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Where are the Progenitors of Magnetic Cataclysmic Variables (Polars)?

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Abstract.
As over a thousand white dwarf plus M dwarf composite spectrum binaries with high quality spectra are now tabulated from the Sloan Digital Sky Survey alone, a remarkable discovery has been made. No pairing of a magnetic white dwarf of two megagauss or greater field strength with an M dwarf has been found. At this field strength, Zeeman splitting of hydrogen or helium lines would be detectable. Thus there are no known progenitors of magnetic cataclysmic variables – AM Herculis systems or polars. The formation of the strong magnetic field by a dynamo mechanism within the common envelope of a binary system has been proposed as the possible explanation.

1. Introduction
Dozens of close white dwarf plus nondegenerate (usually M) dwarf pairs have been found in the Sloan Digital Sky Survey (SDSS) which are close enough to be pre-cataclysmic variables. Dozens more have been catalogued by Ritter and Kolb (2003, 2006). In none of these CV progenitors, however, is the white dwarf strongly magnetic. Any field of about 2 megagauss (MG) or larger should have been detectable via Zeeman splitting of the Balmer or He I lines – we arbitrarily define these as “strongly magnetic”. Yet CV systems involving a strongly magnetic white dwarf account for a lower limit of 10% of known systems (Araujo-Belancor et al. 2005, Thomas and Beuermann 1998). Double this percentage if you include the Low Accretion Rate Polars (LARPs) to be discussed later. To be sure, a few pre-CV systems involve a white dwarf with an apparent, weaker magnetic field, perhaps the best-studied case being V471 Tauri. The presence of a field is inferred because the X-ray emission varies with the apparent rotation period of the white dwarf in this binary system, as it presumably accretes some of the wind from the K secondary star to the magnetic poles. However, the field strength has not been measured, and is evidently too weak to show Zeeman-split lines (probably \(< \!< 1 \text{ MG})

In SDSS Data Release Five, some 1,253 spectroscopically-observed close binary systems involving a white dwarf and a nondegenerate (nearly always M) dwarf (hereafter WD+M) have been identified and catalogued by Silvestri et al. (2007, hereafter S07). Only those with signal-to-noise ratio of at least 5 per pixel were included, and having DA or DB white dwarf spectra. Of all these pairs, none has been found where the white dwarf is observed to be magnetic. A working catalog of WD+M binaries is also maintained by Boris Gaensicke and collaborators (cf. Dillon et al. 2008) and the total may now exceed 1,600 pairs (B. Gaensicke, private communication, 2008).
These investigations extend the size of the sample and strengthen greatly the statistics on the apparent absence of magnetic white dwarf pairings with a nondegenerate dwarf star, as first discussed at length in Liebert et al. (2005, hereafter L05). In addition to the polars which allow no accretion disk to form, also relevant are some of the intermediate polars or DQ Herculis systems in which a partial accretion disk forms, and the white dwarf gets spun up to a rotation period shorter than the orbital period. Some intermediate polars have primaries with smaller magnetic field strengths than polars. Others in longer period systems may have field strengths comparable to the polars.

The best explanation for this apparent absence of magnetic white dwarfs associated with M dwarfs put forth in L05 is that there has been evidence that at least some strongly magnetic white dwarfs have higher than average masses (see below). As demonstrated by representative simulations in S07, the smaller radius and luminosity of a massive magnetic primary could cause its spectrum to be masked more easily by an M companion.

In Figure 1 – which is Figure 3 from S07 – simulated magnetic and nonmagnetic WD+M composite spectra are shown by coadding single WD and M dwarf spectra. The listed ratio is that of the fluxes of the two components at the halfway point in wavelength of the spectra, 6500Å. Clearly the more massive and cooler the white dwarf, and the more luminous the M dwarf, the more easily the Zeeman spectral features of the former may be masked.

Liebert (1988) summarized the evidence that several, nearby magnetic white dwarfs with trigonometric parallaxes had relatively large masses, small radii and lay below the sequence of most white dwarfs in an HR Diagram. These objects included several known since the 1970s – Grw+70 8247, G 227-35, G 240-72 and GD 229. Since then, many more magnetic white dwarfs have been shown to be massive (Wickramasinghe and Ferrario 2005). However, there is also evidence that some of them have more ordinary masses near 0.6M⊙ or less. The presence of a very strong field generally prevents any direct measurement of the mass through log g. Therefore, the mass estimates for magnetic white dwarfs have been possible for only a modest fraction of the known objects (Wickramasinghe and Ferrario 2000).

It is of interest to note that decided differences are apparent in the fraction of white dwarfs that are magnetic between apparent magnitude-limited samples vs a volume-limited sample. In the Palomar Green Survey (Green, Schmidt, and Liebert 1986, hereafter PG) – an example of the former, only 2% are strongly magnetic. In the Holberg et al. (2008) “local” sample, of the 126 white dwarfs, 16 objects or 12.7(+/-4)% are strongly magnetic. The local sample is arguably close to volume-limited, since all lie within 20 pc according to best distance estimates. This distinction has been discussed in Liebert, Bergeron, and Holberg (2005), in the PhD dissertation of A. Kawka (2004) and in Kawka et al. (2007). Both groups argue that that the likely true frequency of strong magnetism in white dwarfs approaches or exceeds 10%.

2. Assessing the Statistics

At the same time the known number of WD+M pairs now exceeds 1,200, the number of magnetic white dwarfs has grown to over 160, with some 100 of these found in the SDSS (Vanlandingham et al. 2005), with a few additions since then. In the most recent compilation by Kawka et al. (2007), 149 magnetic white dwarfs are listed with B = 3 MG or larger.

How many of these magnetic white dwarfs would be expected to have a companion, if the assumption were made that WD+M pairings occur with the same frequency as for nonmagnetic white dwarfs? The “local”sample of white dwarfs within 20 pc (Holberg et al. 2008) has been searched for companions thoroughly. In fact 19.6 (+/-4.5)% have main sequence companions. Assuming that the binary frequency were similar, we might therefore expect 14-24% of the 149 magnetic white dwarfs – a total of 21-35 WDs – to have such companions. There are none. By the square-root-of-N as one sigma, the absence of any pairings yields already a four sigma level of significance.
Figure 1. Combination of a magnetic (left panel) and nonmagnetic (right panel) white dwarf spectrum with an M dwarf where the ratio listed is that of the fluxes of the two components at the halfway point in wavelength (6500 Angstroms). The purpose is to simulate what a spectrum would look like if a strongly magnetic white dwarf were to be paired with an M dwarf. The Zeeman-split features are less deep than the nonmagnetic hydrogen lines, and are more easily masked by the M dwarf. If the magnetic white dwarf has a small radius (large mass), it is more easily masked. This may be an important selection effect, but one doubts that this can be the entire explanation.
One can also use larger, more distant samples to improve on these statistics. Many of the several hundred hot white dwarfs found in the PG Survey show the existence of a companion in the optical spectrum. Further improvement was provided by Holberg and Magargal (2005). Using the Two Micron All Sky Survey detections at 1.2-2.0 micron JHK bands to look for excess over the white dwarf Rayleigh-Jeans tail, the fraction having apparent companions is increased. These authors found that 23% of the PG sample had “definite” and 29% had “definite or probable” cool companions. Assuming now that the 149 strongly magnetic WDs had binary frequency similar to the PG, 34 to 43 should have had companions. We now encroach on a six sigma level of significance.

3. Low Accretion Rate Polars (LARPs)

Technically, a recently-discovered class of close, accreting binaries with strongly-magnetic primary stars may be detached systems (Schmidt et al. 2007). The M dwarf is arguably not filling its Roche lobe, though it is losing mass through a wind, and it is believed that the field of the white dwarf captures most or all of this wind. The accretion rate is therefore fixed by the amount of the secondary’s wind. Typically the loss/transfer rates are only of the order of $10^{-13}$ or $10^{-14} \, M_{\odot}\, \text{yr}^{-1}$. The magnetic fields of the primaries are generally rather large (40 to perhaps 80 MG), and the secondaries are mid-to-late M dwarfs. Periods range from 1.37 hours, where the secondary is later than M6, to over four hours.

These may be regarded as close binaries which have eluded full Roche-lobe overflow, but they are in some sense near misses. Schmidt et al. argue that their optical and X-ray luminosities are so low that they weren’t discovered in X-ray surveys and are scarcely more luminous than fully-detached WD+M binaries. They are known to be accreting because the appearance of cyclotron harmonics. Given the low luminosITIES, the true space density of the LARPs could be comparable to that of the polars.

4. The Origin of Strong Magnetic Fields in White Dwarfs

For decades the presumption had been made that the magnetic fields in white dwarfs are fossil in nature, and that probably the white dwarfs are descended from magnetic Ap/Bp main sequence stars (Angel, Borra and Landstreet 1981). This interpretation has recently been called into question, because the fraction of of strongly magnetic white dwarfs seems to be too high to be covered by this limited range of progenitors (Wickramasinghe and Ferrario 2005, Kawka et al. 2007).

In Tout et al. (2008), a novel, new hypothesis has been put forth – due mainly to the first two authors. Strong magnetic fields in white dwarfs are formed in the common envelope phase of a close binary where at least the primary core is degenerate. Two stellar cores circle at close range in a differentially-rotating, convective envelope, which generates a strong dynamo. The strong magnetic field forms around the primary core. Frictional braking brings the cores together before the envelope is lost. If both cores are degenerate, they merge with the formation of a single magnetic white dwarf which may therefore generally be massive. If the secondary core is nondegenerate, they come into contact as a magnetic CV – either a polar, intermediate polar, or LARP.

I have to raise some issues about this hypothesis which require further attention:

–The generation of the magnetic field in the common envelope always must bring the two cores into a merger or an accretion phase. Yet most post-common envelope binaries are not precataclysmic systems. The orbital period is shortened but not by enough.

–Polars are always observed to be old systems with rather cool white dwarf primaries, with cooling times approaching or exceeding 1 Gyr (Sion et al. 1999). The LARPs appear to have cool white dwarf primaries as well. Yet if they come out of the common envelope already in contact, at least a few primaries of AM Herculis / LARP systems should be hot.
–Is it reasonable to assume that at least 10% of pre-white dwarfs are close, common envelope binaries?

Nonetheless, this is the first new idea for the origin of strong magnetism in white dwarfs since their original discovery. It deserves further study. There is evidence that the magnetic field distribution in white dwarfs is bimodal, with many having kilogauss fields (Aznar Cuadrado et al. 2004, Wickramasinghe and Ferrario 2005). It may well be that the fossil field idea is applicable to white dwarfs with weaker fields, as the primary of V 471 Tauri could be a descendant of an Ap/Bp progenitor in the Hyades cluster.

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