White Dwarfs as Probes of Fundamental Physics: Tracers of Planetary, Stellar and Galactic Evolution
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A new look at magnetic white dwarfs

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Abstract. We present a homogeneous analysis of a large sample of magnetic white dwarf stars (with SDSS, PanSTARRS and Gaia data) using state-of-the-art magnetic atmosphere models and fitting techniques. We discuss the properties of the sample as well as the implication on our understanding of the nature and evolution of such objects.

Keywords. stellar: white dwarf, magnetic field, atmospheric modelling

1. Introduction

It is estimated that about 10 to 20% of white dwarfs are magnetic at some level (Kawka & Vennes 2005; Liebert *et al.* 2003; Kepler *et al.* 2015). Thanks mainly to the *Sloan Digital Sky Survey* (SDSS), their number has increased significantly in the last 15 years or so, from about 70 known objects at the turn of the last millennium to now over 600 (Ferrario *et al.* 2015; Kepler *et al.* 2015). Yet, despite these observational developments, there still remain a lot of open questions concerning the origin of magnetic white dwarfs (MWDs). Possible progenitors include mergers, binary evolution, and fossil field evolution contributing in proportions that still need to be quantified appropriately. While there is some evidence that MWDs are more massive than their non-magnetic counterparts, this is based on a relatively small number of object (and very few with a parallax measurement), and relatively ancient atmosphere models.

In fact, most of the studies of MWDs can be traced back to the work of Wickramasinghe & Martin in the '70s and '80s (hydrogen/helium line splitting with the Zeeman effect and off-centered dipole geometry field), Jordan in the '90s (use of tables calculated by the Tübingen group to model the line splitting of hydrogen and helium under arbitrary magnetic field intensities, and the decomposition of magnetic field geometries into finite elements), with a few additional contributions from Bergeron, Vennes and Kawka (see Ferrario *et al.* 2015 and references therein). The latest analysis of a large sample, that of Külebi *et al.* (2009), is already a decade old, a time when parallax measurements where few and far between and computer resources much more limited than today.

Here we present preliminary work on magnetic white dwarfs based on our newly developed magnetic atmosphere code. This code is currently the only one, to our knowledge, that can treat line splitting for any chemical composition (stars of spectral type DA, DB, DZ, DQ etc.) while solving magnetized radiative transfer with Stokes parameters (ie. computing the emergent polarized flux) for an arbitrary magnetic field geometry (not limited to an offset dipole).

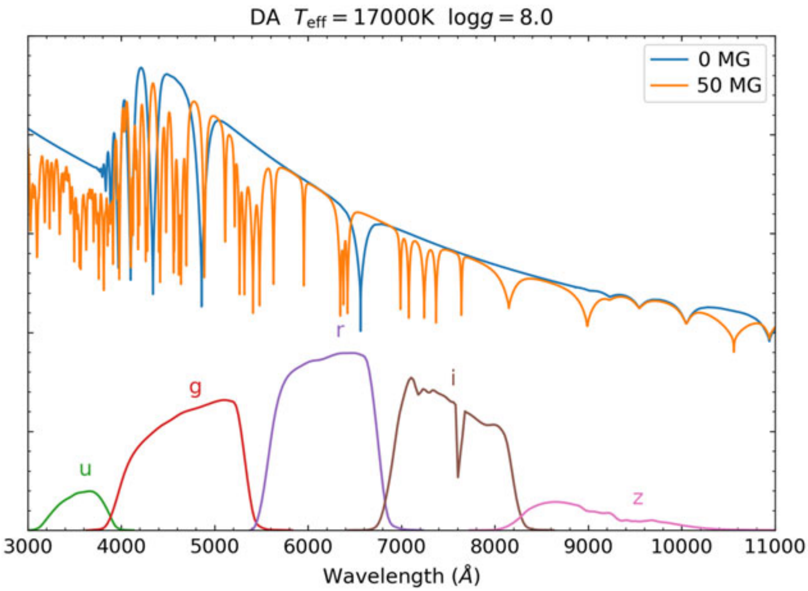

Figure 1. Comparisons of synthetic spectra with 0 and 50 MG magnetic field strengths. Note that the splitting of the lines under a large field provides additional blanketing in adjacent photometric bands (SDSS *ugriz* shown here).

2. Analysis

Atmospheric parameters for magnetic white dwarfs are notoriously difficult to obtain due to the complex line profiles and positions that arise as a result of a possibly variable magnetic strength (and corresponding line splitting) across the surface of the star. Moreover, the reliability of the mass determination from spectral line fitting is somewhat questionable since it is still unclear how to treat Stark and Zeeman broadening simultaneously when the fields are strong. We thus decided to revisit magnetic DA white dwarfs due to the recent release of Gaia data. Indeed, decent estimations can now be obtained from fits to the energy distribution when parallax measurements are available, a situation that was unfortunately possible only for about two dozen objects before the mission. Thanks to the second data release, **289** MWDs now have a parallax measurement, 235 of which are DAs according to the *Montreal White Dwarf Database* (Dufour *et al.* 2017). Of those DAs, we selected a subsample of **127** stars taken from Külebi *et al.* (2009) that had both a Gaia parallax and SDSS photometry and revisit their atmospheric parameters using the photometric method assuming the magnetic field strength and geometry they had determined.

Briefly, the method consists of the simple derivation of the atmospheric parameters of the star by fitting the solid angle ($4\pi\frac{R^2}{D^2}$) and effective temperature from a comparison of the observed flux f_ν to those of our model grid (H_ν, effective temperatures from 5000 to 30,000 K, $\log g$ from 6.5 to 9.5, and a magnetic field intensity, B, form 0 to 500 MG):

$$f_\nu = 4\pi \left(\frac{R^2}{D^2}\right) H_\nu \left(T_{\rm eff}, g, \text{composition}, B\right) \tag{2.1}$$

where D is the distance (calculated from the parallax) and R is the radius of the star. Since D is known, the derived value of R can be converted to mass/surface gravity using the white dwarf mass-radius relationship. Figure 1 shows two synthetic spectra, one at zero-field and another with a (constant) 50 MG magnetic field. This particular example

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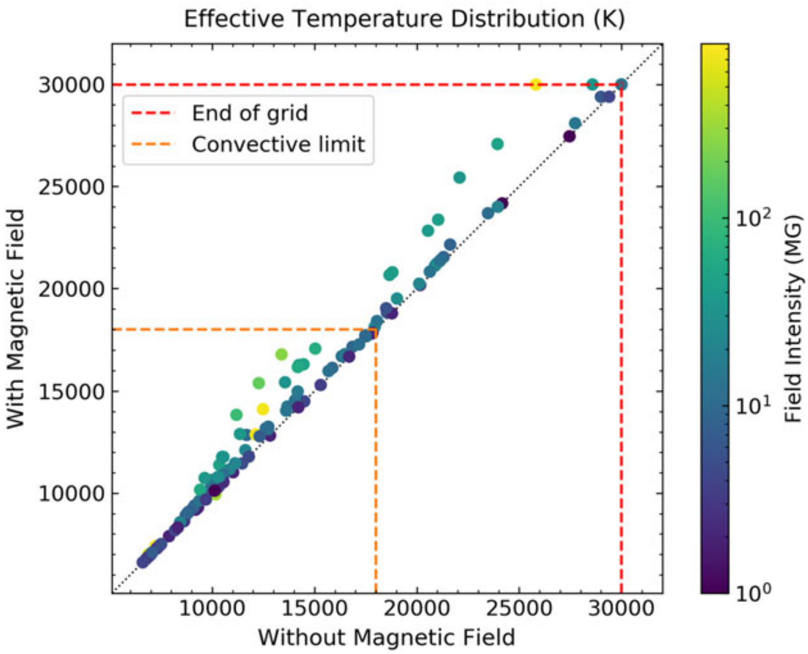

Figure 2. Comparison of effective temperatures derived with and without the inclusion of magnetic field splitting. Fits including the magnetic field yield slightly higher effective temperatures and the strength of this effect is correlated with the intensity of the field.

shows that the u and g bands are heavily affected by the shifted lines at 50 MG. Our approach now explicitly takes into account the impact of the line splitting and blanketing due to the presence of the magnetic field. Taking this into account could thus significantly affect the effective temperature determination for high magnetic field strengths, hence also affecting the radius, and thus mass, determination.

3. Results

Figure 2 compares the effective temperatures obtained assuming no magnetic field to those obtained when assuming the field intensity determined by Külebi *et al.* (2009). The effective temperatures derived when including the magnetic field are generally greater or equal to the non-magnetic ones. The difference in derived effective temperatures is due to the strong magnetic shifting of the lines into different photometric bands (a weak field will only move those spectral lines slightly, not affecting the photometry significantly).

As a consequence of the higher effective temperature, a smaller radius (and thus a larger mass) is needed to fit the solid angle. Figure 3 shows the mass distribution of our sample. Clearly, the shape of the distribution is not centered around $0.6M_{\odot}$, as is usually found in samples of non-magnetic DA white dwarfs (see Genest-Beaulieu & Bergeron 2019 for example). More interestingly, our magnetic DA sample of stars with parallax-derived masses seems to indicate the presence of a correlation between mass and field strength. The average mass of stars with a magnetic field intensity lower than 3 MG is $0.69\,M_{\odot}$ while it is $0.86\,M_{\odot}$ for those with a field higher than 3 MG.

Is this correlation the signature of some different mass loss mechanism depending on the magnetic field strength? Or maybe we are in the presence of two distinct populations (low field/low mass = fossil, high field/high mass = mergers)?

To conclude, we have shown that it is important to take into account the magnetic field splitting for an accurate effective temperature (and thus mass) determination of

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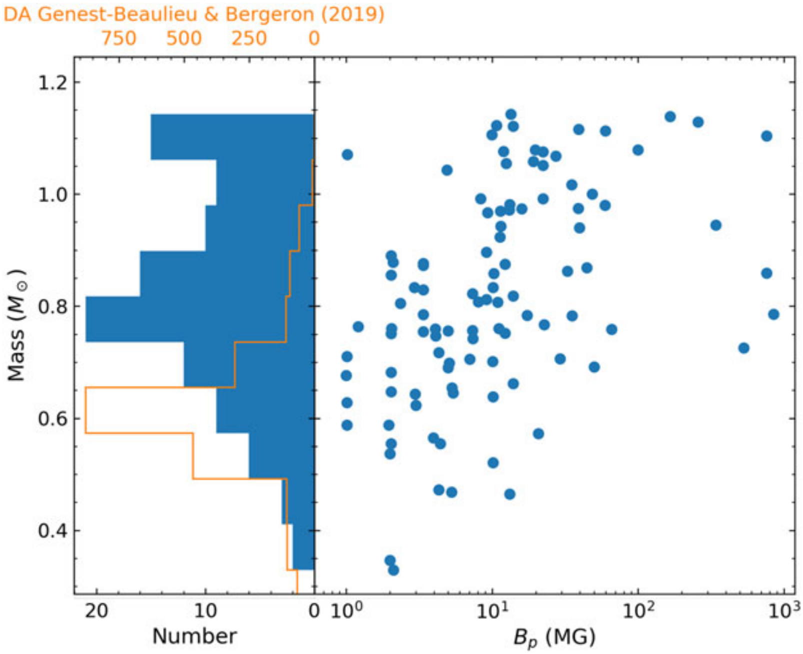

Figure 3. Left: mass distribution of magnetic DAs (blue) compared to non-magnetic DAs (Genest-Beaulieu & Bergeron 2019, orange). Right: Mass vs field intensity for our sample.

magnetic DA white dwarfs. In future work, we plan to extend our study to a larger sample of magnetic DAs as well as to all known magnetic white dwarfs in general, regardless of their spectral type.

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