Do Magnetic Fields Prevent Hydrogen from Accreting onto Cool Metal-line White Dwarf Stars?

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Abstract. It is generally assumed that metals detected in the spectra of a few cool white dwarfs cannot be of primordial origin and must be accreted from the interstellar medium. However, the observed abundances of hydrogen, which should also be accreted from the interstellar medium, are lower than expected from metal accretion. Magnetic fields are thought to be the reason for this discrepancy. We have therefore obtained circular polarization spectra of the helium-rich white dwarfs GD 40 and L745-46A, which both show strong metal lines as well as hydrogen. Whereas L745-46A might have a magnetic field of about $-6900$ G, which is about two times the field strength of $3000$ G necessary to repell hydrogen at the Alfvén radius, only an upper limit for the field strength of GD 40 of $4000$ G (with 99% confidence) can be set which is far off the minimum field strength of $144000$ G to repell hydrogen.

1. Introduction

A few helium-rich white dwarfs at the cool end of the white dwarf sequence show evidence for metal lines in their spectra. Since radiation forces are not strong enough to compete with gravity for temperatures below 40000 K it is expected that metals sink down on time scales which are short compared to the cooling age. If nevertheless metals are observed in the atmospheres, they must have come from outside the star. The most popular mechanism for this is accretion from interstellar matter. The observed metal abundances in helium-rich white dwarfs are in agreement with accretion in solar element proportions (Dupuis et al. 1992, 1993a, 1993b). However, the observed abundances of hydrogen are much too low to be compatible with the accretion rates inferred from metal accretion. The mechanism most widely discussed as reason for this “hydrogen screening” is the propeller mechanism adopted to white dwarfs by Wesemael & Truran (1982): Metals are accreted in the form of grains onto a slowly rotating, weakly magnetized ($10^3$-$10^5$ G) white dwarf, whereas ionized hydrogen is repelled at the Alfvén radius.
2. Observation

Flux and circular polarization spectra of the white dwarfs GD 40 and L745-46A were observed with the VLT-UT1 and PMOS. Grism 600R (dispersion 1Å/pix) with order sorting filter GG435 was used resulting in a spectral range of about 5200–7300Å. The signal-to-noise ratio in the vicinity of Hα and the helium lines of GD 40 amounts to 190 and 260, respectively, and to 280 for Hα of L745-46A. The mean circular polarization in a spectral range between 5500Å and 6800Å amounts to 0.02%, and 0.03% for GD 40, and L745-46A, respectively, one order of magnitude lower than the expected values for kilogauss magnetic fields.

3. Determination of Magnetic Fields

3.1. Weak-Field Approximation

According to the theory of line formation in a weak magnetic field the splitting of a spectral line is proportional to the mean longitudinal field $B_l$. Provided that the Zeeman splitting of a spectral line is small compared to intrinsic (thermal and pressure) broadening (e.g. Angel & Landstreet 1970) — which is the case for white dwarfs and field strengths of up to about 10kG – the amount of polarization can be determined by the weak-field approximation, which is valid even in the presence of instrumental broadening, but is not generally correct in the case of rotational broadening (Landstreet 1982):

$$\frac{V}{T} = -g_{\text{eff}} \cdot 4.67 \cdot 10^{-13} \lambda^2 \frac{dI}{d\lambda} B_l$$

with $g_{\text{eff}}$ the effective Landé factor which equals 1 for hydrogen Balmer lines (e.g. Bagnulo et al. 2002). For the HeI line at 5875Å $g_{\text{eff}} = 1.16$ (Leone et al. 2000).

3.2. Fitting Procedure

In order to determine the mean longitudinal component of the magnetic field the observed circular polarization was compared to the predictions of the weak-field approximation in an interval of ±20Å around Hα and the HeI lines at 5875Å and 6678Å. The best-fit for $B_l$, the only free parameter, was found by a $\chi^2$ minimization procedure (see Aznar Cuadrado et al. 2004 for details).

3.3. Propeller Mechanism

Minimum magnetic field strengths necessary for the propeller mechanism to work were calculated according to Wesemael & Truran (1982). Assuming a white dwarf mass of 0.6$M_\odot$, a radius of 0.013 $R_\odot$, an accretion rate of $10^{-15}$ $M_\odot$/yr the corresponding minimum magnetic field strengths from their Eq. 4a are $144000^{+25000}_{-17000}$ G and $3000\pm500$ G for GD 40 and L745-46A, respectively. The error accounts for a reading error of 1mm in their Fig. 1. Further errors are introduced by the stellar radius which enters the formula with third power and the accretion rate.
4. GD 40: Circular Polarization

The inspection of the individual polarization spectra of GD 40 did not show any obvious features or variations in the polarization which cannot be attributed to noise. For the Hα line the field strength and the respective 68.3%/99% confidence ranges from the weak-field approximation amount to \((2747\pm6892/15000)\)G and for the two HeI lines at 5875Å and 6678Å to \((-1683\pm1528/3936)\) G and \((-716\pm1848/4758)\) G, respectively. A fit to all three lines results in a magnetic field strength of 1131 G and a 99% confidence level of ±2973 G. For comparison the derived field strength for a field star amounts to \(-438\pm318/819\) G (68.3%/99% confidence range). Thus we conclude that GD 40 does not posses a magnetic field with an upper limit of about 4000 G.

5. L745-46A: Circular Polarization

The best-fit magnetic field strength predicted by the weak-field approximation for the spectral range of Hα is \(-6900\) G with 68.3% and 99% confidence ranges of ±2100 G and ±5550 G. Although the field strength clearly exceeds the statistical 1σ error one has to be cautious, because the result solely depends on the vicinity of the Hα line. However, if this field could be confirmed, it would be strong enough to prevent hydrogen from accreting according to the prediction from the propeller mechanism of 3000 G.

6. Conclusion

For L745-46A the predicted magnetic field strength from the weak field approximation amounts to \(-6900\) G with a formal 1σ error of 2100 G and a 99% statistical confidence range of ±5550 G. This magnetic field strength exceeds the minimum field strength of 3000 G necessary for the propeller mechanism to work. However, one should keep in mind, that this result is based on the Hα line only. If the detection is confirmed, this means for the first time an indication that magnetic fields may play a role in the accretion of hydrogen and metals onto cool helium-rich white dwarfs.

However, we could not detect signatures of a magnetic field in the circular polarization or flux spectrum of GD 40. This does not necessarily mean, that no magnetic field is present, because if we are looking on the magnetic equator of a magnetic dipole \((i=90°)\), the components of the magnetic field along the line of sight completely cancel and no circular polarization can be detected. According to Wesemael & Truran (1982) a field strength of about 144000 G is needed for GD 40 to let the propeller mechanism work. If we now assume that we could detect a field strength of 4000 G (derived upper limit field strength from the fit to all three lines with a confidence of 99%) we could estimate an inclination angle of greater than 84° for which the longitudinal field strength becomes to low to be detected (Brown et al. 1977). Therefore the chance to miss a magnetic field of 144000 G is only about 6%. From our observations we must therefore conclude that in GD 40 probably other mechanisms than magnetic fields prevent hydrogen from accreting. More details can be found in Friedrich et al. (2004).
Figure 1. Observed (gray) circular polarization spectra of GD 40 and L745-46A together with the respective polarization spectra (bold) predicted by the weak-field approximation for field strengths of 2747 G, 9639 G, and 17747 G for Hα, −1683 G, −3211 G, and −5619 G for the HeI line at 5875 Å, −716 G, −2564 G, and −5474 G for the HeI line at 6678 Å (all GD40), and −6900 G, −9000 G, and −12450 G for Hα (L745-46A). For each spectral line the first field strength denotes the best fit value, the second and third value the best fit value plus the 68.3% and 99% confidence range, respectively.
Acknowledgments. Work on white dwarfs in Kiel was supported by the DFG (KO-738/7-1); it is supported in Tübingen by the DLR (50 OR 0201).

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