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Mass distribution of massive magnetic white dwarf stars

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Abstract. We present the catalog of 112 massive isolated white dwarfs, both magnetic and nonmagnetic, with masses $M \geq 0.8 M_\odot$. Mass determinations and other parameters of the white dwarfs were taken from the literature available. 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. Mass distribution of massive magnetic white dwarfs is flat, whereas nonmagnetic WDs exhibit steeper mass distribution towards the highest masses. We note that all four most massive stars with masses $M \geq 1.3 M_\odot$ are magnetic white dwarfs. We also conclude that the secondary maximum at $1.04 M_\odot$, clearly seen at the mass distribution of all white dwarfs from our sample, is caused exclusively by nonmagnetic white dwarfs.

Key words: catalogs – stars: white dwarfs

1 Introduction

Masses of white dwarf stars are always smaller than the Chandrasekhar mass, which is equal to 1.44 solar masses in the case of hydrogen, non-rotating objects. It is well known that the mass distribution of isolated white dwarfs exhibits a distinct peak at about $0.6 M_\odot$ (Weidemann 1990), with a substantial number of known objects with higher masses. Exact values of the peak mass are slightly different in particular papers, which presented various homogeneous samples of isolated white dwarfs. Bergeron et al. (1992) have analyzed a sample of 129 DA white dwarfs, and determined their masses by means of fitting hydrogen Balmer line profiles. They obtained a value of $0.562 M_\odot$ for the peak mass. Liebert & Bergeron (1995) analyzed 200 white dwarfs from the Palomar Green survey (Green et al. 1986), with a peak mass of $0.56 M_\odot$. Most recently Marsh et al. (1997a,b) have performed determination of masses (and also other stellar parameters) for an extensive set of white dwarfs selected from the ROSAT all-sky survey in the extreme ultraviolet (EUV). They obtained a peak mass value $\approx 0.55 M_\odot$. Other values of the peak mass were determined as $0.603 M_\odot$ (Weidemann & Koester 1984), $0.571 M_\odot$ (McMahan 1989), and $0.570 M_\odot$ (Finley et al. 1997).

The shape of the mass distribution exhibits also a distinct tail towards higher masses. This tail is not satisfactorily reproduced in most of the papers. Nor did the above surveys reach much higher masses, and were only sparsely populated by white dwarfs $> 1 M_\odot$. Marsh et al. (1997a,b) have distinguished between populations of normal ($\approx 0.6 M_\odot$) and massive ($\sim 1.0 M_\odot$) white dwarf stars. The latter consists of 13 white dwarfs only. Such a small sample of massive white dwarfs in their paper did not allow investigation of any details of the mass distribution in that region. In spite of that, Marsh et al. (1997a,b) suggested that the massive ($M \geq 0.8 M_\odot$) white dwarf stars form the 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 a close binary system. Extensive determinations of 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.

2 The catalog

We prepared the catalog and the mass distribution of massive white dwarfs with masses $M \geq 0.8M_\odot$. Our research is based on mass determinations available in the literature. We follow the opinion that investigation of 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 Galaxy disk. The limiting mass $0.8M_\odot$ has been chosen arbitrarily. Masses presented in our catalog represent a rather inhomogeneous sample. We disregard differences between particular methods of mass determination[1], since we intended to collect as many massive white dwarf stars as possible. In this way we attempt to minimize uncertainties and random fluctuations caused by a very small number of massive stars available in previous investigations.

The Massive White Dwarf Catalog (Należyty & Madej 2004) consists of 112 white dwarf stars, both magnetic and nonmagnetic WDs. A shortened version of the catalog is presented in Table 1. The full catalog of individual published measurements is available on the Internet at the address: *http://www.astrouw.edu.pl/∼nalezyty/mwd/* . In Table 1 data on each star were compressed to a single row. Columns list the following data: WD designation by its equatorial coordinates (in most cases corresponding to the designations in the McCook & Sion (1999) white dwarfs catalog), name of the star, pairs of the T_{eff}, $\log g$, mass $M/M_\odot$, and their errors. The nineth and following columns give: radius R in kilometers, mean surface magnetic field B_s, polar field B_p, distance d in kiloparsecs, remarks, and reference list. In most cases stellar parameters were independently determined by several authors. Values of T_{eff}, $\log g$, $M/M_\odot$, and the remaining parameters presented in Table 1 are arithmetic averages of individual data. 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 no error estimates in Table 1. It should be stressed here that white dwarfs in interacting binaries (as, for example, cataclysmic variables) were not included in our catalog.

3 Massive magnetic vs. nonmagnetic stars

3.1 Distribution of masses

An essential result of our catalog is the mass distribution of massive white dwarfs, both for objects with a magnetic field and for nonmagnetic ones, i.e. without any magnetic field or with an existing magnetic field, but not yet discovered. Our catalog consists of 25 magnetic white dwarfs, and 87 nonmagnetic white dwarf stars. It is interesting to investigate the differences between mass distributions of both magnetic and nonmagnetic white dwarfs in our sample. We display our mass distributions in Figs. 1–2.

Figure 1 presents the mass distribution of 25 isolated magnetic white dwarfs, with masses taken from our catalog. When constructing this histogram and the histograms in Figs. 2–4, we arbitrarily assumed that stars with masses located exactly at the edges between bins are attributed to the bin with stars of higher masses. I.e. if a star has its mass equal to $1.0M_\odot$, then it falls into the $1.0 - 1.05M_\odot$ bin. The histogram consists of bins with a $0.05M_\odot$ width, and the Y-axis indicates the absolute number of white dwarfs.

The mass distribution of massive magnetic white dwarfs seems to be flat and does not exhibit any particular features, except for the absence of stars with masses in the range $1.15 - 1.20M_\odot$ (Fig. 1). However, due to the very small number of stars in each bin, typically $1 - 4$ stars, this gap is most likely statistically insignificant. Probability that this gap is accidental equals to ~ 0.09.

On the contrary, the mass distribution of nonmagnetic white dwarfs is qualitatively different from the distribution of magnetic WDs in that it shows a steeper decrease towards the highest masses. In particular, we did not find any nonmagnetic white dwarf with mass higher than $1.30M_\odot$. The only stars (4 stars) with such extreme masses are known as magnetic white dwarfs and are shown in Fig. 1. Moreover, the mass

[1] Masses of isolated white dwarfs are usually determined with help of spectral analysis. 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. 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. They yield 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). The review of various methods of mass determination has been given by Bergeron et al. (1992), cf. also Koester (2002).

Table 1: Catalog of massive white dwarfs

WD	name	T_{eff}	ΔT_{eff}	log g	Δlog 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	45107	1362	9.01	0.15	1.21	0.06	3907			101		1a, 1b, 2, 3, 4
0008+330	HS0008+3302	10300		8.35		0.83		6960			85		14
0009+501	GR381	6400				0.89				70		m	17
0022+274	LP349–013	25000				0.862					29	b	8
0033+016	EG004	10700		8.66		1.02		5440			32.9		6
0041+092	BD+08°102	28960	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	39465	294	9.01	0.04	1.21	0.03	3830			80	m	1a, 1b, 2, 3, 4, 18
0146+072	HS0146+0723	25000		8.27		0.80		7520			210		14
0235–125	PHL 1400	32018	252	8.49	0.05	0.95	0.03	6170			66		1a, 1b, 2, 3, 12
0239+500J	EUVE J0239+500	34211	389	8.517	0.043	0.96	0.02	6130			96		2, 3
0317–853	EUVE J0317–855	43210	3290	9.19	0.30	1.34	0.01	2408	505	395		mbc	4, 5, 17, 22, 23, 24, 25
0346–011	GD 50	41743	736	9.12	0.04	1.25	0.03	3520			29		1a, 1b, 2, 4, 7, 12, 13
0347+171	V471 Tau	34060	580	8.40	0.14	0.90	0.07	6240			47	bc	1a, 1b, 29, 30, 31
0349+247	EG025	32180	320	8.69	0.05	1.046	0.012	5081					7, 9, 11, 19, 32
0352+049	KUV03520+0500	36900	500	8.71	0.15	1.05	0.08	5280			106		4, 14
0406+169	EG029	15190		8.30		0.806	0.013	7300			53.2		8, 9, 11, 16
HD27483		22000		8.5		0.95		6300			46	bt	27
0443–037J	EUVE J0443–037	68740	3600	8.946	0.174	1.25	0.04	3970			144		2, 3, 4
0518–105	RE0521–102	32727	323	8.67	0.02	1.04	0.01	5380			99	b	1a, 1b, 2, 3, 12
0531–022	EUVE J0534–022	29867	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	56820		8.88		1.15		4490			309		4
0630–050	RE0632–050	43029	686	8.32	0.13	0.81	0.07	7790					1a, 1b, 2, 3
0633+200J	0630+200	75792		8.398		0.947		7090					3
0642–166	Sirius B	24700	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	35200		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	15701		8.562		0.944		5861					13
0729–384	y Pup	43200	200	8.5		0.87	0.04	6100			172	bt	27, 33
0730+487	GD 86	15510		8.49		0.90		6220					7
0743–391J	EUVE J0743–391	40200		8.66		1.04	0.01	5500			147		2
0816+376	GD 90	11000				0.86			8			m	5
0823–253	1RXSJ0823.6–2525	43200		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	21620	310	8.45		0.916	0.007	6550			174		8, 9, 16
0836+199	EG060	14060		8.34		0.864	0.021	7240					9
0853+163	GR904	2000				0.83			3			m	5
0856+331	EG182	10390		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	56400		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	16000		8.75		1.07		5000			120		14
0945+245.1	LB11146A	14500		8.5		0.91		6200			40	b	35
0945+245.2	LB11146B	16000		8.5		0.99	0.09	6100	375	670	40	mb	5, 17, 35
0946+485	HS0946+4848	11700		8.69		1.04		5300			80		14
0946+534	EG251	8760		8.45		0.87		6400			23.0		6
0949+494	HS0949+4935	15000		8.39		0.86		6800			190		14
0957+854J	EUVE J0957+854	51636	325	8.32	0.06	0.83	0.02	7470			139		2, 12
1015+014	PG1015+015	14000				1.03			85			m	5
1017+366	GD 116	16000				0.89			56			m	5, 37
1024–303J	RE1024–302	35710	520	8.95	0.15	1.13	0.06	4520			64	b	1a, 1b, 3, 4
1031+234	TON 527	25000				1.11			500			m	5
1036–204	GR535	7500				1.34			150			m	5
1038+633	PG1038+634	24800		8.39		0.85		6780					7
1052+273	GD 125	23064	314	8.340	0.071	0.814	0.047	7031					7, 13
1055–072	EG074	7420		8.42		0.85		6550			12.2		6
1102+748	GD 466	19800		8.37		0.83		6850					7
1127–311.1	ESO439–162	5400				1.13			67			mb	5
1134+300	GD 140	21470	220	8.46	0.02	0.87	0.03	6310			15.3		3, 7, 15

Table 1: Catalog of massive white dwarfs – continued

WD	name	T_{eff}	ΔT_{eff}	log g	Δlog g	$M/M_\odot$	$\Delta M/M_\odot$	R	B_s	B_p	d	Rem.	References
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	12210	340	8.70	0.04	1.03	0.02	5250			16.4		6, 10, 13
1241+482	HS1241+4821	14800		8.54		0.95		6100			90		14
1309+853	GR436	5600				0.83			15			m	5
1334–160	EG101	18790	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	38260	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	22839	102	8.327	0.034	0.815	0.006	7143					3, 7
1501+664	H 1504+65	170000		8.0		0.86		10700			630		38
1531–022	GD 185	18870		8.39		0.84		6740					7
1535–774J	EUVE J1535–774	54800	3200	9.12	0.02	1.29	0.03	3580			107		2, 4
1543–366	RE1546–364	45208		8.875		1.168		4546			107		3
1609+135	EG117	9080		8.75		1.07		5030			18.3		6
1609+631	PG1609+631	31033		8.408		0.893		6806					3
1625+093	GR327	6870		8.44		0.88		6510			23.4		6
1642+413	RE J1643+411	27677	1139	8.376	0.156	0.858	0.105	6944					3, 12
1658+440	EUVE J1659+440	30410	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	47556	1434	8.957	0.067	1.191	0.050	4185				b	3, 12
1725+586	RE J1726+583	55100	1083	8.32	0.08	0.869	0.052	7410					1a, 1b, 3, 12
1727–360	EUVE J1727–360	32600		9.04		1.21		3830					4
1740–706	RE1746–703	47690	1120	8.95	0.04	1.16	0.03	4270					1a, 1b, 3, 4, 39
1743–521	BPM25114	20000				1.34			25			m	5
1745+607J	HS1745+6043	35600		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^{o}8247	13540	1470	8.58		1.09	0.07	5760	230		13.0	m	5, 6, 36
2010+310	GD 229	23000				1.28			500			m	5
2020–425	REJ2024–42	29028	431	8.412	0.128	0.911	0.059	6878					1a, 1b, 3
2039–682	EG140	16065		8.444		0.872		6450					13
2043–635	BPM13537	25971		8.358		0.855		7054					3
2055+164	EUVE J2055+1627	38400		8.37		0.85		6940			104		4, 40
2107–216	GR581	5830		8.40		0.85		6700			23.7		6
2126+191	IK Peg	34320	750	8.5	0.3	1.13	0.05	5890			50	bc	27, 28, 41
2157+815	HS2157+8153	10700		8.71		1.05		5200			35		14
2220+133	PG2220+134	22600		8.81		1.10		4700			50		14
2246+223	EG155	10330		8.57		0.97		5890			19.0		6
2251–070	GR453	4580		8.38		0.82		6740			8.1		6
2257–073	BD–07^{o}5906B	37517		8.25		0.92		8290			111	b	28
2303+465	PSR B2303+46	45000				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	28000		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-motion binaries.

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

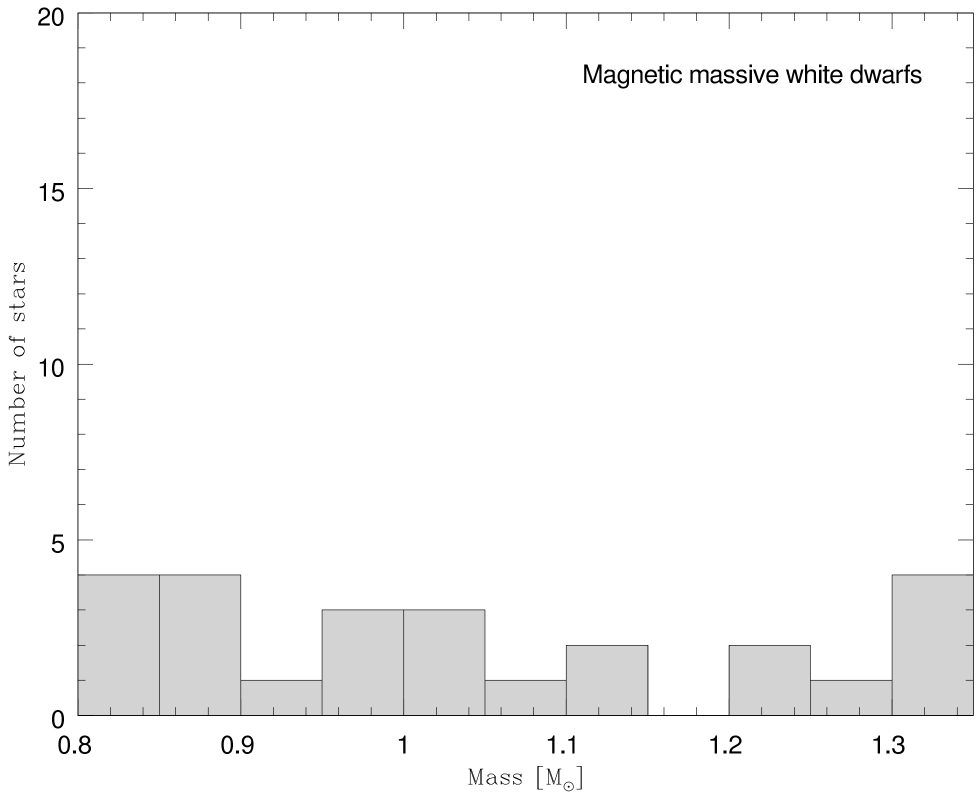

Figure 1: *Mass distribution of magnetic massive white dwarf stars. Mass distribution is flat, and no local maximum can be seen in the figure.*

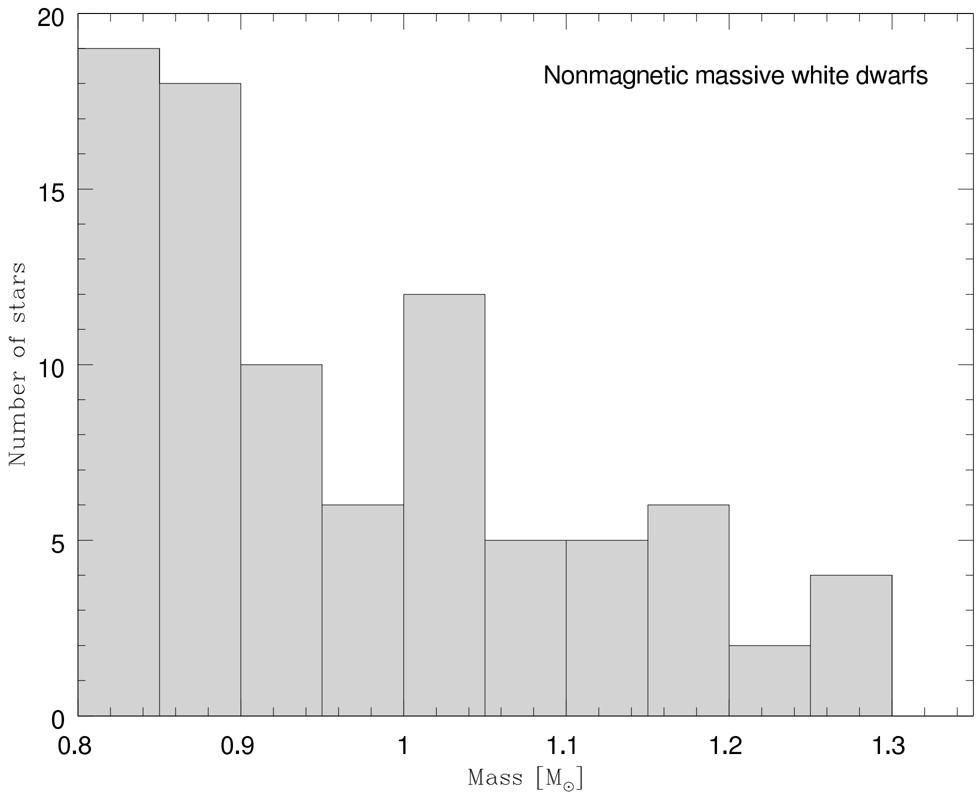

Figure 2: *Mass distribution of nonmagnetic massive white dwarf stars. Local maximum at* $1.04M_{\odot}$*, as shown in Figure 1, should be attributed solely to the above nonmagnetic white dwarfs.*

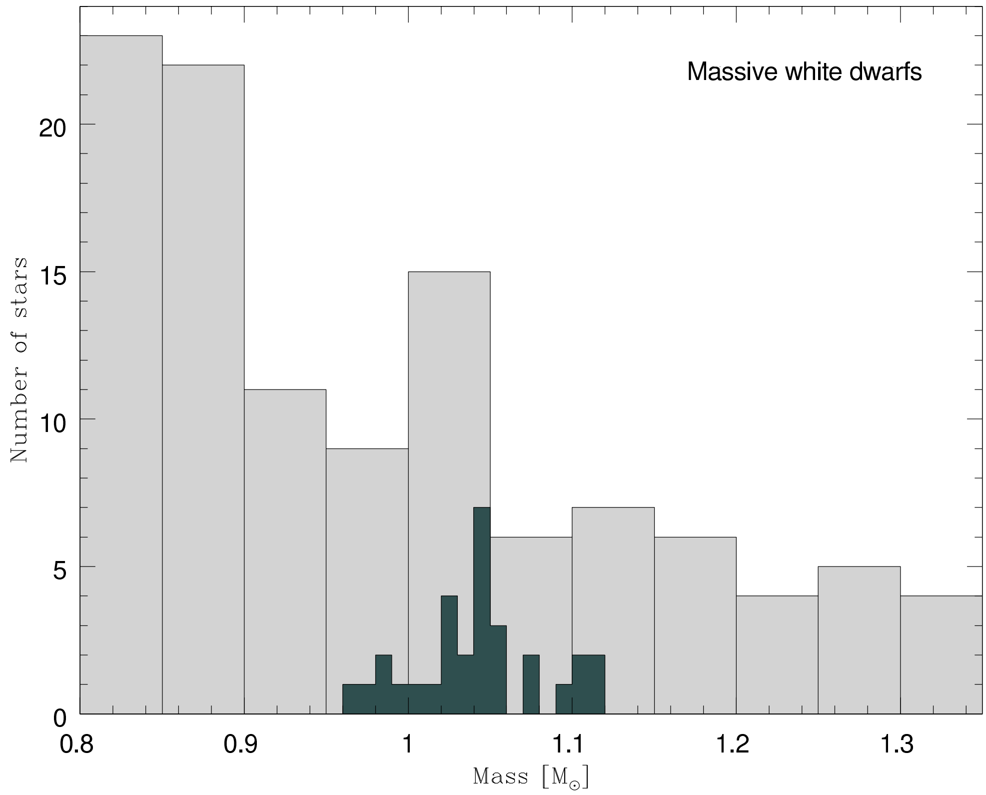

Figure 3: *Mass distribution of all 112 massive white dwarf stars of our catalog (gray scale). The histogram shows the local maximum of mass distribution in the range* $1.0 - 1.05M_\odot$*. The inserted dark tone histogram with a finer resolution of* $0.01M_\odot$ *clearly suggests that the local maximum of WD mass distribution is located at* $\approx 1.04M_\odot$*.*

distribution of these stars clearly shows the secondary maximum of mass distribution in the single bin of $1.0 - 1.05M_\odot$, which contains a significantly larger number of stars (12 objects, see Fig. 2). Of course, the mass distribution of all massive white dwarfs in our catalog, both magnetic and nonmagnetic, shows the same single bin consisting of 15 stars (Fig. 3), which seems to demonstrate the existence of the secondary maximum in the mass distribution of massive, isolated white dwarfs.

Of course, our mass distributions determined in such an inhomogeneous sample is unintentionally blurred by the fact that mass determinations have been made by different methods.

One cannot rule out the possibility that in future some nonmagnetic white dwarfs in Fig. 2 will move to the histogram in Fig. 1 if a nonzero magnetic field is detected there.

We point out here that our mass distribution of magnetic massive white dwarfs (Fig. 1) differs significantly from the distribution obtained by Valyavin and Fabrika (1998, 1999). Both authors claim that the mass distribution of magnetic white dwarf stars exhibits the main maximum at $0.8M_\odot$, and the secondary maximum at $\approx 1.15M_\odot$ (see Figure 2 in their paper). Both maxima in their paper are separated by a deep minimum of mass distribution at $1.05M_\odot$. Our Fig. 1 does not exhibit any such features.

3.2 Incidence of magnetism in massive stars

Based on Table 1, we can immediately estimate a relative fraction of magnetic white dwarfs in the whole group of massive white dwarfs with masses higher than $0.8M_\odot$. Among 112 massive stars listed in Table 1 we collected 25 stars, which are presently known as magnetic objects. Therefore the average relative fraction of isolated magnetic massive white dwarfs equals to 22 % in our sample. This result is very similar to the conclusion made by Vennes (1999) who found that the fraction of magnetic white dwarfs equals approximately 25 % for hot stars with masses exceeding $1M_\odot$. However, we stress the essential difference between both analyses: the sample of hot massive white dwarfs searched by Vennes (1999) was derived from the *EUVE* catalog of hot stars, whereas our sample is not restricted only to hot objects.

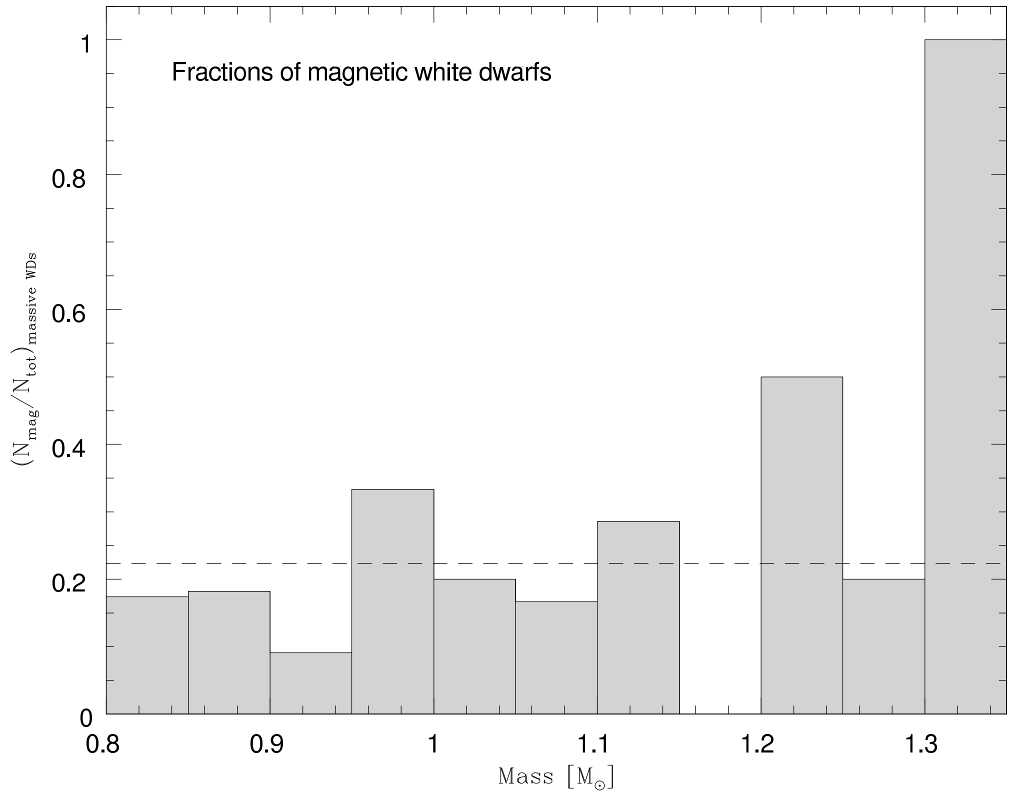

Figure 4: *Relative fractions of magnetic white dwarfs as a function of stellar mass, N_{mag}/N_{tot}. One can note that the incidence of magnetism increases with white dwarf mass. The dashed line shows the average fraction of magnetic white dwarfs among isolated massive WDs.*

Data collected in Table 1 allow us to study the distribution of magnetic white dwarfs in more detail. Figure 4 presents relative fractions of magnetic white dwarfs as a function of mass. Fig. 4 clearly suggests that the incidence of magnetism increases with mass of isolated white dwarfs, and reaches 100 % in the highest mass bin, $1.30 - 1.35 M_\odot$. We are aware, however, that the number of considered magnetic stars is low and cannot exclude strictly the impact of random fluctuations.

4 Conclusions

We have performed an extensive search of the available literature and selected all known white dwarfs of masses $\geq 0.80 M_\odot$. The list contains stars which are believed to be isolated, or are members of detached (noninteracting) binary systems. We excluded white dwarfs which are members of close (interacting) binary systems. A total of 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 mass distribution of massive magnetic white dwarfs seems to be flat, whereas the distribution of nonmagnetic stars looks steeper, decreasing towards the Chandrasekhar maximum mass. The mass distribution of all massive isolated white dwarfs apparently exhibits a local maximum at $1.04 M_\odot$, which is caused exclusively by nonmagnetic white dwarfs.

We report here that a small group of the most massive stars in our sample, $M > 1.30 M_\odot$, includes 4 magnetic white dwarfs. Nonmagnetic white dwarfs in the sample are likely to have masses less than $1.30 M_\odot$.

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