We propose a scenario for the formation of DA white dwarfs with very thin Helium buffers. For these stars we explore the possible occurrence of diffusion-induced CNO flashes, during their early cooling stage. In order to obtain very thin helium buffers, we simulate the formation of low mass remnants through an AGB final/late thermal pulse (AFPT/LTP scenario). Then we calculate the consequent white dwarf cooling evolution by means of a consistent treatment of element diffusion and nuclear burning. Based on physically sounding white dwarf models, we find that the range of helium buffer masses for these diffusion-induced novas to occur is significantly smaller than that predicted by the only previous study of this scenario. As a matter of fact, we find that these flashes do occur only in some low-mass ($M < 0.6M_\odot$) and low metallicity ($Z/Z_{ZAMS} < 0.001$) remnants about $10^6$ to $10^7$ yr after departing from the AGB. For these objects, we expect the luminosity to increase by about 4 orders of magnitude less than in a decade. We also show that these novae-induced novas should display a very typical eruption lightcurve, with an increase of about 1 magnitude per year before reaching a maximum of $M_V = -5$ to -6. Our simulations show that surface abundances after the outburst are characterized by $\log_{10} N_H/N_He > 0.15$...0.6 and N+C+O by mass fractions. Contrary to previous speculations we show that these events are not recurrent and do not change substantially the final H-content of the cool (DA) white dwarf.

### Introduction

Since the first simulations of white dwarf evolution that included a simultaneous treatment of diffusion and cooling (i.e. Ben & MacDonald 1985, 1986) it was noticed that diffusion could trigger convection CNO-flashes. In fact, the inward diffusion of H and the outward diffusion of C within the pure He zone (usually named “He-buffer”, see Fig. 1) left after the last thermal pulse can lead to a runaway CNO-burning. This produces a very rapid expansion, of the order of years, of the outer layers of the white dwarf pushing the star back to a giant configuration and increasing its visual magnitude from $M_\odot$ to $M_\odot$ -6 in a few years. We term this extreme event as “diffusion-induced nova” (DIN) although it leads to a much slower brightening than classical novae. Ben & MacDonald (1986) noticed that after such events the stars will become, in a few years, so luminous and so hot that, with hardly He enriched surface compositions. A more speculative mood they also suggested that DINs may be recurrent, finally leading to He-deficient compositions. Later, prompted by this speculation, D’Antona & Mazzitelli (1990) suggested that the He-rich envelopes recently reduced during cooling could be responsible for DA white dwarfs with thin He-envelopes, as inferred in some DA white dwarfs (Catalanha & Kepler2009).

The main purpose of the present work is to study the possibility that DINs could take place in physically sounding white dwarf models with a realistic evolutionary history. We will also identify a detailed scenario for the creation of white dwarfs with thin enough He-buffers for DIN events to occur. Specifically, to perform this study we compute realistic white dwarf models by means of “cradle to grave” stellar evolution simulations. Then we compute white dwarf cooling sequences by considering a simultaneous treatment of element diffusion and evolution.

### The proposed evolutionary scenario

Whether white dwarfs with thin He-buffer can be actually formed relies on identifying a scenario in which they could be formed under standing on the dynamical evolution. As shown in Fig. 1, after a He flash on the TP-AGB, the mass of the He-buffer region becomes strongly reduced by interstellar convection. Such thin He-buffer survives until the reignition of the H-burning shell. In particular, the first thermal pulses of low-mass stars ($M < 1.5M_\odot$) are not very strong and, thus, no third dredge up takes place in numerical models. Hence, it is not unreasonable to accept that low-mass stars experiencing an AGB final thermal pulse (AFPT) or a Late Thermal Pulse (LTP) will end as DA white dwarfs with thin He-buffers. In those cases, as no third dredge up happens, the very thin He-buffer remains the last helium shell flash (other than AFPT) that, during the thermal pulse phase that follows the flash, the stellar winds will erode an important fraction of the remaining (already depleted) He-rich envelope, preserving a reignition of the H-burning shell and an increase in the He buffer mass. As a result, the He-buffer evolves until the final white dwarf stage. Then, when the star is in the white dwarf cooling phase, the inward diffusion of H and the outward diffusion of C within the He-buffer leads to the ignition of a CNO-burning shell and ultimately to a CNO-flash (see Fig. 2).

### Results

- We have identified a definite scenario leading to the formation of DA white dwarfs with thin He-buffers. Such white dwarfs are naturally formed in low-mass stars, that do not experience third dredge up during the TP-AGB, and suffer from either an AFPT or a LTP.

- We have explored the parameter space of the DIN scenario and shown that there is a range of values of $M_*, Z/Z_{ZAMS}$ and He-buffer masses for which DIN occur in physically sounding white dwarf models. Our results suggest that DINs take place in white dwarfs with $M_\sim 0.6$ and $Z/Z_{ZAMS} < 0.001$ and thin He-buffers —as those provided by the scenario described above.

- Our simulations provide a very detailed description of the events before, during and after the DIN event. In particular, our results show that DIN events are not recurrent as previously speculated. Thus, DINs do not form H-deficient white dwarfs, nor DA white dwarfs with thin He-envelopes.

- We have qualitatively described the mechanism by which the CNO-buffer becomes unstable. Our analysis shows that the occurrence of CNO-flashes depends strongly on the intensity of the CNO-burning shell (as compared to the core luminosity), and its temperature. This seems to be in agreement with the fact that only our sequences with $M < 0.6$ and $Z/Z_{ZAMS} < 0.001$ and thin He-buffers experienced DIN events.

- Regarding the criterion presented by Iben & MacDonald (1986) for the occurrence of DIN events, we find that such criterion is misleading as the He-buffer mass is not the only parameter that determines whether a DIN event will take place or not. In particular, for more massive remnants our simulations do not predict DIN for any possible He-buffer masses.

- Our simulations provide a very detailed description of the surface abundances and lightcurves during the outbursts. In particular we find that typical lightcurves display a maximum of $M_V = -5...5.5$, a brightness speed of a few magnitudes per year, and a mild He- and N-enrichment. With $N = 10^{-10}$...10$^{-9}$ by mass fraction and $\log_{10} N_H/N_He > 0.15...0.6$. Also, in all our sequences we find surface abundances with $N > C > O$ by mass fraction.

- We find that the inclusion of erupting events at the boundaries of the CNO-burning shell drive the convection zones to higher He, N, C and O abundances than in the case in which no convection is occurring. Relative surface CNO abundances in these cases are $N > C > O$ (by mass fractions), although the precise values will be strongly dependent on the C and O composition of the He, C-, and O-rich interstellar.

Figure 1. Sketch of a Kippenhahn diagram of the proposed scenario for the formation of DA white dwarfs with thin He-buffer.

Figure 2. Evolutionary track in the HR-diagram of one of our DIN-sequences ($M_\sim 0.5946 M_\odot$, see Table for more details). The blue part of the curve describes the pre-white dwarf evolution. Note the last thermal pulse during the departure from the AGB (AFPT, blue loop) which leads to the formation of a thin He-buffer in the white dwarf as described in Fig. 1. The black curve shows the evolution of the white dwarf stage and the diffusion induced nova event. Black dots indicate the time before and after the maximum energy release during the CNO-flash. Note that, after the CNO-flash the star acquires a giant configuration in about 15 yr. This violent change in the luminosity and temperature of the star leads to a very characteristic visual lightcurve for these objects (see Fig. 3).

As a consequence of convective mixing of the pure H envelope with material from the He-buffer the surface abundances of the star during the outburst are strongly enriched in He and N (see Table).

Table 1. Surface properties of the DIN models used in this work. DINs of this last sequence were obtained from ZAMS properties as follows: cooling time at the moment of the DIN (AFPT/flash), evolution time from the maximum energy release at the last stage to $log L = 4$ yr (determined at this second and red $L$ and $T$ phase stage) and surface abundances. DINs were only obtained for pre-white dwarfs models, which have undergone the previous dredge up phase and then experienced the DIN event. DINs obtained for pre-white dwarfs models, which have not experienced the previous dredge up phase, were not considered in the present work. DINs were obtained for the expanded ZAMS progenitors. DIN properties are obtained from the model predicted by standard AGB wind prescriptions. The remnant was obtained by applying such winds at high mass during the He-burning phase. These DINs were obtained with the standard and $O$-rich composition, as described in Section 2.4. Radial convective zone properties are obtained from the complete code for both CNO-rich and CNO-poor models. Surface abundances are obtained from MIST 155 stars.

**Figure 3.** Predicted lightcurves and temperatures for our DIN simulated sequences during the outburst.