A catalogue of isolated massive white dwarfs[★]

Mass distribution of massive stars

M. Należyty¹ and J. Madej²

¹ Astronomical Observatory, University of Warsaw, Al. Ujazdowskie 4, 00-478 Warsaw, Poland

² N. Copernicus Astronomical Center, Bartycka 18, 00-716 Warsaw, Poland

Received 9 April 2003 / Accepted 15 January 2004

Abstract. We present in this paper a catalogue of 112 massive isolated white dwarfs, with masses $M > 0.8 M_{\odot}$. Mass determinations and other parameters of white dwarfs were compiled from the available literature. For each star we present averaged values of mass, effective temperature, logarithm of surface gravity $\log g$, radius, distance, and the surface magnetic field for magnetic white dwarfs. The mass distribution of our sample is a slowly decreasing continuum function for masses larger than $0.9 M_{\odot}$, with an overlapping secondary maximum at $1.04 M_{\odot}$. We conclude that the mass distribution of known massive magnetic white dwarfs is flat, whereas nonmagnetic WDs exhibit a steeper mass distribution towards the highest masses. The secondary maximum at $1.04 M_{\odot}$ is caused exclusively by nonmagnetic white dwarfs. We note that the 4 most massive stars with masses $M \geq 1.3 M_{\odot}$ are magnetic white dwarfs. Our results show also, that the occurrence of magnetism in massive white dwarfs does not depend on the cooling age (above $T_{\text{eff}} = 5000$ K).

Key words. catalogs – stars: white dwarfs

1. Introduction

The masses of white dwarf stars are always smaller than the Chandrasekhar mass, which is equal to 1.44 solar mass in the case of hydrogen non-rotating objects. It is well known, however, that the mass distribution of isolated white dwarfs exhibits peak at mass $\approx 0.60 M_{\odot}$ (Weidemann 1990), with a substantial number of known objects with higher masses. The analysis of recently obtained homogeneous samples of isolated white dwarfs has led to a slightly different peak mass value. Bergeron et al. (1992, hereafter BSL) have analyzed the sample of 129 DA white dwarfs, and determined their masses by means of fitting hydrogen Balmer line profiles. They obtained a peak mass value of $0.562 M_{\odot}$. Liebert & Bergeron (1995) analyzed 200 white dwarfs from the Palomar Green survey (Green et al. 1986), with peak mass $0.56 M_{\odot}$. However, the above surveys did not reach to much higher masses, and were only sparsely populated by white dwarfs $> 1 M_{\odot}$. Only recently Marsh et al. (1997a,b) determined the masses (and also other stellar parameters) of an extensive set of white dwarfs selected from the ROSAT all-sky survey in the extreme ultraviolet (EUV). They distinguished between the populations of normal ($\approx 0.6 M_{\odot}$) and massive ($> 1.0 M_{\odot}$) white dwarf stars.

Extensive determinations of the WD mass distribution were also presented in recent papers by Vennes et al. (1997a,b, 1998), and Vennes (1999), which were based on the *Extreme Ultraviolet Explorer* (EUVE) observations.

In this paper we present and discuss the catalogue and the mass distribution of massive white dwarfs with masses $M > 0.8 M_{\odot}$. Our research is based on mass determinations available in the existing literature. Investigation of the mass distribution of white dwarfs on the massive branch can put significant constraints on both early and late stages of stellar evolution, including star forming stages in the Galactic disc. The limiting mass $0.8 M_{\odot}$ in this paper has been chosen arbitrarily. Masses presented in the following sections represent a highly inhomogeneous sample, since we intended to collect as many massive white dwarf stars as possible.

Masses of isolated white dwarfs are probably correlated with the chemical composition of their cores. White dwarf cores are generally believed to be built of carbon and oxygen. However, there exists a number of papers, which study the mass-radius relations, cooling sequences, and photometric colors for helium-core white dwarfs (Serenelli et al. 2001, 2002; Rohrmann et al. 2002), which are located at the low mass end of mass distribution. Similarly white dwarfs with mass higher than the average mass can be correlated with the population of magnesium-core or iron-core stars studied by Provencal et al. (1998), Provencal & Shipman (1999), Panei et al. (2000), Madej et al. (2003). The present catalogue listing the

Send offprint requests to: M. Należyty,
e-mail: nalezyty@astrouw.edu.pl

★ The full Table 1 is only available in electronic at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/420/507>

massive isolated white dwarfs probably contains white dwarfs with cores consisting of heavier elements.

Masses of isolated white dwarfs are usually determined with the help of spectral analysis. The observed visual spectra can be fitted with theoretical spectra to determine effective temperatures T_{eff} and surface gravities $\log g$ for some assumed chemical composition, mostly pure hydrogen. A classical paper by Shipman (1979) explained the method of radius R and mass M determination from known values of T_{eff} , $\log g$, distance d , and visual magnitude m_V , based on some reasonable grid of synthetic spectra. Nowadays there exists three principal methods of mass and radius determination of isolated white dwarfs, which are used depending on the exact set of available observational parameters, which include also estimates of the gravitational redshift (cf. discussion in Schmidt 1997).

Other techniques of mass determination result from orbital solutions in isolated binaries containing a white dwarf (Sirius B, Procyon B, for instance). A review of the various methods of mass determination has been given by BSL (1992), cf. also Koester (2002).

In the present paper, we disregard the differences between particular methods of M and R determination, and collect isolated massive white dwarfs in a single set of stars. In this way we attempt to investigate the most numerous set of star which is actually available, and avoid random fluctuations of small numbers of binned stars. It is necessary to stress here that white dwarfs in interacting binaries were not included in our catalog.

2. The catalogue

In this paper we present an analysis of the catalogue of all massive white dwarfs, compiled from the available literature. Our catalogue consists of 112 white dwarf stars, both magnetic and nonmagnetic WDs. The full catalogue is not printed in this paper, and available in electronic form at the CDS. A shortened version of the catalogue is presented in Table 1.

The data for each star were compressed into a single row. The columns of Table 1 list the following data: WD designation by its equatorial coordinates, name of the star, and values and errors of T_{eff} , $\log g$, $M/M_{\odot}$. The ninth and following columns give; radius R in kilometers, mean surface magnetic field B_s , polar field B_p , distance d in kiloparsecs, remarks, and a reference list.

In most cases the stellar parameters were independently determined by several authors. Values of T_{eff} , $\log g$, $M/M_{\odot}$, and remaining parameters presented in Table 1 are arithmetic averages of the individual data. The errors are just formal errors of the above averages. In this way we could neglect error determinations given in individual papers. Parameters of white dwarfs determined in a single paper have not been assigned any error estimates in Table 1.

3. The mass distribution of white dwarf stars

The mass distribution of isolated white dwarfs exhibits a relatively narrow peak at about $0.6 M_{\odot}$. Precise values of the peak mass were determined to be $0.603 M_{\odot}$ (Weidemann & Koester 1984), $0.571 M_{\odot}$ (McMahan 1989),

Fig. 1. Mass distribution for all 112 massive white dwarf stars of our catalogue (gray scale). The wide-binned histogram shows the local maximum of the mass distribution in the range $1.0\text{--}1.05 M_{\odot}$. The inserted dark tone histogram with finer resolution of $0.01 M_{\odot}$ clearly suggests that the local maximum of the WD mass distribution is located at $\approx 1.04 M_{\odot}$.

$0.562 M_{\odot}$ (BSL 1992), $0.56 M_{\odot}$ (Liebert & Bergeron 1995), $0.570 M_{\odot}$ (Finley et al. 1997), and $\approx 0.55 M_{\odot}$ (Marsh et al. 1997a,b).

The shape of the mass distribution also exhibits a distinct tail towards higher masses, which hardly any of the above papers reproduced satisfactorily. Weidemann & Koester (1984) did not include white dwarfs of masses higher than $1.0 M_{\odot}$, and there are only few such massive stars in other early papers presented in their list. Marsh et al. (1997) recognized the existence of a high-mass population ($>0.8 M_{\odot}$), consisting a total of 13 white dwarfs only. Small sample of massive white dwarfs in that paper did not make it possible to investigate any details of the mass distribution in that region. In spite of this, Marsh et al. (1997) suggested that the massive white dwarf stars form a second population, clearly differing from the main population with a mass peak at about $0.6 M_{\odot}$, which probably were formed by coalescence of normal white dwarfs in close binary system.

4. The tail of the massive WD distribution

White dwarfs and their averaged masses collected in Table 1 form a rather inhomogeneous sample, as we did not discriminate between various methods of mass determination. This was done to increase the total number of massive white dwarfs in the sample. In this way we attempt to minimize the uncertainties and fluctuations caused by the very small number of massive stars available in previous investigations.

Figure 1 presents the mass distribution of all 112 isolated white dwarfs, with averaged masses compiled in Table 1. The main histogram consists of bins with $0.05 M_{\odot}$ width which shows, that above $0.9 M_{\odot}$ the number of stars per bin continuously decreases towards higher masses, and only the single bin $1.0\text{--}1.05 M_{\odot}$ contains a significantly larger number of stars

Table 1. Catalogue of massive white dwarfs.

WD	Name	T_{eff}	ΔT_{eff}	$\log g$	$\Delta \log g$	$M/M_{\odot}$	$\Delta M/M_{\odot}$	R	B_s	B_p	d	Rem.	References
0000–345	GR406	7000				0.92			70			m	5
0003+436J	RE0003+433	45 107	1362	9.01	0.15	1.21	0.06	3907			101		1a, 1b, 2, 3, 4
0008+330	HS0008+3302	10 300		8.35		0.83		6960			85		14
0009+501	GR381	6400				0.89				70		m	17
0022+274	LP349–013	25 000				0.862					29	b	8
0033+016	EG004	10 700		8.66		1.02		5440			32.9		6
0041+092	BD+08°102	28 960	50	8.50		0.90		6180			55	b	27, 28
0046+051	EG005	6770		8.40		0.83		6620			4.3		6
0115+159	EG009	9800		8.38		0.82		6740			15.4		6
0136+251	PG0136+251	39 465	294	9.01	0.04	1.21	0.03	3830			80	m	1a, 1b, 2, 3, 4, 18
0146+072	HS0146+0723	25 000		8.27		0.80		7520			210		14
0235–125	PHL 1400	32 018	252	8.49	0.05	0.95	0.03	6170			66		1a, 1b, 2, 3, 12
0239+500J	EUVE J0239+500	34 211	389	8.517	0.043	0.96	0.02	6130			96		2, 3
0317–853	EUVE J0317–855	43 210	3290	9.19	0.30	1.34	0.01	2408	505	395		mbc	4, 5, 17, 22, 23, 24, 25
0346–011	GD 50	41 743	736	9.12	0.04	1.25	0.03	3520			29		1a, 1b, 2, 4, 7, 12, 13
0347+171	V471 Tau	34 060	580	8.40	0.14	0.90	0.07	6240			47	bc	1a, 1b, 29, 30, 31
0349+247	EG025	32 180	320	8.69	0.05	1.046	0.012	5081					7, 9, 11, 19, 32
0352+049	KUV03520+0500	36 900	500	8.71	0.15	1.05	0.08	5280			106		4, 14
0406+169	EG029	15 190		8.30		0.806	0.013	7300			53.2		8, 9, 11, 16
HD27483		22 000		8.5		0.95		6300			46	bt	27
0443–037J	EUVE J0443–037	68 740	3600	8.946	0.174	1.25	0.04	3970			144		2, 3, 4
0518–105	RE0521–102	32 727	323	8.67	0.02	1.04	0.01	5380			99	b	1a, 1b, 2, 3, 12
0531–022	EUVE J0534–022	29 867	133	8.587	0.054	1.00	0.02	5760			101		2, 3
0548–001	EG248	6400	100	8.32		0.81	0.03	7040	8		11.1	m	5, 6
0557–165J	1RXSJ0557.0–1635	56 820		8.88		1.15		4490			309		4
0630–050	RE0632–050	43 029	686	8.32	0.13	0.81	0.07	7790					1a, 1b, 2, 3
0633+200J	0630+200	75 792		8.398		0.947		7090					3
0642–166	Sirius B	24 700	100	8.61	0.04	1.02	0.01	5670			2.64	b	1a, 1b, 15, 26
0644+025	GR484	7410		8.66		1.01		5420			18.5		6
0653–564	EUVE J0653–564	35 200		8.88		1.15	0.01	4490			107		2, 4
0654+027	EG181	9450		8.51		0.91		6110			38.5		6
0659–063	LHS1892	6520		8.71		1.04		5190			12.3		6
0701–587	BPM18398	15 701		8.562		0.944		5861					13
0729–384	y Pup	43 200	200	8.5		0.87	0.04	6100			172	bt	27, 33
0730+487	GD 86	15 510		8.49		0.90		6220					7
0743–391J	EUVE J0743–391	40 200		8.66		1.04	0.01	5500			147		2
0816+376	GD 90	11 000				0.86			8			m	5
0823–253	1RXSJ0823.6–2525	43 200		9.02		1.21	0.01	3910	3		105	m	4, 34
0827+328	EG249	7270		8.39		0.85		6780			22.3		6
0836+197	LB 5893	21 620	310	8.45		0.916	0.007	6550			174		8, 9, 16
0836+199	EG060	14 060		8.34		0.864	0.021	7240					9
0853+163	GR904	2000				0.83			3			m	5
0856+331	EG182	10 390		8.84		1.11		4610			20.5	b	6
0912+536	EG250	7580	420	8.28		0.87	0.12	7230	70		10.3	m	5, 6
0913+442	EG064	8620	130	8.24	0.05	0.826	0.093	7760			28.9	bp	6, 11
0916–197J	EUVE J0916–197	56 400		9.12	0.2	1.29	0.02	3600			164	b	2, 4
0930+294	GR324	8330		8.38		0.84		6820			32.1		6
0943+472	HS0943+4724	16 000		8.75		1.07		5000			120		14
0945+245.1	LB11146A	14 500		8.5		0.91		6200			40	b	35
0945+245.2	LB11146B	16 000		8.5		0.99	0.09	6100	375	670	40	mb	5, 17, 35
0946+485	HS0946+4848	11 700		8.69		1.04		5300			80		14
0946+534	EG251	8760		8.45		0.87		6400			23.0		6
0949+494	HS0949+4935	15 000		8.39		0.86		6800			190		14
0957+854J	EUVE J0957+854	51 636	325	8.32	0.06	0.83	0.02	7470			139		2, 12
1015+014	PG1015+015	14 000				1.03			85			m	5
1017+366	GD 116	16 000				0.89			56			m	5, 37
1024–303J	RE1024–302	35 710	520	8.95	0.15	1.13	0.06	4520			64	b	1a, 1b, 3, 4
1031+234	TON 527	25 000				1.11			500			m	5
1036–204	GR535	7500				1.34			150			m	5
1038+633	PG1038+634	24 800		8.39		0.85		6780					7
1052+273	GD 125	23 064	314	8.340	0.071	0.814	0.047	7031					7, 13
1055–072	EG074	7420		8.42		0.85		6550			12.2		6

Table 1. continued.

WD	Name	T_{eff}	ΔT_{eff}	$\log g$	$\Delta \log g$	$M/M_{\odot}$	$\Delta M/M_{\odot}$	R	B_s	B_p	d	Rem.	References
1102+748	GD 466	19 800		8.37		0.83		6850					7
1127+311.1	ESO439-162	5400				1.13			67			mb	5
1134+300	GD 140	21 470	220	8.46	0.02	0.87	0.03	6310			15.3		3, 7, 15
1136-285	ESO439-026	4490		9.02		1.19		3880			40.8		6
1215+323	EG089	7100		8.68		1.02		5320			31.1		6
1236-495	LTT 4816	12 210	340	8.70	0.04	1.03	0.02	5250			16.4		6, 10, 13
1241+482	HS1241+4821	14 800		8.54		0.95		6100			90		14
1309+853	GR436	5600				0.83			15			m	5
1334-160	EG101	18 790	210	8.32		0.811	0.010	7180				bp	7, 11
1350-090	LP 907-037	9500				0.98			0.1			m	5
1440+750J	HS1440+7518	38 260	1680	8.71	0.10	1.04	0.03	5470	7.7		98	m	2, 4, 12, 17
1444-174	LHS 378	4960		8.37		0.81		6770			14.5		6
1446+286	TON 214	22 839	102	8.327	0.034	0.815	0.006	7143					3, 7
1501+664	H 1504+65	170 000		8.0		0.86		10 700			630		38
1531-022	GD 185	18 870		8.39		0.84		6740					7
1535-774J	EUVE J1535-774	54 800	3200	9.12	0.02	1.29	0.03	3580			107		2, 4
1543-366	RE1546-364	45 208		8.875		1.168		4546			107		3
1609+135	EG117	9080		8.75		1.07		5030			18.3		6
1609+631	PG1609+631	31 033		8.408		0.893		6806					3
1625+093	GR327	6870		8.44		0.88		6510			23.4		6
1642+413	RE J1643+411	27 677	1139	8.376	0.156	0.858	0.105	6944					3, 12
1658+440	EUVE J1659+440	30 410	100	9.36		1.32	0.02	2780	2.3		27	m	2, 4, 5, 12, 17, 18
1705+030	GR494	7050		8.35		0.80		6870			17.5		6
1711+667J	RE1711+664	47 556	1434	8.957	0.067	1.191	0.050	4185				b	3, 12
1725+586	RE J1726+583	55 100	1083	8.32	0.08	0.869	0.052	7410					1a, 1b, 3, 12
1727-360	EUVE J1727-360	32 600		9.04		1.21		3830					4
1740-706	RE1746-703	47 690	1120	8.95	0.04	1.16	0.03	4270					1a, 1b, 3, 4, 39
1743-521	BPM25114	20 000				1.34			25			m	5
1745+607J	HS1745+6043	35 600		8.68		1.05		5400			120		14
1748+708	GR372	6550	960	8.36		0.98	0.17	6850	150		6.1	m	5, 6
1814+248	G183-035	7000				0.83			10			m	5
1829+547	GR374	6640	360	8.50		1.02	0.12	6150	120		15.0	m	5, 6
1900+705	Grw+70°8247	13 540	1470	8.58		1.09	0.07	5760	230		13.0	m	5, 6, 36
2010+310	GD 229	23 000				1.28			500			m	5
2020-425	REJ2024-42	29 028	431	8.412	0.128	0.911	0.059	6878					1a, 1b, 3
2039-682	EG140	16 065		8.444		0.872		6450					13
2043-635	BPM13537	25 971		8.358		0.855		7054					3
2055+164	EUVE J2055+1627	38 400		8.37		0.85		6940			104		4, 40
2107-216	GR581	5830		8.40		0.85		6700			23.7		6
2126+191	IK Peg	34 320	750	8.5	0.3	1.13	0.05	5890			50	bc	27, 28, 41
2157+815	HS2157+8153	10 700		8.71		1.05		5200			35		14
2220+133	PG2220+134	22 600		8.81		1.10		4700			50		14
2246+223	EG155	10 330		8.57		0.97		5890			19.0		6
2251-070	GR453	4580		8.38		0.82		6740			8.1		6
2257-073	BD-07°5906B	37 517		8.25		0.92		8290			111	b	28
2303+465	PSR B2303+46	45 000				1.1		3000			2500	b	42
2312-024	GR554	6840		8.41		0.84		6590			26.7		6
2348-444J	ESO292-43	5400		8.72		1.04		5130			26.2		6
2359-434	EG165	8715		8.581		0.956		5770					13
θ Hya	HR3665	28 000		8.5		0.83		5900			40	b	27

Remarks – (m) magnetic white dwarfs; (b) white dwarfs with companion(s); (c) close binary or multiple systems; (t) triple systems; (p) common proper-motions binaries.

References – (1a) Marsh et al. (1997a); (1b) Marsh et al. (1997b); (2) Vennes et al. (1997); (3) Finley et al. (1997); (4) Vennes (1999); (5) Fabrika & Valyavin (1998); (6) Bergeron et al. (2001); (7) Bergeron et al. (1992); (8) Reid (1996); (9) Claver et al. (2001); (10) Bergeron et al. (1995b); (11) Bergeron et al. (1995a); (12) Napiwotzki et al. (1999); (13) Bragaglia et al. (1995); (14) Homeier et al. (1998); (15) Provencal et al. (1998); (16) Heber et al. (1997); (17) Wickramasinghe & Ferrario (2000); (18) Schmidt et al. (1992); (19) Wegner et al. (1989); (20) Putney (1997); (21) Bergeron et al. (1994); (22) Barstow et al. (1995); (23) Burleigh et al. (1999); (24) Ferrario et al. (1997); (25) Jordan & Burleigh (1999); (26) Holberg et al. (1998); (27) Burleigh (1999); (28) Vennes et al. (1998); (29) Barstow et al. (1997); (30) Werner & Rauch (1997); (31) O'Brien et al. (2001); (32) Wegner et al. (1991); (33) Burleigh et al. (1998); (34) Ferrario et al. (1998); (35) Liebert et al. (1993); (36) Suh & Mathews (2000); (37) Saffer et al. (1989); (38) Werner (1991); (39) Dupuis & Vennes (1997); (40) Vennes et al. (1997); (41) Wonnacott et al. (1993); (42) van Kerkwijk & Kulkarni (1999); (43) Moran et al. (1998).

(15 objects). We believe, that this single bin demonstrates the existence of a secondary maximum in the mass distribution of massive isolated white dwarfs.

When constructing the histogram in Fig. 1 we arbitrarily assumed that stars with masses located exactly at the edges between bins are counted in the bin with stars of higher masses. I.e. if a star has its mass equal to $1.0 M_{\odot}$, then it is counted to the $1.0\text{--}1.05 M_{\odot}$ bin.

We have therefore constructed and overlapped in Fig. 1 a second histogram with a finer ($0.01 M_{\odot}$) spacing, which demonstrates the structure of the mass distribution function in the vicinity of the secondary maximum, in the range of $0.96\text{--}1.12 M_{\odot}$. The maximum is most likely located at about $1.04 M_{\odot}$.

Of course, the mass distribution determined in this sample has been unintentionally blurred by the fact that the mass determinations were done with different methods. In spite of this, the secondary maximum at $\approx 1.04 M_{\odot}$ is clearly visible in Fig. 1.

The above results can be immediately be compared to the previous mass distribution by Vennes (1999). Our conclusion that there is secondary maximum in the mass distribution at $1.04 M_{\odot}$ remains in full agreement with the above mentioned paper (see his Fig. 8). However, our results deny the possible existence of a secondary maximum at $1.25 M_{\odot}$. The other qualitative difference between Vennes (1999) and our paper is that we demonstrate the existence of a distinct slope in the mass distribution, when we decrease mass towards $0.8 M_{\odot}$.

We note that the present paper is based on a more numerous collection of massive white dwarfs. We tentatively estimated on the basis of Fig. 8 and Table 7 of Vennes (1999) that the number of white dwarfs with masses $M \geq 0.8 M_{\odot}$ in his paper is of the order 30, whereas our results are based on a much bigger sample of 112 stars.

5. Massive magnetic vs. nonmagnetic stars

5.1. Distribution of masses

It is interesting to investigate the differences between the mass distribution of the magnetic and nonmagnetic white dwarfs in our sample. It is well established that magnetic white dwarfs apparently have a much higher than average mean mass (Liebert et al. 2003; Kawka et al. 2003). The former paper states that the mean mass of magnetic white dwarfs in their sample equals to $0.93 M_{\odot}$, as compared with the average white dwarf mass of $0.60 M_{\odot}$ (Weidemann 1990). We show our mass distributions in Figs. 2 and 3.

The mass distribution of massive magnetic white dwarfs seems to be flat and does not exhibit any particular features, except the absence of stars with masses in the range $1.15\text{--}1.2 M_{\odot}$ (Fig. 2). However, due to the very small numbers of stars in each bin, typically 1–4 stars, this gap most likely is statistically insignificant. One can note, that the only stars with masses exceeding $1.30 M_{\odot}$ are known magnetic white dwarfs (4 stars), and they are shown in Fig. 2.

In contrast, the mass distribution of nonmagnetic white dwarfs clearly shows the secondary maximum of the mass distribution in the single bin of $1.0\text{--}1.05 M_{\odot}$ (Fig. 3). Moreover,

Fig. 2. Mass distribution for magnetic massive white dwarf stars. The mass distribution is flat, and no local maximum can be seen in the figure.

Fig. 3. Mass distribution for nonmagnetic massive white dwarf stars. The local maximum at $1.04 M_{\odot}$, as shown in Fig. 1, should be attributed solely to the above nonmagnetic white dwarfs.

the mass distribution of these stars is qualitatively different from magnetic WDs in that it shows a steeper decrease towards highest masses. In particular, we found no nonmagnetic white dwarf with mass greater than $1.30 M_{\odot}$.

One cannot rule out the possibility that in future some nonmagnetic white dwarfs in Fig. 3 would move to the histogram in Fig. 2, when a non-zero magnetic field is detected.

We point out here that our mass distribution of magnetic massive white dwarfs (Fig. 2) differs significantly from the distribution by Valyavin & Fabrika (1999). Both authors claim that the mass distribution of magnetic white dwarf stars exhibits a main maximum at $0.8 M_{\odot}$, and a secondary maximum at $\approx 1.15 M_{\odot}$ (see Fig. 2 in their paper). The two maxima in their

paper are separated by a deep minimum in the mass distribution at $1.05 M_{\odot}$. Our Fig. 2 does not show any such features.

5.2. Incidence of magnetism in massive stars

Table 1 immediately provides an estimate of the relative fraction of magnetic white dwarfs in the whole group of massive white dwarfs with masses greater than $0.8 M_{\odot}$. Among 112 massive stars listed in Table 1 we collected 25 stars that are presently known as magnetic objects. Therefore the fraction of isolated magnetic massive white dwarfs in our sample is 22%.

This result is very similar to the conclusion by Vennes (1999), who found that the fraction of magnetic white dwarfs is approximately equal to 25% for hot stars with masses exceeding $1 M_{\odot}$. However, we stress the essential difference between both analyzes: the sample of hot massive white dwarfs compiled by Vennes (1999) was derived from the *EUVE* catalogue of hot stars, whereas our sample is not restricted to hot objects.

The data collected in Table 1 allow us to study the distribution of magnetic white dwarfs in a more detailed way. Figure 4 presents the relative fractions of magnetic white dwarfs as a function of mass. Figure 4 clearly suggests that the incidence of magnetism increases with mass, and reaches 100% in the highest mass bin, $1.30\text{--}1.35 M_{\odot}$. We are aware, however, that the numbers of magnetic stars considered are low, and we cannot exclude strictly random fluctuations.

5.3. The evolution of magnetic fields in white dwarfs

We have also attempted to examine the number distribution of massive white dwarfs with respect to effective temperature. Obviously such a distribution has a direct connection to the cooling age of white dwarfs. Figure 5 displays the number distribution of both magnetic (dark tone) and nonmagnetic white dwarfs (light tone) from our Table 1 of massive objects. We remind the reader that we selected 25 magnetic and 87 nonmagnetic massive stars to construct the two histograms in Fig. 5.

It is evident that the distribution in both subclasses of white dwarfs is very similar in that both exhibit a sharp maximum for T_{eff} between 5000 and 10000 K. This result has been presented also in Valyavin & Fabrika (1998, 1999). However, they suggested that the frequency of cool magnetic stars (of any mass) is greater than that of hot magnetic stars. Our Fig. 5 shows that the distribution of massive magnetic white dwarfs vs. T_{eff} essentially does not differ from the distribution of all massive objects, therefore effective temperatures below (and also above) 10000 K do not influence the relative occurrence of magnetism in white dwarfs. In other words, our results show that the occurrence of magnetism in massive white dwarfs does not depend on the cooling age (above $T_{\text{eff}} = 5000$ K).

Figure 5 most probably demonstrates the selection effect that is the reason why we have not yet discovered the majority of the coolest white dwarfs below $T_{\text{eff}} < 5000$ K, both magnetic and nonmagnetic. We also conclude that our results in Fig. 5 contradict the suggestion of Valyavin & Fabrika (1998, 1999)

Fig. 4. Relative fractions of magnetic white dwarfs as a function of stellar mass, $N_{\text{mag}}/N_{\text{tot}}$. Note that the incidence of magnetism increases with white dwarf mass. The dashed line denotes the average fraction of magnetic white dwarfs among isolated massive WDs.

Fig. 5. Number distribution of magnetic (dark tone) and nonmagnetic (light tone) white dwarfs. The distributions of both types of massive white dwarf stars a very sharp maximum in the range $5000 \leq T_{\text{eff}} < 10000$ K. Computations show that the relative fraction of magnetic white dwarfs vs. T_{eff} remains almost constant, $0.2 < N_{\text{mag}}/N_{\text{tot}} < 0.4$ up to $T_{\text{eff}} = 40000$ K.

that we observe a magnetic field decay below $T_{\text{eff}} < 6000$, at least in the group of massive white dwarfs.

6. Conclusions

We have performed an extensive search of the available literature and selected all known white dwarf stars of masses at or above $0.80 M_{\odot}$. Included here are stars which are believed to be isolated, or are members of detached (noninteracting) binary systems. We excluded white dwarfs that are members of close (interacting) binary systems. In total, 112 massive white dwarfs

were selected, and some of them are known as strongly magnetic stars with a surface field B_s approaching 500 megagauss.

The catalogue of all known stellar parameters is presented in Table 1, which lists for each star its parameters (T_{eff} , $\log g$, mass M) averaged over all the available individual determinations.

The mass distribution of massive magnetic white dwarfs is rather flat, whereas the distribution of nonmagnetic stars seems to be steeper, decreasing towards the maximum Chandrasekhar mass. However, the mass distribution of all massive isolated white dwarfs apparently exhibits a distinct local maximum at $1.04 M_{\odot}$, which seems to be caused exclusively by nonmagnetic white dwarfs in our sample.

We report here the observation that the small group of the most massive stars in our sample, $M > 1.30 M_{\odot}$, consists of 4 magnetic white dwarfs. Nonmagnetic white dwarfs apparently are less massive than $1.30 M_{\odot}$.

Our results show that the occurrence of magnetism in massive white dwarfs does not depend on the cooling age (above $T_{\text{eff}} = 5000$ K).

Acknowledgements. This research has been supported by grant No. 1 P03D 001 26 from the Polish Committee for Scientific Research.

References

- Barstow, M. A., Jordan, S., O'Donoghue, D., et al. 1995, *MNRAS*, 277, 971
- Barstow, M. A., Holberg, J. B., Cruise, A. M., & Penny, A. J. 1997, *MNRAS*, 290, 505
- Bergeron, P., Kidder, K. M., Holberg, J. B., et al. 1991, *ApJ*, 372, 267
- Bergeron, P., Saffer, R., & Liebert, J. 1992, *ApJ*, 394, 228 (BSL)
- Bergeron, P., Wesemael, P., Beauchamp, A., et al. 1994, *ApJ*, 432, 305
- Bergeron, P., Liebert, J., & Fulbright, M. S. 1995a, *ApJ*, 444, 810
- Bergeron, P., Wesemael, R., Lamontaigne, R., et al. 1995b, *ApJ*, 449, 258
- Bergeron, P., Leggett, S. K., & Ruiz, M. T. 2001, *ApJS*, 133, 413
- Bragaglia, A., Renzini, A., & Bergeron, P. 1995, *ApJ*, 443, 735
- Burleigh, M. 1999, 11th European Workshop on White Dwarfs, ed. S.-E. Solheim, & E. G. Meistas, ASP Conf. Ser., 169, 249
- Burleigh, M. R., & Barstow, M. A. 1998, *MNRAS*, 295, L15
- Burleigh, M. R., Jordan, S., & Schweizer, W. 1999, *ApJ*, 510, L37
- Claver, C. F., Liebert, J., Bergeron, P., & Koester, D. 2001, *ApJ*, 563, 987
- Dupuis, J., & Vennes, S. 1997, *ApJ*, 475, L131
- Fabrika, S. N., & Valyavin, G. G. 1998, *Bull. Spec. Astrophys. Obs.*, 45, 84
- Ferrario, L., Vennes, S., & Wickramasinghe, D. T. 1998, *MNRAS*, 299, L1
- Ferrario, L., Vennes, S., Wickramasinghe, D. T., Bailey, J., & Christian, D. J. 1997, *MNRAS*, 292, 205
- Finley, D. S., Koester, D., & Basri, G. 1997, *ApJ*, 488, 375
- Green, R. F., Schmidt, M., & Liebert, J. 1986, *ApJS*, 61, 305
- Heber, U., Napiwotzki, R., & Reid, I. N. 1997, *A&A*, 323, 819
- Holberg, J. B., Barstow, M. A., Bruhweiler, F. C., Cruise, A. M., & Penny, A. J. 1998, *ApJ*, 497, 935
- Homeier, D., Koester, D., Hagen, H.-J., et al. 1998, *A&A*, 338, 563
- van Kerkwijk, M. H., & Kulkarni, S. R. 1999, *ApJ*, 516, L25
- Jordan, S., & Burleigh, M. 1999, 11th European Workshop on White Dwarfs, ed. S.-E. Solheim, & E. G. Meistas, ASP Conf. Ser., 169, 235
- Kawka, A., Vennes, S., Wickramasinghe, D. T., & Schmidt, G. D. 2003, 13th European Workshop on White Dwarfs, ed. R. Silvotti, & D. de Martino (Dordrecht: Kluwer), in press
- Koester, D., Schulz, H., & Weidemann, V. 1979, *A&A*, 76, 262
- Koester, D. 2002, *A&AR*, 11, 33
- Liebert, J., & Bergeron, P. 1995, in White Dwarfs, ed. D. Koester, & K. Werner, Lecture Notes in Physics (Springer), 12
- Liebert, J., Bergeron, P., Schmidt, G. D., & Saffer, R. A. 1993, *ApJ*, 418, 426
- Liebert, J., Bergeron, P., & Holberg, J. B. 2003, *AJ*, 125, 348
- Madej, J., Pietrachowicz, M., Joss, P. C., et al. 2003, *A&A*, 412, 837
- Marsh, M. C., Barstow, M. A., Buckley, D. A., et al. 1997a, *MNRAS*, 286, 369
- Marsh, M. C., Barstow, M. A., Buckley, D. A., et al. 1997b, *MNRAS*, 287, 705
- McCook, G. P., & Sion, E. M. 1999, *ApJS*, 121, 1
- McMahan, R. K. 1989, *ApJ*, 336, 409
- Moran, C., Marsh, T. R., & Dhillon, V. S. 1998, *MNRAS*, 299, 218
- Napiwotzki, R., Green, P. J., & Saffer, R. A. 1999, *ApJ*, 517, 399
- O'Brien, M. S., Bond, H. E., & Sion, E. M. 2001, *ApJ*, 563, 971
- Panei, J. A., Althaus, L. G., & Benvenuto, O. G. 2000, *A&A*, 353, 970
- Provencal, J. L., & Shipman, H. L. 1999, 11th European Workshop on White Dwarfs, ed. J.-E. Solheim, & E. G. Meistas, ASP Conf. Ser., 169, 293
- Provencal, J. L., Shipman, H. L., Hog, E., & Thejll, P. 1998, *ApJ*, 494, 759
- Putney, A. 1997, *ApJS*, 112, 527
- Reid, N. I. 1996, *AJ*, 111, 2000
- Saffer, R. A., Liebert, J., Wagner, R. M., Sion, E. M., & Starrfield, S. G. 1989, *AJ*, 98, 668
- Schmidt, H. 1997, in White Dwarfs, ed. J. Isern, M. Hernanz, & E. García-Berro, Proc. of the 10th European Workshop on White Dwarfs, 3
- Schmidt, G. D., Bergeron, P., Liebert, J., & Saffer, L. 1992, *ApJ*, 394, 603
- Serenelli, A. M., Althaus, L. G., Rohrmann, R. D., & Benvenuto, O. G. 2001, *MNRAS*, 325, 607
- Serenelli, A. M., Althaus, L. G., Rohrmann, R. D., & Benvenuto, O. G. 2002, *MNRAS*, 337, 1091
- Shipman, H. L. 1979, *ApJ*, 228, 240
- Suh In-Saeng, & Mathews, G. J. 2000, *ApJ*, 530, 949
- Rohrmann, R. D., Serenelli, A. M., Althaus, L. G., & Benvenuto, O. G. 2002, *MNRAS*, 335, 499
- Valyavin, G. G., & Fabrika, S. N. 1998, *Bull. Spec. Astrophys. Obs.*, 45, 69
- Valyavin, G. G., & Fabrika, S. N. 1999, 11th European Workshop on White Dwarfs, ed. S.-E. Solheim, & E. G. Meistas, ASP Conf. Ser., 169, 206
- Vennes, S. 1999, *ApJ*, 525, 995
- Vennes, S., Korpela, E., & Bowyer, S. 1997a, *AJ*, 114, 1567
- Vennes, S., Thejll, P. A., Galvan, R. G., & Dupuis, J. 1997b, *ApJ*, 480, 714
- Vennes, S., Christian, D. J., & Thorstensen, J. R. 1998, *ApJ*, 502, 763
- Wegner, G., Reid, I. N., & McMahan, R. K. 1989, in White Dwarfs, ed. G. Wegner (New York: Springer), IAU Coll., 114, 378
- Wegner, G., Reid, I. N., & McMahan, R. K. 1991, *ApJ*, 376, 186
- Weidemann, V. 1990, *ARA&A*, 28, 103
- Weidemann, V., & Koester, D. 1984, *A&A*, 132, 195
- Werner, K. 1991, *A&A*, 251, 147
- Werner, K., & Rauch, T. 1997, *A&A*, 324, L25
- Wickramasinghe, D. T., & Ferrario, L. 2000, *PASP*, 112, 873
- Wonnacott, D., Kellett, B. J., & Stickland, D. J. 1993, *MNRAS*, 262, 277