

# The Magnetic Fields of White Dwarfs in Cataclysmic Variables

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## Abstract

The origin of magnetic fields in isolated and binary white dwarfs has been investigated in a series of recent papers. One proposal is that magnetic fields are generated through an  $\alpha$ - $\Omega$  dynamo during common envelope evolution. Here we present population synthesis calculations showing that this hypothesis is supported by observations of magnetic binaries.

## 1 Introduction

The magnetic cataclysmic variables (MCVs) comprise a magnetic white dwarf (MWD) accreting matter from a low-mass M-dwarf companion. The accretion flows in MCVs are magnetically confined and form funnels in the most strongly magnetic and synchronously rotating *polars* (Ferrario & Wehrse, 1999) or curtains in the *intermediate polars* (IPs, Ferrario et al., 1993a) where fields are not strong enough to prevent the formation of a truncated accretion disk. The strength and structure of the magnetic fields in polars have been established via cyclotron and Zeeman spectroscopy (Ferrario et al., 1992, 1993b, 1996; Schwobe et al., 1999) to be in the range  $\sim 10^7$ – $10^8$  G (see Ferrario et al., 2015b, and references therein). It is much more difficult to determine the field strengths of the white dwarfs (WDs) in the IPs because the radiation from these systems is dominated by their accretion disks which swamp photospheric and cyclotron emission from the accretion shocks (Ferrario & Wickramasinghe, 1993). Nonetheless, fields in IPs have been estimated to be below a few  $10^7$  G (see Ferrario et al., 2015b, and references therein).

In this paper we report population synthesis calculations that investigate the hypothesis that fields in MCVs result from binary interaction during common envelope (CE) evolution. This hypothesis was first advanced by Tout et al. (2008), following the earlier work of Regós & Tout (1995), as an alternative to the fossil field hypothesis (e.g., see Mestel, 1958; Woltjer, 1964; Angel et al., 1981; Tout et al., 2004; Ferrario et al., 2015a). According to Tout et al. (2008) the strong

fields in MWDs derive from the differential rotation generated by the stellar cores while they spiral in toward each other during CE evolution. If they merge, they give rise to a single, strongly magnetic WD. If they survive and emerge from CE nearly in contact, they evolve into MCVs. The calculations presented here for MCVs are an extension of those performed by Briggs et al. (2015) and Briggs et al. (2018b) for the isolated high-field magnetic WDs explained as the outcome of stellar mergers (see also Nordhaus et al., 2011; García-Berro et al., 2012).

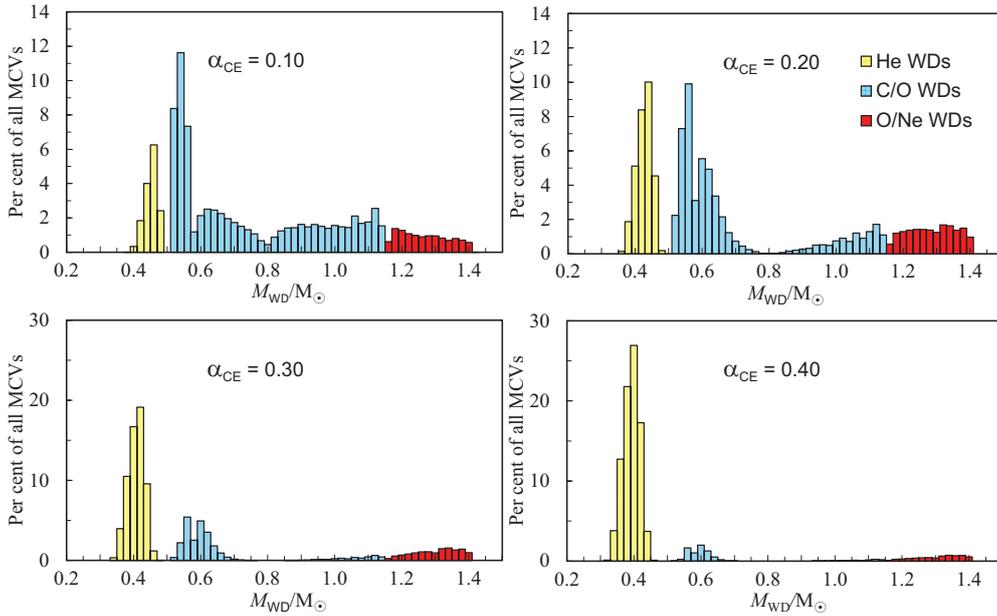
## 2 Calculations

We have generated and evolved for 9.5 Gyr (age of the Galactic Disc, Kilic et al., 2017) a synthetic population of binaries using the rapid binary star evolution algorithm, BSE, of Hurley et al. (2002). The initial (main sequence) parameters are the mass of the primary ( $1.0 - 10.0 M_{\odot}$ ), the mass of its companion ( $0.1 - 2.0 M_{\odot}$ ), and the orbital period ( $1 - 10\,000$  days). The mass of the primary follows Salpeter’s mass function while its companion is chosen to give a flat mass ratio  $q$  distribution (Hurley et al., 2002; Ferrario, 2012) with  $q \leq 1$ . The initial period distribution is selected to be uniform in the logarithm.

Briggs et al. (2018b) used the dynamo results of Wickramasinghe et al. (2014) to assign a field to each of their synthetic WD resulting from stars that merge during CE evolution according to

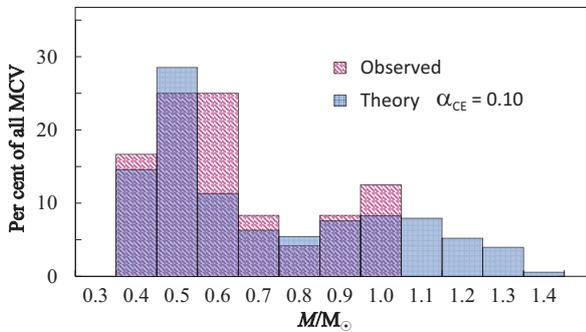
$$B = B_0 \left( \frac{\Omega}{\Omega_{\text{crit}}} \right) \text{G}, \quad (1)$$

where  $\Omega$  is the orbital angular velocity of the system at the point the envelope is ejected and  $\Omega_{\text{crit}}$  is the break-up angular velocity of the nascent WD. The parameter  $B_0$  was determined empirically by finding the best theoretical fit to the observed field distribution of isolated MWDs (Briggs et al., 2018b). While the shape and width of the field distribution is determined by the CE efficiency parameter  $\alpha$  (found to be  $\leq 0.3$ , see Briggs et al., 2015, 2018b,a, for further details on the



**Figure 1:** Synthetic mass distribution of the magnetic WDs just before mass transfer begins.

modelling procedure), different  $B_0$ 's shift the field distribution to lower or higher fields. Here we will show that the field prescription of equation (1) to model the fields of isolated MWDs can also represent the field distribution of the MWDs in MCVs.



**Figure 2:** Comparison of the theoretical mass distributions to observations from Zorotovic et al. (2011).

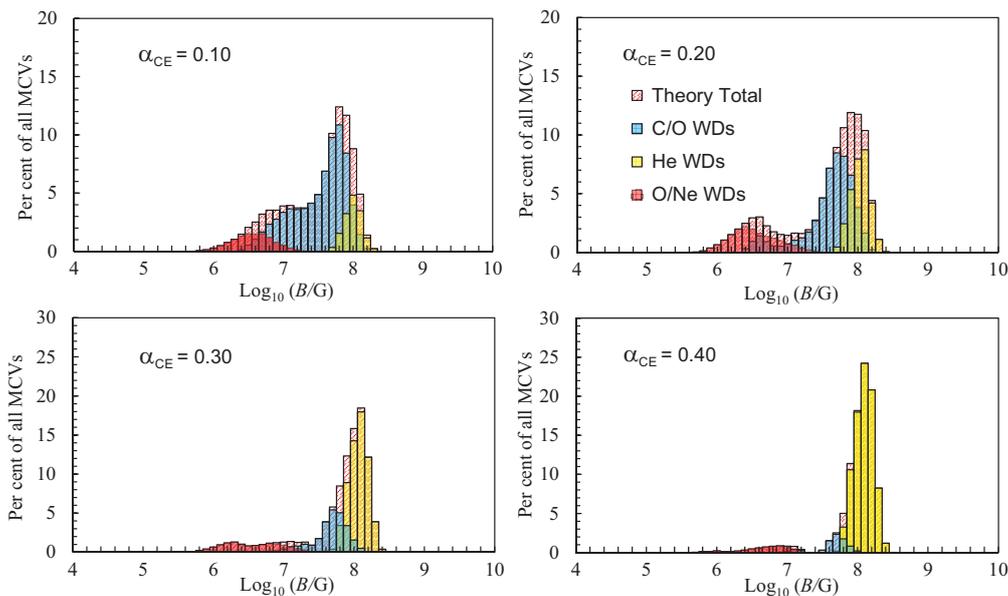
### 3 Results

We have varied the CE efficiency parameter  $\alpha$  to investigate its effects on the theoretical population of MCVs. Fig. 1 shows that at low  $\alpha$  the type of binaries that evolve to the beginning of Roche lobe overflow (RLOF) mostly contain a CO WD. As  $\alpha$  increases the binaries with He WDs become the predominant type. Because the observed fraction of He WDs tends to be low among CVs (Zorotovic et al., 2011) we can say that a synthetic population produced with a low  $\alpha$  can

better reproduce observations.

The WD mass distribution has a dip near  $M_{\text{WD}} = 0.8 M_{\odot}$  which widens as  $\alpha$  gets larger. This is caused by systems that, as  $\alpha$  increases, emerge from CE at longer orbital periods. But the longer the period, the more massive the WD must be for mass transfer to take place. Thus this gap is due to systems emerging from CE at large separations but whose WDs are not enough massive to allow RLOF to take place. The second narrower gap near  $0.5 M_{\odot}$  separates systems with He WDs (CE occurred when the primary was an RGB star) from those with CO WDs (CE occurred when the primary was an AGB star). Because the current sample of PREPs (see Ferrario et al., 2015b) is far too small, we have compared our synthetic WD mass distribution to the observed sample of WDs in non-magnetic Pre-CVs (Zorotovic et al., 2011). This comparison is shown in Fig. 2 for  $\alpha = 0.10$  (see Briggs et al., 2018a, for further details on the modelling procedure). We note that the observed population exhibits the WD mass dip near  $0.8 M_{\odot}$  that is predicted by theory. This comparison seems to suggest that the WD mass distribution in pre-magnetic CVs does not differ substantially from that in classical non-magnetic CVs (extreme cases such as PG1346+082 Provencal et al., 1997, are not considered in this context).

We now analyse the field distribution of MCVs. Fig. 3 shows that the strongest magnetic systems are those that host a He WD. The reason is that binaries that go through CE evolution when the primary star is on the RGB have shorter orbital periods and thus generate highly magnetic WDs, as expected from equation (1). The field distribution is dominated by binaries with



**Figure 3:** Synthetic magnetic field distribution of the magnetic WDs just before mass transfer begins.

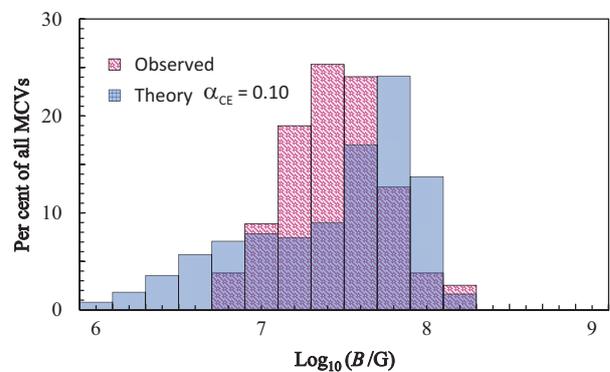
COWDs when  $\alpha \leq 0.2$ . As  $\alpha$  increases the distribution becomes narrower, is dominated by He WDs, and moves to higher fields. This is because most of those binaries that enter CE when the primary is on the RGB end up merging at low  $\alpha$  but do not at high  $\alpha$ . Instead, they produce a population of strongly magnetic, short period systems with low-mass He WDs. The dip at  $8 \times 10^6$  G is caused by the dearth of WDs with masses near  $0.8 M_{\odot}$  (see above) and the fact that equation (1) links mass to field strength.

The comparison between theoretical and observed field distributions is shown in Fig. 4. We note that we do not know what the underlying (real) field distribution of the WDs in MCVs is at the very low and very high ends of the field distribution. This is because at low fields the observed radiation is dominated by the truncated accretion disk so that photospheric Zeeman and cyclotron features are not visible. These systems are thus excluded from the list of Ferrario et al. (2015b) that only contains systems with field measurements. At high fields the mass accretion from the companion star is hindered (Li et al., 1994, 1998; Hoard et al., 2002, 2004) so that these systems are faint and thus difficult to detect. Despite these caveats the comparison of the magnetic field distribution shows that the range of fields derived for our synthetic population is consistent with observations of MCVs.

Despite the limitations of our modelling, we have illustrated that the observed properties of the white dwarfs in MCVs can be explained in terms of a population of binaries emerging from CE exchanging mass or close to contact as first advanced by Tout et al. (2008). Our calculations are also in support of the hypothesis that the low-accretion rate polars (LARPS) are pre-

MCVs (LARPS were renamed PREPS by Schwöpe et al., 2009, to avoid confusion with polars in a low state of accretion).

The full results of these studies are reported in Briggs et al. (2018a).



**Figure 4:** Comparison of the theoretical field strength for  $\alpha = 0.1$  and observations from Ferrario et al. (2015b).

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