Abstract. We study the evolution of solid, CO white dwarfs after explosive carbon ignition at central densities around $10^{10} \text{ g cm}^{-3}$ triggered by steady accretion in a close binary system, in order to elucidate whether these stars can collapse to form a neutron star. We show that as long as the velocity of the burning front remains below a critical value of $0.006c_s$ ($\sim 60 \text{ km s}^{-1}$), gravitational collapse is the final fate. These calculations support the accretion-induced collapse (AIC) scenario for the origin of a fraction of low-mass X-ray binaries.

1. Introduction

Nowadays, there is an increasing amount of evidence which points to the fact that at least a fraction of low-mass X-ray binaries (LMXBs) should be the result of the accretion-induced collapse (AIC) of a white dwarf in a low-mass binary system (Taam and van den Heuvel, 1986).

The idea that white dwarfs can collapse to form neutron stars is relatively old (Canal and Schatzman, 1976; Canal and Isern, 1979; Canal et al., 1980; also Miyaji and Nomoto, 1987). However, this straightforward hypothesis has to face several problems, some of which are not yet completely solved. Actually, in order to reach the limiting mass by the accretion process, the white dwarf must avoid different explosive phenomena such as nova outbursts and Type I supernova explosions.

The behaviour of the external layers of an accreting white dwarf depends basically on the rate of mass transfer and on the chemical composition of the accreted material. Even though a lot of work has been done on this issue, much of it is based on very restrictive assumptions (steady spherical accretion, for instance). In general, accretion of material lighter than carbon will induce its burning. Only steady burning or non-disruptive flashing regimes can be allowed in neutron star formation scenarios. For which conditions this actually happens is still largely undetermined, but it seems that there are several combinations of the parameters mentioned above which allow the star to retain the accreted material and to grow in mass.

Even though the white dwarf manages to accrete mass steadily, the subsequent collapse is not yet guaranteed because explosive thermonuclear burning always happens in the contracting core before reaching Chandrasekhar's mass (but often close to it). The burning might propagate through the entire star, releasing enough energy to blow it apart.
completely. The only process which can oppose nuclear burning is electron capture on the incinerated material.

Whether the electron captures can overcome the thermonuclear burning or not depends on the density range covered by explosive ignition, and the burning front velocity. In turn, both questions depend critically on the physical state of the star's interior when ignition occurs. In the case of fluid interiors and in CO white dwarfs, which will be the focus of our attention, explosive carbon ignition always takes place at central densities in the interval $2-4 \times 10^9$ g cm$^{-3}$; the burning propagates via Rayleigh–Taylor instability, with typical velocities of the order of $0.2c_s$ ($c_s$ being the local sound speed which for these densities is of the order of $10^9$ cm s$^{-1}$). These comparatively low central densities and high burning front velocities make electron captures unable to remove pressure fast enough, so that we always get Type I supernova explosions (Nomoto et al., 1984).

However, as the detached phase of the close binary system may be very long ($\sim 2-3 \times 10^9$ years) the stellar interior may be partially or totally solid when accretion begins. Which fraction of the core remains solid, if any, when explosive ignition takes place depends on the initial mass and temperature of the star as well as on the mass accretion rate. Central ignition densities for CO white dwarfs that are partially solid at the beginning of mass transfer cover the range $6 \times 10^9$ g cm$^{-3} \leq \rho_c \leq 1.5 \times 10^{10}$ g cm$^{-3}$ (Hernanz et al., 1988). Not only is the ignition density higher in solid white dwarfs but also no hydrodynamical instability can develop in solid layers. Therefore, conduction is the burning propagation mechanism. Although conductive front velocities are somewhat uncertain, current estimates give $0.005c_s \leq v_{\text{cond}} \leq 0.01c_s$ (Woosley and Weaver, 1986). These comparatively low velocities, together with the faster electron capture rates associated with those high ignition densities, represent very favourable conditions for collapse of the white dwarf.

ONeMg white dwarfs have also been proposed as good candidates for accretion-induced collapse (Miyaji and Nomoto, 1987). However, their final fate remains unclear (Garcia, 1989).

2. Results and Discussion

We have followed the evolution of partially or totally solid CO white dwarfs by means of an implicit, one dimensional hydrodynamic code (Kutter and Sparks, 1972) which incorporates the relevant physics. Our initial models are isothermal white dwarfs with central densities of $9.3 \times 10^9$ g cm$^{-3}$ and $1.1 \times 10^{10}$ g cm$^{-3}$, respectively. They correspond to two of the final models calculated by Hernanz et al. (1988), who followed the accretion phase. In the star with lower central density the solid fraction is 60% of the total mass while in the case of the higher central density the whole star is solid. We artificially incinerated the central alyer by increasing its temperature above the deflagration temperature and then followed the ulterior evolution.

As we have already mentioned, one of the critical parameters in our calculations is the velocity of the conductive burning front. This is only roughly known. Woosley and