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New white dwarfs in the Hyades

Results from kinematic and photometric studies

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ABSTRACT

Aims. On the basis of the PPMXL catalogue (Röser et al. 2010, AJ, 139, 2440) we searched for white dwarfs that are also member candidates of the Hyades in a region up to 40 pc from the cluster centre.

Methods. We used the proper motions from PPMXL in the convergent point method to determine probable kinematic members. We cross-matched the kinematic candidates with catalogues containing white dwarfs and, finally, checked the kinematic with the photometric distances for consistency.

Results. We found the 10 classical white dwarfs in the Hyades and determined their individual kinematic distances. Additionally, we identified 17 new probable (former) Hyades white dwarfs, i.e. white dwarfs co-moving with the bulk space motion of the Hyades cluster. At present, none of them can be excluded from membership on the basis of the measured radial velocities. For another 10 objects, the kinematic and the photometric distances disagree, which rates them as probable non-members. Among the probable members, five white dwarfs are in binary systems, three are known, two are new. There is good indication for an empirical magnitude-distance (from centre) relation, such that the dimmer white dwarfs are farther away from the cluster centre than the brighter ones. Our sample becomes incomplete close behind the centre of the cluster. Follow-up observations are encouraged to independently confirm the predicted radial velocities and the distances of the candidates.

Key words. open clusters and associations: individual: Hyades – white dwarfs – stars: kinematics and dynamics

1. Introduction

The 650 Myr old Hyades cluster is, in many respects, a test case for theories of stellar evolution in, and dynamical evolution of, open clusters in our Galaxy. The white dwarfs, in particular, shed light on the high-mass end of the initial mass function (IMF) in open clusters and the subsequent development of the cluster's mass function. In an influential paper, Weidemann et al. (1992) have analysed the white dwarf population in the Hyades, and concluded that the cluster should contain at least 21 white dwarfs dimmer than the 7 confirmed white dwarf members known at that time. The authors derived this finding from adopting a Salpeter IMF normalised via the 24 brightest main-sequence stars presently residing in the Hyades. From different considerations, Gunn et al. (1988) arrived at a number between 50 and 150 white dwarfs originally present in the cluster. On the other hand, von Hippel (1998) counted only 10 white dwarfs as known members in the Hyades when he investigated the contribution of white dwarfs to the masses of open clusters.

To summarise, not much progress has been made to solve the discrepancy between the number of white dwarfs estimated from the IMF and the actual number of white dwarfs found in the Hyades. Weidemann et al. (1992) mention in their paper that white dwarfs initially present in the bound Hyades have left the cluster in the meantime, and the authors suspect them in the Hyades supercluster as defined by Eggen (1958). Weidemann et al. (1992) checked the McCook & Sion (1999) catalogue by analysing the space motions of the white dwarfs therein, and claim to have detected a handful of stars moving within 13 degrees from the Hyades convergent point and tangential velocities within ±2 km s^{-1} of the cluster motion. Extending the search to ±5 km s^{-1}, they found that about 2/5 of all nearby white dwarfs may be related to the Hyades. Unfortunately, Weidemann et al. (1992) did not publish the data of their candidates, therefore we could not compare them with our results below. As a mechanism for white dwarf loss, Fellhauer et al. (2003) proposed that white dwarfs could be expelled from their parent cluster through non-spherically symmetric mass loss during the post-main-sequence evolution, which leads to a recoil speed of a few kilometres per second for the white dwarf remnant.

Weidemann et al. (1992) also discussed the possibility that missing white dwarfs can hide themselves behind the red dwarf companion in binary systems. They estimated that the missing ones could only be found, even in the B, V bands, if the other component is later than spectral type G.

In a previous paper (Röser et al. 2011, henceforth Paper I) we have analysed the Hyades cluster and their surroundings up to 30 pc to search for main-sequence stars as member candidates. We found that the present-day tidal radius is about 9 pc, and 275 $M_{\odot}$ (364 stellar systems) are gravitationally bound. Outside the tidal radius we found another 100 $M_{\odot}$ in a volume between one and two tidal radii (halo), and another 60 $M_{\odot}$ up to a distance of 30 pc from the centre. From their kinematics we infer that the stars outside the tidal radius are formerly bound members that left the cluster. It is therefore appropriate to repeat a selection process similar to that in Paper I to search for white dwarfs up to 30 pc and more from the cluster centre. Compared to earlier studies of Hyades white dwarfs, which performed deep searches in limited fields-of-view, we have the advantage to be able to use the deep all-sky astrometric survey PPMXL (Röser et al. 2010).

This paper presents candidates that have five out of six phase space parameters compatible with their Hyades origin. Once available, their true space motion in radial direction must confirm or reject them. Our list of candidates from Table 1 can serve as an input catalogue for future observations. Therefore we are hesitant at this stage to draw far-reaching conclusions, e.g. on the IMF of the Hyades, on the problematics of cooling ages, or on the initial mass-final mass relation.

The paper is structured as follows: after a short listing of the so-called "classical" Hyades white dwarfs in Sect. 2, we describe our selection process in Sect. 3. Section 4 follows with comments to each individual candidate. The questions of spatial distribution and completeness of the sample are covered in Sect. 5. Finally, the discussion in Sect. 6 completes the paper.

2. The "classical" Hyades white dwarfs

The paper by von Hippel (1998) lists 10 white dwarfs that we call henceforth the "classical" Hyades white dwarfs. There are seven single white dwarfs and three in binary systems. We list them with their primary identifiers in SIMBAD (Data base of the Centre de Données astronomiques de Strasbourg, CDS). The seven single white dwarfs are EGGR 26, 29, 36, 37, 39, 42, and 316. The three stars in binary systems are HR 1358, EGGR 38, and V471 Tau. Data for these stars are given in Table 1 (the first ten rows). In some cases there is no consistency about actual membership in the cluster. For instance, Weidemann et al. (1992) exclude EGGR 29 from membership, because they put it at 60 pc, where its tangential velocity would be discordant from the bulk tangential velocity, whereas De Gennaro et al. (2009) used it for their determination of the white dwarf age of the Hyades.

Reid (1992) lists two additional candidates RHya 102 and RHya 145. He also examined all candidates for Hyades white dwarfs proposed by van Altena (1969), and discarded all of them except vA54 and vA71, which were outside his field-of-view. We discuss these four objects in Sect. 4.

Throughout the paper we use the following abbreviations for star names:

VR	van Rhijn & Raimond (1934);
HZ	Humason & Zwicky (1947);
HG7	Giclas et al. (1962);
HR	Catalogue of bright stars, Hoffleit (1964);
EGGR	Eggen & Greenstein (1965);
vA	van Altena (1969);
RHya	Reid (1992);
WD	McCook & Sion (1999), updated version 2008;
LB	(Luyten, Blue), Luyten W.J., Various lists published by Luyten under the general title: A Search for Faint Blue Stars (50 papers);
LP	(Luyten, Palomar obs.), Published from 1963 to 1981 in Univ. Minnesota, Minneapolis, fascicules 1 to 57;
GJ	CNS3, Catalogue of Nearby Stars, (Gliese & Jahreiß 1991).

3. The selection process

In Paper I we described in detail how we selected MS (main sequence) Hyades candidates from their kinematic and photometric properties in the PPMXL catalogue (Röser et al. 2010). More specifically, we used the Carlsberg-UCAC (CU) subset containing improved proper motions and photometry by including UCAC3 (Zacharias et al. 2010) and CMC14, Carlsberg Meridian Catalog 14 (Copenhagen Univ. Obs. et al. 2006). Paper I also contains a description of the convergent point method, which served as a baseline for the selection. For our general selection process we did not permit the tangential motion to differ from the one given by the bulk motion of the cluster by more than 4 km s^{-1}, and we considered only stars closer than 30 pc from the cluster centre. The stars had to be in the CU subset to PPMXL to ensure that they have CMC14 and/or 2MASS (Skrutskie et al. 2006) measurements. These kinematic selection criteria were fulfilled by 15 757 stars out of the 140 million contained in the CU subset, which were shown in Fig. 1 of Paper I. Two features from the kinematic selection via the convergent point method are worth to be explained in more detail. First, for each candidate that is supposed to share the bulk space motion of the cluster, the convergent point method predicts a radial velocity that only depends on the position α, δ of the star. In consequence, the radial velocity of each candidate has to be measured to confirm it is still member. Second, the convergent point method attributes (predicts) a so-called secular parallax to each candidate by minimising the difference between the space motion of the cluster centre and the space motion of a candidate star. In a very strict sense the secular parallax is not the least-squares solution in the plane perpendicular to the line-of-sight, but this difference is small in all practical cases. So, the second confirmation of membership comes from an independent measurement of the distance to the star. If the result of this independent distance determination does not confirm the prediction, this means in turn that the difference in space motion between the bulk of the cluster and the candidate increases. This may rule out a given star as a member candidate.

As an independent check of the predicted distances of kinematic candidates, we can consider their location in different colour-absolute-magnitude diagrams. In Paper I we used B, V-photometry for bright stars; for stars fainter than $M_{K_s} = 4$ the basic photometric data were r' from CMC14 and JHK_s. Only for 724 out of 15 757 kinematic candidates, the membership was confirmed by photometric selection in Paper I.

The procedure adopted in Paper I is a two-step procedure. The first step is the kinematic selection, and the second is the check of kinematically predicted distances with photometric ones, i.e. a comparison with isochrones. In principle, the same approach could be applied to find white dwarfs among kinematic candidates. This would require an all-sky, accurate, multi (at least two)-colour photometric survey. Concentrating on a 30 pc radius around the centre of the Hyades, such a survey should at least cover 12.1% of the celestial sphere or 5000 square degrees. The only survey that fulfils this requirement is 2MASS in the near-infrared. However, even at the central distance of the Hyades (46.3 pc), white dwarfs will be at the limiting magnitude of 2MASS and also of CMC14, where the photometric quality becomes very poor. Therefore, we introduced an intermediate step, in which all kinematic candidates from Paper I were cross-matched with the white dwarf catalogues by Luyten (VizieR Online Data Catalog III/70) and McCook & Sion (1999), the updated version (VizieR Online Data Catalog III/235B). Each match was individually checked using the VizieR data base from the CDS. After rejecting obvious red dwarfs (from Luyten candidates), we identified 20 white dwarfs that passed the kinematic selection, among which were all 10 classical Hyades white dwarfs. Ten more stars would be added if the kinematic criteria were relaxed to 40 pc and 5 km s^{-1}. Finally, we found

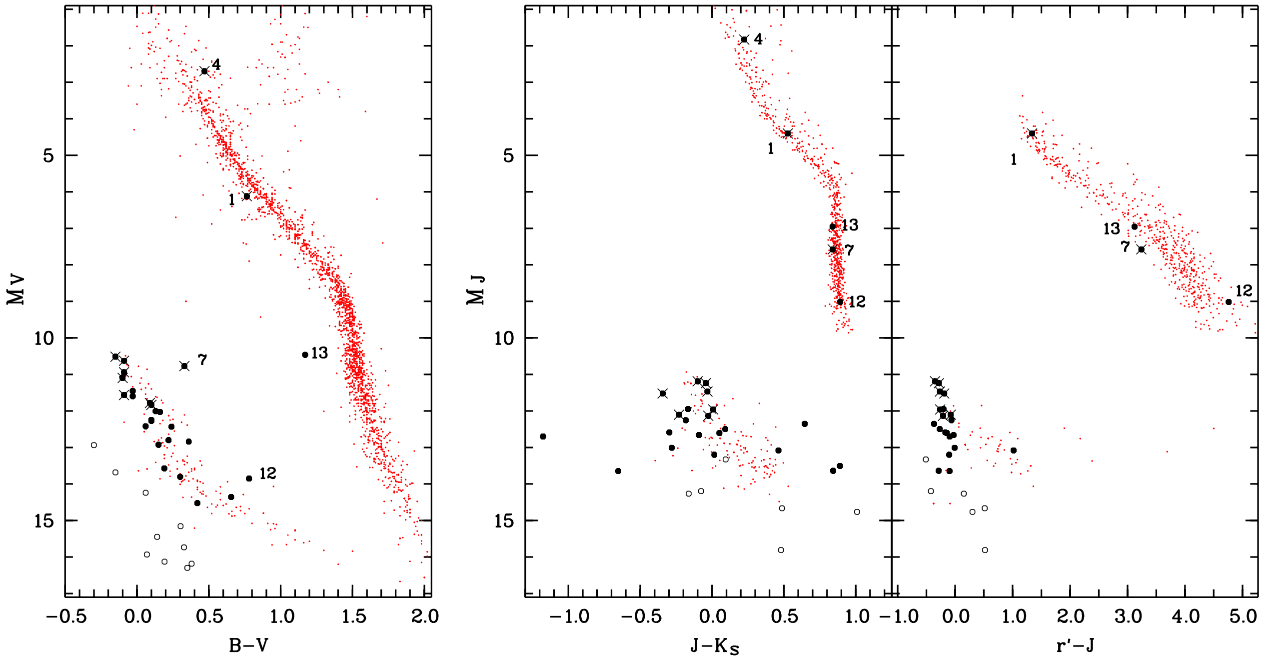

Fig. 1. Colour-absolute-magnitude diagrams: M_V vs. $B - V$ (*left*), M_J vs. $J - K_s$ (*middle*) and M_J vs. $r' - J$ (*right*). In all diagrams the black dots show the probable Hyades white dwarfs from this paper, the 10 classical white dwarfs are marked additionally with crosses. The black circles show also spectroscopically confirmed white dwarfs from McCook & Sion (1999), which are probably non-Hyades though. The small (red) dots in the *left panel* show the main and the degenerate sequences of stars from the CNS3 (Gliese & Jahreiß 1991). In *the middle and the right panels* the degenerate sequences are again from CNS3, while the 724 Hyades members from Paper I represent the main sequences. Note that the brightest stars have no r' magnitudes (*right panel*) in CMC14. Spectroscopic binaries are marked by their numbers in Table 1.

six faint white dwarf candidates in the PPMXL (i.e. without CMC14 and/or 2MASS measurements). One more white dwarf was found in the Prosser and Stauffer data base (presently available from Stauffer, priv. comm.), although it is not explicitly mentioned there as a white dwarf. For this star, No. 20 in Table 1, PPMXL gives wrong proper motions, therefore we took them from Ducourant et al. (2006). In total, the sample of the Hyades white dwarf candidates contains 37 stars. All but three of them (12, 15, 30) are spectroscopically confirmed white dwarfs.

For these 37 stars we then examined if their loci in colour-absolute magnitude diagrams are consistent with those of white dwarfs. As mentioned above, 2MASS and CMC14 are not well suited for the fainter candidates. Unfortunately, the UKIRT Infrared Deep Sky Survey (UKIDSS, Lawrence et al. 2007) provides no help for this problem, because in the region of the Hyades it is constrained to the central 292 square degrees, and only K-band photometry is available for these. Indeed, except for the 10 already known white dwarfs, only stars No. 20, 21, and 22 even have K-band photometry in UKIDSS. Since the vast majority of stars in the PPMXL and its CU subset do not have appropriate photometric data in the optical, we took the B, V magnitudes for the Hyades white dwarf candidates from the VizieR data base (CDS). The sources are given as footnotes to Table 1. For three white dwarfs (entries 28, 29, 35 in Table 1), no original V measurements are available. In McCook & Sion (1999) they are SDSS white dwarfs, and we converted their *ugriz* magnitudes into V and $B - V$ using the transformations from Jester et al. (2005). Also, all 37 stars have been visually inspected on the digitised sky survey charts from IRSA (NASA/IPAC Infrared Science Archive) to avoid coarse misidentifications of the different surveys.

In the following paragraphs we check if the kinematically selected stars populate allowed loci in the colour-absolute-magnitude diagrams (CMDs). In Fig. 1 we show three CMDs (M_V vs. $B - V$, left), (M_J vs. $J - K_s$, middle) and (M_J vs. $r' - J$, right). As references for the loci of the degenerate stars we have taken the white dwarfs from the CNS3 in all three panels (small red dots). For main sequence dwarfs the loci of the 724 Hyades from Paper I (also small red dots) are taken in the middle and right diagrams. Because in most cases we could not find precise B and V magnitudes for our sample of stars from Paper I, we took the main sequence in the left panel again from the CNS3.

All 37 stars discussed in this paper are marked in black in Fig. 1. The field white dwarfs from the CNS3 show a relatively well-defined sequence in the optical (the left diagram), and a number of our Hyades white dwarf candidates follow this sequence. We conclude that the convergent point method has correctly predicted the distances for these stars and refer to them as probable Hyades members marked as solid dots in Fig. 1. The classical 10 Hyades white dwarfs are additionally indicated by crosses. In this panel we find 10 white dwarfs, marked by open circles which would be sub-luminous if set at their kinematic distances. We conclude that these stars must be at farther distances from the Sun than predicted, therefore have higher tangential velocities, and must be rated as probable non-Hyades. The best coincidence between the probable Hyades white dwarfs and the reference loci is seen in the left panel, one of the reasons being the better optical photometry available for the white dwarfs in the Johnson B, V system. In the near-infrared, NIR, panel (middle) the scatter in the $J - K_s$ colour is much larger than in $B - V$, because the fainter stars are at the detection limit of 2MASS, especially in the K_s band. To a moderate extent, this holds for the $r' - J$ colour, too.

We find five stars in the middle panel (M_J vs. $J - K_s$) that perfectly lie on the Hyades NIR main sequence. We marked these stars in Fig. 1 with their numbers from Table 1. All five are included in our sample of 724 Hyades members in Paper I. Four of them (1, 4, 7 and 13 or HR 1358, EGGR 38, V471 Tau

Table 1. White dwarfs as Hyades candidates.

Star No.	Other name	SpT	D [pc]	r_c [pc]	$v_\perp$ [km s^{-1}]	M_V [mag]	$B-V$ [mag]	M_J [mag]	$J-K_s$ [mag]	$r'-J$ [mag]	X	Bin.	Ref. B, V
1	V471 Tau	DA1.5	47.3	7.5	0.1	6.12	0.76	4.40	0.53	1.34	y	y	1,1
2	EGGR 26, HZ 4	DA4	35.1	13.5	0.9	11.83	0.10	12.11	–0.23	–0.08	y	–	2,2
3	EGGR 29, LB 227	DA3	51.7	6.6	–0.4	11.78	0.09	12.13	–0.03	–0.21	y	–	3,3
4	HR 1358	DA3	49.1	3.9	–0.2	2.70	0.47	1.83	0.22	–	y	y	1,1
5	EGGR 36, VR 7	DA2.5	44.1	2.4	–0.8	11.10	–0.10	11.53	–0.34	–0.19	y	–	2,2
6	EGGR 37, VR 16	DA	47.7	1.5	–0.5	10.62	–0.09	11.23	–0.04	–0.28	y	–	2,2
7	EGGR 38, HZ 9	DA2.5	43.2	3.3	–0.9	10.78	0.33	7.58	0.84	3.24	y	y	2,2
8	EGGR 39, HZ 7	DA2.3	45.7	3.4	0.3	10.94	–0.09	11.47	–0.03	–0.27	–	–	2,2
9	EGGR 316, LP 475-242	DB4	46.9	3.3	–0.7	11.56	–0.09	11.96	0.01	–0.26	–	–	2,2
10	EGGR 42, HZ14	DA2	46.0	5.2	0.2	10.51	–0.15	11.18	–0.10	–0.35	–	–	2,2
11	WD 0120-024	DC	39.0	36.3	0.8	14.52	0.42	13.50	0.89	–	–	–	7,4
12	LP 649-0071	–	34.3	29.1	–1.3	13.85	0.78	9.01	0.89	4.76	y	?	8,5
13	WD 0217+375	DA	25.1	29.6	0.6	10.46	1.17	6.95	0.84	3.12	–	y	7,7
14	WD 0230+343	DA	37.8	24.1	0.8	12.84	0.36	13.63	0.84	–0.29	–	–	6,6
15	LP 246-0014	–	35.1	23.5	2.4	13.80	0.30	13.65	–0.65	–0.10	?	–	8,7
16	WD 0259+378	DA3	66.0	33.6	–4.0	11.44	–0.03	12.35	0.64	–0.37	–	–	3,3
17	WD 0312+220	DA2.5	44.4	14.3	4.7	12.43	0.24	13.01	–0.28	–0.01	y	–	7,7
18	LP 653-0026	DA3.5	28.5	23.0	–1.9	12.93	0.15	13.20	0.02	–0.10	–	–	3,3
19	WD 0348+339	DA4	38.5	16.1	–0.5	12.27	0.10	12.59	–0.30	–0.17	–	–	3,3
20	HG7-85	DA	38.4	9.2	–1.2	12.02	0.16	12.50	0.09	–0.27	y	–	0,0
21	WD 0433+270	DC8	20.1	26.8	–0.5	14.35	0.65	13.08	0.46	1.02	y	–	3,3
22	WD 0437+122	DA	66.9	21.3	1.6	13.57	0.19	–	–	–	–	–	9,9
23	WD 0625+415	DA3	47.7	28.9	–2.9	11.60	–0.03	11.95	–0.17	–0.20	–	–	3,3
24	WD 0637+477	DA3.6	36.2	30.6	–1.4	12.00	0.13	12.25	–0.18	–0.06	–	–	3,3
25	WD 0641+438	DA	41.9	30.2	3.0	12.42	0.06	12.66	–0.09	–0.03	–	–	8,4
26	WD 0743+442	DA5	33.5	35.6	1.3	12.24	0.10	12.60	0.05	–0.14	–	–	3,3
27	WD 0816+376	DA5	38.7	39.6	–0.9	12.80	0.22	12.70	–1.18	–0.10	–	–	3,3
28	WD 0233-083.1	DA	53.3	32.5	1.5	16.13	0.19	–	–	–	–	–	x,x
29	WD 0300-083.1	DA4.4	37.9	25.0	–0.0	15.93	0.07	–	–	–	–	–	x,x
30	LP 652-0342	–	31.6	25.2	0.2	14.25	0.06	14.27	-0.16	0.15	–	–	5,5
31	WD 0533+322	DA4	11.2	36.1	1.1	16.18	0.38	–	–	–	–	–	1,1
32	WD 0543+436	DA5	21.3	30.3	–2.0	15.45	0.14	14.76	1.01	0.30	–	–	3,3
33	WD 0557+237	DA6	13.2	34.4	–2.1	16.29	0.35	15.80	0.48	0.52	–	–	2,2
34	1RXSJ062052.2+132436	DA	29.7	24.1	–0.6	12.94	–0.30	13.33	0.09	–0.51	y	–	2,2
35	WD 0758+208	DA	38.7	36.8	–0.8	17.73	0.33	–	–	–	–	–	x,x
36	WD 0816+387	DA6.5	19.1	38.6	3.8	15.16	0.30	14.67	0.49	0.52	–	–	3,3
37	WD 0820+250.1	DA1.5	28.0	38.1	3.1	13.68	–0.15	14.20	–0.08	–0.42	y	–	7,7

Notes. Stars No. 1 to 10 are the 10 "classical" Hyades white dwarfs as given, e.g. by von Hippel (1998). Stars No. 11 to 22 are probably former Hyades white dwarfs that fulfil the kinematic and photometric criteria. Stars No. 23 to 27 do also fulfil the kinematic and photometric criteria, but we rate them as possible non-Hyades because of their long distance from the centre in the Z direction (as was done for MS stars in Paper I). Stars No. 28 to 37 are probable non-Hyades white dwarfs that photometrically do not share the loci of white dwarfs in the colour-magnitude diagrams. The printed table gives the entries necessary for the figures in this paper; the full table with additional information is available from the CDS, Strasbourg, France.

References. (0) Stern et al. (1995); (1) Kharchenko (2001); (2) McCook & Sion (1999); (3) Mermilliod & Mermilliod (1994); (4) Silvestri et al. (2005); (5) Salim & Gould (2003); (6) Klemola et al. (1987); (7) Lasker et al. (2008); (8) Zacharias et al. (2004); (9) Reid (1992); (x) converted from SDSS ugriz.

and WD 0217+375, respectively) are known as binaries containing a WD and a MS component. The first three belong to the classical Hyades members, whereas WD 0217+375 (13) has not be associated with the Hyades before. LP 649-0071 (12) is rated a white dwarf in Luyten's White Dwarf Catalogues, though it has a NIR-colour typical of red dwarfs. This indicates a possible binary nature of this object. We discuss its properties in more detail in Sect. 4. In Table 1 we summarise the data for the white dwarfs discussed in this paper. Column 1 is a running number, Col. 2 the name(s) of the star in the SIMBAD database, Col. 3 the spectral type taken from McCook & Sion (1999). In Col. 4 we present the distance D of the star from the Sun as calculated from the convergent point method, whereas Col. 5 gives the distance r_c from the cluster centre. Column 6 is the tangential velocity $v_\perp$ perpendicular to the direction to the convergent point. It is a measure of how well the motion of the star and cluster coincide. Columns 7 to 11 give M_V, $B-V$, M_J, $J-K_s$ and $r'-J$. Column 12 describes whether or not the star is detected as an x-ray source (in VizieR), Col. 13 whether it is a known spectroscopic binary. Finally, Col. 14 presents the sources of the B and V magnitudes. For code x,x we used the transformations from ugriz (SDSS) to B, V as given in Jester et al. (2005). An extended version of Table 1 is published only in machine-readable form via the CDS. It contains additional entries for each star including, e.g. precise positions, proper motions, apparent magnitudes to ease the preparation of follow-up observations, as well as the velocities derived from the convergent point method.

The 37 stars in Table 1 are divided into four classes. The first ten stars of class 1 are the "classical" Hyades. Stars 11 to 22 form class 2 of new probable Hyades co-movers. The five

Table 2. Predicted and measured radial velocities for stars from Table 1

Star No.	RV_{pr} [km s^{-1}]	RV_S [km s^{-1}]	RV_V [km s^{-1}]	Ref. S,V	Comments
1	34.4	23 ± 10	37.4	1,2	binary
2	35.4	46.3 ± 4.2	46.3 ± 4.2	5,5	
4	38.1	37.0 ± 2	38.7 ± 0.3	1,6	binary
7	38.9	–10.4 ± 9.7	36.7 ± 1.5	7,3	cpm, sep. 13″ (?)
8	39.5	43.5 ± 4.0	43.5 ± 4.0	5,5	
10	40.2	105	105	8,8	no redshift correction
11	9.9	9.8 ± 8.9	9.8 ± 8.9	7,7	cpm, sep. 43″
13	19.5	5.8 ± 8.6	5.8 ± 8.6	7,7	cpm, sep. 2″
18	33.0	50.9 ± 3.3	49.9 ± 4.6	4,5	
21	37.6	–	36.3	–,9	
25	36.1	–11.7 ± 8.3	–11.7 ± 8.3	7,7	cpm, sep. 143″
36	34.6	19.8 ± 6.5	19.8 ± 6.5	7,7	cpm, sep. 34″

Notes. Radial velocities from literature for the stars from Table 1. The first column gives the star number, the second column (RV_{pr}) the radial velocity predicted by the convergent point method. In the next three columns we show the radial velocities found in SIMBAD (RV_S), resp. VizieR (RV_V), and the corresponding references. The sixth column gives comments.

References. (1) Wilson (1953); (2) Barbier-Brossat & Figon (2000); (3) Barbier-Brossat et al. (1994); (4) Pauli et al. (2003); (5) Pauli et al. (2006); (6) Nordström et al. (2004); (7) Silvestri et al. (2002); (8) Greenstein & Trimble (1967); (9) Zuckerman et al. (2003)

stars of class 3 fulfil the kinematic and photometric criteria, but are more than 20 pc away from the centre in Z direction (perpendicular to the galactic plane). Stars with these characteristics have been ruled out in Paper I, because all of them had discordant radial velocities (whenever a radial velocity measurement was available). Finally, class 4 consists of 10 stars that fulfil the kinematic criteria, but would be sub-luminous in the CMD if set at their predicted distances.

We also checked if measured radial velocities of the 37 candidates were available to compare them with the predicted ones from the convergent point method. Only for 12 of the 37 candidates we found radial velocities in the literature. For six of them (the stars Nos. 1, 4, 7, 8, 11, 21), the predicted and the measured radial velocities (from at least one source) agree well. EGGR 42 (10) was assumed to have Hyades radial velocity by Greenstein & Trimble (1967) and this was used to obtain its Einstein redshift (see also the remark on this star in the next section). WD 0816+387 (36) was already rejected as a Hyades member by the photometric criteria, so a disagreement between measured and predicted radial velocities is to be expected. On the other hand, the discordant radial velocities for the stars Nos. 2, 13, 18, and 25 require a more detailed discussion.

A reliable determination of space velocities of white dwarfs is a challenging task. For isolated white dwarfs the apparent radial velocities must be corrected for gravitational redshift, which requires the knowledge of the mass-radius ratios, i.e. quantities that cannot be observed directly. For stars Nos. 2, 8, and 18, Pauli et al. (2006) determined radial velocities from high-resolution spectra, whereas spectroscopic distances and gravitational redshifts were computed from the fundamental parameters derived by Koester et al. (2001). The relatively high radial velocity for EGGR 26 (2) by Pauli et al. (2006) would reject this star as a Hyades member, though in numerous studies its membership is found to be confirmed (e.g., Weidemann et al. 1992; De Gennaro et al. 2009). The discrepancy for EGGR 26 may probably be explained by underestimated uncertainties introduced when deriving the redshift corrections. The same reason for discrepancy may possibly hold for LP 653-0026 (18), too: recently, Koester et al. (2009) published an updated version of their catalogue of the fundamental parameters of white dwarfs where two different sets of parameters were considered to be equally probable for this star. A re-calculation of the radial velocities seems to be reasonable for white dwarfs from Pauli et al. (2006).

For four of our candidates (the stars Nos. 7, 11, 13, 25), radial velocities were obtained by Silvestri et al. (2002) from line-of-sight velocities of M dwarfs in common proper motion pairs (cpm), each consisting of an M-dwarf and a white dwarf. The authors assume that typical separations between the components are about 1000 AU, such that orbital motion can be neglected. For star No. 13, where measured and predicted radial velocities differ by 1.6σ, the separation is 2″, corresponding to about 50 AU, given a distance of 25 pc. Here the orbital motion cannot be neglected, and even a small correction of a few km s^{-1} could make the difference between measured and predicted radial velocities insignificant. On the other hand, if the separation is large in a cpm pair, the argument of a common radial velocity becomes weaker because of an increasing probability of an unphysical optical pair. This could be the case of star No. 25, WD 0641+438, where the separation between the white dwarf and its MS companion reaches 143″. The PPMXL lists more or less compatible motions for these stars (μ = 139 mas/yr, Θ = 180 deg; μ = 104 mas/yr, Θ = 183 deg), respectively. However, the 2MASS colours for the MS star indicate that this star should be a late K dwarf at a distance of at least 500 pc, which excludes them as physical binary.

Finally, the reason for the discrepancy between the predicted and measured radial velocity (Silvestri et al. 2002) for HZ 9 (7) seems to be a misinterpretation. Silvestri et al. (2002) regarded it as a cpm pair with another star 13″ away. However, the proper motion of the latter is completely different (11.4 mas/y) from the proper motion of the white dwarf HZ 9 (115 mas/y). On the other hand, Stauffer (1987) analysed the radial-velocity curve of HZ 9, confirmed its binary nature, and determined an M dwarf–white dwarf separation of less than 1 AU and a radial velocity of 36.7 km s^{-1} for the system, which agrees well with the predicted radial velocity. To summarise the above discussion: none of the 10 classical candidates and of the 17 new probable former Hyades white dwarfs can be unambiguously discarded on the basis of the presently measured radial velocities. Given the problematics of obtaining the true radial motion of the candidates, we can only encourage new measurements for which this paper may serve as an input catalogue.

4. Individual stars

1 = V471 Tau = WD 0347+171 is a spectroscopic binary K2V+DA (Hussain et al. 2006), included in our sample of 724 Hyades members from Paper I, a strong X-ray source LX 45 = 229.6 ± 10.0. LX 45 is the X-ray luminosity from Stern et al. (1995), derived from the assumption that the star has a heliocentric distance of 45 pc. Units are 10^{28} erg s^{-1} (0.1–1.8 keV). Its trigonometric parallax from Hipparcos (van Leeuwen 2009) of 22.7 ± 1.5 mas agrees well with the predicted one.

2 = EGGR 26 = HZ 4 = WD 0352+096 is considered as a certain member in e.g. Weidemann et al. (1992) and De Gennaro et al. (2009), though seems just to leave the Hyades (the estimated distance from the cluster centre is 13.5 pc). A weak X-ray source LX 45 < 1.4.

3 = EGGR 29 = LB 227 = WD 0406+169: De Gennaro et al. (2009) use it in their analysis, whereas Weidemann et al. (1992) declare it to be a non-member. Weidemann et al. (1992) reject this white dwarf as a Hyades member since the mass they derived from the surface gravity sets the star to a distance of 60 pc from the Sun, with a velocity difference to the adopted cluster velocity higher than 12 km s^{-1}. Using the convergent point method, we obtain a distance of 52 pc from the Sun, a distance from the cluster centre of 7 pc, and the velocity difference of less than 0.5 km s^{-1} for EGGR 29. These results support the assumption of its Hyades membership. A weak X-ray source LX 45 < 0.9.

4 = HR 1358 = HD 27483 = WD 0418+137: this system consists of two F6V stars with orbital period of 3.05 days, and a DA3 white dwarf companion (Böhm-Vitense 1993). The MS binary is included in the sample of the 724 Hyades members from Paper I, X-ray source LX 45 = 19.9 ± 2.9. Its trigonometric parallax from Hipparcos (van Leeuwen 2009) of 21.1 ± 0.5 mas agrees well with the predicted one.

5 = EGGR 36 = VR 7 = WD 0421+162 is considered to be a certain Hyades member in Weidemann et al. (1992) and De Gennaro et al. (2009), a weak X-ray source LX 45 < 1.4.

6 = EGGR 37 = VR 16 = WD 0425+168 is used as a certain Hyades member in Weidemann et al. (1992) and De Gennaro et al. (2009), X-ray source LX 45 = 4.2.

7 = EGGR 38 = HZ 9 = WD 0429+176 is a spectroscopic binary DA2.5+dM, included in the sample of the 724 Hyades members from Paper I, X-ray source LX 45 = 2.7.

8 = EGGR 39 = HZ 7 = WD 0431+126 is used as a certain Hyades member in Weidemann et al. (1992) and De Gennaro et al. (2009), a weak X-ray source LX 45 < 0.9.

9 = EGGR 316 = LP 475-242 = WD 0437+138 is accepted as a Hyades member (von Hippel 1998), though Weidemann et al. (1992) do not discuss it, because they are rating the data available for the star as too uncertain. A weak X-Ray, LX45 < 0.9.

10 = EGGR 42 = HZ 14 = WD 0438+108 is used as a certain Hyades member in Weidemann et al. (1992) and De Gennaro et al. (2009), a weak X-Ray LX45 < 1.0. Its radial velocity has been determined by Greenstein & Trimble (1967), who give an apparent radial velocity of 105 km s^{-1}. In this case the authors did not try to determine the Einstein redshift from (M/R), but assumed that it is a Hyades member, and must therefore have the Hyades radial velocity.

11 = WD 0120-024 is one of the absolutely faintest white dwarf candidates in our Hyades sample, it is not observed in CMC14. Its predicted and observed radial velocities agree well.

12 = LP 649-0071: at the position of this object we find the MS-star no. 8 ($M = 0.17\,M_\odot$) of our sample from Paper I, and at the same time there is the blue object LP 649-0071 ($m_{\rm pg} = 16.9$) from Luyten's White Dwarf Catalogues. The proper motions of the blue Luyten object and our red object coincide remarkably. We took $B = 17.31$ from NOMAD and $V = 16.53$ from Salim & Gould (2003). The red component has a parallax of 29.13 mas ± 0.41 mas. This object is found as 2XMMi J021352.1-033059 in the *XMM-Newton* Serendipitous Source Catalogue 2XMMi-DR3, with a flux of 4.0877×10^{-14} mW m^{-2} (0.2–12 keV). Galex (Morrissey et al. 2007) finds a faint object with FUV magnitude of 24.0 and NUV magnitude of 23.1 at the position of this star, probably too faint for a white dwarf with this parallax. The binary nature of this object as well as its white dwarf nature have to be verified.

13 = WD 0217+375 is a component of a close binary with a separation of 2″, not resolved in our catalogue. According to Silvestri et al. (2005), the spectral type is M5V+DA. A parallax of 39.8 mas is predicted by the convergent point method. This agrees well with the parallax of 40 mas given for this star in the CNS3 (Gliese & Jahreiß 1991).

14 = WD 0230+343: 2MASS photometric flags "ACU".

15 = LP 246-0014 is a high proper motion ($\mu_\alpha \cos\delta$ = 228.4 mas/yr, μ_δ = −50.8 mas/yr) blue star, listed in Luyten's White Dwarf Catalogues. It is located in between two brighter stars. From this region a strong X-ray emission was measured by ROSAT, but it is not clear which of these objects is an X-ray source. There are no Galex observations in the area around this star. The white dwarf nature of LP 246-0014 has to be verified.

16 = WD 0259+378 is one of the white dwarfs most distant to the Sun in our candidate sample. It has a relatively high residual velocity of 4 km s^{-1} with respect to the Hyades, which is probably a reason for its "unusual" location $X, Y = -54$ pc, 32 pc in Fig. 2. Its 2MASS photometry is highly uncertain, especially in the H and $K_{\rm s}$ bands, which have photometric flags "UD".

17 = WD 0312+220: 2MASS photometric flags "BCU".

18 = LP 653-0026 = WD 0339-035: 2MASS photometric flags "ABC".

19 = WD 0348+339: 2MASS photometric flags "ABD".

20 = HG7-85 = LP 474-95? is a white dwarf observed by Koester et al. (2009), HS0400+1451 (Hamburg Schmidt survey). This star, first mentioned by Giclas et al. (1962) as a member of the Hyades, is found in the Prosser & Stauffer data base (presently available from J. Stauffer, priv. comm.). The authors identify it with LP 474-95, a star which cannot be found in the CDS database. It is also not contained in McCook & Sion (1999). The proper motions in PPMXL are incorrect. Therefore, we took the proper motions from Ducourant et al. (2006). The star is also contained in Stern et al. (1995), which give an X-ray luminosity <1.1 if a distance of 45 pc is assumed.

21 = GJ 171.2 B = EGGR 40 = WD 0433+270: this star forms a cpm pair with BD+26 730, which is included as No. 461 in Paper I. The measured trigonometric parallax and radial velocity of BD+26 730 agree well with the predicted ones. Also, the measured radial velocity of the white dwarf (Table 2) coincides well with the predicted one. With spectral type DC8, the white dwarf WD 0433+270 is the reddest in our candidate sample. Its possible membership in the Hyades is extensively discussed in Catalán et al. (2008). We further discuss its importance for the sample in Sect. 6.

22 = LP475-249 = WD 0437+122 = Reid 405 is the most distant white dwarf in our candidate sample, too faint to be measured in 2MASS and CMC14. A possible membership in the Hyades was discussed by Reid (1992). Owing to a relatively high velocity with respect to the cluster, this star was excluded as a Hyades member. Based on new proper motions from PPMXL, the residual velocity $v_\perp$ turns out to be about 1.63 km s^{-1} which is consistent with the Hyades motion.

23 = WD 0625+415: this white dwarf has proper motions consistent with Hyades membership. Also, its location in the M_V vs. $B - V$ diagram indicates a correct distance predicted by the convergent point method. However, at z = 11.3 pc WD 0625+415 is more than 20 pc above the cluster centre. In Paper I we found that all stars with $\Delta z > 20$ pc should be rejected as Hyades members. Figure 4 gives an additional

argument that this star is probably a field white dwarf, though the radial velocity must be measured to support this assumption.

24 = WD 0637+477 is probably a field white dwarf, the same case as star No. 23 above.

25 = WD 0641+438 is probably a field white dwarf, the same case as star No. 23 above.

26 = WD 0743+442 is probably a field white dwarf, the same case as star No. 23 above.

27 = WD 0816+376 is probably a field white dwarf, the same case as star No. 23 above.

28 = WD 0233-083.1 is rejected as a Hyades candidate because of its location in the M_V vs. $B-V$ diagram. The predicted distance seems to be underestimated. No 2MASS, CMC14 and reliable B, V measurements are found. M_V and $B-V$ are estimated from SDSS ugriz.

29 = WD 0300-083.1: the same case as star No. 28 above.

30 = LP 652-0342 is rejected as a Hyades candidate because of its location in the M_V vs. $B-V$ diagram. The predicted distance is underestimated. This is supported by the trigonometric parallax (3.9 ± 4.2 mas) from van Altena et al. (1995).

31 = WD 0533+322 is rejected as a Hyades candidate because of its location in the M_V vs. $B-V$ diagram. The predicted distance seems to be underestimated. No 2MASS, CMC14 measurements.

32 = WD 0543+436 is rejected as a Hyades candidate because of its location in the M_V vs. $B-V$ diagram. The predicted distance is underestimated.

33 = WD 0557+237: the same case as star No. 32 above.

34 = 1RXSJ062052.2+132436: the same case as star No. 32 above.

35 = WD 0758+208: the same case as star No. 28 above.

36 = WD 0816+387: the same case as star No. 32 above.

37 = WD 0820+250: the same case as star No. 32 above.

Other stars:

vA54 = HG7-128 = LP 474-185 is an M5V star (Skiff 2010), has Rosat observation (LX45 < 2.2). This is star number 170 of Paper I. van Altena finds in his first paper (van Altena 1966) $B-V = 1.82$, later he corrects it to $B-V = 0.90$ (van Altena 1969). This is definitely a red dwarf, and there is no indication for a white dwarf companion.

vA71 = EGGR 32 = WD 0412+14 is classified as sdK: by Skiff (2010). Liebert (1975) rates it as a very metal-poor subdwarf with "K-star" colour, but with strong, sharp hydrogen lines. The General Catalog of Trigonometric Parallaxes (van Altena et al. 1995) gives a parallax of 0.003 ± 0.004 arcseconds. This star is not a member of the Hyades. No X-ray detection.

RHya 102 = HG7-126: this star fails the kinematic criterion to be included as Hyades member. Its tangential velocity $v_\perp$ is -6.1 km s^{-1}. The convergent point method puts it at a distance D from the Sun of 60.8 pc. With this distance it has $M_V = 12.26$; and with $B-V = -0.08$ it perfectly fits the CMD in Fig. 1. It also fits the luminosity-distance relation in Fig. 4, see Sect. 6. We discard it, however, because of kinematic reasons.

RHya 154: the proper motions given by Reid (1992), (76, −34) mas/y and those from the CU subset (67, −46) disagree. In consequence the $v_\perp$-component of the tangential velocity is -3.1 km s^{-1} for Reid, and -8.1 km s^{-1} in the CU. One would count it as a kinematic member with Reid's data, and discard it with ours. The distance from the Sun is $D = 66$ pc (Reid), 70.6 pc (CU). Reid gives $V = 16.51$ and $B-V = -0.22$, which converts into $M_V = 12.26$, and puts it 1 mag below the white dwarf sequence. So, we count it as a non-member.

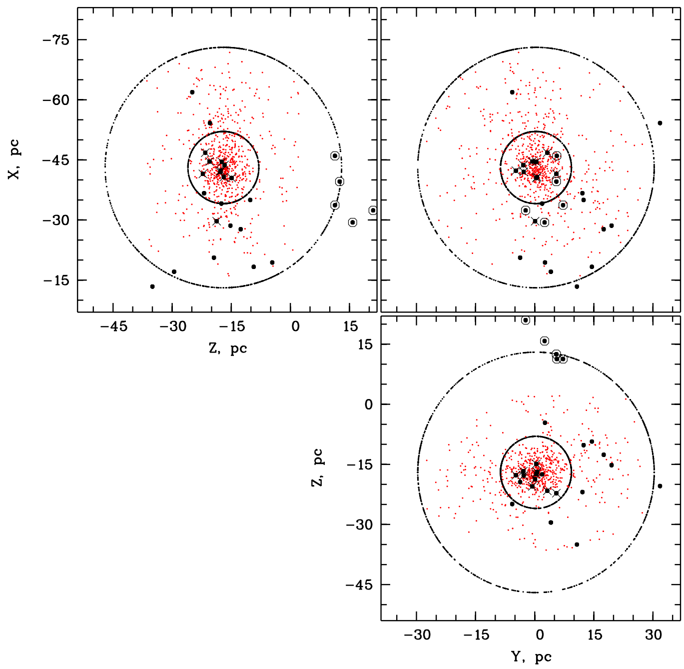

Fig. 2. The spatial distribution in the galactic X, Y, Z coordinate system of the Hyades white dwarf candidates of this paper. They are marked by the same symbols as in Fig. 1. The small (red) dots in the background distribution represent the 724 stars from Paper I. Probable field white dwarfs (Nos. 23 to 27) are additionally marked by open circles. The two large circles display the tidal radius (9 pc), and a radius of 30 pc, as in Paper I.

5. Spatial distribution and completeness

In Fig. 2 we show the distribution of the candidates from Table 1 (only stars no. 1 to 27) on top of the background of the 724 members from Paper I. We use the galactic rectangular coordinate system X, Y, Z with origin in the Sun, and axes pointing to the Galactic Centre (X), to the direction of galactic rotation (Y), and to the North Galactic Pole (Z). All classical white dwarfs except one are located within the tidal radius of the cluster. All newly found candidates lie outside the tidal radius, hence they are no longer gravitationally bound to the cluster, but share the fate of hundreds of former main-sequence members that left the bound region. The five probable field white dwarfs (Nos. 23 to 27) are all at $z > 10$ pc. Of particular interest here is the distribution in the X, Y-plane. We note that all white dwarfs (except No. 16) follow the tilted distribution of the main-sequence stars. By tidal interaction with the gravitational field of the Galaxy, stars can leave the cluster on both sides via the Lagrangian points L_1 and L_2 of the Galaxy-cluster-star system, where L_1 is in the direction to the Galactic centre, i.e. towards larger (less negative) X, the Sun-facing side of the cluster, while L_2 lies on the opposite side of the cluster centre. All white dwarfs outside the tidal radius (except Nos. 16 and 22) populate the Sun-facing part of the cluster, and may have left it through L_1. The deficit of newly found candidates at longer distances from the Sun needs explanation. To investigate this we plot in Fig. 3 the r', J and K_s magnitudes as a function of the distance D from the Sun. The background points in Fig. 3 represent again the sample of 724 from

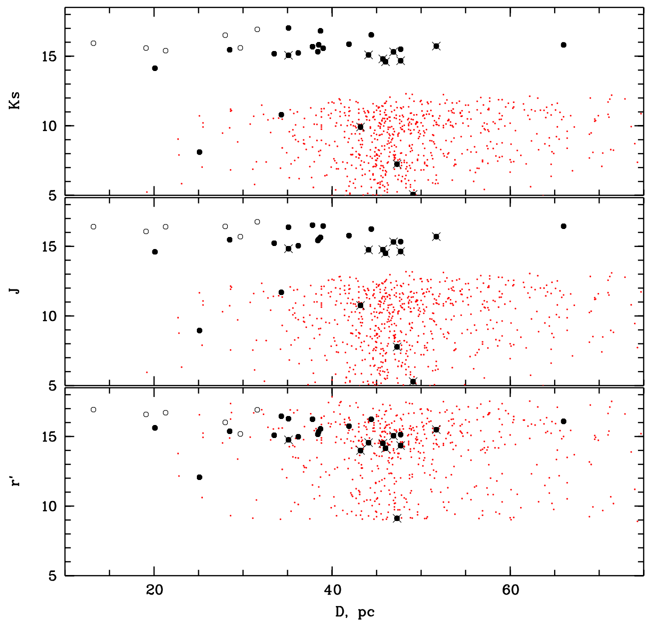

Fig. 3. Distribution of the apparent magnitudes r', J and K_s over the distance D from the Sun. The stars from Table 1 are marked by the same symbols as in Fig. 1. The small (red) dots in the background distribution represent the 724 stars from Paper I.

Paper I. In the NIR distributions we note that the magnitude limit of the sample of 724 in the J and K_s bands is at much brighter magnitudes than the 2MASS completeness limit of $J = 15.8$ and $K_s = 14.3$ (see http://www.ipac.caltech.edu/2mass/releases/allsky/doc). For fainter red dwarfs or even brown dwarfs there was no optical counterpart in CMC14, i.e. in the CU subset to PPMXL. This is different with the white dwarfs. We see from Fig. 3 that the fainter, hitherto unknown Hyades white dwarfs all are well beyond the 2MASS completeness limit in J and K_s. The photometric accuracy in the K_s band at 16.0 typically is 0.25 mag, fainter ones have no accuracy estimate at all. The situation is somewhat better in the J band. In the r' band the red and white dwarfs are comparable. The faintest white dwarfs are near the completeness limit of CMC14 at $r' = 16.8$. With these remarks it becomes clear that we can reveal new Hyades white dwarfs beyond a distance of about 50 pc from the Sun in the CU subset of PPMXL only by chance.

The PPMXL goes about 3 magnitudes deeper than its CU subset, so possibly white dwarfs with Hyades motion could be found therein. However, PPMXL photometry in optical bands is from USNO-B1.0, and therefore inappropriate for this kind of work. These distant white dwarfs could only be found by cross-matching PPMXL kinematic candidates with the catalogue from McCook & Sion (1999) if the latter would be complete down to the limiting magnitude of PPMXL. However, except for its SDSS part, which only marginally covers the Hyades area, the McCook & Sion catalogue is quite incomplete already at $V \approx 16$ (see, e.g. Napiwotzki et al. 2003). Consequently, our Table 1 contains only two white dwarfs farther away than 50 pc from the Sun.

6. Discussion

The convergent point method supplemented by photometric selection provides five out of six phase-space parameters. Generally, this allows quite a reliable selection of open cluster members. We find that only nine "classical" Hyades white dwarfs reside within the tidal radius of the cluster ($r_c < 9$ pc), hence are tidally bound. Outside the tidal radius, up to a distance of 40 pc from the centre, we find 18 white dwarfs co-moving with the cluster at relatively low velocity dispersion (cf. Fig. 4, top panel).

When Catalán et al. (2008) discussed WD 0433+270 (No. 21 in Table 1), this star was very isolated in the M_V vs. $B-V$ colour-magnitude diagram of Fig. 1. There was a large gap between the reddest classical white dwarf EGGR 26 (No. 2) at $M_V = 11.83$ and $B-V = 0.10$, and WD 0433+270 at $M_V = 14.35$ and $B-V = 0.65$. With our new candidates the gap does no longer exist, and, from kinematics, we strongly infer that WD 0433+270 was in fact a former member of the Hyades with all the implications that Catalán et al. (2008) rate as tantalising. Although the question of the cooling age is most critical for WD 0433+270, if it is an ejected member of the Hyades cluster, the cooling ages of the other candidates between the dimmest classical white dwarf, EGGR 26 (3.1×10^8 yr, see Weidemann et al. 1992) and WD 0433+270 should be re-discussed after they are confirmed by their radial velocities. Note that WD 0433+270 is the most nearby star of all our candidates at a distance of 20.1 pc from the Sun. Given the incompleteness of the catalogue by McCook & Sion (1999), it may not be surprising to detect other "red" white dwarfs of the Hyades once a deep, accurate optical photometric survey like, e.g. PanSTARSS becomes available.

The one-dimensional velocity dispersion in Fig. 4 increases with increasing distance from the cluster centre. This behaviour is similar to that of the red dwarfs as shown in Fig. 12 of Paper I. From this we infer that the white dwarfs we reveal here can leave the cluster by the same mechanism as the red dwarfs do. Once the progenitor star develops into a white dwarf and its envelope is pushed away, it will be treated within the cluster as a low-mass object such as the other low-mass stars that are preferentially ejected from the cluster compared to their higher mass brothers. This may mean that, in general, an additional mechanism as proposed by Fellhauer et al. (2003) is not needed to explain the white dwarf distribution we find. It is not ruled out that the dynamical process of Fellhauer et al. (2003) has not been active in the Hyades, but the kilometre-per-second kicks that the stars got would very probably move them away from the centre much faster, so we would be unable to find most of them with the constraints we adopted.

In Paper I we found mass segregation for giants and main-sequence stars in the Hyades, i.e., a strong concentration of the most massive stars ($M > 2\,M_\odot$) towards the cluster centre and flatter distributions for lower mass stars. Usually, such a concentration of the massive stars is observed already in the first few 10^7 yr of a cluster's life (within the relaxation time scale). Since these stars are the progenitors of white dwarfs, one expects to find recently formed white dwarfs in the vicinity of the cluster centre. However, once they are no longer massive, they behave like other 0.6 to 0.8 $M_\odot$ main-sequence stars. Owing to tidal interaction with the gravitational field of the Galaxy, the chance of evaporation from the cluster becomes higher, and it is increasing with the time passed after degeneration. Therefore, merely from the point of view of dynamical evolution, we could expect the older white dwarfs at longer distances from the cluster centre. For the white dwarfs of this paper we find that only the absolutely brightest white dwarfs still are within the tidal radius, whereas the dimmer ones left the cluster. As we already noted above, the dimmest of the classical white dwarfs, EGGR 26, has a mass of 0.62 $M_\odot$ and a cooling age of 3.1×10^8 yr (Weidemann et al. 1992). We find it 13.5 pc away from the cluster centre, so it is already outside the tidal radius of the cluster. In the lower panel of Fig. 4 we see that the absolute magnitude M_V of white dwarfs increases with increasing distance from the centre, to show that possibly the more distant (from the centre) white dwarfs had more time to move away from the cluster centre and to cool down. Those must have formed earlier from more massive progenitors. This empirical luminosity-distance relation has approximately a slope of 4.5 mag in 40 pc.

In Fig. 4 (bottom) the five stars marked with their running numbers from Table 1 are binaries, their absolute brightness in M_V is not representative for the white dwarf component. However, there is a group of six stars in the bottom panel of Fig. 4 that do not follow the simple luminosity-distance relation of the others. They lie roughly between 30 and 40 pc from the centre at M_V between 11.5 and 13.0 mag. Five of these stars (Nos. 23 to 27) are marked as possible field stars because they are far away from the centre in Z direction. Kinematic and photometric main-sequence candidates have been rejected in Paper I with the same argument. The loci of stars Nos. 23 to 27 in Fig. 4 (bottom) give additional arguments to rule them out and mark them as field white dwarfs. The sixth star, WD 0259+378 (no. 16), has low $z - z_{\mathrm{centre}}$, which is why we keep it as a probable member for the time being. We note that these six stars have proper motions and loci in the M_V vs. $B - V$ diagram that are consistent with Hyades membership. With the radial velocities measured, one will be able to decide on their membership with more reliability. On the other hand, we should not exclude the possibility that these stars experienced an additional kick when leaving the cluster, and WD 0259+378 may be a good example of the dynamical mechanism proposed by Fellhauer et al. (2003).

As has been explained in Sect. 5, we cannot make a claim for the completeness of our sample of Hyades white dwarf candidates. However, the probability seems to be low to detect new white dwarfs of $M_V < 12$ within 10 pc from the cluster centre (or 36 pc $< D <$ 56 pc): the apparent magnitudes of these stars would clearly be $V < 16$ where the catalogue of McCook & Sion (1999) is nearly complete in this region. Indeed, the number of white dwarfs in front of and behind the cluster centre (D = 46.3 pc) is well balanced within $r_c < 10$ pc. The detection of dimmer white dwarfs is, however, biased towards shorter distances D from the Sun. If the population of white dwarfs behind the centre were similar to that in front of it, and the empirical luminosity-distance relation is valid, we estimate that one will find in the future some 8 to 12 more white dwarfs within a radius of 40 pc from the centre of the cluster. Depending on whether the white dwarfs (Nos. 23 to 27) are excluded from, or are included in the consideration, this would yield a total number of 30 to 40 white dwarfs as present-day plus former members of the Hyades. This number coincides well with the postulation of Weidemann et al. (1992), who claimed that there should be at least 21 white dwarfs dimmer than their seven confirmed Hyades white dwarfs.

Although we did not detect new white dwarf candidates within the tidal radius, but only in a 30 pc sphere around the centre of the Hyades, this result is similar to that of Paper I. There we found that, at present, 364 main-sequence stars (275 $M_\odot$) are gravitationally bound, and 360 stars (160 $M_\odot$) are co-moving outside the present-day tidal radius of the cluster. This is qualitatively consistent (see Fig. 8 in Paper I) with N-body simulations of an open cluster comparable to the Hyades (Kharchenko et al. 2009). So, we can expect that white dwarfs are also subject to cluster evaporation as main-sequence stars are. As an alternative, Famaey et al. (2007) proposed that stars outside the tidal radius of the Hyades, but co-moving in space with the bulk

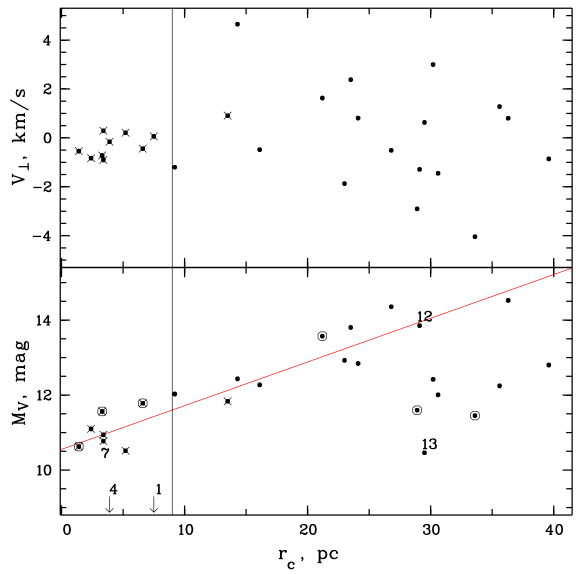

Fig. 4. As a function of the distance from the cluster centre (r_c) this figure shows the distribution of $v_\perp$, the velocity component perpendicular to the direction to the convergent point (*upper panel*); the absolute magnitudes M_V derived from the secular parallaxes (*lower panel*). White dwarf candidates with distances D > 46.3 pc from the Sun are additionally marked by larger circles. Spectroscopic binaries are marked by their numbers in Table 1. The red line shows an approximate fit to an empirical magnitude-distance relation explained in the text.

Hyades motion, could be older field stars trapped in orbital resonance with the Hyades cluster, a mechanism already described by Dehnen (1998). With the observations we have so far we cannot decide upon the relative efficiency of the two mechanisms, evaporation or capture. Radial velocity measurements are needed to confirm the co-moving, but cannot distinguish between the two mechanisms either. Only the determination of the chemical composition (chemical tracking) of the co-moving stars outside the tidal radius will finally decide about the origin at least for the main-sequence stars. Piskunov et al. (2008) found empirically that typical open clusters lose between 3 to 14 $M_\odot$ Myr^{-1} into the field in the first 260 Myr of their life. So, the 160 $M_\odot$ in the 30 pc volume around the centre can be easily explained with the Hyades lifetime of some 650 Myr. The capture mechanism must be at least as efficient as that to compete with evaporation.

To summarise: Within the tidal radius of the Hyades we only find nine "classical" bright white dwarfs. It is very improbable that, at present, more white dwarfs brighter than M_V = 12 are tidally bound in the cluster. Outside the tidal radius we find 18 white dwarfs that are co-moving with the Hyades cluster and could be former tidally bound members. As a consequence of our selection process, the sample presented here is incomplete and is essentially restricted to the Sun-facing part of the cluster. We find five white dwarfs in binary systems, three were already known as Hyades members, two are new candidates. Again, this search is incomplete, because we can reveal them only if the white dwarf nature of one of the components is already known. There is an empirical luminosity-distance (from cluster centre) relation such that the white dwarfs are dimming by about 1 mag per 10 pc distance from the centre. Given the spatial incompleteness of our sample, we estimate that some 20 to 30 white dwarfs should co-move with the bulk Hyades motion in a volume between 9 pc (tidal radius) and 40 pc from the centre. This number is consistent with an extrapolation of the present day mass function (PDMF) of the cluster (Fig. 10 of Paper I) towards white dwarf progenitors. For a full confirmation of the newly found candidates, more measurements of radial velocities are needed. At present, none of the 10 classical candidates and of the 17 new probably former Hyades white dwarfs can be excluded from membership on the basis of the available measurents of radial velocities. For white dwarfs, the measurements of apparent radial velocities must be corrected for gravitational redshift. This correction requires determinations of the mass-radius ratio for each object. This, of course, may introduce additional uncertainties in the determination of the true (kinematic) radial velocity. Once the candidates are confirmed, theories of white dwarf evolution are challenged to explain their nature and their origin.

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References

Barbier-Brossat, M., & Figon, P. 2000, A&AS, 142, 217
Barbier-Brossat, M., Petit, M., & Figon, P. 1994, A&AS, 108, 603
Böhm-Vitense, E. 1993, AJ, 106, 1113
Catalán, S., Ribas, I., Isern, J., & García-Berro, E. 2008, A&A, 477, 901
Copenhagen Univ. Obs., Inst. of Astronomy, Cambridge, UK, & Real Instituto Y Observatorio de La Armada, F. E. S., Carlsberg Meridian Catalog 14 2006, (VizieR Online Data Catalog I/304)
De Gennaro, S., von Hippel, T., Jefferys, W. H., et al. 2009, ApJ, 696, 12
Dehnen, W. 1998, AJ, 115, 2384
Ducourant, C., Le Campion, J. F., Rapaport, M., et al. 2006, A&A, 448, 1235
Eggen, O. J. 1958, MNRAS, 118, 65
Eggen, O. J., & Greenstein, J. L. 1965, ApJ, 141, 83
Farihi, J., Becklin, E. E., & Zuckerman, B. 2005, ApJS, 161, 394
Famaey, B., Pont, F., Luri, X., et al. 2007, A&A, 461, 957
Fellhauer, M., Lin, D. N. C., Bolte, M., et al. 2003, ApJ, 595, L53
Giclas, H. L., Burnham, R., & Thomas, N. G. 1962, Lowell Observatory Bulletin, 5, 257
Gliese, W., & Jahreiß, H. 1991, Nearby Stars, Preliminary 3rd Version, (Astron. Rechen-Institut, Heidelberg) (VizieR Online Data Catalog V/70A)
Greenstein, J. L., & Trimble, V. L. 1967, ApJ, 149, 283
Gunn, J. E., Griffin, R. F., Griffin, R. E. M., & Zimmerman, B. A. 1988, AJ, 96, 198
Hoffleit, D. 1964, Catalogue of bright stars, 3rd rev.ed. (New Haven, Conn., Yale University Observatory)
Humason, M. L., & Zwicky, F. 1947, ApJ, 105, 85
Hussain, G. A. J., Allende Prieto, C., Saar, S. H., & Still, M. 2006, MNRAS, 367, 1699
Jester, S., Schneider, D. P., Richards, G. T., et al. 2005, AJ, 130, 873
Just, A., Berczik, P., Petrov, M. I., & Ernst, A. 2009, MNRAS, 392, 969
Kharchenko, N. V. 2001, Kinematika i Fizika Nebesnykh Tel, 17, 409
Kharchenko, N. V., Berczik, P., Petrov, M. I., et al. 2009, A&A, 495, 807
Klemola, A. R., Jones, B. F., & Hanson, R. B. 1987, AJ, 94, 501
Koester, D., Napiwotzki, R., Christlieb, N., et al. 2001, A&A, 378, 556
Koester, D., Voss, B., Napiwotzki, R., et al. 2009, A&A, 505, 441
Lasker, B. M., Lattanzi, M. G., McLean, B. J., et al. 2008, AJ, 136, 735
Lawrence, A., Warren, S. J., Almaini, O., et al. 2007, MNRAS, 379, 1599
Liebert, J. 1975, ApJ, 200, L95
McCook, G. P., & Sion, E. M. 1999, ApJS, 121, 1, (VizieR Online Data Catalog III/235B).
Mermilliod, J.-C., & Mermilliod, M. 1994, Catalogue of Mean UBV Data on Stars, VI (Berlin Heidelberg New York: Springer-Verlag) (VizieR Online Data Catalog II/168), 1387
Morrissey, P., Conrow, T., Barlow, T. A., et al. 2007, ApJS, 173, 682
Napiwotzki, R., Christlieb, N., Drechsel, H., et al. 2003, The Messenger, 112, 25
Nordström, B., Mayor, M., Andersen, J., et al. 2004, A&A, 418, 989
Pauli, E.-M., Napiwotzki, R., Altmann, M., et al. 2003, A&A, 400, 877
Pauli, E.-M., Napiwotzki, R., Heber, U., et al. 2006, A&A, 447, 173
Piskunov, A. E., Kharchenko, N. V., Schilbach, E., et al. 2008, A&A, 487, 557
Reid, N. 1992, MNRAS, 257, 257
Röser, S., Demleitner, M., & Schilbach, E. 2010, AJ, 139, 2440
Röser, S., Schilbach, E., Piskunov, A. E., et al. 2011, A&A, 531, A92
Salim, S., & Gould, A. 2003, ApJ, 582, 1011
Silvestri, N. M., Oswalt, T. D., Wood, M. A., et al. 2001, AJ, 121, 503
Silvestri, N. M., Oswalt, T. D., & Hawley, S. L. 2002, AJ, 124, 1118
Silvestri, N. M., Hawley, S. L., & Oswalt, T. D. 2005, AJ, 129, 2428
Skiff, B. A. 2010, Catalogue of Stellar Spectral Classifications, (VizieR Online Data Catalog, B/mk)
Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163
Stauffer, J. R. 1987, AJ, 94, 996
Stern, R. A., Schmitt, J. H. M. M., & Kahabka, P. T. 1995, ApJ, 448, 683
van Altena, W. F. 1966, AJ, 71, 482
van Altena, W. F. 1969, AJ, 74, 2
van Altena, W. F., Lee, J. T., & Hoffleit, E. D. 1995, Yale Trigonometric Parallaxes 4th ed. (New Haven, Conn., Yale University Observatory), (VizieR Online Data Catalog, I/238A)
van Leeuwen, F. 2009, A&A, 497, 209
van Rhijn, P. J., & Raimond, J. J. 1934, MNRAS, 94, 508
von Hippel, T. 1998, AJ, 115, 1536
Weidemann, V., Jordan, S., Iben, I., Jr., & Casertano, S. 1992, AJ, 104, 1876
Wilson, R.E. 1953, General Catalogue of Stellar Radial Velocities, (Washington D.C., Carnegie Inst.), 601, (VizieR Online Data Catalog III/21)
Zacharias, N., Monet, D. G., Levine, S. E., et al. 2004, BAAS, 36, 1418
Zacharias, N., Finch, C., Girard, T., et al. 2010, AJ, 139, 2184
Zuckerman, B., Koester, D., Reid, I. N., & Hünsch, M. 2003, ApJ, 596, 477