Studies of magnetic and suspected-magnetic southern white dwarfs

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ABSTRACT

Optical spectrophotometry and circular spectropolarimetry are presented for several candidate magnetic white dwarfs that were identified during the Hamburg/ESO survey for bright QSOs. Two objects, HE 1211$-$1707 and HE 1043$-$0502, are shown to be rare examples of white dwarfs that show neutral helium lines in a high magnetic field, in these cases $\sim$50 MG and $\sim$800 MG, respectively. The former is also found to be rotating with a period of $\sim$2 hr. HE 1045$-$0908 is a hydrogen-line star with a polar field strength of $\sim$20 MG, spinning with a period in the range $\sim$2 -- 4 hr. Attempts at modeling the limited amount of phase-resolved data that is available suggest that the field structure on this star departs substantially from a simple centered dipolar geometry. Two rather cool white dwarfs with unidentified broad absorption spectral features, HE 0236$-$2656 and HE 0330$-$0002, are confirmed polarimetrically to be magnetic. Line identifications for these stars are not yet possible, but the atmospheres are probably helium-rich, with spectral features formed by trace compounds of hydrogen, carbon, and perhaps other metals. HE 0003$-$5701 and HE 0338$-$3853 were proposed by Reimers et al. (1996) alongside two similar objects to be magnetic DB white dwarfs, with Zeeman-split lines of helium in magnetic fields all near 20 MG. However, our observations show that the first two, and by extension all four, are nonmagnetic white dwarf + cool dwarf pairs. They are deserving of study in their own right as possible close binaries. Finally, a lack of circular polarisation suggests that HE 0000$-$3430 and HE 0127$-$3110 are also nonmagnetic. HE 0000$-$3430 appears to be a featureless DC white dwarf over the spectral range observed here, while the sole absorption line near 5890 Å in HE 0127$-$3110 could be either He I $\lambda$5876 or the Na I D doublet, but there are difficulties with either interpretation.

Key words: stars: binaries; stars: individual: magnetic fields - white dwarfs.

1 INTRODUCTION

Magnetic white dwarfs offer an important glimpse into the roles that magnetism may play in the formation and evolution of stars with moderate mass. At the same time, they provide unique laboratories for studying the behavior of matter in fields far stronger than can be obtained terrestrially. More than 5 dozen examples have been found with field strengths between $\sim 3 \times 10^4$ G and $10^9$ G, and the list of atomic and molecular species represented includes virtually every substance seen among white dwarfs in general, including H, He, Na, Mg, Ca, C$_2$, and additional molecules that are as yet unidentified.

Modeling of spectroscopic and spectropolarimetric data on magnetic stars is a powerful technique for gaining information into the field distributions over the stellar surfaces, particularly for the objects in which the observations can be phase-resolved over a rotational cycle. This information is crucial for evaluating alternatives for the origin and evolution of the fields, and for relating magnetic structures found among one class of star to other stages of evolution. Unfortunately, a lack of thorough observational material has traditionally handicapped studies of white dwarfs in the southern hemisphere. During the course of a spectropolarimetric survey for magnetic fields among southern white dwarfs, special attention was paid to several known or proposed magnetic examples. This paper reports the results on 9 objects which emerged from the Hamburg/ESO survey for bright QSOs (e.g., Wisotzki et al. 1995).

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2 OBSERVATIONS

The data presented here were acquired with the Steward Observatory CCD Spectropolarimeter (Schmidt, Stockman, & Smith 1992) attached to the 74-inch reflector on Mt. Stromlo. Since that description was published, the instrumental performance has been upgraded with an improved camera lens and a thinned, back-illuminated LORAL 1200x800 CCD with near-unity quantum efficiency and <6e⁻ read noise. For the current application, the f/18 Cassegrain telescope beam was adapted to the f/9 spectrograph optics with a small converging lens placed ahead of the slit. The instrument was configured for circular spectropolarimetry over the region $\lambda\lambda 4220 - 7300$ Å with $\sim 9$ Å resolution, and data were acquired in multiple wavelength sequences of typical duration 12 – 14 minutes. Shorter sequences were used for HE 1211–1707 in order to resolve variations over the known short rotation period (Reimers et al. 1996). Because it was not possible to align the instrument to the parallactic angle and the arrival of clouds occasionally prevented obtaining a nightly flux calibration standard, the large-scale absolute flux calibrations of the program stars are probably accurate to only $\sim 20\%$. This difficulty has no systematic effect on the polarimetry, since both senses of polarisation for the determination of a Stokes parameter are accumulated simultaneously in parallel spectra on the CCD. Terrestrial absorption features were removed using spectra of hot white dwarfs taken with the same instrumental setup, but because of differences in airmass, cancellation is not always complete beyond 7000 Å. A summary of the observations is presented as Table 1. Included is a measure of the circular polarisation summed over the entire spectrum and the monochromatic Palomar AB magnitude $m_{5500}$ determined from the slit spectrum.

3 RESULTS

3.1 Magnetized neutral helium at 50 MG and 800 MG in HE 1211–1707 & HE 1043–0502

HE 1211–1707 presents an interesting spectrum with a series of time-variable absorption features that are clearly indicative of rotation (Reimers et al. 1996). Our data sets, obtained on two nights separated by a few days, each consist of a sequence of 15 consecutive 6 min observations spanning $\sim 100$ min. The circular polarisation summed over the spectrum and over all rotational phases is not strong but significant at $v \sim 1\%$ (Table 1), confirming the presence of a magnetic field. Figure 1 presents the spectral flux series from 25 Feb., shown per unit frequency to highlight the structure. Because of the comparatively faintness of the star, the observations were averaged by pairs prior to plotting, with UT progressing upward as noted at the right. The initial two spectra reveal the broad features near $\lambda\lambda 4700, 5250, 5750$ discussed by Reimers et al., with maximum depths of $\sim 20\%$. By 30 min into the sequence, all but the A5750 feature have disappeared, but that line has sharpened significantly. The next two spectra, at 45 – 55 min into the series, reveal the emergence of shallow depression centered near $\lambda 5050$. The last (single) exposure shows a return of the structure seen at the beginning of the sequence, and suggests that nearly a full spin cycle has been completed. We infer that the rotation period is $P \sim 2$ hr. The sequence from 22 Feb. mimics Figure 1, offset in phase. The spectrum-summed circular polarisation from the individual observations shows a roughly sinusoidal modulation from $v \sim 0\%$ to $+3\%$, with a period of $\sim 100 - 120$ min and a peak near the maximum strength of the $\lambda 5050$ feature. Unfortunately, the lack of coverage of a complete cycle in either series or in the data of Reimers et al. precludes phasing the two nights, so the spin period cannot be quoted more accurately.

The $4300 - 7300$ Å flux distribution of HE 1211–1707 implies a surface temperature of $T_{\text{eff}} \sim 12,000$ K, considerably cooler than that indicated by the $IUE$/optical flux ratio (Reimers et al. 1996) and suggesting line blanketing of the optical continuum. The temperature regime is one where either a hydrogen- or helium-atmosphere white dwarf might be expected. Reimers et al. (1996) noted some evidence for Balmer lines in a magnetic field of $\sim 80$ MG, but the features could not be identified unambiguously and other features remained unidentified altogether. Our mean spectrum, shown in Figure 2, depicts a large amount of structure, including the aforementioned broad features and a very diffuse dip extending from $\sim 6200$ Å to the red. The rather modest $0 - 3\%$ range for the phase-modulated circular polarisation, together with the fact that $v$ does not exceed $\sim 1.5\%$ in the coadded polarisation spectrum, suggests that the field strength is not extremely high. There is some evidence for a slight decline in circular polarisation with wavelength.

Very recently, calculations of many of the transitions of neutral helium have become available for a wide range in the applied magnetic field. In Figure 3 we reproduce the behavior of the principal lines for $0 < B < 900$ MG, taken from the calculations of Becken & Schmelcher (1998, 2000, 2001) and Becken, Schmelcher, & Diakonos (1999). We see here that at moderate field strengths, $B \lesssim 50$ MG, the range 5000 – 7000 Å is dominated by the Zeeman triplet of $2^3P - 3^3D \lambda 5876$, rapidly-moving $\sigma^-$ components of $2^1P - 3^3D \lambda \lambda 6678$, and $\sigma^+$ components of $2^3S - 3^3P \lambda 5015$. Due to the quadratic Zeeman effect, the $\pi$ components of $\lambda 5876$ are shifted to $\sim 5750$ Å. The $\sigma^+$ features reach wavelengths of $\sim 6500$ Å and $\sim 5100$ Å, respectively, and each of these will be smeared over a few hundred angstroms even in the $x2$ pole-to-equator field spread of a centered dipole. Thus, the $\lambda 5876$ triplet offers an attractive match to the three long-wavelength features at $\sim 5250, 5750,$ and 6200 Å in our summed spectrum of HE 1211–1707, for a field strength of $B \sim 50$ MG. We note that Jordan (2001) has also recently advanced a helium explanation for the features of this star.

We have investigated this interpretation through spectral modeling using a transfer code for polarised radiation. The approach follows that described by Wickramasinghe & Martin (1979) but uses an atmospheric structure appropriate for a helium-atmosphere white dwarf. Unfortunately, the new calculations of He I transitions mentioned above do not provide oscillator strengths and have not yet been completed for all transitions of interest. Therefore, our current models are based on extrapolations of the perturbation calculations of Kemic (1974), which characterize 18 transitions up to a limiting field strength of 10 MG or 20 MG, depending on transition. Wherever possible, the $B(\lambda)$ curves of Kemic were extended to higher fields using the newer calculations (i.e., for the triplets $\lambda\lambda 5876, 4714, 4472,$ and...
width of the observed profile as being due to magnetic broadening, the field strength must range up to \(\sim 800\) MG and down to \(\sim 450\) MG over the stellar surface. In this regime, the \(\sigma^+\) component of the same zero-field line \((2^4S_0 - 3^4P_{1/2})\) is moving quickly to the red from its minimum near \(\lambda 4812\) (\(251\) MG), and is a likely explanation for the shallow depression between \(5000\) Å and \(6000\) Å. The only other feature expected is an extremely smeared trough covering \(\sim 6300 - 7000\) Å arising from the \(\sigma^+\) component of \(\lambda 5876\) \((2^3P_0 - 3^3D_{1/2})\) as it moves back from a wavelength maximum near \(\lambda 7143\) (\(258\) MG). This may also be present, weakly, in the observed flux spectrum in Figure 4. Unfortunately, the limitations that plagued our modeling of HE 1211–1707 - the lack of oscillator strengths and incompleteness of wavelengths for some lines - are fatal at these much higher field strengths, and we must be satisfied for the time being with visual matches to the \(B(\lambda)\) curves. However, we find these assignments convincing and conclude that HE 1043–0502 has a field of \(\sim 450 - 800\) MG over the surface, higher even than GD 229, and the strongest field yet measured on a DB white dwarf.

3.2 The rotating magnetic DA HE 1045–0908

A rich Zeeman spectrum of hydrogen was detected in HE 1045–0908 by Reimers et al. (1994) and modeled as arising from a dipolar field distribution of strength \(B_d \sim 31\) MG viewed nearly equator-on. The exposure time of Reimers et al. was unspecified, but it is clear in our data series shown in Figure 5 that systematic variations occur in both spectral flux and circular polarisation over the 1 hr duration of the observations. At the beginning of the sequence, the lines are ill-defined and circular polarisation is modest, reaching at most \(v = 5\%\) in the \(\sigma^+\) components of \(\text{H}\beta\). The features become even more diffuse in the next spectrum, but sharpen and increase in polarisation thereafter. By the last two exposures, even the \(\sigma^-\) components of \(\text{H}\alpha\) are obvious in total flux, and polarisation excursions reach nearly \(\pm 10\%\). These characteristics can be understood intuitively in terms of the rotation of an oblique magnetic field pattern, with the initial observations of the sequence being dominated by a wide spread in field strength, while the better-defined features in later measurements depict a more restricted range. Depending on the geometry, Figure 5 therefore probably represents about one-quarter to one-half of a full rotational cycle, implying that the spin period is likely in the range \(\sim 2 - 4\) hr.

The mean observed spectrum of HE 1045–0908 is compared to a series of spectral models in the top panel of Figure 5. All of the models are seen at low inclination, \(20^\circ < i < 30^\circ\) and at a small azimuth to the dipole axis. This basic geometry is indicated by the general lack of weak-field Zeeman features in the observed spectra. The models differ in the longitudinal offset of the assumed dipole field structure and in the corresponding polar field strength, which range from from \(B_d = 19\) MG; \(\Delta R/R = 0.0\) to \(B_d = 9\) MG; \(\Delta R/R = 0.3\). Of the 3, the highly offset geometry best reproduces the width and shape of \(\text{H}\alpha\) \(\pi\) and \(\sigma^+\), but predicts a too localized and displaced \(\sigma^-\) component. Differences around \(\text{H}\beta\) are less pronounced.

Difficulties appear when these particular models are applied to the spectrum and polarisation variations. Here we
see that the observed Hα σ components broaden out almost completely at some phases. This behaviour is inconsistent with spectral variations expected from centered or longitudinal (z)-offset dipole models. By z-offsetting the dipole, the field spread increases as viewing angle increases, and the contributions from lower field regions tend to dominate the spectrum. Note also that in these models the field direction changes very quickly over the surface so that as the viewing angle increases, the sign of circular polarisation of the σ components also changes. This is not observed.

We conclude that, without high-quality observations over a complete rotation cycle, attempts at detailed modeling of the field geometry over the stellar surface of HE 1045−0908 are probably premature. We suspect that more general offsets (transverse as well as along the dipole axis) or substantial departures from a dipolar geometry may be required to explain the spectral and polarisation variations seen in the data. This star may be a particularly interesting target for modeling using modern genetic algorithms (e.g., Hakala 1995) for approaching global optimization of a large number of parameters that describe a magnetic field structure. We note that several efforts at modeling phase-dependent variations of several other magnetic white dwarfs point toward substantial departures from simple magnetic geometries, with quadrupoles, offset dipoles, and even magnetic “spots” being demanded by the data (e.g., Schmidt et al. 1986; Maxted et al. 2000).

3.3 HE 0236−2656 & HE 0330−0002: Cool magnetic white dwarfs with unidentified features

Together with HE 1043−0502 discussed in §3.1, HE 0236−2656 and HE 0330−0002 were flagged as suspicious by Reimers et al. (1998) on the basis of broad, unidentified absorption features in their spectra. As indicated in Table 1, both stars show substantial broadband circular polarisation and thus can now be confirmed as magnetic white dwarfs. Each star was observed twice separated by a few days, and in each case consistent results were obtained on the two occasions. The spectra shown in Figure 6 therefore represent the means of the epochs. HE 0236−2656 shows a deep, broad (∆λ ∼ 250 Å) feature centered near 5800 Å, and there is some evidence for the very shallow and extended depression around 4700 Å that was noted by Reimers et al. 4700 Å. The circular polarisation is uniform at ν ∼ −1.5% outside the λ5800 feature, but increases in magnitude to nearly −5% within the trough. A single absorption line near λ6635 also dominates HE 0330−0002, but that feature is more triangular in appearance and shows structure in the blue wing. The circular polarisation in HE 0330−0002 is predominantly negative over the spectral region observed and becomes stronger toward the blue, but changes sign sharply to positive values within the line. There may be an additional weak depression near 6100 Å and again around 4700 Å. Together with a narrower line at ∼6900 Å, the latter appears as a more defined feature in the Reimers et al. spectrum.

The continuum energy distributions of both stars suggest that they are rather cool, T ∼ 6000 − 7000 K. At these temperatures, He-atmosphere white dwarfs are common, but spectral features are generally due to trace abundances of atomic and/or molecular carbon and other metals. The spectra of very few of these species are known in magnetic fields of sufficient strength to produce continuum circular polarisation of a few per cent (B ≥ 50 MG). For comparison, the reader is directed to LP 790−29 (8600 K; C3 at 50 MG; Liebert et al. 1978), G99−37 (6200 K; C2, CH at ∼3 MG; Angel, Hintzén, & Landstreet 1975), LHS 2229 (∼4600 K; C2H at ∼100 MG; Schmidt et al. 1999), and LHS 2534 (6000 K; metallic atoms at 1.9 MG; Reid, Liebert, & Schmidt 2001).

It seems likely that both HE 0236−2656 and HE 0330−0002 are He-dominated stars with yet other combinations of field strength and/or atomic and molecular species.

3.4 HE 0003−5701 & HE 0338−3853: Non-magnetic DA + cool dwarf binaries

Four stars were proposed as magnetic DB white dwarfs by Reimers et al. (1998) on the basis of single low-resolution spectra. All show flat to bluish continua in Fν, a rather narrow feature near λ5890 that was assigned to the π component of He I λ5876, and more diffuse absorption around λ5100 that was interpreted as He I λ4921. The implied field strength for each star was ~20 MG. Helium-atmosphere stars comprise only ~10% of all white dwarfs, and at the time of these claims, no magnetic white dwarf had been positively identified solely with He features. The report of 4 new magnetic DBs was therefore remarkable.

Two of the proposed magnetic DB stars, HE 0003−5701 and HE 0338−3853, were observed as part of this study. Neither show circular polarisation at a level exceeding v = 1% anywhere in the spectrum, and the spectrum-added value for HE 0003−5701 is an insignificant −0.14% (Table 1). Observations for HE 0338−3853 were obtained under poorer observing conditions, so the results, ⟨v⟩ ∼ ±0.4%, should not be regarded as real detections. More importantly, the spectra shown in Figures 7 and 8 reveal that the narrow spectral line in both stars is actually Na I D λ5890,5896 at zero magnetic field, and the diffuse feature at shorter wavelengths is the Mg I/MgH complex prominent in late-type stars. From the detailed correspondence between the host of absorption lines in the two Hamburg/ESO objects and the cool dwarfs also shown in those figures, it is clear that both proposed magnetic DB stars are actually binaries containing a late-type component. A third candidate, HE 0026−2150, was originally identified as a binary on the basis of an H emission line in the composite spectrum (Reimers et al. 1998), but the true origin of the absorption features was not inferred. Upon inspection of the original spectra, it now seems clear that all four of the proposed magnetic DB stars – HE 0003−5701, HE 0026−2150, HE 0107−0158, and HE 0338−3853 – are in fact non-magnetic white dwarf + cool dwarf binary systems, and as such provide interesting additions to lists of similar objects which have been assembled in recent years (see, e.g., Marsh 2000; Vennes, Christian, & Thorstensen 1998).

A dozen spectral templates of nearby Gliese dwarfs

* As discussed in §3.1, GD 229, HE 1211−1707 & HE 1043−0502 are now known to be magnetic DBs. Feige 7 (e.g. Achilleos et al. 1992), LB 11146 (Liebert et al. 1993) and LB8827 (Wesemael et al. 2001) are all magnetic DBA (mixed hydrogen-helium) white dwarfs.
with spectral types K0 V – M4 V were obtained for the purpose of decomposing the spectra of HE 0003–5701 and HE 0338–3853, using the same instrumental setup and during the same observing runs as for the magnetic white dwarf candidates. The examples shown in Figures 7 and 8 represent our best attempts at identifying the spectral type which quantitatively accounts for the observed features of each star. The results of the subtraction are shown in the bottom panels of the figures. The cleanest outcome is obtained for the fainter of the two objects, HE 0338–3853, where the spectrum can be well-represented by a hot (non-magnetic) DA white dwarf and the K5(±1) dwarf GL 186 shown in the proportion 50:50(±5) at 5500 Å. Indeed, the only significant artifact in the difference spectrum is a slight oversubtraction of the cool star for $\lambda \gtrsim 6900$ Å. The inferred continuum shape and absorption lines for the hot component can be compared to the DA star MCT 0455, which has been found by Vennes et al. 1997 to have a temperature of 57,000 K. Based on H$\beta$ and H$\gamma$, we cannot constrain the surface gravity of the DA component in HE 0338–3853, but if we allow for variations within the range $7.0 \leq \log g \leq 9.5$, the effective temperature is restricted to $87 – 97 \times 10^{3}$ K. The star could possibly be a hot sdO similar to BD+28$^{\circ}$2411, but we find no evidence for He II $\lambda 4686$.

The hot star and its companion have comparable V-band magnitudes which we estimate to be $V_{KMV} = V_{DA} \sim 17.7$. The absolute magnitude of a K5V star is $M_{V, K5V} = 7.3$, so assuming that the two stars are physically paired, the implied effective temperature of the hot star is $\gtrsim 80,000$ K and surface gravity $\log g \gtrsim 7.0 – 7.5$. A lower effective temperature would require a larger stellar radius, characteristic of a hot sdO star.

The observed spectrum of HE 0003–5701 is redder and more highly-structured than for HE 0338–3853, suggesting a larger fraction of the light is due to the cool companion. Best cancellation of features occurs for a 60% contribution at $\lambda 5500$ of the spectrum of GJ 3318. This star is also typed as K5 V but appears slightly redder than GL 186 in our data. Uncertainties in the parameters of the decompositions are probably about twice those for HE 0038–3853, i.e. $\sim 2$ spectral subclasses and $\pm 0.1$ in relative brightness. The difference spectrum shows the overall continuum shape and smoothness of a hot white dwarf, but retains large-scale lumps suggestive of a slightly incorrect template. Interestingly, H$\alpha$ emerges as a narrow emission line regardless of the template used. Emission cores may also be present in H$\beta$ and H$\gamma$, though the latter is contaminated by Hg I $\lambda 4358$ from Canberra city lights. We cannot rule out intrinsic coronal activity as the source of the Balmer emission, but EUV-illumination by the white dwarf is a more likely explanation. Radiative heating of the companion may also modify its emergent energy distribution from that of an isolated dwarf and contribute to difficulties with the spectral subtraction. Similar conclusions can be offered about the nature of the stellar components of this binary as were made for HE 0038–3853 above, but the emission cores in the white dwarf spectrum preclude a detailed line profile analysis. Together with HE 0026–2150, HE 0003–5701 presents a promising candidate for period determination through radial velocity studies. We note that the fourth magnetic DB proposed by Reimers et al. (1998), HE 0107–0158, is so heavily dominated by the hot component that, if it is also a white dwarf, the companion must be quite cool.

### 3.5 The unpolarised stars HE 0000–3430 & HE 0127–3110

The spectrum of HE 0000–3430 obtained by Reimers et al. (1996) is nearly featureless longward of 5000 Å, and the claim of a magnetic field ranging between $\sim 40$ MG and $120$ MG over the stellar surface was based largely on structure around 4700 Å. The star is comparatively bright, and our flux spectra obtained on two consecutive nights each exhibit an extremely smooth continuum, featureless to within fluxing irregularities, down to at least 4400 Å (Figure 9). The circular polarisation is null in the spectrum average to better than 0.15% and there are no polarimetric features or trends with wavelength to a per-pixel precision of $\sigma_{c} \lesssim 1\%$. Since a magnetic white dwarf with a field strength near 100 MG and virtually any viewing angle would be expected to show continuum polarisation considerably larger than these limits, we cannot confirm the star as being magnetic and can only suggest that the line identifications of Reimers et al. (1996) may be spurious. As those authors noted, the continuum slope of HE 0000–3430 is rather shallow, indicating $T \sim 7000$ K. Assuming that the star is indeed a white dwarf, the lack of spectral features suggests that it is most likely one of the He-atmosphere examples that are common in this temperature range.

HE 0127–3110 was observed on two occasions within a week. Both the spectrum and lack of circular polarisation are entirely consistent between the data sets, so the combined results are shown in Figure 9. We confirm the narrow absorption feature around $\lambda 5890$ reported by Reimers et al. (1996), but find no evidence for the broad features around 4650 Å and 5080 Å that are contained within our spectral range. The circular polarisation shows no spectral features and the coadded value is essentially zero at both epochs. This is at odds with a magnetic field of 100 – 200 MG as was required for the model of Reimers et al.

The sole feature in our flux spectrum of HE 0127–3110 exhibits a red-shifted profile extending from $\lambda 5850$ to $\sim \lambda 5980$, suggesting an assignment with the Na I D lines $\lambda\lambda 5890, 5896$ or possibly He I $\lambda 5876$. The former are occasionally seen in the spectra of metallic-line (DZ) white dwarfs. However, in G165-7 (Wehrse & Liebert 1980), where the 6 Å doublet splitting is not resolved due to pressure broadening, the resulting feature is symmetric, quite unlike the profile smeared to the red in Figure 9. The observed profile cannot be attributed to magnetic effects, since Na I D is seen to form a classic symmetric Zeeman triplet with overall width similar to that in Figure 9 in the magnetic white dwarf LHS 2534 ($B = 1.9$ MG; Reid et al. 2001). It is possible that the line profile in HE 0127–3110 is contaminated by improper sky subtraction of the bright low-pressure Na I D lines from Canberra city lights, but the spectra of both nights show the same distortion. It should also be pointed out that both of the confirmed DZ stars with Na I absorption also show strong lines of Mg I, Ca I, and other metals. If a Mg I $\lambda 5170$ complex is present in Figure 9, it is exceedingly weak. Finally, the stars where the Na I lines are certain have $T_{\text{eff}} \sim 6000 – 7500$ K, significantly cooler than HE 0127–3110. The He I $\lambda 5876$ explanation faces problems.
as well, since features of λ4472 and λ6678 of would be expected at similar strength for a wide range of temperature (Wegner & Nelan 1987). Thus, even though the absence of polarisation suggests that the star is nonmagnetic, line identification remains uncertain.

4 SUMMARY AND CONCLUSIONS

Spectropolarimetric observations of several suspected southern magnetic white dwarfs have confirmed the existence of substantial fields on HE 1211−1707, HE 1043−0502, HE 1045−0908, HE 0236−2656 and HE 0330−0002. The new data also clearly show that the proposed magnetic DB white dwarfs HE 0003−5701, HE 0026−2150, HE 0107−0158, and HE 0338−3853 are actually nonmagnetic DA plus cool dwarf pairs. Finally, two stars, HE 0000−3430 and HE 0127−3110, are found to be polarimetrically null, but the latter remains interesting due to the presence of an unidentified broad absorption line in its spectrum.

Perhaps the most important result is the addition of HE 1211−1707 (~50 MG) and HE 1043−0502 (~800 MG) to the class of magnetic DB stars along with the prototype of the class, GD 229. Though He I features have long been assumed to be present in certain existing magnetic white dwarfs, only now is it possible to make firm identifications of the highly shifted spectral features, thanks to the development of computational techniques for solving the multielectron problem in magnetic fields of arbitrary strength (e.g., Becken & Schmelcher 1998). Including LB 8827 (Wesemael et al. 2001), Feige 7 (Achilleos et al. 1992), and GD 229 (Jordan et al. 1998), the spectrum of neutral helium has now been empirically verified over the full range 1 ≤ B ≤ 800 MG, essentially the same as is spanned by magnetic DAs. The number of white dwarfs that evidence magnetic He I lines amounts to ~10% of the total magnetic sample, roughly consistent with the fraction of DB+DBAs among white dwarfs in general, if the small number statistics and probable selection effects are considered.

Our detailed understanding of the field structures on magnetic white dwarfs will continue to improve with the evolution of more sophisticated modeling techniques for the often non-dipolar field geometries which are now known to exist over many stars. The recovery of this information requires high-quality, full phase-coverage, spectroscopic and spectropolarimetric data, and in the case of the helium-line stars, the calculation of some wavelengths as well as oscillator strengths for all transitions over a wide range in magnetic field. The results presented here should help to fuel the interest in remedying both of these limitations.

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Table 1. Log of Observations.

| Object       | $m_{5500}$ | UT Date      | #Obs×Expo(s) | ($\langle v \rangle$)% | Comment          |
|--------------|------------|--------------|--------------|-------------------------|------------------|
| HE 0000−3430 | 15.0       | 2000 Dec. 31 | 2×720        | +0.05 cirrus            |
|              |            | 2001 Jan. 1  | 2×720        | −0.14                   |
| HE 0003−5701 | 15.5       | 2000 Dec. 28 | 2×720        | +0.14                   |
| HE 0127−3110 | 16.1       | 2001 Feb. 18 | 2×720        | −0.09                   |
|              |            | 2001 Feb. 22 | 3×720        | −0.07                   |
| HE 0236−2656 | 17.1       | 2001 Feb. 17 | 3×720        | −1.27                   |
|              |            | 2001 Feb. 20 | 2×720        | −1.19                   |
| HE 0330−0002 | 16.9       | 2001 Feb. 18 | 2×720        | −1.42 cirrus            |
|              |            | 2001 Feb. 23 | 2×720        | −0.90                   |
| HE 0338−3853 | 17.0       | 2000 Nov. 25 | 4×800        | −0.41 cirrus            |
|              |            | 2000 Nov. 26 | 2×800        | +0.44 poor seeing       |
| HE 1043−0502 | 17.1       | 2001 Feb. 18 | 9×720        | +1.49                   |
|              |            | 2001 Feb. 22 | 9×720        | +1.62                   |
| HE 1045−0908 | 16.4       | 2001 Feb. 21 | 5×720        | −0.07 to −0.87 rotating $P \sim 2$ − 4 hr |
| HE 1211−1707 | 17.1       | 2001 Feb. 22 | 15×360       | +0.94 rotating $P \sim 2$ hr |
|              |            | 2001 Feb. 25 | 15×360       | +1.22                   |

\[
\text{Number of waveplate sequences and exposure time per sequence}
\]
\[
\text{Spectrum-summed circular polarisation}
\]
Figure 1. Spectral sequence for HE 1211−1707 obtained on 25 Feb. 2001. UT is noted at the right.

Figure 2. Mean spectrum of HE 1211−1707, averaged over both nights and shown as $F_\nu$ to enhance the weak spectral features. For comparison are plotted two crude He-atmosphere spectral models, labeled by the dipolar magnetic field strength, inclination, azimuth, and longitudinal field offset (in units of the stellar radius), respectively. At the bottom is the phase-averaged observed circular polarisation, binned into 100 Å increments.

Figure 3. Dependence of major transitions of He I on magnetic field strength for $0 < B < 900$ MG, from the calculations of Becken & Schmelcher (1998, 2000, 2001) and Becken, Schmelcher, & Diakonos (1999). Wavelengths and uncertainties are provided for turnaround points, where the strongest spectral features are to be expected.

Figure 4. Total flux (top) and coadded circular polarisation (bottom) spectra of HE 1043−0502. Comparison of the observed spectrum with the $B(\lambda)$ curves in Figure 3 suggest that the features are He I lines in a magnetic field $B \sim 450 − 800$ MG.
Figure 5. Sequences of total flux (middle) and circular polarisation (bottom) for HE 1045−0908, obtained 2001 Feb. 21. A rotation period of a few hours is indicated by the variations with UT (hrs), noted at the right. Top panel: Observed phase-averaged spectrum and 3 model spectra for the indicated dipolar magnetic field strength, inclination, azimuth, and longitudinal field offset.

Figure 6. (Top): Flux and circular polarisation spectra for HE 0236−2656, the latter binned into 50 Å increments. The polarisation is small and uniformly negative outside the λ5800 absorption feature, but increases to \( v \sim -5\% \) within the trough. (Bottom): As in the top panel for HE 0330−0002. The polarisation becomes increasingly negative with decreasing wavelength and changes sign within the broad λ6650 absorption feature. Subtle depressions in spectral flux may also exist around λ4700 and λ6100.
Figure 7. (Top): Observed total flux spectrum of HE 0338−3853 compared with the K5 V dwarf GL 186. The detailed correspondence of spectral features throughout the spectra attest to the presence of a late-type component. (Bottom): Difference spectrum portraying the white dwarf component. A representative hot DA white dwarf, MCT 0457−281, is also shown, displaced upward for clarity.

Figure 8. As in Figure 7 for HE 0003−5701. Narrow emission at Hα signifies illumination of the cool dwarf in a close binary system.

Figure 9. (Top): HE 0000−3430. Underlying the featureless (DC) flux spectrum is the circular polarisation spectrum, with units indicated on the scale at the right. (Bottom): A single feature is detected near 5890 Å in HE 0127−3110. Like HE 0000−3430, the object shows no significant circular polarisation.