to be radiated away more efficiently, and thus resulting in a more rapid decline of the luminosity during the quiescent phase.

To evaluate the impact of the accretion rate, we increased it during the periodic accretion phase to the upper limit of the stable burning regime. The results presented in Fig. 6b demonstrate that a higher accretion rate promotes a faster accumulation of H-rich material on the WD surface, thereby accelerating the onset

of thermal runaway due to the increased mass accreted within the same period.

Observational studies suggest that DN typically exhibit long quiescent timescales. Assuming a constant outburst duration, this corresponds to a smaller duty cycle. To explore this effect, we set $d = 0.001$. As shown in Fig. 6c, while the overall decline in quiescent luminosity follows a similar trend, the mass accumulation timescale increases significantly, with the first nova eruption occurring after approximately 10^5 years.

Additionally, since observed outbursts are generally short-lived, we attempted to model an outburst duration of 10 days. However, due to numerical constraints, achieving such a short timescale requires a significantly shorter time step, making long-term simulations computationally demanding. Consequently, we simulated this scenario over a 5000-year period: the results are displayed in Fig. 6d. These findings suggest that the long-term decline in quiescent luminosity is primarily governed by the WD's core temperature, whereas variations in accretion parameters (such as the accretion rate, outburst duration, and duty cycle) have a small effect on this trend.

Table 1 summarizes the nova eruption parameters and outcomes for several models with an initial WD mass of $1.0 M_{\odot}$. The table lists the initial luminosity (L^i), duty cycle (d), accretion rate ($\dot{M}_{\text{acc}}$), and outburst timescale (τ_{out}). For models with multiple nova eruptions, the ‘Nova #’ column indicates the order of the eruptions (i.e. 1 = first eruption, 2 = second eruption, 3 = third eruption, etc.), and the outcome parameters include the

Table 1. Comparison of nova eruption parameters and outcomes for models with $M_{\text{WD}}^i = 1.0 M_{\odot}$.

Set	L^i ($L_{\odot}$)	d	$\dot{M}_{\text{acc}}$ ($M_{\odot} \text{ yr}^{-1}$)	τ_{out} (days)	Nova #	t (year)	η_{acc}	M_{env} ($10^{-3} M_{\odot}$)
1	1	0.01	4×10^{-7}	100	1	5648	0.167	2.071
					2	10 247	0.141	2.079
					3	15 454	0.118	2.083
2	10^{-2}	0.01	4×10^{-7}	100	1	6231	0.114	3.404
					2	11 940	0.090	3.411
3	1	0.01	4.7×10^{-7}	100	1	4910	0.181	2.071
					2	8582	0.146	2.077
					3	12 809	0.131	2.082
4	1	0.01	4×10^{-7}	10	–	–	–	–
5	1	0.001	4×10^{-7}	100	1	66 697	0.075	2.088

Notes. Table 1 lists the nova eruption parameters and outcomes for models with an initial WD mass of $1.0 M_{\odot}$. Columns give the initial luminosity (L^i), duty cycle (d), accretion rate ($\dot{M}_{\text{acc}}$), and outburst duration (τ_{out}). For models with nova eruptions, we list the eruption time t , the mass accumulation efficiency η_{acc} , and the envelope mass M_{env} .

evolutionary timescale reached at the time of the nova eruption, the mass accumulation efficiency (η_{acc}), and the envelope mass (M_{env}) for each event. The results show that increasing the accretion rate effectively enhances the mass accumulation efficiency; however, even when raised to the upper limit of the stable burning regime for H-rich material, it still fails to enable the stable H burning. The WD with lower L^i exhibit reduced η_{acc} in subsequent nova outbursts. A decrease in the d also leads to lower η_{acc} . Moreover, the η_{acc} declines with each nova eruption because even though eruptions raise the WD temperature, this warmth is lost to radiative cooling during quiescence. Consequently, the CO core cools and becomes increasingly degenerate, necessitating the accumulation of a thicker H-rich envelope before each eruption, which in turn results in more violent outbursts.

When accreted material from the disc settles onto the WD, the accompanying spin AM is input to change its rotation. To analyse the effect of rotation, we constructed a uniformly rotating WD model with an initial surface spin of $\Omega \approx 0.002 \text{ rad s}^{-1}$ ($\Omega/\Omega_{\text{crit}} = 0.026$, where Ω_{crit} is the critical angular velocity at which the centrifugal force balances gravity at the stellar equator), while keeping other parameters identical to Set 1 in Table 1. The WD accreted H-rich material at the same accretion rate and specific AM. After 2000 years of stable accretion, the WD reaches a surface spin rate of $\Omega \approx 0.007 \text{ rad s}^{-1}$ ($\Omega/\Omega_{\text{crit}} = 0.045$). In our simulation, AM transport is treated as a diffusive process within MESA. We included the effects of Eddington–Sweet circulation and dynamical shear instability, as the latter plays a key role in transporting AM in the highly degenerate core and the former dominates in the non-degenerate envelope of WD (Yoon & Langer 2004). As shown in Fig. 7a, the rotating WD still undergoes nova outbursts during periodic accretion. The first outburst occurs slightly later than that in Set 1, which can be attributed to the reduction in effective gravity caused by rotation. This lowers the pressure at the base of the accreted envelope, requiring a somewhat higher ignition mass and thus delaying the onset of the first outburst. In contrast, the third outburst in the rotating model is triggered slightly earlier. As the nova cycles proceed, rotation gradually modifies the thermal structure of the accreted envelope, leading to a shallower pressure gradient and slower cooling, so the ignition conditions for the third outburst are reached earlier. As shown in Fig. 7b, the mass evolution of the rotating WD is nearly identical to that of Set 1. The accumulation efficiency of the first nova outburst

is 0.165, while the subsequent two novae reach efficiencies of 0.138 and 0.105, respectively. Although a decreasing trend is still present, the overall retention efficiency in the rotating model is slightly lower than that in the non-rotating case, because the reduction in effective gravity makes it easier for material to be ejected. The green line in Fig. 7c shows the evolution of the WD’s spin velocity: during quiescent phases, the rotation accelerates as the radius contracts, while during outbursts it decreases as the envelope expands. The radius undergoes rapid expansion during nova eruptions, leading to a significant decrease in the spin rate. After the third nova outburst, the rotation rate has increased noticeably compared to its initial value, indicating a long-term spin-up trend. Overall, our results suggest that, even with rotation, the net mass accumulation remains inefficient over repeated nova cycles, and the WD is unlikely to reach the M_{Ch} over long-term evolution.

4. Discussions and conclusions

According to King et al. (2003), DNe could theoretically accrete sufficient mass to bring $1 M_{\odot}$ WDs to M_{Ch} . However, our simulations fail to produce SNe Ia because the periodic accretion pattern cannot sustain stable H burning. In Set 1, the equivalent mass transfer rate was $\dot{M}_2 = \dot{M}_{\text{acc}} \times d = 4.0 \times 10^{-9} M_{\odot}/\text{yr}$. Assuming a linearly decreasing η_{acc} , this efficiency would approach zero after roughly 6×10^5 years. During this period, approximately $2.4 \times 10^{-3} M_{\odot}$ of H-rich material is accreted, but as little as $2 \times 10^{-4} M_{\odot}$ remains on the WD surface. This amount of material is insufficient to approach M_{Ch} . Set 3 exhibits the highest mass accumulation efficiency. Nevertheless, its η_{acc} also trends towards zero after 5×10^5 years, with $\dot{M}_2 = 4.7 \times 10^{-9} M_{\odot}/\text{yr}$. Despite accreting $2.4 \times 10^{-3} M_{\odot}$ of H-rich material (with an average η_{acc} of ~ 0.09), only $2 \times 10^{-4} M_{\odot}$ likely persists on the WD surface, again failing to reach M_{Ch} . While η_{acc} is strongly dependent on the input stellar wind model, its secular decline remains a universal feature (since the pronounced cooling effect drives the temperature reduction in the CO core).

In DNe, WDs are generally more massive than isolated WDs, with some up to $1.2 M_{\odot}$ (Godon et al. 2006). The mass ratio of the system is typically $q \lesssim 1$. Based on our simulations, assuming an extreme case of a $1.2 M_{\odot}$ WD and a $1.2 M_{\odot}$ MS donor system with a duty cycle of $d = 0.1$, the maximum mass

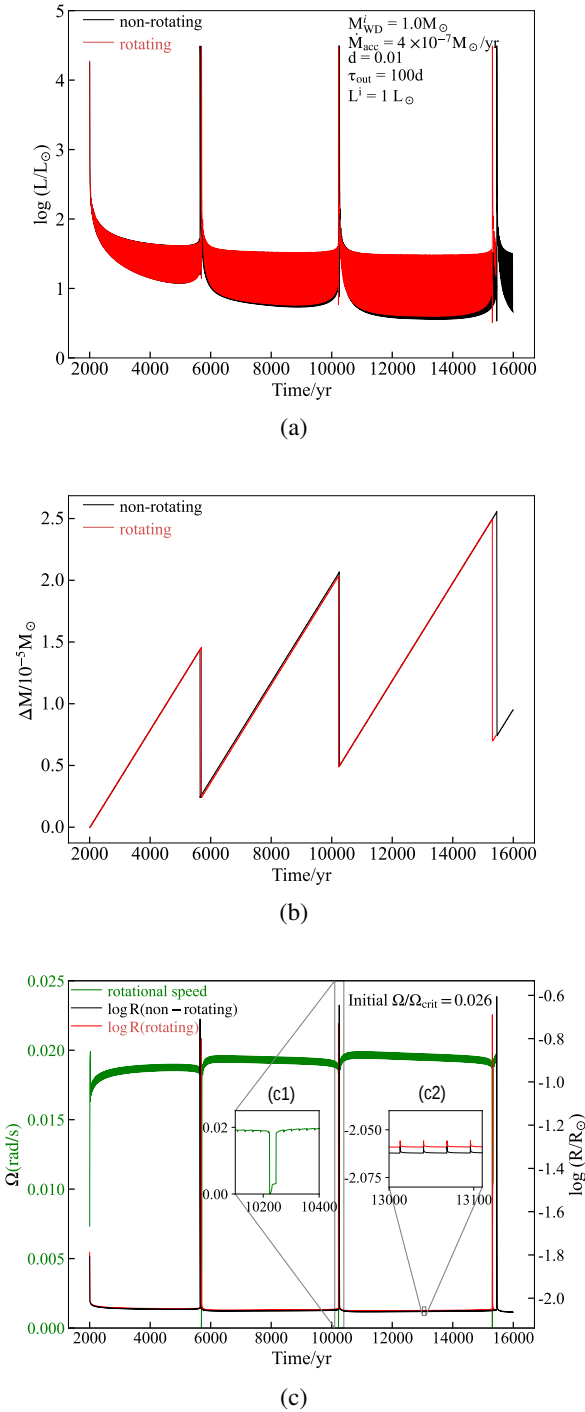


Fig. 7. Comparison of the long-term evolution of a rotating and a non-rotating $1.0 M_{\odot}$ CO WD under periodic accretion. Panel (a): Evolution of the luminosity ($\log L$). Panel (b): Evolution of the WD mass (ΔM). Panel (c): Evolution of the rotational angular velocity (Ω) and radius ($\log R$). The two insets provide zoomed-in views: (c1) highlights the rapid variations in Ω over the interval 10 200–10 400 yr, and (c2) shows the evolution of $\log R$ over the interval 13 000–13 100 yr. The initial 2000 yr of stable accretion are not shown.

transfer rate that keeps the accretion rate within the H stable burning regime is $\dot{M}_2 = 6.2 \times 10^{-8} M_{\odot}/\text{yr}$. At this mass transfer rate, complete mass transfer from the donor to the WD would occur over $\sim 2 \times 10^7$ years. However, achieving a SN Ia before the donor’s mass is fully transferred requires an average accretion

efficiency $\eta_{\text{acc}} > 0.148$ due to the mass loss caused by nova outbursts. However, in practice, the core of the WD is steadily cooling, leading to a gradual reduction in the accretion efficiency for nova outbursts; moreover, the exhaustion of the donor’s H-rich envelope terminates mass transfer. Therefore, DNe are highly unlikely to produce SNe Ia.

In addition, King et al. (2003) proposed that the duty cycle (d) typically ranges between 0.1 and 0.001. In our simulations, we did not explore larger values of d , because a larger duty cycle corresponds to a shorter quiescent phase, which leads to more frequent accretion cycles within the same evolutionary timescale. This significantly increases the computational cost. Therefore, we only considered cases with $d = 0.001$ and $d = 0.01$. Theoretically, smaller values of d should increase the equivalent accretion rate, thus promoting the growth of the WD mass. However, as seen in Sets 1 and 5, a reduced d extends the cooling time of the WD, leading to easier nova outbursts and a lower likelihood of producing SNe Ia. For larger d , considering that the outburst timescale of a DN is of the order of a day, the short quiescent state limits the accumulated mass of each cycle. Even if sufficient mass is retained, the equivalent accretion rate during the outburst may not reach the stable H-burning regime. Our results suggest that even for very small d , H shell flashes still occur, leading to recurrent nova outbursts and inefficient mass retention. This differs from Liu et al. (2023), who proposed that a very small d can trigger optically thick winds and that a larger d leads to H shell flashes that eject most of the accreted material. Moreover, considering only d is insufficient because d represents the ratio of the outburst to quiescent timescales. Even if d remains constant, variations in either the outburst or quiescent durations may lead to different evolutionary outcomes.

Some observations have found nova shells around DNe (Shara et al. 2007, 2012), and many CVs have been shown to transition between novae and DNe (Zemko et al. 2017; Kato & Kojiguchi 2021; Murphy-Glasyher et al. 2022), meaning that at least some novae will evolve into DNe. Our simulations are consistent with the established picture that repeated DN accretion outbursts can gradually lead to the accumulation of sufficient mass to trigger nova eruptions.

In this study, we simulated the periodic accretion mode in DN systems. However, uncertainty remains as to whether the entire disc matter can immediately settle onto the WD. Moreover, our model does not incorporate binary evolution; changes in the binary orbital period and the accretion rate could alter the accretion mode. Additionally, our simulations employed a simplified super-Eddington wind prescription to calculate mass ejection. However, the mass retention efficiency during nova eruptions is highly sensitive to stellar wind assumptions; for example, slower winds may allow a portion of the ejected material to fall back onto the WD surface. These factors can introduce additional uncertainties into our results.

Using MESA, we simulated the evolution of a $1.0 M_{\odot}$ CO WD via periodic accretion. Our main results are summarized as follows: (i) H-rich material cannot burn stably during periodic accretion; degeneracy during a long quiescence triggers nova eruptions. (ii) The temperature increases during the DN outburst phase but falls more during the quiescence phase, resulting in a gradual decay in luminosity during the quiescence phase. (iii) The decline in mass accumulation efficiency in nova cycles prevents WD from reaching M_{Ch} , making DNe unlikely to be progenitors of SNe Ia. More observational identifications and theoretical simulations of DN systems are needed to shed more light on this problem.

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