Abstract

The absence of magnetic white dwarfs with a non-degenerate low-mass stellar companion in a wide binary is still very intriguing and at odds with the hypothesis that magnetic white dwarfs are the progenies of the magnetically peculiar Ap/Bp stars. On the other hand, we cannot resort to a process that impedes the generation of a strong magnetic field in the main or pre-main sequence progenitors of white dwarfs if they are in a multiple stellar system, because such a process would also prevent the formation of magnetic cataclysmic variables consisting of a magnetic white dwarf accreting mass from a low-mass companion. This is the reason why it has been proposed that fields in white dwarfs may be linked to their binarity and are generated through a dynamo mechanism during common envelope evolution.

1 Introduction

Following the discovery of the first magnetic main sequence star, 78 Vir (Babcock, 1947), highly magnetic compact stars were predicted to exist under the assumption of magnetic flux conservation during stellar evolution (e.g., Wolter, 1964; Angel et al., 1981; Tout et al., 2004). The search by Preston (1970) for Zeeman split lines in the spectra of white dwarfs (WDs) yielded zero results. Subsequent searches for continuum polarisation in WDs exhibiting unusual or continuous spectra led to the discovery of the first MWD, Grw+70°824 (Kemp et al., 1970). Over the past 50 years hundreds of isolated and binary MWDs have been discovered (e.g. see Ferrario et al., 2015b) and for decades it was assumed that the MWDs were the descendents of the magnetic main sequence Ap/Bp stars. However, some recent results on the pairing properties of MWDs have thrown some doubts on this hypothesis (Tout et al., 2008).

Kleinman et al. (2013) compiled a comprehensive catalogue of nearly 20,000 WDs with SDSS spectra and also identified about 800 magnetic objects while Kepler et al. (2013) provided fields of more than 500 MWDs. Liebert et al. (2015) visually searched the 1,735 WD+dM pairs (nearly 10% of the WD sample) for detached MWDs+dM, but the only seemingly detached system they found in the Kleinman et al. (2013) sample turned out to be the well known polar STLMi (Ferrario et al., 1993b) in a very low state of accretion. Thus, their search yielded null results, similarly to the study previously conducted by Liebert et al. (2005) on a much smaller sample of objects. This finding showed that the hypothesis that magnetic fields in WDs and pairing with a detached, non-degenerate, low-mass red star are independent is at the 9σ level. This discovery strengthens the hypothesis of Regős & Tout (1995) and Tout et al. (2008) that high field MWDs (10^6 < B/G < 10^9) are generated by a dynamo mechanism during common envelope evolution that leads to a merging event (see also Nordhaus et al., 2011; Garcia-Berro et al., 2012). This hypothesis for the generation of fields in WDs was investigated further by Wickramasinghe et al. (2014). Population synthesis calculations to explore its viability were carried out by Briggs et al. (2015) and Briggs et al. (2018b). In this paper, I will present new results on MWDs and on the origin of their fields. Comprehensive reviews on magnetic field generation in stars, from pre-main sequence to the compact star phase, can be found in Ferrario et al. (2015a); Ferrario (2018).

2 The Ap and Bp stars as the progenitors of the MWDs

The magnetic main sequence Ap/Bp stars have fields between a few hundreds G to tens of kG. Originally the estimated birth rate of MWDs seemed to be compatible with the fossil field hypothesis (Angel et al., 1981) that predicts Ap/Bp stars to evolve into MWDs under magnetic flux conservation. However, more recent studies by Kawka & Vennes (2004) showed that the birth rates and fields of Ap/Bp stars are not consistent with those of MWDs under flux conservation. Fig. 1 shows the observed field distribution normalised to the observed space density of MWDs compared to the predicted field distribution of magnetic Ap/Bp rem-
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Figure 1: Full line: measured mwd incidence. dotted line: predicted magnetic incidence of Ap/Bp remnants (from Kawka & Vennes 2004).

nants normalised to the predicted space density (from Kawka & Vennes 2004). Thus, the fields of Ap/Bp stars (i) only map onto the highest field MWDs and (ii) the birthrate of Ap/Bp is not sufficiently high to explain the incidence of magnetism among WDs. This inconsistency was also highlighted by the work of Wickramasinghe & Ferrario (2005). In order to make the fossil field hypothesis remain a viable option to explain the origin of magnetic fields in WDs, Wickramasinghe & Ferrario (2005) proposed a model where 40% of main sequence stars with $M > 4.5 M_\odot$ are magnetic with dipolar fields of 10-100 G, a field regime that had not yet been investigated. However, their assumption was not corroborated by observations performed in following years with new state-of-the-art spectropolarimeters (Aurière et al., 2007). These surveys not only ruled out the existence of a population of weakly magnetic Ap/Bp stars but also revealed the presence of a “magnetic desert” between 300 G (which turned out to be the lower bound of magnetism in Ap/Bp stars) and the detection limit of the surveys. Thus, this discovery revealed that magnetic Ap/Bp stars are either magnetic at the 300 G level or are not magnetic at all (Aurière et al., 2007).

These findings leave a sizeable fraction of MWDs at the low-field end of the distribution ($\sim 10^6$ to a few $10^7$ G) without obvious progenitors of the magnetic Ap/Bp class. Furthermore, the studies of Wickramasinghe & Ferrario (2005) also disclosed that the higher than average mass of MWDs (Liebert, 1988; Ferrario et al., 2015b) cannot be explained via the Ap/Bp progenitor scenario unless either the initial to final mass function of WDs is significantly altered by the presence of a magnetic field or an hitherto undetected population of massive and weakly magnetic main sequence stars can evolve into MWD. The latter hypothesis, however, seems to be unlikely given the observational evidence discussed above.

3 The common envelope hypothesis for the origin of MWDs

Briggs et al. (2015) and Briggs et al. (2018b) conducted population synthesis calculations to verify the validity of the common envelope merging scenario hypothesis of Tout et al. (2008). In this scenario the magnetic field is generated from the differential rotation of cores that spiral in toward each other during common envelope evolution. The closer the cores get before the envelope is ejected the stronger the field that is produced. Thus, the isolated MWDs arise when stars merge while the next strongest fields are generated in binaries that come out of common envelope on close orbits and will evolve into magnetic cataclysmic variables (MCVs) which are composed of a MWD accreting matter from a low-mass companion. The fields in MCVs are measured via cyclotron and Zeeman spectroscopy and are in the range $\sim 10^7 - 10^8$ G (see, e.g., Ferrario et al., 1992, 1996) for the more strongly magnetic “polars” and $\sim 10^6 - 10^7$ G in the more weakly magnetic “intermediate polars” (e.g. see Ferrario et al., 1993a; Ferrario & Wickramasinghe, 1993). The existence of MCVs highlights the fact that the pairing of MWDs with low-mass red dwarf stars is indeed possible, what is puzzling is the absence of wide, non-interacting binaries of this kind even if such a pairing is very common among non-magnetic WDs.

Tout et al. (2008) proposed that the low-accretion rate polars (LARPS), whose stellar components are close enough to allow the WD to capture a weak stellar wind from its low-mass companion, could be pre-polars waiting for gravitational radiation to bring the stars sufficiently close to allow Roche lobe overflow (see also Schwope et al., 2009, who renamed these systems pre-polars or “PREPs” to differentiate them from polars in a low-state of accretion). Although this scenario for the origin of fields in WDs is very attractive, Potter & Tout (2010) found that the time-scale for the diffusion of the field into the WD is much longer than the presumed lifetime of the common envelope. Therefore Wickramasinghe et al. (2014) proposed that during common envelope evolution a weak seed poloidal field deeply anchored in the WD gets wound up by differential rotation in the envelope of the merged object that will evolve into a WD. In this model, the dynamo action would amplify the poloidal field until a stable poloidal/toroidal structure is achieved.

The population synthesis calculations of Briggs et al.
have shown that the common envelope hypothesis successfully explains the mass distribution of MWDs (see Fig. 2). They found that the major contribution to the observed population of MWDs comes from the degenerate core of AGB stars merging with low-mass main-sequence stars. Merging events of a WD with another WD also occur but at a much lower rate and the resulting objects occupy the high-mass end of the MWD distribution. Briggs et al. (2018b) extended their studies to the field distribution of MWDs and assigned a field strength to each member of their synthetic sample on the basis of the dynamo model results of Wickramasinghe et al. (2014). According to this model the field strength achieved by the WD during common envelope evolution is proportional to the orbital angular velocity

\[ \Omega = \frac{2\pi}{P_{\text{orb}}} \]

of the system when the envelope is ejected. In this simple picture the object emerging from common envelope has a field

\[ B = B_0 \left( \Omega \right) \frac{\Omega}{\Omega_{\text{crit}}} \]  

where \( \Omega_{\text{crit}} \) is the break-up angular velocity of the WD and the parameter \( B_0 \) is determined empirically to best map the theoretical field range to the observed one. This means that different \( B_0 \) shifts the field distribution to lower or higher fields. The actual shape of the field distribution is given by the common envelope efficiency parameter \( \alpha \) which they found to be less than about 0.3 (see Briggs et al. 2015, 2018b for further details on the modelling).

Because the field \( B \) in equation (1) is inversely proportional to the orbital period, \( P_{\text{orb}} \), Briggs et al. (2018b) find that low-mass MWDs arising from the merging of the degenerate core of an RGB star with a very-low mass convective star (CS) gives rise to fields generally stronger than those predicted for more massive MWDs created by the degenerate core of an AGB star merging with a main sequence star. The merging of two WDs are not part of this prediction but because \( \Omega_{\text{crit}} \) can only be reached during the merging of a very compact double WD system (double degenerate “DD” channel), such mergers are envisaged to produce MWDs that are strongly magnetic, massive, and rapidly spinning. The MWD REJ0317-853 (Barstow et al. 1995; Ferrario et al. 1997; Vennes et al. 2003) is certainly a good DD merger candidate. So far, there are not many MWDs for which mass and field are both known, so it is not possible to verify this theoretical prediction. Nonetheless, observations seem to indicate that the currently known ultra-massive MWDs do have fields at the low end of the distribution (e.g., 1RXS J0823.6-2525, PG 1658+441, Ferrario et al. 1998; Schmidt et al. 2001).

Ferrario (2012) shows that the combination of stellar components that can best fit all current observational constraints of wide binary systems yields 18% of WDs paired with an M dwarf, 47% of Sirius-type systems and 35% of non-interacting WD-WD systems (that is, objects such as PG 1346+082, Provencal et al. 1997, are excluded). We already know that there are no MWDs paired with M dwarfs in a wide binary. The studies of Rolland & Bergeron (2015) have revealed that more than 60% of objects in their sample must be in wide binaries composed of either a MWD and a featureless (DC) WD or a MWD and a hydrogen (DA) WD. Kawka et al. (2017) list all non-interacting double WD systems in which one of the two components is magnetic. Some of these are very wide common proper motion systems so that the two stars could not have interacted during their evolution. Interestingly, some of these binaries show that the ages of the two components are inconsistent if single star evolution is assumed. Thus Kawka et al. (2017) suggest that they might have been triple systems composed of two stars that merged during common envelope evolution and a third star that never interacted with the other two. They also show that the magnetic field of one of the two components of the DD system NLTT 12758 may have arisen during CE evolution, in a manner similar to that proposed by Briggs et al. (2018a) for MCVs. In summary, it would be interesting to further investigate the characteristics of magnetic DD systems to establish whether the shorter period systems may all have formed via binary interaction while the longer period (and thus wider) systems may have initially been triple systems. If neither of these channels can be invoked to explain the existence of at least some of these magnetic DD systems, the possibility of these arising from single star evolution (the Ap/Bp channel) remains open.

The detection and thus study of a hitherto unknown population of MWDs hidden in the glare of brighter companions (spectral type K or earlier) may be of a much more challenging nature.
3.1 Cool magnetic white dwarfs

About 30 per cent of WD spectra show evidence for Ca, Si, Mg, Fe, Na and other metals (Zuckerman et al., 2003) and about 13 to 23% of cool ($T_{\text{eff}} < 8000$ K) metal polluted WDs are magnetic (Kawka & Vennes, 2014; Kawka, 2018; Hollands et al., 2015, 2017). Thus, the incidence of magnetism among cool polluted WDs is much higher than among ordinary WDs (about 3 percent; Ferrario et al., 2015b). It is tempting to hypothesise that the generally weak magnetic fields observed in these cool and polluted WDs ($0.1 \leq B/10^7 G \leq 1.1$, Hollands et al., 2017; Kawka, 2018) may be caused by a WD accreting a gaseous giant planet (that would generate their weak fields) and other rocky debris that would pollute their atmospheres. The engulfment of giant planets and rocky debris could occur during the AGB evolution when planets and other minor bodies drift toward the degenerate stellar core owing to frictional forces as they moves through the envelope of the star (e.g., Li et al., 1998). However, if magnetism (and possibly pollution) arise early in the life of a WD, then one would expect that hot (and possibly polluted) WDs would exhibit the same incidence of magnetism as cool and polluted WDs, but this does not seem to be the case. Farihi et al. (2011) propose a different mechanism involving close stellar encounters that would perturb the orbits of outer bodies such as large gaseous planets and asteroid belts and cause their inward migration and subsequent accretion by the WD. Over a cooling age of 2 – 9 billion years, this kind of stellar encounters is not unlikely to occur and could account for the existence of the cool and polluted MWD G77–50 (Farihi et al., 2011). This mechanism may also explain the high incidence of magnetism among cool white dwarfs (Liebert & Sion, 1979; Fabrika & Valyavin, 1999; Kawka et al., 2007). Although this result has not been fully corroborated by observations yet, future observations of a larger sample of cool MWDs may shed some light on this issue and will allow us to accept or reject the possibility that weak fields could be generated via the accretion of giant gaseous planets (Kawka et al., 2018).

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