Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **451,** 4259–4265 (2015) doi:10.1093/mnras/stv1280

Optical spectroscopy of candidate Alpha Persei white dwarfs

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Accepted 2015 June 4. Received 2015 June 3; in original form 2015 April 9

ABSTRACT

As part of an investigation into the high-mass end of the initial mass–final mass relation we performed a search for new white dwarf members of the nearby (172.4 pc), young (80–90 Myr) α Persei open star cluster. The photometric and astrometric search using the United Kingdom InfraRed Telescope (UKIRT) Infrared Deep Sky Survey and SuperCOSMOS sky surveys discovered 14 new white dwarf candidates. We have obtained medium resolution optical spectra of the brightest 11 candidates using the William Herschel Telescope and confirmed that while 7 are DA white dwarfs, 3 are DB white dwarfs and 1 is an sdOB star, only three have cooling ages within the cluster age, and from their position on the initial mass–final mass relation, it is likely none are cluster members. This result is disappointing, as recent work on the cluster mass function suggests that there should be at least one white dwarf member, even at this young age. It may be that any white dwarf members of α Per are hidden within binary systems, as is the case in the Hyades cluster, however the lack of high-mass stars within the cluster also makes this seem unlikely. One alternative is that a significant level of detection incompleteness in the legacy optical image survey data at this Galactic latitude has caused some white dwarf members to be overlooked. If this is the case, *Gaia* will find them.

Key words: white dwarfs.

1 INTRODUCTION

The initial mass–final mass relation (IFMR) describes the relationship between the main-sequence mass of a star with $M \lesssim 10\,\mathrm{M}_{\odot}$ and the mass of the white dwarf (WD) created after it dies (e.g. Iben & Renzini 1983). Understanding the form of this relation is important since it provides information on the amount of gas enriched with He, N and other metals that are returned to the interstellar medium by the death of low- and intermediate-mass stars. Additionally, the form of the upper end of the IFMR is relevant to studies of Type II supernovae as it can provide a constraint on the minimum mass of star that will experience this fate (e.g. Siess 2006).

The form of a theoretical IFMR is extremely difficult to predict due to the many complex processes occurring during the final phases of stellar evolution (e.g. third dredge-up, thermal pulses, mass-loss). This means that robust empirical data are essential for constraining its form. However, these data can be challenging to obtain, as it requires determining the main-sequence mass of a star that has long since died. This difficulty can be alleviated by investigating WD members of open star clusters (Weidemann 1977, 2000; Dobbie et al. 2006; Casewell et al. 2009; Dobbie et al. 2012). Here, since the age of the population can be determined from the location of the main-sequence turn-off (King & Schuler 2005) or a lithium age if the cluster is sufficiently young, the lifetime and mass of the progenitor star of any WD member can be estimated by calculating the difference between the cooling time of the WD and the cluster age.

During the last decade we have seen substantial progress in mapping the IFMR, with several groups exploiting mosaic imagers and telescopes with blue sensitive spectrographs to perform detailed studies of cluster WDs (e.g. Kalirai et al. 2007; Casewell et al. 2009; Dobbie et al. 2009; Williams, Bolte & Koester 2009). However, despite clear headway, the IFMR remains very poorly sampled by observations for $M_{\mathrm{init}} \gtrsim 5.5$–$6\,\mathrm{M}_{\odot}$. Indeed, there are only a handful of WDs here (Williams et al. 2009; Dobbie et al. 2012). So, while

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it is extremely important to have a good understanding of the top end of the IFMR, its form here remains greatly uncertain.

In a bid to obtain crucial new data in this initial mass regime, we have used the extensive imaging obtained as part of the United Kingdom InfraRed Telescope (UKIRT) Infrared Sky Survey Galactic Clusters Survey (UKIDSS GCS; Lawrence et al. 2007) to search the open cluster α Per for candidate WD members. This population has several characteristics which suggest it is particularly well suited to this type of investigation yet until now it has not been exploited. It is nearby, 172.4 pc (van Leeuwen 2009) and despite residing at low Galactic latitude ($b = -6.053$; Kharchenko et al. 2013), foreground extinction is low, $E(B-V) < 0.1$ (Prosser 1992). Thus, intrinsically faint members will appear comparatively bright and can be studied in detail with spectrographs on modern telescopes in modest integration times. α Per also has a distinct proper motion (μ_α cos δ, $\mu_\delta \sim +23, -27$ mas yr^{-1}; van Leeuwen 2009) which helps to distinguish members for the general field population. The cluster age is especially well constrained, $\tau = 90 \pm 10$ Myr (Stauffer et al. 1999: corresponding to $M_{\rm initial} \sim 5.5$ M$_\odot$), via the lithium depletion boundary technique (Stauffer et al. 1999), helping to minimize uncertainty in the progenitor mass determinations. The main-sequence turn-off age for this cluster is 50 Myr (Mermilliod 1981), but for young clusters the lithium age is more reliable, and so in this work we use 90 ± 10 Myr as the cluster age.

Moreover, α Per is sufficiently old for WDs to have formed, but young enough that the oldest of these remain at $T_{\rm eff} \gtrsim 12\,500$ K. Hydrogen rich atmospheres of WDs are also dominated by radiative energy transport in this region, so models are less complicated, and more reliable in this regime (Bergeron, Saumon & Wesemael 1995).

Studies of the α Per cluster have located some higher mass members (Prosser 1992; Prosser, Randich & Simon 1998; Deacon & Hambly 2004) but because of its youth, most studies have mainly concentrated on discovering new brown dwarf members (e.g. Barrado y Navascués et al. 2002; Deacon & Hambly 2004; Lodieu et al. 2005, 2012). A detailed mass function of the cluster was calculated in Lodieu et al. (2012) who studied ∼56 deg^2 of the cluster and determined that the mass function is similar in shape to that of the Pleiades and can be represented by a log normal with a characteristic mass of 0.34 M$_\odot$ and a dispersion of 0.46. This similarity to the Pleiades indicates that α Per may indeed harbour WD members and is constant with results from older studies (e.g. Sanner & Geffert 2001) which suggest that α Per may be richer than the Pleiades.

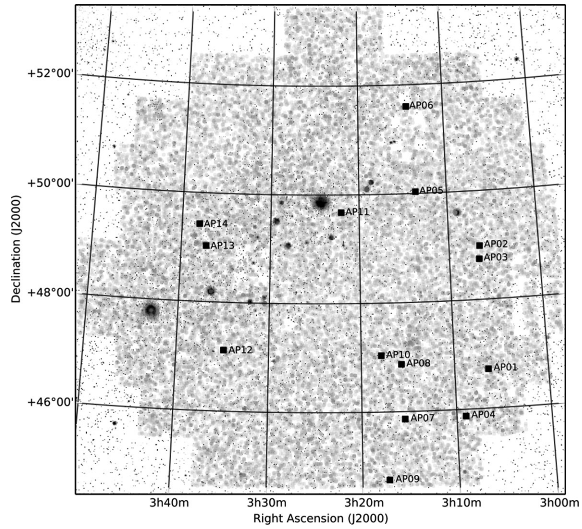

Figure 1. The surveyed region of α Per.

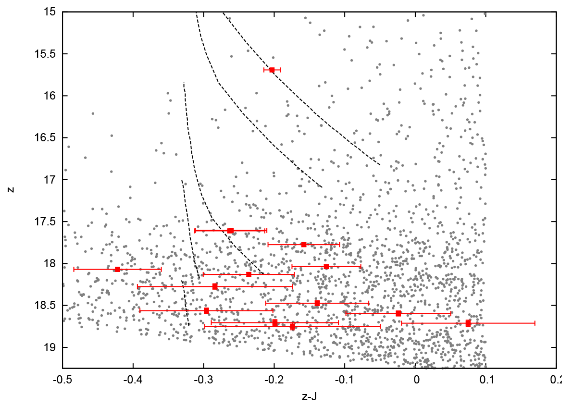

Figure 2. Z, $Z-J$ colour magnitude diagram of the selected region. The UKIDSS selected objects are shown in grey, with the WD candidates in red. The synthetic photometry from Holberg & Bergeron (2006) is shown as dashed lines, each representing log g from 7.0 in steps of 0.5 to log g of 9.0, from brightest to faintest.

2 SAMPLE SELECTION

To predict the UKIDSS colours of likely α Per WDs we used grids of model H-rich WD photometry appropriate to DA WDs. These grids are based upon the work of Bergeron et al. (1995) but are revised to include updates from Holberg & Bergeron (2006), Kowalski & Saumon (2006) and Tremblay, Bergeron & Gianninas (2011). These model-based predictions and the cluster parameters, ($\tau = 120$ Myr, $m - M = 6.27$ and $E(B-V) = 0.1$ van Leeuwen 2009) informed our selection criteria. We selected all objects (1) between RA of 02:48:00 and 03:52:00, and declination of 40° and 55° from the UKIDSS GCS (Fig. 1; Lawrence et al. 2007); (2) with $Z > 15.0$, $J \leq 19.25$ (a conservative limit based on our assumed cluster parameters), $0.1 \geq Z - J \geq -0.5$ and $0.1 \geq Y - J \geq -0.5$ and (3) with classifiers in Z and $Y = -1$ (stellar) and the post processing bit code to be less than 16, selecting the cleanest images (Hambly et al. 2008). These criteria resulted in the selection of 2060 objects which were then cross-matched with the SuperCOSMOS Sky Survey (Hambly et al. 2001) within 2 arcsec.

The cross-matched sample was then further selected by proper motion, $40.0 > \mu_\alpha cos\delta > 5.0$ mas yr^{-1}, $-10.0 > \mu_\delta > -50.0$ mas yr^{-1}. This cut removed objects that appeared to fall very close to the background object centre of motion (0,0), reducing the chances of contaminating objects being selected. We then requested that the errors on the proper motion be less than 8 mas yr^{-1} and that the total proper motion be within 24 mas yr^{-1} of the cluster motion (23, −27 mas yr^{-1}; van Leeuwen 2009). This cut resulted in 26 objects, which was thinned down to 14 after rejecting objects that were flagged as being blended in the SuperCOSMOS data. These objects can be seen in Figs 2 and 3 and in Table 1.

Some estimates of the mass function suggest that α Per could be ∼2–3 times as rich as the marginally older Pleiades which harbours at least one WD, LB1497 (Sanner & Geffert 2001). However, other mass functions suggest the two clusters are in fact very similar (Lodieu et al. 2012). Thus, assuming that the initial mass functions of these populations are at least comparable in form, it is possible that some of the WD candidates listed in Table 1 are α Per members.

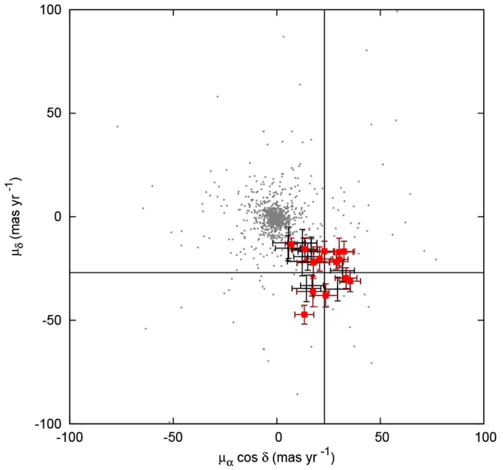

Figure 3. Proper motion diagram. The 2060 objects selected from the photometric selection using the colour–magnitude diagrams are shown in grey. The proper motion selected objects are shown in black with error bars, and the 14 WD candidates are plotted as red boxes. with error bars. The cluster motion is marked at 23, −27 mas yr^{-1}.

3 OPTICAL SPECTROSCOPY

To accurately measure the effective temperatures and surface gravities of the candidate WD stars, as well as reliably assess cluster membership and estimate their initial and final masses, we obtained medium resolution optical spectroscopy of the 11 brightest candidates in Table 1 using the Intermediate dispersion Spectrograph and Imaging System (ISIS) on the William Herschel Telescope on La Palma. We observed on the nights of 2011 September 03, 04 and 05 using the 300B and 1200R gratings simultaneously, with exposure times of between 2000 and 7200 s, split into at least two separate exposures to aid with cosmic ray rejection. A 1 arcsec slit was used to provide spectral resolution of ≈3.5 Å.

The spectra were reduced using IRAF (Tody 1986, 1993). The CCD frames were debiased and flat fielded using CCDPROC and cosmic ray hits were removed using LACOS SPEC (van Dokkum 2001). The spectra were then extracted using routines within the APEXTRACT package, and wavelength calibration was done using the CuAr+CuNe arc spectra. We used the WD spectral standard stars GD71 (Greenstein 1969) and EG131 (Luyten 1949) to remove the instrument response and to provide flux calibration.

On examining the spectra it became clear that only seven of the WDs, APWD01, APWD02, APWD04, APWD05, APWD07, APWD09 and APWD12 were DA WDs, with APWD10, APWD11 and APWD13 appearing to be DBs. The remaining object APWD08, is a hot subdwarf.

4 MODELLING WD SPECTRA

The data were compared to the predictions of WD model atmospheres using the spectral fitting programme FITSB2 (v2.04; Napiwotzki et al. 2004). The same grid of pure-H model spectra was used as in Casewell et al. (2009). It was calculated using the plane-parallel, hydrostatic, non-local thermodynamic equilibrium (non-LTE) atmosphere code TLUSTY, v200 (Hubeny 1988; Hubeny & Lanz 1995) and the spectral synthesis code SYNSPEC v48 (Hubeny & Lanz 2001). The models include a treatment for convective energy transport according to the ML2 prescription of Bergeron, Wesemael & Fontaine (1992), adopting a mixing length parameter, $\alpha = 0.6$. These calculations utilized a model H-atom which incorporates

Table 1. ID, RA, Dec., proper motion and UKIDSS magnitudes for the 14 α Per candidate WDs.

ID	RA	Dec.	$\mu_\alpha \cos\delta$	μ_δ	Z	Y	J	H	K
APWD01	03 06 24.00	+46 43 11.3	+28.72 ± 3.49	−21.84 ± 3.48	17.611 ± 0.016	17.849 ± 0.026	17.874 ± 0.047	18.013 ± 0.077	18.085 ± 0.127
APWD02	03 06 34.72	+48 59 13.7	+33.44 ± 5.26	−29.61 ± 4.99	18.130 ± 0.024	18.267 ± 0.028	18.366 ± 0.060	18.197 ± 0.087	18.801 ± 0.228
APWD03	03 06 41.73	+48 44 43.5	+17.44 ± 7.84	−36.12 ± 7.33	18.712 ± 0.037	18.682 ± 0.0411	18.637 ± 0.087	18.816 ± 0.156	18.581 ± 0.181
APWD04	03 09 02.57	+45 52 34.2	+22.98 ± 4.98	−16.64 ± 4.86	18.705 ± 0.035	18.889 ± 0.050	18.904 ± 0.083	–	+19.513 ± 0.389
APWD05	03 13 32.30	+50 01 54.2	+30.26 ± 4.17	−20.65 ± 3.96	17.605 ± 0.021	17.828 ± 0.029	17.866 ± 0.046	17.731 ± 0.080	17.962 ± 0.107
APWD06	03 14 18.43	+51 36 08.7	+20.67 ± 6.33	−20.38 ± 5.89	18.750 ± 0.040	18.801 ± 0.060	18.924 ± 0.118	–	–
APWD07	03 15 27.46	+45 51 48.0	+13.57 ± 5.76	−15.68 ± 5.51	18.076 ± 0.022	18.333 ± 0.032	18.492 ± 0.058	–	–
APWD08	03 15 41.48	+46 52 11.0	+7.00 ± 2.93	−13.24 ± 2.96	15.692 ± 0.005	15.883 ± 0.007	15.895 ± 0.0105	15.958 ± 0.0173	16.025 ± 0.026
APWD09	03 17 13.62	+44 45 17.0	+17.66 ± 7.92	−22.18 ± 7.66	18.037 ± 0.021	18.177 ± 0.029	18.163 ± 0.044	18.124 ± 0.089	18.636 ± 0.263
APWD10	03 17 50.09	+47 02 07.7	+32.45 ± 5.09	−16.76 ± 4.97	18.274 ± 0.032	18.564 ± 0.052	18.558 ± 0.105	18.426 ± 0.150	–
APWD11	03 22 02.12	+49 40 34.8	+23.62 ± 5.63	−38.04 ± 5.62	17.775 ± 0.019	17.961 ± 0.030	17.933 ± 0.047	17.950 ± 0.086	17.972 ± 0.112
APWD12	03 34 51.78	+47 07 17.1	+30.12 ± 6.78	−17.03 ± 6.70	18.473 ± 0.029	18.528 ± 0.038	18.612 ± 0.067	18.445 ± 0.138	18.688 ± 0.213
APWD13	03 37 12.37	+49 01 42.9	+13.30 ± 4.57	−47.27 ± 4.57	18.562 ± 0.031	18.746 ± 0.047	18.858 ± 0.089	–	–
APWD14	03 38 01.60	+49 25 35.6	+35.39 ± 5.06	−31.18 ± 5.06	18.596 ± 0.0301	18.668 ± 0.042	18.620 ± 0.068	18.565 ± 0.166	–

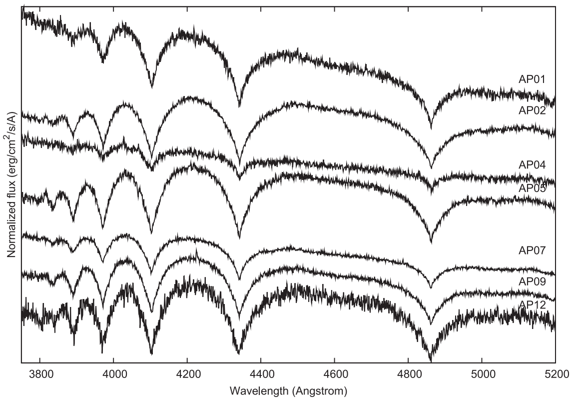

Figure 4. ISIS spectra of the seven DA WDs.

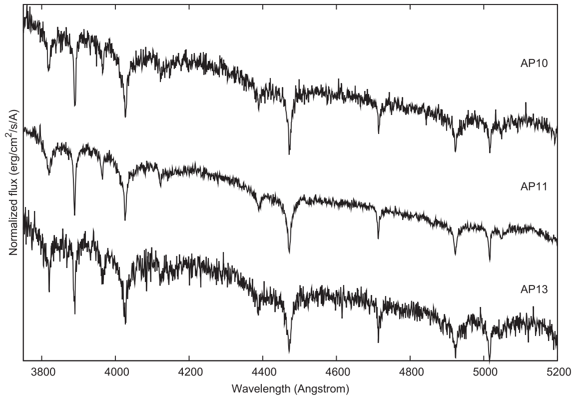

Figure 5. ISIS spectra of the three DB WDs.

explicitly the eight lowest energy levels and represents levels n = 9–80 by a single superlevel. The dissolution of the high lying levels was treated by means of the occupation probability formalizm of Hummer & Mihalas (1988) generalized to the non-LTE atmosphere situation by Hubeny, Hummer & Lanz (1994). All calculations include the bound–free and free–free opacities of the H^- ion and incorporate a full treatment for the blanketing effects of H I lines and the Lyman α, β and γ satellite opacities as computed by N. Allard (Allard et al. 2004). During the calculation of the model structure the lines of the Lyman and Balmer series were treated by means of an Approximate Stark profile but in the spectral synthesis step detailed profiles for the Balmer lines were calculated from the Stark broadening tables of Lemke (1997). The grid of model spectra covered the $T_{\rm eff}$ range of 13000–20000 K in steps of 1000 K and log g between 7.5 and 8.5 in steps of 0.1 dex. These models have been used throughout our work on the IFMR and we continue to use them in this work for consistency.

We used FITSB2 to fit our grid of model spectra to the DA WD spectra using the seven Balmer absorption lines (H α is not in the observed wavelength range) ranging from H β to H 10. Points in the observed data lying more than 3σ from the model were clipped from subsequent iterations of the fitting process (Fig. 4). We list the results of model fitting for the DA WDs in Table 2.

The effective temperature and surface gravity of the DBs was measured by comparing the normalized observed energy distribution with the wavelength range 3750–5150 Å to a grid of similarly normalized synthetic spectra. These were generated using ATM and SYN, tuned for the treatment of helium-rich atmospheres. The model fitting was undertaken using XSPEC as in Baxter et al. (2014) and the results can be seen in Fig. 5.

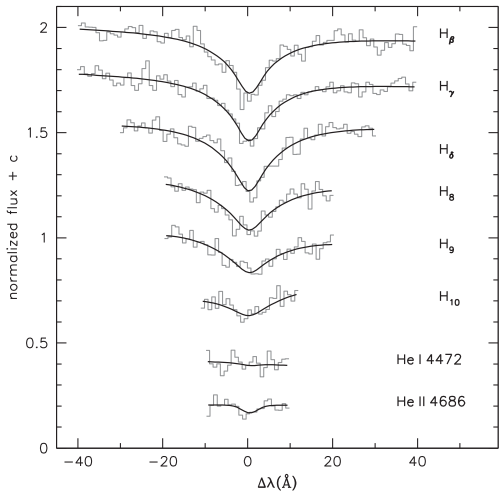

Figure 6. $T_{\rm eff}$ and log g fit of APWD08, the sdOB star. The fit is the thick black line, and the data are shown as the lower resolution histogram.

The remaining object APWD08 was determined to be a hydrogen-rich sdOB star (Fig. 6). The atmospheric parameters were derived as described in Geier et al. (2011) by fitting model spectra calculated in LTE and adopting a metal content of 10 times the solar value to account for known peculiarities in hot subdwarf atmospheres caused by diffusion (O'Toole & Heber 2006). Assuming the canonical sdB mass of 0.47 $M_\odot$, the distance to APWD08 is ∼2 kpc, and therefore it is definitely not a α Per member.

The errors given in Table 2 for $T_{\rm eff}$ and log g are formal fitting errors and are unrealistically small as they neglect systematic

Table 2. ID, $T_{\rm eff}$, log g, and calculated mass and radii for the 11 observed α Per candidate WDs.

ID	$T_{\rm eff}$ (K)	log g	Mass ($M_\odot$)	Radius ($R_\odot$)	Cooling age (Myr)
APWD01	26804 ± 190	8.48 ± 0.03	0.93 ± 0.04	0.938 ± 0.084	92.3 ± 16.8
APWD02	14138 ± 116	8.35 ± 0.02	0.83 ± 0.05	1.034 ± 0.093	406.3 ± 52.9
APWD04	35138 ± 295	7.89 ± 0.05	0.60 ± 0.03	1.498 ± 0.133	5.2 ± 0.4
APWD05	15182 ± 109	7.84 ± 0.02	0.53 ± 0.04	1.493 ± 0.133	145.8 ± 20.0
APWD07	24409 ± 145	7.99 ± 0.02	0.63 ± 0.03	1.356 ± 0.085	24.5 ± 4.1
APWD08	38600 ± 700	5.64 ± 0.08	–	–	–
APWD09	12582 ± 140	8.40 ± 0.02	0.86 ± 0.05	0.993 ± 0.090	607.4 ± 79.9
APWD10	16180 ± 190	8.03 ± 0.09	0.61 ± 0.03	1.280 ± 0.080	174.9 ± 17.6
APWD11	15850 ± 80	8.09 ± 0.04	0.64 ± 0.03	1.227 ± 0.077	203.6 ± 19.2
APWD12	13858 ± 315	7.93 ± 0.05	0.57 ± 0.03	1.388 ± 0.087	225.6 ± 23.1
APWD13	16760 ± 205	8.12 ± 0.09	0.66 ± 0.03	1.202 ± 0.076	177.7 ± 17.5

Table 3. Gravitational redshift and radial velocity for the 11 observed α Per candidate WDs.

ID	V_{gr} (km s^{-1})	RV (km s^{-1})
APWD01	62.95 ± 3.00	− 42.95 ± 17.06
APWD02	50.96 ± 7.42	15.23 ± 10.91
APWD04	25.56 ± 3.74	93.00 ± 8.83
APWD05	22.37 ± 3.55	15.09 ± 8.75
APWD07	29.46 ± 3.15	− 38.82 ± 8.60
APWD09	54.98 ± 7.96	− 57.92 ± 11.28
APWD10	30.36 ± 3.34	49.94 ± 8.67
APWD11	33.46 ± 3.65	− 12.16 ± 8.79
APWD12	35.31 ± 5.46	− 102.59 ± 9.69
APWD13	35.18 ± 3.83	− 20.18 ± 8.87

uncertainties, e.g. flat fielding errors and model shortcomings. In subsequent discussion here we follow Napiwotzki, Green & Saffer (1999) and assume an uncertainty of 2.3 per cent in $T_{\rm eff}$ and 0.07 dex in log g for the DA WDs, and an error of 2.0 per cent in $T_{\rm eff}$ and 0.05 dex in log g as in Bergeron et al. (2011) for the DB WDs. Both fitting programs also fit radial velocity. These were measured for the DA WDs using H β and H γ, and the He lines for the DB WDs (Tables 2 and 3).

5 CLUSTER MEMBERSHIP OF WDS

As in our earlier work (e.g. Casewell et al. 2009), we have utilized a grid of evolutionary models based on a mixed CO core composition and a thick H surface layer (e.g. Fontaine, Brassard & Bergeron 2001) to estimate the mass and cooling time of each DA WD from our measurements of effective temperature and surface gravity (see Table 2). The same models, but with a thin H surface layer were used for the DB WDs. Cubic splines have been used to interpolate between the points within these grids. The lifetime of the progenitor star of each WD has then been calculated by subtracting the cooling time from the age of the cluster (90 ± 10 Myr: Stauffer et al. 1999). Examining these cooling times, it is clear that only three objects have cooling times that are less than the cluster age, APWD01, APWD04 and APWD07. The rest are much older, and are likely to be field objects. To constrain the mass of the progenitor star for these three objects, we have used the stellar evolution models of Girardi et al. (2000) for solar metallicity, again using cubic splines to interpolate between the points in the grid. Assuming they are members of α Per, the progenitor mass for APWD01 is 6.185 ± 0.402 $M_\odot$, APWD04 is 5.629 ± 0.279$M_\odot$ and APWD07 is 5.734 ± 0.305 $M_\odot$. Both of the progenitor masses for APWD04 and APWD07 put these objects well below any semi-empirical and theoretical IFMR derived from cluster objects (Fig. 7). APWD01 does however, look as though it may be a cluster member from its position on the diagram.

The cluster radial velocity of α Per is −1.6 km s^{-1} (van Leeuwen 2009) and using the mass and radius in Table 2, the gravitational redshift and hence the absolute radial velocity of the candidate cluster members was determined (Table 3, Fig. 3). It can be seen that none of the candidates have a radial velocity that is consistent with membership once the errors are taken into account, although APWD02 and APWD11 are closest to the cluster value. However, from Table 2, the cooling age of these WDs is much too long for them to be cluster members, and so we conclude that none of the WDs studied here are members of the α Per open star cluster.

6 DISCUSSION ON THE NUMBER OF WD MEMBERS OF α PER

Our results were disappointing, as although we had a high level of success in identifying new WDs, none are cluster members, despite

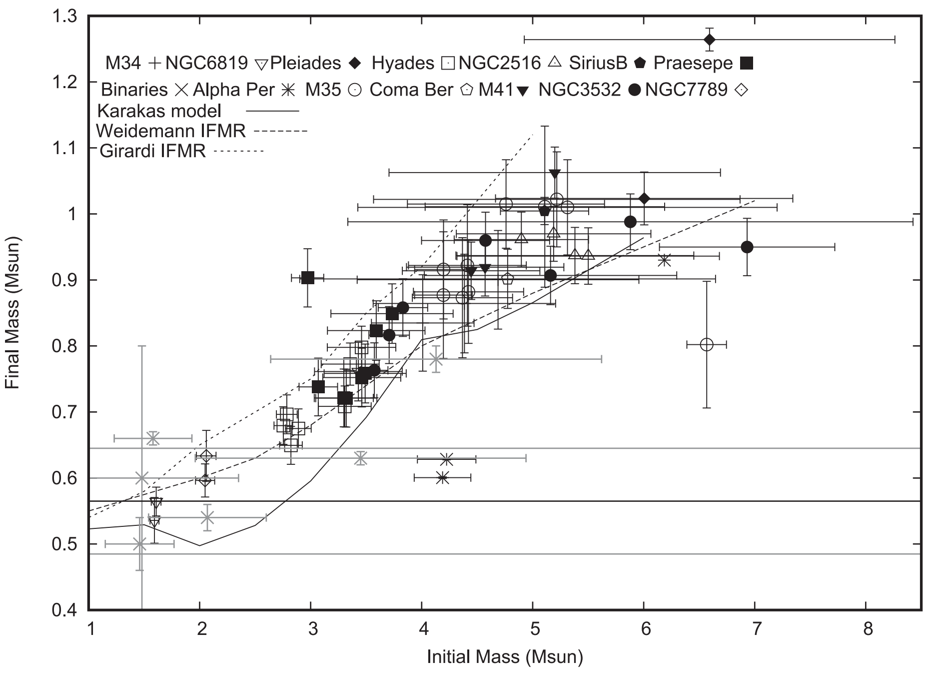

Figure 7. The IFMR of the available cluster and wide binaries data showing the position of the three α Per candidate members. The dashed black line is the semi-empirical Weidemann (2000) IFMR, the thick solid line is the IFMR as given by the Girardi et al. (2000) models and the grey dot–dashed line is the initial mass–core mass at the first thermal pulse relation from Karakas, Lattanzio & Pols (2002). The peak in the field WD mass distribution (thin solid line) and ± 1σ is represented by the thin dotted lines. The plotted WDs are from Weidemann (1987), Weidemann (2000), Ferrario et al. (2005), Dobbie et al. (2006), Williams & Bolte (2007), Catalán et al. (2008), Kalirai et al. (2008), Rubin et al. (2008), Casewell et al. (2009), Dobbie et al. (2009) and Williams et al. (2009).

the mass functions suggesting at least one WD member is possible. As α Per is young, we do not expect it to contain many WDs – the Pleiades only contains one, LB1497 (Eggen & Greenstein 1965), and an additional object GD50, that may belong to the Pleiades moving group (Dobbie et al. 2006). The fact that we have identified 11 WD candidates, 10 of which are bona fide degenerates in the vicinity of α Per, and yet none are cluster members is perhaps highlighting the scarcity of WDs in 100 Myr old clusters.

There is also a known deficit of WDs in open clusters (Weidemann et al. 1992; von Hippel 1998). This has been attributed in part to dynamical evolution causing WDs to evaporate from clusters. Mass segregation alone is not sufficient to remove WDs, as the average mass of a WD ($\sim$0.6 $M_{\odot}$) is still more massive than most open cluster members and so is unlikely to suffer any effects to preferentially remove them from the cluster (e.g. Hurley & Shara 2003; Baumgardt & Makino 2003. It has however, been suggested that a velocity kick resulting from asymmetrical mass-loss during post-main-sequence evolution may preferentially remove WDs from a cluster (Weidemann et al. 1992; Fellhauer et al. 2003). As α Per is younger than the Pleiades and so it is unlikely significant mass segregation has occurred within the cluster (Moraux et al. 2003). The answer to our question may simply be that α Per did not form many intermediate mass star WD progenitors.

The age of α Per is 90 $\pm$ 10 Myr from measurements of the lithium depletion boundary (Stauffer et al. 1999). By using the models of Girardi et al. (2000), we determined the mass of a star that has a main-sequence lifetime of 100 Myr to be 5.36 $M_{\odot}$. This is the minimum stellar mass required to form a WD in α Per. We then combined this stellar mass with the IFMR presented in Casewell et al. (2009), to give a WD final mass of 1.0 $M_{\odot}$. This is the least massive WD predicted to exist in the cluster. Such a WD would have practically no cooling time.

We used the same method to determine the maximum mass of a star that could form a WD (assuming the maximum mass of a WD is 1.4 $M_{\odot}$, which gives an initial mass of 8.71 $M_{\odot}$. Such a star has a main-sequence lifetime of 4 Myr, and hence a maximum cooling age of 96 Myr. The models of Fontaine et al. (2001) give such a WD a $T_{\rm eff}$ of 40 000 K and a log g of 9.27, much higher than any of the WDs detected in our survey. Indeed, even though the highest mass the Holberg & Bergeron (2006) synthetic colours cover is 1.2 $M_{\odot}$, such a WD should have a J magnitude of 18.188 and $J - H = 0.114$ and $J - K = -0.218$. Seven of the selected WD candidates are fainter than this, however the majority have the correct colours suggesting that the colour cuts made were reasonable. It may be that simply no WDs have formed within the cluster age. This would appear to be borne out by the survey of Heckmann & Luebeck (1958) who discovered three B3 stars, one of which is a subgiant within the cluster, and nothing of earlier spectral types. These data were used by Lodieu et al. (2012) who created a detailed mass function of the cluster, but again, the highest mass stars discovered in the cluster to date are 5 $M_{\odot}$, and there are 8 $\pm$ 3 stars in this mass bin which ranges from 4.13 to 5 $M_{\odot}$. Extrapolating this relationship into the region we are interested in gives $\sim$1.4 high-mass stars at 5.36 $M_{\odot}$ and only $\sim$0.4 at 8.71 $M_{\odot}$ assuming a bin size of 1 $M_{\odot}$, again confirming the hypothesis that there are very few, if any, high enough mass stars in α Per to form high mass WDs at this young age.

Another possible scenario is that the WDs remain bound to the cluster, but are hidden in binary systems, as for the Hyades (Boehm-Vitense 1993; Franz et al. 1998; Debernardi et al. 2000). Williams (2004) simulated three clusters to investigate the initial mass functions and the probability of hidden high mass WDs in binaries. They found that for the Pleiades, their simulations agreed with the observations and that LB1497 is likely to be the only WD in the cluster. Their work on Praesepe and the Hyades however, highlighted the lack of high mass WDs, and they suggest that it is more likely for high mass progenitor stars to be located in binaries with massive evolved stars, than with lower mass companions, thus making them less likely to be detected. It may be that any high mass WD members of the cluster are in such binaries, but again, the lack of high-mass stars in general in α Per makes it seem unlikely.

The final scenario to consider is that the WD candidates in this work were selected for their high reliability of being WDs, which was prioritized over the completeness of the survey. The UKIDSS GCS is estimated as being 100 per cent complete over the magnitude range we studied (Lodieu et al. 2012), and the image morphology selection of class $= -1$, ensures only stellar-like sources are selected, although this is known to be conservative. The SuperCOSMOS data however, was cross-matched to this clean GCS sample, and even using the COSMOS crowded field algorithm, it is estimated that the completeness is only 60 per cent at this low Galactic latitude (Beard, MacGillivray & Thanisch 1990). This low completeness will dominate our survey and may mean we have potentially missed the one or two expected WD cluster members. The data from *Gaia* should locate any missing WDs in this cluster, should they be there.

7 SUMMARY

We have obtained spectra of 11 WD candidate members of the α Per open star cluster, and confirmed that while seven are DA WDs, three are DB WDs and one is an sdOB star, none are cluster members. This result is disappointing, as recent work on the cluster mass function suggests that there should be at least one WD member, even at this young age. It may be that any WD members of α Per are hidden within binary systems, as is the case in the Hyades cluster, however the lack of high-mass stars within the cluster also makes this seem unlikely. We also conclude that the high level of incompleteness in the SuperCOSMOS survey may mean that we have missed any WD members, although *Gaia* is likely to locate them, should they exist.

ACKNOWLEDGEMENTS

SLC acknowledges the support of the College of Science and Engineering at the University of Leicester. NL was funded by the Ramón y Cajal fellowship number 08-303-01-02. Based on observations made with the William Herschel Telescope operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias. The UKIDSS project is defined in Lawrence et al. (2007). UKIDSS uses the UKIRT Wide Field Camera (WFCAM; Casali et al. 2007 and a photometric system described in Hewett et al. (2006). The pipeline processing and science archive are described in Irwin et al. (in preparation) and Hambly et al. (2008). This research has made use of data obtained from the SuperCOSMOS Science Archive, prepared and hosted by the Wide Field Astronomy Unit, Institute for Astronomy, University of Edinburgh, which is funded by the UK Science and Technology Facilities Council. This research has also made use of NASA's Astrophysics Data System.

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