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High-mass White Dwarfs and the Energy Budget of Common Envelope Evolution

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Abstract. Common envelope is the most important evolutionary process in the formation of all close compact binaries. It is well known that during the common envelope phase a fraction of the orbital energy is used to expel the envelope. However, it is not clear yet whether or not additional energy sources, such as the recombination energy of the envelope, play a decisive role. Here we demonstrate that recombination energy can only be considered as important if close binaries containing high-mass white dwarfs ($M_{\rm wd} \gtrsim 0.8 M_{\odot}$) at relatively long orbital periods ($P_{\rm orb} \gtrsim$ 1–3 days) exist.

1. Introduction

The concept of common envelope evolution is simple. Initially the more massive star in a main sequence binary evolves into the red giant phase (or asymptotic giant phase) and overfills its Roche lobe. Mass is then transferred to the main sequence companion, which also overfills its Roche lobe. The core of the giant and the companion star orbit within a common envelope formed by the outer layers of the giant and friction leads then to a dramatic shrinkage of the orbit. A fraction of the released orbital energy is used to expel the envelope and a close white dwarf/main sequence (WDMS) binary is formed. We call these systems post-common envelope binaries or PCEBs.

Unfortunately, common envelope evolution is a three-dimensional problem and involves a large number of hydrodynamic and thermodynamic processes on both time and scale lengths spanning very large ranges. Thus common envelope is generally treated with a parametrised equation in which a fraction of the orbital energy $\alpha_{\rm CE}$ is used to unbind the envelope (Paczynski 1976; Webbink 1984; Iben & Livio 1993). $\alpha_{\rm CE}$ is commonly known as the common envelope efficiency. Whilst there exist indications for $\alpha_{\rm CE}$ being generally small i.e. $\alpha_{\rm CE} \sim 0.25$ (Zorotovic et al. 2010; Ricker & Taam 2012) it remains unclear if, and to what extent, additional energy sources play an important role in unbinding the envelope (Han et al. 1994; Soker & Harpaz 2003; Webbink 2008). Recombination energy of the envelope is often considered the most promising candidate and indeed the current configuration of the close WDMS binary IK Peg can only be understood if this energy is taken into account (Davis et al. 2010; Zorotovic et al. 2010).

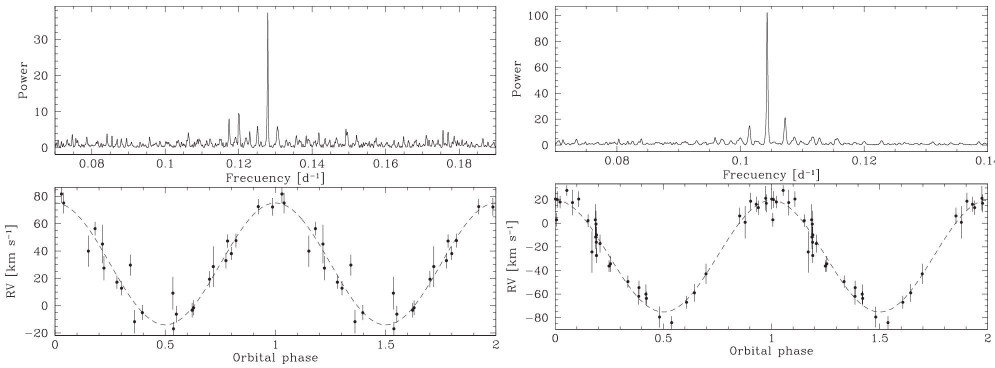

Figure 1. Top panels: ORT/TSA periodogram obtained from the radial velocity data of SDSSJ 1211-0249 (left) and SDSSJ 2221+0029 (right). Clear peaks at 0.128 d^{-1} (left) and 0.104 d^{-1} (right) can be seen. Bottom panels: the radial velocity curves folded over the period provided by the periodograms in the top panels.

As part of our ongoing survey of PCEBs from SDSS (Rebassa-Mansergas et al. 2008, 2011; Schreiber et al. 2010; Nebot Gómez-Morán et al. 2011) we have identified SDSSJ 1211-0249 and SDSSJ 2221+0029 as the second and third longest orbital period PCEBs (containing a white dwarf primary) after IK Peg. Based on their long-orbital periods we here reconstruct their evolution and discuss the implications of recombination energy during the common envelope phase. More details of this work are described by Rebassa-Mansergas et al. (2012b).

2. Observations

SDSSJ 1211-0249 and SDSSJ 2221+0029 have been identified as WDMS binaries in SDSS by Rebassa-Mansergas et al. (2010, 2012a). Follow-up observations of these two systems were performed for measuring the orbital periods at the VLT, WHT, Gemini South, NTT, Calar Alto 3.5 and Magellan Baade telescopes. A periodogram and radial velocity curve folded on the best orbital period for each system is shown in Figure 1. The orbital periods are given in Table 1. The stellar parameters of both systems were obtained applying the decomposition-fitting routine by Rebassa-Mansergas et al. (2007) and are also provided in Table 1.

3. The energy budget of common envelope evolution

We used the method by Zorotovic et al. (2010) based on the orbital and stellar parameters obtained in the previous section to reconstruct the evolution of our two systems without incorporating any recombination energy. We found possible progenitors in both cases, implying that additional energy sources are not specifically required during common envelope evolution.

Recombination energy is expected to be most important when the white dwarf progenitor radius is large and the envelope is loosely bound (Webbink 2008), i.e. the white dwarf progenitor evolved through the asymptotic giant branch and formed a relatively massive white dwarf. Inspection of Table 1 reveals that our two systems contain

Table 1. Binary parameters obtained for SDSSJ 1211-0249 and SDSSJ 2221+0029

	SDSS J1211–0229			SDSS J2221+0029		
$M_{\rm wd}[{\rm M}_\odot]$	0.52	±	0.07	0.54	±	0.03
$M_{\rm sec}[{\rm M}_\odot]$	0.41	±	0.05	0.38	±	0.07
q	0.79	±	0.15	0.70	±	0.15
$P_{\rm orb}$ [d]	7.818	±	0.002	9.588	±	0.002
$K_{\rm sec}[{\rm km\,s^{-1}}]$	44	±	3	49	±	2
${\rm Sp}_{\rm sec}$	M2.5	±	1	M3	±	0.5
$T_{\rm eff(WD)}$ [K]	13130	±	860	18440	±	150
$\log g_{\rm (WD)}$	7.84	±	0.13	7.85	±	0.06

low-mass white dwarfs and it is therefore not surprising that recombination energy was not specifically required during their evolution. Conversely IK Peg not only has a long orbital period but also contains a high mass white dwarf.

In order to find out what specific PCEBs would provide direct evidence for recombination energy being important during the common envelope we use the reconstruction algorithm described in Zorotovic et al. (2011) both with and without incorporating recombination energy. We performed this exercise for core masses ranging from 0.3 to $1.3{\rm M}_\odot$ and secondary star masses of $0.4 \pm 0.1\,{\rm M}_\odot$. Among all possible progenitors we selected the maximum orbital period for each combination of white dwarf and secondary star masses.

In Figure 2 we show the resulting PCEB maximum orbital period as a function of white dwarf mass, where the positions of SDSSJ 1211-0249 and SDSSJ 2221+0029 are indicated by black solid dots. The dashed lines correspond to the maximum orbital periods obtained incorporating recombination energy, while the solid lines represent the maximum orbital periods if the envelope is expelled by the use of orbital energy only.

Direct evidence for recombination energy contributing in expelling the envelope will be provided if any PCEB is located above the solid line in Figure 2 (for a given secondary star mass). In other words, only if we can identify long orbital period PCEBs ($P_{\rm orb} \gtrsim 1$–3 days) containing relatively massive white dwarfs ($M_{\rm wd} \gtrsim 0.8\,{\rm M}_\odot$) we can confirm recombination energy as an important ingredient during common envelope evolution. So far not a single known PCEB with well determined stellar parameters apart from IK Peg has a long orbital period *and* contains a high-mass white dwarf (Zorotovic et al. 2011).

4. Conclusions

We have reconstructed the evolution of the second and third longest orbital period PCEBs containing a white dwarf primary and have evaluated whether recombination energy plays an important role during common envelope evolution. Our results show that our two systems do not require recombination energy, presumably due to their white dwarfs being of low mass. In order to confirm recombination energy as a necessary ingredient we have demonstrated that PCEBs containing massive white dwarfs at long orbital periods should exist. If no such system will be detected, the contri-

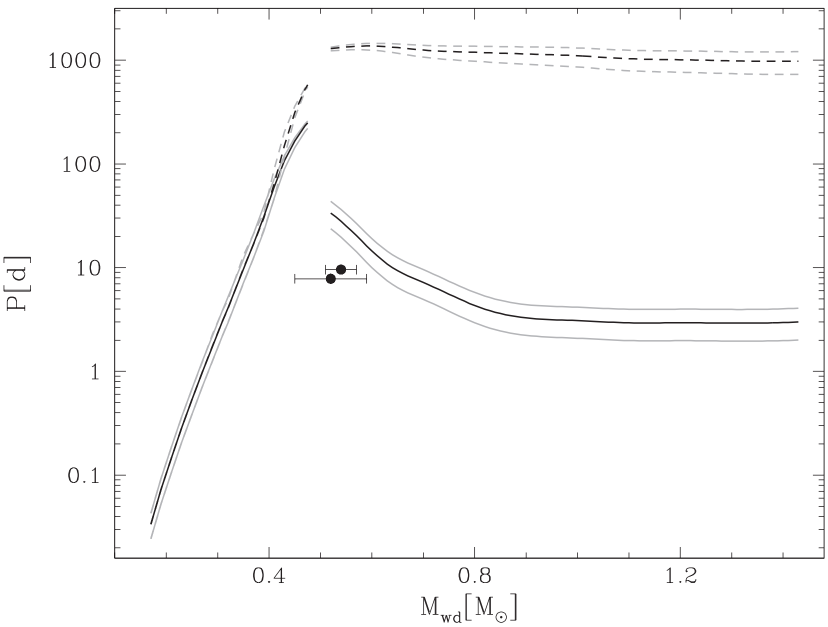

Figure 2. Maximum orbital period versus white mass assuming a secondary star mass of M_{sec} = 0.4 (black lines) $\pm\,0.1\,M_{\odot}$ (gray lines). The dashed lines correspond to the maximum orbital period if all recombination energy goes into common envelope ejection, while the solid lines provides the same limit but without taking into account possible contributions from recombination. Any system located between the two lines would provide direct evidence for the contributions of recombination energy.

bution of recombination energy during common envelope evolution is likely of minor importance.

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