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The Fraction of DA White Dwarfs with Kilo–Gauss Magnetic Fields

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Abstract. Current estimates for white dwarfs with fields in excess of 1 MG are about 10%; according to our first high-precision circular-polarimetric study of 12 bright white dwarfs with the VLT (Aznar Cuadrado et al. 2004) this number increases up to about 25% in the kG regime. With our new sample of ten white dwarf observations (plus one sdO star) we wanted to improve the sample statistics to determine the incident of kG magnetic fields in white dwarfs. In one of our objects (LTT 7987) we detected a statistically significant (97% confidence level) longitudinal magnetic field varying between (-1 ± 0.5) kG and $(+1 \pm 0.5)$ kG. This would be the weakest magnetic field ever found in a white dwarf, but at this level of accuracy, systematic errors cannot completely be ruled out. Together with previous investigations, the fraction of kG magnetic fields in white dwarfs amounts to about $11 - 15\%$, which is close to current estimates for highly magnetic white dwarfs (> 1 MG).

1. Introduction

Until recently, magnetic fields below 30 kG could not be detected with the exception of the very bright white dwarf 40 Eri B ($V = 8.5$), in which Fabrika, Valyavin, & Burlakova (2003) found a magnetic field of 4 kG. However, by using the ESO VLT, we could push the detection limit down to about 1 kG in our first investigation of 12 DA white dwarfs with $11 < V < 14$ (Aznar Cuadrado et al. 2004). In three objects of this sample we detected magnetic fields between 2 kG and 7 kG on a 5 σ confidence level. Therefore, we concluded that the fraction of white dwarfs with kG magnetic fields is about 25%. For one of our cases, LP 672–001 (WD 1105–048), Valyavin et al. (2006) confirmed the presence of a kG magnetic field.

2. Observations

The spectro-polarimetric data of our new sample of ten bright normal DA white dwarfs plus one high-metallicity sdO star were obtained in service mode between May 5 and August 4, 2004, with the FORS1 spectrograph at the 8 m UT2 of the VLT. We checked all candidates for spectral peculiarities and magnetic fields strong enough to be detected in intensity spectra taken with the high-resolution Echelle spectrograph UVES at the Kueyen (UT2) of VLT in the course of the SPY project (Napiwotzki et al. 2003). The spectra and circular polarimetric data covered the wavelength region between 3600 Å and 6000 Å with a spectral resolution of 4.5 Å.

In order to avoid saturation the exposures were split into a sequence: after every second observation the retarder plate was rotated from $\alpha = -45^\circ$ to $\alpha = +45^\circ$ and back in order to suppress spurious signals in the degree of circular polarisation (calculated from the ratio of the Stokes parameters V and I).

3. Determination of the Magnetic Fields

The theoretical V/I profile for a given mean longitudinal magnetic field $\langle B_z \rangle$ (expressed in Gauss) below about 10 kG is given by the weak-field approximation (e.g. Angel & Landstreet 1970) without any loss of accuracy:

$$\frac{V}{I} = -g_{\rm eff} C_z \lambda^2 \frac{1}{I} \frac{\partial I}{\partial \lambda} \langle B_z \rangle \qquad (1)$$

where $g_{\rm eff}$ is the effective Landé factor (= 1 for all hydrogen lines of any series, Casini & Landi degl'Innocenti 1994), λ is the wavelength expressed in Å, and the constant $C_z = e/(4\pi m_e c^2)$ ($\simeq 4.67 \times 10^{-13}\,{\rm G}^{-1}{\rm Å}^{-1}$).

We performed a χ^2-minimisation procedure in order to find out which mean longitudinal magnetic field strength best fits the observed data in wavelength intervals of ±20 Å around Hβ and Hγ. The resulting best-fit values for the magnetic field strengths from the individual lines and their statistical 1σ errors are listed in Table 1 for each observation. We also provided the weighted means from both lines.

Our fitting procedure was validated with extensive numerical simulations using a large sample of 1000 artificial noisy polarisation spectra (Aznar Cuadrado et al. 2004). It was concluded that at our noise level kG fields can reliably be detected.

4. Results

As can be seen from Table 1 none of the measurements of the circular polarisations reached the same level of confidence as the three magnetic objects found in the first sample (Paper I). The highest level of confidence was achieved by LTT 7987 (WD 2007−303) where a $2.4\,\sigma$ and $2.0\,\sigma$ level was reached for the two respective observations. The corresponding mean longitudinal field strengths were -1093 ± 453 G and 970 ± 485 G. Single observations of CD−38°10980 (WD 1620−391) resulted in -1116 ± 406 G and LTT 8189 (WD 2039−202) in -1297 ± 512 G, which corresponds to $2.8\,\sigma$ and $2.5\,\sigma$, respectively.

Table 1. Magnetic fields derived from the Hγ and Hβ lines for our sample of white dwarfs. $B(\sigma)$ provides the magnetic field in units of the σ level. Detections exceeding the 2σ levels are given in bold. Multiple observations that were averaged prior to analysis are labelled AVERAGE.

Target	Date	B(G)		B(G)	$B(\sigma)$
		Hγ	Hβ	Hγ,β	Hγ,β
WD 1148−230	08/05/04	−520 ± 655	−980 ± 590	−774 ± 438	1.76
(EC 11481−2303,	18/05/04	−30 ± 1325	20 ± 1095	0 ± 844	0.00
(sdO)	AVERAGE	−490 ± 625	−860 ± 500	−716 ± 390	1.83
WD 1202−232	18/05/04	1280 ± 865	260 ± 940	812 ± 636	1.28
(EC 12028−2316)	25/05/04	660 ± 550	−370 ± 325	−103 ± 280	0.37
	AVERAGE	−200 ± 260	850 ± 425	85 ± 221	0.39
WD 1327−083	25/05/04	300 ± 1010	−320 ± 1080	10 ± 737	0.01
(G 14−58)	27/05/04	−2800 ± 740	2790 ± 835	−340 ± 553	0.61
	AVERAGE	−1230 ± 555	1410 ± 520	175 ± 379	0.46
WD 1620−391	10/05/04	150 ± 785	−1580 ± 475	**−1116 ± 406**	2.75
(CD−38°10980)	17/05/04	−2390 ± 1220	−20 ± 735	−651 ± 629	1.03
	25/05/04	120 ± 640	−770 ± 595	−357 ± 435	0.82
	AVERAGE	−500 ± 480	−920 ± 365	**−766 ± 290**	2.63
WD 1845+019	05/05/04	−340 ± 1410	−150 ± 1175	−227 ± 902	0.25
(Lan 18)	10/05/04	−30 ± 1145	6000 ± 2390	1095 ± 1032	1.06
	AVERAGE	−130 ± 815	500 ± 670	245 ± 517	0.47
WD 1919+145	06/05/04	1240 ± 1080	−1440 ± 1220	62 ± 808	0.08
(GD 219)	10/05/04	930 ± 1290	110 ± 990	413 ± 785	0.53
	AVERAGE	1180 ± 870	−500 ± 815	285 ± 594	0.48
WD 2007−303	06/05/04	−1460 ± 1270	−1040 ± 485	**−1093 ± 453**	2.41
(LTT 7987)	12/05/04	1540 ± 780	610 ± 620	**970 ± 485**	2.00
	AVERAGE	120 ± 495	−390 ± 375	−204 ± 298	0.67
WD 2014−575	14/05/04	2410 ± 1735	1240 ± 1260	1643 ± 1019	1.61
(RE J2018−572)	27/06/04	310 ± 4295	1160 ± 3340	839 ± 2636	0.32
	28/06/04	2820 ± 2060	−4470 ± 1455	−2043 ± 1188	1.71
	AVERAGE	2380 ± 1205	−1120 ± 895	124 ± 718	0.17
WD 2039−202	17/05/04	−2670 ± 1595	40 ± 965	−686 ± 825	0.83
(LTT 8189)	10/06/04	−780 ± 730	−1800 ± 720	**−1297 ± 512**	2.53
	AVERAGE	−1240 ± 655	−1290 ± 535	**−1269 ± 414**	3.06
WD 2149+021	26/06/04	340 ± 1060	730 ± 930	560 ± 699	0.80
(G 93−48)	09/07/04	−530 ± 945	−1690 ± 890	−1144 ± 647	1.78
	04/08/04	−1300 ± 985	350 ± 705	−208 ± 573	0.36
	AVERAGE	−600 ± 555	−130 ± 490	−335 ± 367	0.91
WD 2211−495	14/05/04	110 ± 1655	−1940 ± 1060	−1343 ± 892	1.51
(RE J2214−491)	28/06/04	−190 ± 1795	640 ± 1190	386 ± 991	0.39
	AVERAGE	−390 ± 1155	−900 ± 795	−736 ± 654	1.12

With two observations exceeding 2 σ, LTT 7987 (WD 2007−303) would be the most convincing case for being a positive detection. The probability that two independent and uncorrelated observations of a single star have that level of confidence can be estimated in the following way: the likelihood that an observations exceeds 2 σ is 4.6%. Therefore, the chance that at least one observation of the white dwarfs exceeds 2 σ is $(1-0.954^{23}) = 66.1\%$. Then the probability that the same star has a second observation exceeding 2 σ is $0.661 \times 0.046 = 3.0\%$. Therefore, from a purely statistical point of view we must regard this detection as significant (with 97% confidence).

Both measurements of the sdO star EC 11481−2303 are below the 2 σ level. This is interesting by itself and confirms the finding by O'Toole et al. (2005) that there is no correlation between the metallicity and the presence of a magnetic field with kG strength.

5. Conclusion

While we detected magnetic fields in three out of 12 programme stars in our first investigation, we found at most (if at all) one object in our new sample of ten DA white dwarfs. Putting both samples together we arrive at a fraction of 14−18% of kG magnetism in white dwarfs; the lower value is obtained assuming that LTT 7987 is not magnetic. However, if confirmed, LTT 7987 would have the lowest magnetic field (1 kG) ever detected in a white dwarf.

Recently, Valyavin et al. (2006) have also performed a search for circular polarisation in white dwarfs. They confirmed our detection (Aznar Cuadrado et al. 2004) of a varying longitudinal magnetic field in LP 672−001 (WD 1105−048): they measured field strengths between -7.9 ± 2.6 kG to 0.1 ± 2.7 kG, compared to our values of -4.0 ± 0.7 kG to -2.1 ± 0.4 kG. However, they did not discover any significant magnetic field in their five other programme stars. If we combine their and our results together, the fraction of kG magnetic fields in DA white dwarfs amounts to 15% (4/(12+10+5)) or 11% (3/(12+10+5)), if we disregard the detection in LTT 7987. However, it is problematic to merge both samples, because the signal-to-noise ratio of our VLT measurements is much higher than the observations with the 6 m telescope of the Special Astrophysical Observatory. Since our uncertainties are on the average 2−3 times smaller (partly also due to the fact that Valyavin et al. 2006 have used Hα only) we must put a higher statistical weight on our sample with a fraction of 11% to 15% of magnetic to field-free (i.e. below detection limit) white dwarfs.

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