Understanding white dwarf binary evolution with white dwarf/main sequence binaries: first results from SEGUE

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Abstract. Close white dwarf binaries make up a wide variety of objects such as double white dwarf binaries, which are possible SN Ia progenitors, cataclysmic variables, super soft sources, or AM CVn stars. The evolution and formation of close white dwarf binaries crucially depends on the rate at which angular momentum is extracted from the binary orbit. The two most important sources of angular momentum loss are the common envelope phase and magnetic braking. Both processes are so far poorly understood. Observational population studies of white dwarf/main sequence binaries provide the potential to significantly progress with this situation and to clearly constrain magnetic braking and the CE-phase. However, the current population of white dwarf/main sequence binaries is highly incomplete and heavily biased towards young systems containing hot white dwarfs. The SDSSII/SEGUE collaboration awarded us with 5 fibers per plate pair in order to fill this gap and to identify the required unbiased sample of old white dwarf/main sequence binaries. The success rate of our selection criteria exceeds 65\% and during the first 10 months we have identified 41 new systems, most of them belonging to the missed old population.

1. Introduction

Close binaries containing at least one white dwarf span a wide range of interesting and exotic stars, such as detached white dwarf binaries, cataclysmic variables (CVs), or AM CVn binaries. Besides offering the opportunity to study physics under extreme conditions, these objects are extremely important in the general astrophysical context: Supernova Ia arise either from merging binary white dwarfs or from interacting white dwarf/main sequence binaries and AM CVn stars are expected to significantly contribute to the gravitational wave background which will be measured by LISA. All the different types of close white dwarf binaries have two points in common: (1) they evolved through at least one common envelope (CE) phase and (2) they undergo subsequent orbital angular momentum loss (AML). Sad but true, the physics of both the CE and AML are very poorly understood.

In current theories the CE phase is simply approximated by a parameterized energy (Paczynski 1976; Webbink 1984; Willems \& Koll 2004) or angular momentum equation (Nelemans \& Tout 2005). Both descriptions differ significantly in the predicted outcome of the CE phase and in both prescriptions the efficiency to “use” the orbital energy (angular momentum) to expel the enve-
lope is very uncertain. Hence, the CE phase is probably the least understood period of close binary evolution. Once the envelope is expelled, the evolution of the post common envelope binary (PCEB) is mainly driven by AML due to magnetic braking. Unfortunately, the two currently favoured prescriptions for magnetic braking (Verbunt & Zwaan 1981; Andronov et al. 2003), differ by up to two orders of magnitude. Even worse, it is not clear whether magnetic braking is continuously present or if it gets disrupted when the secondary star is fully convective. In order to explain the orbital period gap observed in the period distribution of CVs, one needs to assume the latter (e.g. King 1988; Howell et al. 2001) while observations of single low mass stars do not show any evidence for such a discontinuity (e.g. Pinsonneault et al. 2002).

Significant progress in the theoretical modelling of the CE phase and AML due to magnetic braking will clearly need observational input. A quantitative test of the current theories requires the knowledge of a large and unbiased population of close binaries that underwent a CE and subsequent orbital AML. The ideal class of stars to provide such observational constraints on the CE and magnetic braking models are detached PCEBs consisting of a white dwarf and a main sequence star, as (1) white dwarf binaries are intrinsically numerous, (2) the properties of both stellar components are well-understood, and (3) they have rather short orbital periods ($\sim 2h-50d$).

2. PCEBs in the pre-SDSS era

Schreiber & Gänssicke (2003) analysed the population of PCEBs with determined orbital period and white dwarf temperature. Their sample consisted of only 30 systems – a surprisingly small number when compared with the more than 1000 CVs listed in Downes et al. (2006). Even worse, the detailed analysis of Schreiber & Gänssicke (2003) showed that the small sample of 30 PCEBs is also heavily biased towards hot white dwarfs and late type secondary star spectral types. This bias is a natural consequence of the way PCEBs have been discovered in the past: as white dwarfs in the first place, with some evidence for a faint red companion found later. Finally, Schreiber & Gänssicke (2003) calculated the evolutionary time scale of the 30 young (containing hot white dwarfs) PCEBs and find that most of them have passed only a very small fraction of their PCEB lifetime. This immediately leads to the prediction of a large population of old PCEBs containing cold white dwarfs which has not yet been identified.

3. The biases of the SDSS DR4 sample

Since the first data release of the Sloan Digital Sky Survey (SDSS), the situation changed drastically. Based on SDSS imaging and some DR1 spectra Smolčić et al. (2004) identified a new stellar locus, i.e. the white dwarf/main sequence (WD/MS) binary bridge. The population of these WD/MS binaries consists of wide binaries that will never interact and whose components evolve like single stars and close binaries that went through a common envelope phase (PCEBs).

The SDSS turned out to be also very efficient in spectroscopically identifying new unresolved WD/MS binaries. Recently Silvestri et al. (2006) published a list
of \( \sim 747 \) new WD/MS binary systems found in SDSS/DR4. However, as stated by Silvestri et al. (2006) themselves, the SDSS DR4 sample is again subject to strong observational biases. The WD/MS systems identified in SDSS/DR4 originate primarily from two different channels: the colour selection described in Silvestri et al. (2006) and serendipitous objects from QSO fibres. The color selection used by Silvestri et al. (2006) selects hot systems mainly because of the cut used in \( u - g \) versus \( g - r \) and the SDSS QSO selection algorithm (see Richards et al. 2002, Fig. 7) explicitly excludes the color-color space of cold white dwarf/main sequence binaries. Hence both channels produce predominantly WD/MS binaries with hot white dwarfs, i.e. young objects, which – according to Schreiber & Gänckle (2003) – represent only the minority of all WD/MS binaries.

4. Identifying old PCEBs with SEGUE

A true constraint on AML mechanisms in close binaries will only be possible once a representative sample of PCEBs has been identified. As partners of SDSS II we are running a successful program (PI: M. Schreiber) identifying the missing cold WD/MS binary population. The SEGUE-collaboration awarded us with 5 fibers per SEGUE plate pair (\( \sim 7 \text{deg}^2 \)) and we developed special color-cuts to select WD/MS systems containing cold white dwarfs, i.e.

\[
\begin{align*}
u - g &< 2.25 \\
g - r &> -0.2 \\
g - r &< 1.2 \\
r - i &> 0.5 \\
r - i &< 2.0
\end{align*}
\]

\[
\begin{align*}
g - r &> -19.78 \ast (r - i) + 11.13 \\
g - r &< 0.95 \ast (r - i) + 0.5 \\
i - z &> 0.5 \text{ for } r - i > 1.0 \\
i - z &> 0.68 \ast (r - i) - 0.18 \text{ for } r - i \leq 1.0 \\
i - z &> 0.68 \ast (r - i) - 0.18 \text{ for } r - i \leq 1.0
\end{align*}
\]

The main selection criteria are shown in Fig. 1 as black lines. In the first 10 months 41 SEGUE-plates with WD/MS target selection have been observed. During the first drilling run in Oct. 2005, the above criteria have been applied to reddening corrected magnitudes. This led to the identification of several nearby single M-dwarfs whose reddening corrected colors resemble WD/MS binaries containing cold white dwarfs. The success rate for the Oct. 2005 plates therefore is only \( 14/35 = 40\% \) on 22 plates. Since 2006 we use non-corrected \( ugriz \) magnitudes and our success rate increased to \( 27/40 = 67.5\% \) on 19 plates. Fig. 1 shows the positions of the 75 SEGUE-WD/MS candidates including the 41 WD/MS systems (black open squares). Also shown are the Silvestri et al. (2006) sample (black points) and the QSO and single star population (gray). As an example for the 41 identified systems, Fig. 2 shows the SEGUE spectrum of one cool WD/MS binary.

We determined the white dwarf temperature and the spectral type of the secondary of the 41 WD/MS binaries by fitting simultaneously the composite binary spectrum. The resulting distributions are shown in Fig. 3. Compared to the SDSS DR4 sample published by Silvestri et al. (2006) our sample contains significantly more WD/MS systems with cold white dwarfs and/or early type secondary stars thereby overcoming previous biases in the sample of known WD/MS binaries.
Figure 1. The SEGUE-WD/MS color cuts (black lines) in two color-color diagrams. Quasars and single stars are shown in grey. The (not reddening corrected) positions of the 75 WD/MS candidates selected during the first 10 months are marked as open squares. In the first drilling run we used reddening corrected magnitudes and some nearby M-dwarfs (those below the lower vertical lines) appeared as WD/MS candidates. Since 2006 we select our candidates without reddening correction and the success rate increased to 67.5%. The SDSS/DR4 WD/MS population (Silvestri et al. 2006) is shown as black points. Apparently, the overlap of the with the SEGUE selection is rather small as the latter is especially designed to identify the missing old population.

Figure 2. The spectrum of a SEGUE WD/MS binary and the position in color-color space (using fiber-magnitudes).
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According to the SEGUE baseline $\sim 200$ plate pairs will be observed until mid 2008 and we therefore expect to identify $\sim 400 - 500$ new WD/MS binaries by then. Together with the systems identified by Silvestri et al. (2006) the resulting more than $\sim 1200$ WD/MS systems will form the database to constrain theories of close binary evolution.

5. Constraining close binary evolution with PCEBs

In principal the three big questions of close binary evolution can be answered using a large sample of PCEBs with known orbital period, secondary spectral type, and white dwarf temperature: (1) The disrupted magnetic braking scenario predicts an increase of the relative number of PCEBs by a factor $\sim 1.7$ in the range of secondary spectral types M3-M5 (see Politano & Weiler 2006). To confirm or disprove the predicted increase one needs to identify PCEBs with M3-M5 secondaries among the WD/MS population. As the mean PCEB lifetime can be rather large, the expected increase of the relative number of PCEBs will be more pronounced in the old SEGUE population. (2) The strength of AML can be estimated by comparing the orbital period distributions of PCEBs at different times of the PCEB evolution. A representative sample of PCEBs for secondary spectral types M0-M8 and effective temperatures of the white dwarf of $T_{wd} \sim 10000 - 40000$ K is required. (3) The predictions of the two currently favoured prescriptions of the CE phase differ in particular in the predicted orbital period distribution of long orbital period PCEBs (Nelemans & Tout 2005).
Consequently, identifying the long orbital period end of the PCEB population will clearly constrain current theories of the CE phase.

To sum up, characterizing a large sample of PCEBs provides the potential to solve the three most important problems in close binary evolution. To that end we have initiated a large-scale follow-up programme to identify and characterize the PCEBs among the WD/MS sample involving telescopes at both hemispheres and utilizing multi-epoch spectroscopy, time-resolved photometry, and astrometry with promising first results.

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