White dwarf post common envelope binaries from the SDSS

M R Schreiber\textsuperscript{1}, B T Gaensicke\textsuperscript{2}, M Zorotovic\textsuperscript{3,4}, A Rebassa-Mansergas\textsuperscript{1,2}, A Nebot Gomez-Moran\textsuperscript{5}, J Southworth\textsuperscript{2}, A D Schwope \textsuperscript{5}, S Pyrzas\textsuperscript{2}, C Tappert \textsuperscript{4} and L Schmidtobreick\textsuperscript{3}

\textsuperscript{1} Departamento de Física y Astronomía, Facultad de Ciencias, Universidad de Valparaíso, Valparaíso, Chile
\textsuperscript{2} Department of Physics, University of Warwick, Coventry CV4 9BU, UK
\textsuperscript{3} European Southern Observatory, Casilla 19001, Santiago 19, Chile, AB(European Southern Observatory, Casilla 19001, Santiago 19, Chile
\textsuperscript{4} Departamento de Astronomía y Astrofísica, Pontificia Universidad Católica, Casilla 306, Santiago 22, Chile
\textsuperscript{5} Astrophysikalisches Institut Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany

\textsuperscript{1} Departamento de Física y Astronomía, Facultad de Ciencias, Universidad de Valparaíso, Valparaíso, Chile

\textsuperscript{2} Department of Physics, University of Warwick, Coventry CV4 9BU, UK

\textsuperscript{3} European Southern Observatory, Casilla 19001, Santiago 19, Chile, AB(European Southern Observatory, Casilla 19001, Santiago 19, Chile

\textsuperscript{4} Departamento de Astronomía y Astrofísica, Pontificia Universidad Católica, Casilla 306, Santiago 22, Chile

\textsuperscript{5} Astrophysikalisches Institut Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany

E-mail: Matthias@dfa.uv.cl

Abstract. Post common envelope binaries (PCEBs) consisting of a white dwarf and a main sequence star are ideal systems to calibrate current theories of angular momentum loss in close compact binary stars. The potential held by PCEBs for further development of close binary evolution could so far not be exploited due to the small number of known systems and the inhomogeneity of the sample. The Sloan Digital Sky Survey is changing this scene dramatically, as it is very efficient in identifying white dwarf/main sequence (WDMS) binaries, including both wide systems whose stellar components evolve like single stars and - more interesting in the context of close binary evolution - PCEBs. We pursue a large-scale follow-up survey to identify and characterise the PCEBs among the WDMS binaries that have been found with SDSS. We here present preliminary results of our survey and derive first constraints on current models of white dwarf binary evolution.

1. Introduction

Close white dwarf binary stars span a wide range of interesting objects and are important in many astrophysical contexts. Type Ia supernovae, white dwarfs in close binaries driven over their Chandrasehkar limit, are routinely used as “standard candles” to probe the nature of dark energy. AM CVn stars, very short orbital period binaries with a helium rich donor star, are expected to significantly contribute to the gravitational wave background which will be probed by missions such as LISA (Laser Interferometer Space Antenna). Furthermore, Cataclysmic Variables (CVs), close binaries in which a white dwarf accretes gas from its Roche-lobe filling companion, are excellent laboratories to study the physics of accretion.

The evolution of initially wide main sequence binaries with long orbital periods (>years) into short orbital period (<days) binaries containing white dwarfs depends primarily on the rate at which angular momentum is extracted from the binary orbit. If we wish to understand the populations and relative numbers of close white dwarf binaries in general, we need to understand the angular momentum loss mechanisms driving their formation and evolution. It is thought
that a significant fraction of the angular momentum is extracted from the binary orbit during the short-lived (< 1 – 100 years) but crucial common envelope phase (Webbink 2007): once the progenitor of the white dwarf leaves the main sequence, dynamically unstable mass transfer may lead to the formation of a gaseous envelope around the entire binary. Friction within this envelope is significantly reducing the binary separation as the core of the giant and the main sequence star spiral in towards the centre of mass. Once the common envelope has been ejected, the evolution of the remaining post common envelope binary towards shorter orbital periods is driven by orbital angular momentum loss through gravitational radiation and – much more efficient – magnetic wind braking.

The general concepts of both, the common envelope phase as well as magnetic braking in close binaries, have been developed more than 25 years ago. Meanwhile, quite detailed binary population synthesis (BPS) studies have been carried out and are a commonly adopted method to predict the outcome of binary star evolution, and to investigate e.g. the nature of SN1a progenitors, or the properties of the galactic white dwarf plus main sequence (WDMS) binary population. However, in current BPS models the crucial common envelope phase is usually simply approximated by a parameterized energy equation and the efficiency to “use” the orbital energy to expel the envelope is very uncertain (see Willems & Kolb 2004 for a recent review). Similarly, most of the results obtained by BPS calculations sensitively depend on the prescriptions used for magnetic braking. Present models of magnetic braking differ by up to two orders of magnitude, and, even worse, it is not clear whether magnetic braking is present in all PCEBs, or whether it breaks down in systems where the secondary star is fully convective. In order to explain the orbital period gap observed in the period distribution of cataclysmic variables, one in fact needs to assume the latter “disrupted magnetic braking” (Rappaport et al. 1983), while observations of single low mass stars do not show any evidence for such a discontinuity (Sills et al. 2000). To sum up, the diagnostic potential and predictive power of BPS studies is severely limited by the lack of understanding the detailed physics of the common envelope phase and subsequent orbital angular momentum loss.

On the other hand, it is fair to say that there is also a lack of observational tests on the outcome of close binary evolution, that could be provided by measuring e.g. the fraction of binaries that underwent a common envelope, or the orbital period distribution of post common envelope (PCEB) binaries. We here review the first results obtained from a large observational project especially designed to fill this gap and to provide the much needed observational constraints on models of compact binary formation and evolution. The article is organized as follows. In Section 2 and 3 we review in more detail our current understanding of angular momentum loss in close white dwarf binaries and emphasise the potential of observational population studies to constrain angular momentum loss. In Section 4 we describe our survey and present preliminary survey results in Section 5 and 6.

2. The common envelope efficiency

Since Paczyński (1976) outlined the first ideas of common envelope evolution, it is thought that this phase of binary evolution is producing virtually all the known types of close white dwarf binaries. Common envelope evolution results from dynamically unstable mass transfer from the evolving more massive star to the less massive main sequence star (Paczynski 1976; Webbink 1984; Hjellming 1989). This situation occurs especially if the evolving more massive star fills its Roche-lobe when having a deep convective envelope (usually on the giant or asymptotic giant branch). Then, as a response to mass transfer, the radius of the mass donor may increase while its Roche-radius is decreasing. The resulting runaway mass transfer drives the mass gainer out of thermal equilibrium as it accretes on a time scale faster than its thermal time scale. Consequently, the lower mass star also expands until filling its Roche-lobe, which then leads to a common envelope configuration.
In current binary population models the energy equation relating the total energy of the binary before and after the common envelope phase is scaled with two uncertain dimensionless parameters, called the structural binding energy parameter ($\lambda$) and the common envelope efficiency ($\alpha$). Both parameters can be combined to obtain one uncertain parameter $\alpha \lambda$:

$$\frac{GM_g M_e}{R_g} = \lambda \alpha \left( \frac{GM_c M_2}{2a_f} - \frac{GM_g M_2}{2a_i} \right). \quad (1)$$

Here, $M_g$, $M_c$, $R_g$, $M_e$, and $M_2$ are the masses and radii of the giant, its core, its envelope, and the accreting secondary star respectively, while $a_f$ and $a_i$ are the final and initial binary separation.

Nelemans et al. (2000) and Nelemans & Tout (2005) developed an algorithm to reconstruct the common envelope phase for observed white dwarf binaries. They derive the possible masses and radii of the progenitors of the white dwarfs in these binaries from fits to detailed stellar evolution models Hurley et al. (2000). This information can then be used to reconstruct the mass-transfer phase in which the white dwarf was formed. However, to constrain the common envelope efficiency a much larger and representative sample of white dwarf post common envelope binaries than the one available to Nnelemans & Tout (2005) needs to be analyzed.

3. Disrupted magnetic braking

Once the common envelope has been ejected, the evolution of the post common envelope binary is driven by angular momentum loss through gravitational radiation and magnetic wind braking. While the first is well understood, the latter represents an additional big uncertainty in white dwarf binary formation.

Based on Skumanich (1972) who analyzed the spin down rates of G-type stars, Verbunt & Zwaan (1981) derived a prescription for angular momentum loss due to magnetic braking of the form $\dot{J} \propto P_{\text{orb}}^{-3}$. In order to explain the orbital period gap observed in the period distribution of cataclysmic variables (CVs), Rappaport et al. (1983) proposed the disrupted magnetic braking scenario by assuming that magnetic braking ceases when the secondary star becomes fully convective at $M_{\text{sec}} \sim 0.3 M_\odot$ (which corresponds to $P_{\text{orb}} \sim 3$ h). The disrupted magnetic braking idea is based on the result that the transition region between radiative core and convective envelope plays a crucial role for the stellar dynamo, i.e. for producing stellar magnetic fields (McDermott & Taam 1989). As the donor stars in CVs above the gap are driven out of thermal equilibrium by strong mass transfer (caused by efficient magnetic braking), disruption of magnetic braking for fully convective secondary stars can indeed cause the donor star to relax to thermal equilibrium, to shrink within its Roche-lobe, and to become a detached white dwarf main/sequence binary.

The most important observational support for the disrupted magnetic braking hypothesis has been mentioned already, the famous orbital period gap, i.e. the significant deficit of CVs in the orbital period range of 2 – 3 h. Additional support comes from the fact that (a) the current mass transfer rates derived from observations of CVs above the gap are significantly higher than those of CVs below the gap, (b) the mean accretion rates derived from accretion induced compressional heating are systematically higher above than below the gap (Townsley & Bildsten 2003; Townsley & Gaensicke 2008), and (c) the donor stars in CVs above the gap seem to be slightly expanded compared to main sequence stars which is consistent with the donor stars driven out of thermal equilibrium (Patterson et al. 2005).

In spite of this success, there also exist serious doubts on the reliability of the disrupted magnetic braking scenario. Most importantly, observations of the spin down rates of single stars do drastically disagree with both the strength of magnetic braking according to Verbunt & Zwaan (1981) as well as the disrupted magnetic braking scenario proposed by Rappaport et al. (1983). From observations of young open clusters, Sills et al. (2000) derived slow spin down rates
and did not find any signs for a discontinuity in the braking law of rapidly rotating low-mass stars. Recently, Briggs et al. (2007) measured the X-ray activity of secondary stars in PCEBs and find that there seems to be no discontinuity in the magnetic activity of the secondary stars at the fully convective boundary.

Apparently, independent tests of disrupted magnetic braking are required. Fortunately, Schreiber & Gaensicke (2003) and, more recently, Politano & Weiler (2006) and Davis et al. (2008) demonstrated that observational population studies of post common envelope binaries consisting of a white dwarf and a main sequence star can provide such tests of disrupted magnetic braking. However, performing these tests requires immense observational efforts in order to establish a large and unbiased sample of PCEBs.

4. WDMS binaries from the SDSS

Schreiber & Gaensicke (2003) carried out a detailed theoretical study of the 30 well-observed PCEBs known at that time and were the first to realize the full potential of observational population studies of PCEBs in the context of close compact binary evolution. However, their sample was not only small but also heavily biased. Hence, no clear constraints on white dwarf binary evolution and formation could be derived.

Since the SDSS turned out to be extremely efficient in identifying detached WDMS binaries, this situation changed drastically. The published DR5 SDSS-WDMS sample (Silvestri et al. 2007) consists of more than 1200 mostly young systems containing hot white dwarfs. We find \( \sim 1600 \) WDMS in DR6 and add \( \sim 300 \) systems containing mostly cold white dwarfs from a dedicated survey of WDMS that has been implemented in SEGUE (see also Schreiber et al. 2007). The population of these \( \sim 1900 \) WDMS binaries consists of (a) wide binary systems whose stellar components never interact and evolve like single stars and (b) systems with short orbital periods that went through a common envelope phase – post common envelope binaries (PCEBs). Given the large number of WDMS binaries identified, the number of SDSS PCEBs among them should be sufficient to provide clear new constraints on white dwarf binary formation.

In 2006 we started an extended survey performing follow-up observations at several 4-8m telescopes to identify and characterize the PCEBs among the SDSS WDMS binaries. The project follows a three-step approach. First we derive the stellar parameters of the systems (i.e. the white dwarf mass, the white dwarf temperature, the secondary spectral type, and the distance) using
Figure 3. Radial velocity measurements using VLT/FORS2 for 25 white dwarf/main sequence binaries. The systems in black show 3σ radial velocity variations and we consider them to be strong post common envelope binary candidates.

Figure 4. Radial velocity curve of the secondary star in SDSSJ141451.73-013242.7. The orbital period is 17.45 hr.

Figure 5. Radial velocity curve of the secondary star in SDSSJ104738.24+052320.3. The orbital period is 9.17 hr.

A spectral decomposition method as shown in Fig. 1 and 2 and as explained in detail in Rebassa-Mansergas et al. (2007, 2008). The second step is represented by the identification of PCEBs as close binaries from at least two spectra taken in different nights. Strong radial velocity variations unambiguously identify the PCEBs among the WDMS population and qualify the system for stage three, i.e. the determination of the orbital period from time-series spectroscopy. We obtained at least two spectra of 143 WDMS and identified 55 PCEBs due to the detection of significant radial velocity variations. It appears that the fraction of PCEBs among the SDSS WDMS is about 35%, i.e. slightly higher than predicted by theoretical population synthesis studies. As an example, Fig. 3 shows radial velocity measurements of 25 WDMS with VLT/FORS2 (see also Schreiber et al. 2008). Once a strong PCEB candidate has been identified, we determine the orbital period of the binary by measuring the radial velocity curve of the secondary star. Two examples are given in Fig. 4 and Fig. 5. By the time of writing we have characterized a sample of 43 PCEBs with measured orbital period this way. Our final goal is to establish a sample of ~200 PCEBs until 2010/2011.
5. Testing disrupted magnetic braking
As mentioned previously, the disrupted magnetic braking model postulates that magnetic braking vanishes for fully convective secondary stars. As shown by Politano & Weiler (2006), disrupted magnetic braking implies much shorter evolutionary time scales for non-fully convective secondary stars than for PCEBs having a fully convective companion. Hence, the fraction of PCEBs among WDMS binaries should be significantly higher for the latter. The measurements described in the previous section allow to test this prediction directly. Figure 6 shows the fraction of PCEBs among WDMS binaries as a function of spectral type. Indeed, there seems to be a steep increase around the fully convective boundary, in perfect agreement with the predictions of disrupted magnetic braking. This finding can be considered as a strong argument in favour of disrupted magnetic braking. However, the error bars in Fig. 6 are still rather large, especially for low mass secondary stars, and further measurements are required to derive definite conclusions.

6. Reconstructing the history of the binaries
In Rebassa-Mansergas et al. (2008) we discussed a preliminary orbital period distribution and showed that the measured orbital period distribution seems to imply a low value of $\alpha$ when compared with those predicted by binary population synthesis models. However, the orbital period distributions predicted by BPS models depend not only on the common envelope efficiency but also on the assumed initial mass function, the initial distribution of binary separations, and the modelling of mass transfer.

Here we follow a different approach. We reconstruct the history of the observed population of PCEBs and derive all possible initial parameters for a given system. First, we follow Schreiber & Gaensicke (2003) and reconstruct the post common envelope evolution of the PCEBs for a given angular momentum loss prescription (we here assume classical disrupted magnetic braking according to Rappaport et al. 1983). This requires knowing the cooling ages of the white dwarfs which we derive using the cooling tracks of Wood (1995). As most of the observed PCEBs are relatively young and as most of our PCEBs have low mass secondary stars where gravitational radiation is assumed to be the only angular momentum loss mechanism, the reconstructed zero-age post-CE orbital period distribution is not dramatically different to the observed distribution but peaks at a slightly longer period ($\log(P_{\text{orb}}[\text{days}]) \sim 0.5$). Using the calculated orbital
periods the PCEBs had at the end of the CE phase we can now reconstruct the CE phase following Nelemans & Tout (2005). We assume that the white dwarf mass is equal to the core mass of the giant at the onset of mass transfer and that the mass of the secondary star does not change during common envelope evolution. This allows to reconstruct all possible histories for a given PCEB. Hereby each assumed progenitor mass corresponds to one value of $\alpha \lambda$. The derived values of $\alpha \lambda$ are given in Fig. 7. The different vertical lines for a given system correspond to the uncertainty in the derived white dwarf masses. Apparently, all our systems have solutions for small values of $\alpha \lambda$. This indicates that the efficiency of using orbital energy to expel the envelope is rather small. In other words, if there exits a universal value of $\alpha \lambda$ it should be $\leq 0.5$. However, it has been shown that the binding energy parameter $\lambda$ sensitively depends on the evolutionary stage of the giant when the binary enters the common envelope phase. The envelopes of giants on the asymptotic giant branch are less bound than those of stars on the first giant branch. This effect has to be included before final conclusions on the common envelope efficiency can be drawn.

**Figure 7.** Reconstruction of the common envelope phase of SDSS PCEBs. Assuming the core of the progenitor of the WD to be equal to the white dwarf mass and assuming that the mass of the secondary does not change during the CE, we get one value of $\alpha \lambda$ for a given mass of the Roche-lobe filling giant. Solutions with progenitors on the giant branch are in black while solutions in blue and green correspond to progenitors on the early or late AGB.
7. Summary

The currently available large sample of white dwarf/main sequence (WDMS) binaries provided by the SDSS offer a unique possibility to progress with our understanding of close compact binary evolution. We have performed a large follow-up study of these WDMS which is especially designed to identify a large sample of white dwarf post common envelope binaries. So far we identified 55 PCEBs and measured the orbital period of 43 systems. The preliminary results of the project can be summarized as follows.

- The fraction of PCEBs among WDMS binaries seems to depend sensitively on the mass of the secondary star. While the fraction of PCEBs is \( \gtrsim 40\% \) for late spectral type secondary stars, it is only \( \lesssim 20\% \) for more massive secondary stars. This result is in agreement with the predictions of the disrupted magnetic braking scenario.

- The large majority of PCEBs from the SDSS has orbital periods shorter than a day. This indicates that the common envelope efficiency is probably smaller than generally assumed.

In the near future we will continue our observational campaign to further verify the preliminary conclusions listed above. We will also incorporate an appropriate prescription of the binding energy parameter in the algorithm we use to reconstruct the common envelope phase. Then, we expect to give more definite answers on the two big questions in close white dwarf binary formation and evolution.

References

Briggs K R Napiwotzki R Maxted P F L and Wheatley P J 2007 15th European Workshop on White Dwarfs (Astronomical Society of the Pacific Conference Series vol 372) ed Napiwotzki R and Burleigh M R p 497

Davis P J Kolb U Willems B and Gänsicke B T 2008 MNRAS 398 1563-1576

Hjellming M S 1989 Rapid mass transfer in binary systems Ph.D. thesis AA(Illinois Univ. at Urbana-Champaign, Savoy.)

Hurley J R Pols O R and Tout C A 2000 MNRAS 315 543-569

McDermott P N and Taam R E 1989 ApJ 342 1019–1027

Nelemans G and Tout C A 2005 MNRAS 356 753–764

Nelemans G, Verbunt F, Yungelson L R and Portegies Zwart S F 2000 A&A 360 1011–1018

Paczynski B 1976 IAU Symp. 73: Structure and Evolution of Close Binary Systems p 75

Patterson J Kemp J Harvey D A Fried R E Rea R Monard B Cook L M Skillman D R Vanmunster T Bolt G Armstrong E McCormick J Kraici T Jensen L Gunn J Butterworth N Foote J Bos M Masi G and Warhurst P 2005 PASP 117 1204–1222

Politano M and Weiler K P 2006 ApJ 641 L137-L140

Rappaport S Joss P C and Verbunt F 1983 ApJL 275 713–731

Rebassa-Mansergas A Gänsicke B T Rodríguez-Gil P Schreiber M R and Koester D MNRAS 382 1377-1393

Rebassa-Mansergas A Gänsicke B T Schreiber M R Southworth J Schwope A D Gomez-Moran A N Aungwerojwit A Rodríguez-Gil P Karamanavis V Krumpe M Tremou E Schwarz R Staude A and Vogel J MNRAS 390 1635-1646

Schreiber M R and Gänsicke B T 2003 A&A 406 304

Schreiber M R Gänsicke B T Southworth J Schwope A D and Koester D 2008 A&A 484 441–450

Schreiber M R Nebot Gomez-Moran A and Schwope A D 2007 Astronomical Society of the Pacific Conference Series (Astronomical Society of the Pacific Conference Series vol 372) ed Napiwotzki A and Burleigh M R pp 459–

Sills A, Pinsonneault M H and Terndrup D M 2000 ApJ 534 335–347

Silvestri N M Lemagie M P Hawley S L West A A Schmidt G D Liebert J Szkody P Mannikko L Wolfe M A Barentine J C Brewhington H J Harvaneck M Krzesinski J Long D Schneider D P and Snedden S A 2007 AJ 134 741–748

Skumanich A 1972 ApJ 171 565

Townsley D M and Bildsten L 2003 ApJ 596 L227–L230

Townsley D M and Gaensicke B T 2008 (Preprint arXiv e-prints/0811.2447)

Verbunt F and Zwaan C 1981 A&A 100 L7–L9

Webbink R F 1984 ApJ 277 355–360

Webbink R F 2007 704 (Preprint arXiv e-prints/0704.0280)

Willems B and Kolb U 2004 A&A 419 1057–1076

Wood M A 1995 White Dwarfs (LNP no 443) ed Koester D and Werner K (Heidelberg: Springer) pp 41–45