Backward evolutionary calculations to model double white dwarfs

Marc van der Sluys, Frank Verbunt, Norbert Langer and Onno Pols

Astronomical Institute Utrecht   http://www.astro.uu.nl/~sluys/dwds/

Introduction

We try to model observed double white dwarf systems, binaries consisting of two white dwarfs (WDs). For about ten of these systems the masses are known with some accuracy. We concentrate on three systems consisting of two helium WDs, because of the constraints on the evolution of the components. Some properties of the systems are shown in Table 1[1].

Name	P (d)	M_1	M_2	q
WD 0136+768	1.407	0.37	0.47	1.26 ± 0.03
WD 0957–666	0.061	0.32	0.37	1.13 ± 0.02
WD 1101+364	0.145	0.33	0.29	0.87 ± 0.03

Table 1. Observed double helium white dwarfs. M_1 is the mass of the original primary ($M_\odot$), the firstly formed WD. Mass uncertainties are around 0.05 $M_\odot$.

The short periods in Table 1 indicate that the orbital separation of these systems is a few solar radii or less. This is much smaller than a giant branch (GB) star with a helium core of 0.3 $M_\odot$. Therefore, the orbit must have shrunk a lot during the last mass transfer phase, in an event that is known as a spiral-in or common envelope (CE).

The table also shows mass ratios close to one. According to the core mass–radius relation for giants, the WD mass is a measure for the radius of the giant at the moment of Roche lobe filling, which is in turn a measure for the size of the orbit. Thus, these mass ratios would indicate that the orbit changed very little during the first mass transfer phase. This is different than the standard CE theory predicts. Nelemans et al.[2] have concluded that a conservative first mass transfer phase and a CE as a second mass transfer phase cannot explain the observed WD binaries. They used an adapted CE scenario for the first mass transfer phase to model these systems.

Common envelope

A common envelope is thought to occur when a GB star fills its Roche lobe. Mass transfer is then unstable and the giant will expand very quickly and engulf its WD companion, hence common envelope. Friction causes the orbit to shrink and the energy released in this process heats up and drives away the envelope. The event should last short compared to the evolutionary timescale of the star, so that the helium core does not change. The resulting WD mass ($M_{\rm wd}$) is then equal to the helium core mass ($M_{\rm cor}$) at the onset of the CE. A CE with a short timescale is the only assumption we make in our backward calculations of the second mass transfer phase.

Giant branch models

Before the CE, the binary consisted of the first WD and a GB star. In order to calculate the possible range of these binary systems, we need a relation between the core mass and the radius of giants. We calculated several series of evolutionary models for single stars with masses between 0.8 $M_\odot$ and 2.35 $M_\odot$, from the ZAMS up to core helium ignition. Lower mass stars have not evolved off the MS yet, more massive stars do not develop degenerate helium cores. Between different series, we varied parameters that might influence the core mass or the radius over a wide range. We found that wind mass loss, convective overshoot and an increased He-abundance (by possible accretion in the first mass transfer) have no significant effect. A variation in the mixing length parameter ($\alpha_{\rm ml}$) however, has a strong effect on the radius and is considered here. The results of some models are found in Fig. 1, together with the power law that Nelemans et al. used: $M_{\rm cor} = 10^{3.5} \times M_*^4$.

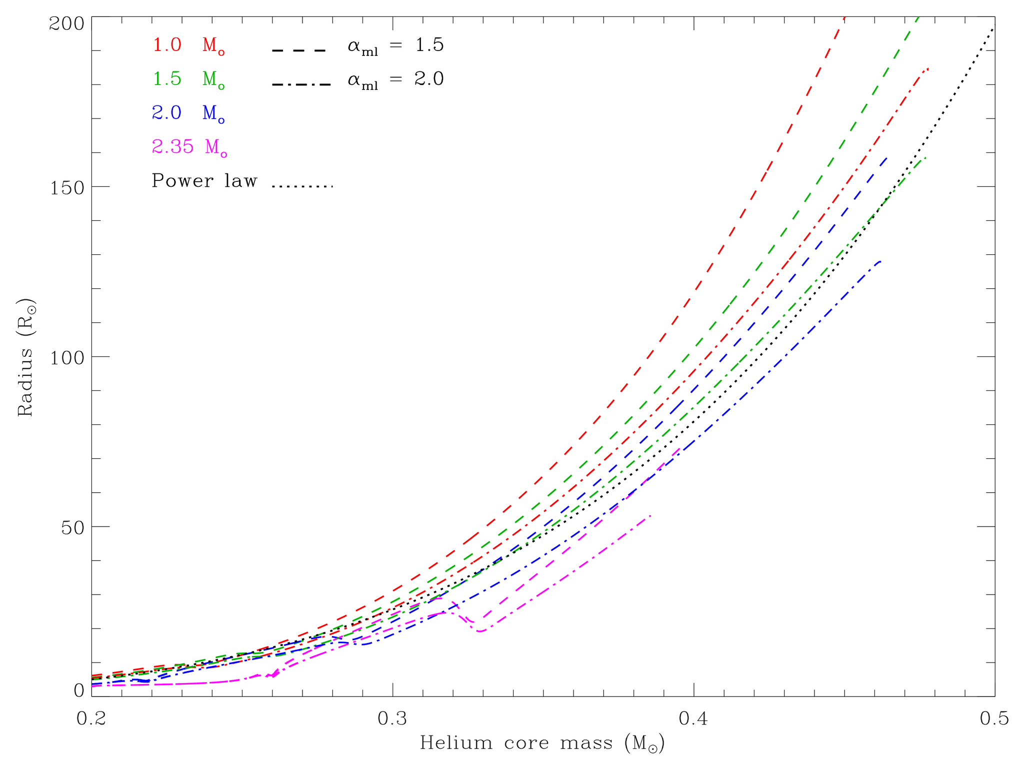

Figure 1. Core mass–radius relations for giants of different masses and two different values for $\alpha_{\rm ml}$. A power law is also plotted.

For each stellar model, we selected the 'moment' where $M_{\rm cor} = M_{\rm wd}$ and calculated the radius of the star. This radius must be equal to the Roche lobe radius of the secondary and thus we can calculate the orbital period of the system, as a function of the secondary mass. The results are shown in Fig. 2.

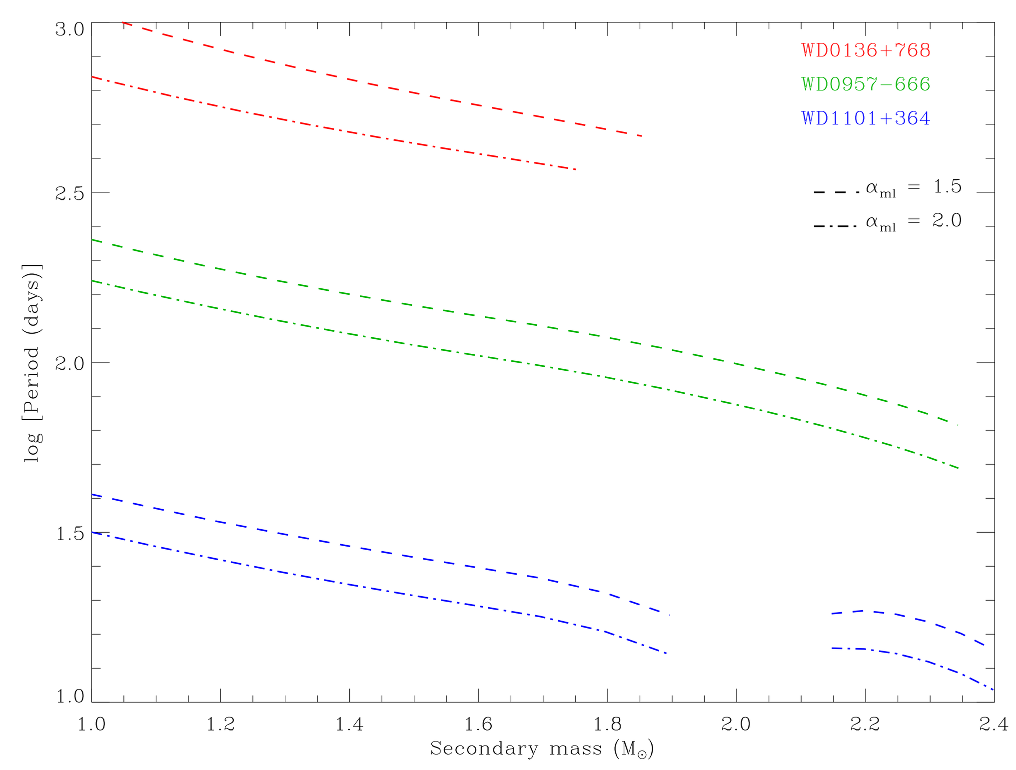

Figure 2. CE outcomes for the three systems using two different values for $\alpha_{\rm ml}$. See the text for more details.

The red and green lines in Fig. 2 end because only low mass stars produce higher mass He-WDs. The gap in the blue lines occurs because these stars shrink when they reach $M_{\rm cor} = M_{\rm wd}$, so that they cannot start to fill their Roche lobe then. A first mass transfer should end with a primary mass as in Table 1 and a combination of secondary mass and period on one of these lines.

The first mass transfer

We are currently trying to find a conservative mass transfer phase that leads to a system in Fig. 2. The system WD 1101+364 is the most promising. If we assume conservative mass transfer, we can calculate the orbit of a progenitor system for each possible distribution of the system mass over the two components. This is shown in Fig. 3.

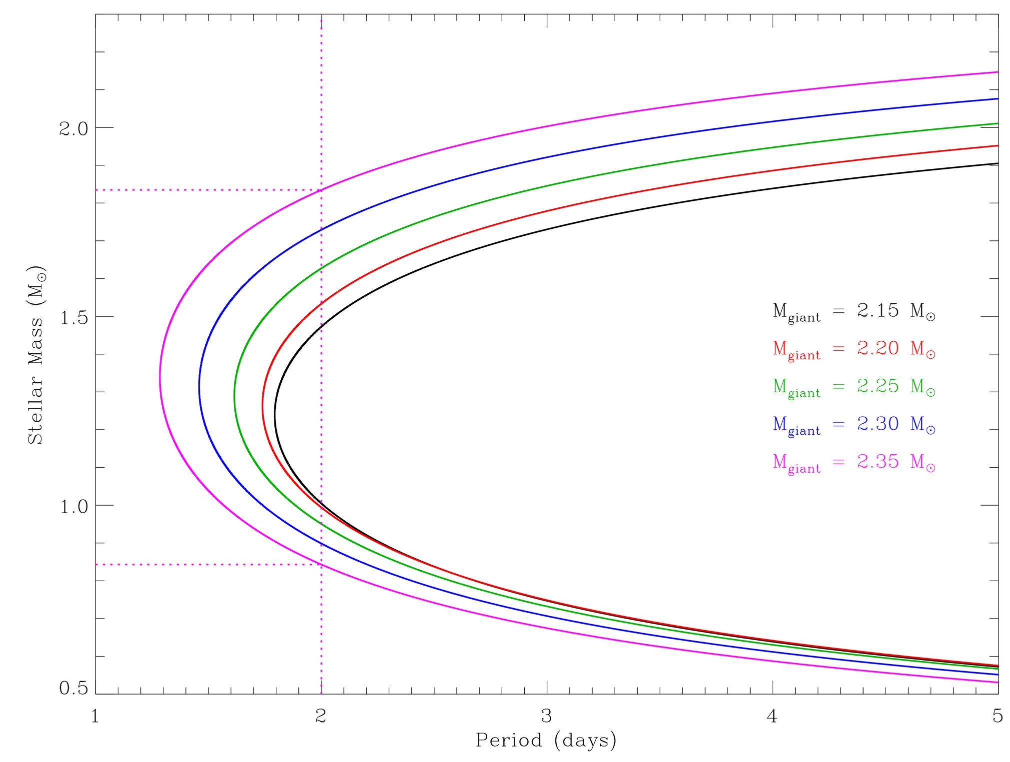

Figure 3. Solutions for stable mass transfer that may lead to a progenitor system for WD 1101+364 with a giant mass between 2.15 and 2.35 $M_\odot$ and $\alpha_{\rm ml}$ = 2.0. See the text below for further interpretation.

The dotted lines in Fig. 3 show the example of a binary system with masses of 1.83 and 0.84 $M_\odot$ and a period of 2 days. If all but 0.33 $M_\odot$ from the primary would be transferred to the secondary, the system would have a secondary mass of 2.35 $M_\odot$ and a period of 12 days, lying on the blue dash-dotted line in Fig. 2.

Future work

The next step is to check whether the systems in Fig. 3 do indeed stop mass transfer when the primary weighs 0.33 $M_\odot$. We use detailed binary evolution models to do this. So far, we find that either the mass transfer is unstable or the system produces a WD of too low mass. Since then more mass is transferred, the secondary becomes too massive and the orbit too wide. Solutions may lie in partially conservative mass transfer, so that larger initial masses may be used. Also, the uncertainty in the WD masses has not been considered here. Although WD 1101+364 may be explained this way, it seems unlikely that we find one mechanism that can explain all three systems.

References:

[1] Maxted, P.F.L et al., 2002, MNRAS 332, 745.
[2] Nelemans, G. et al., 2000, A&A 360, 1011.