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Cluster White Dwarfs and the Initial Mass-Final Mass Relation

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Abstract. Many cluster white dwarfs are used to define the semi-empirical initial mass-final mass relation, however, the high mass and low mass ends remain very poorly sampled. We present the results of a search for new white dwarf members of the young α Persei cluster. We determine that 10 of the 11 objects observed are white dwarfs, however analysis of their masses and cooling times, shows that none are likely to be cluster members.

1. Introduction

The initial mass-final mass relation (IFMR) is a theoretically predicted positive correlation between the main sequence mass of a star with $M \lesssim 10\ M_\odot$ and the mass of the white dwarf remnant left behind after it has expired (e.g. Iben & Renzini 1983). Understanding the form of this relation is important since it provides a handle on the total amount of gas enriched with He, N and other metals low or intermediate mass stars, which account for 95 per cent of all stars, return to the interstellar medium at the end of their lifecycles. Moreover, 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.

The form of the IFMR is extremely difficult to predict from theory alone 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 are by no means simple to obtain, a significant difficulty being the determination of the main sequence mass of a star that has long since ceased to exist. This difficulty can be alleviated by investigating white dwarf members of open star clusters (Weidemann 1977, 2000; Dobbie et al. 2006). Here, since the age of the population can be determined from the location of the main sequence turn-off (King et al. 2005), the lifetime, and ultimately the mass, of the progenitor star of any degenerate member can be estimated by calculating the difference between the cooling time of the white dwarf and the cluster age.

Recent years 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 white dwarfs (e.g. Kalirai et al. 2007; Williams et al. 2009; Casewell et al. 2009; Dobbie et al. 2009). However, despite clear headway, the IFMR remains very poorly sampled by observations for $M_{init} \gtrsim 5.5\text{-}6 M_\odot$. Indeed, there are only a handful of white dwarfs here (Williams et al. 2009, Dobbie et al. in prep). So, while 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 UKIRT Infrared Sky Survey Galactic Cluster 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, m-M=6.18±0.03 (van Leeuwen 2009) and despite residing at low Galactic latitude, foreground extinction is low, E_{B-V}<0.1. 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 ($\mu_\alpha \cos\delta$, μ_δ ~+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, τ=90±10Myr (corresponding to $M_{\rm initial}$~5.5$M_\odot$), via the lithium depletion boundary technique (Stauffer et al. 1999), helping to minimise uncertainty in the progenitor mass determinations. Moreover, α-Per is sufficiently old for white dwarfs to have formed, but young enough that the oldest and probably most massive of these remain at $T_{\rm eff}\gtrsim$12500K where numerous investigations have shown that the modelling is reliable (Bergeron et al. 1995).

2. Data Analysis and Reduction

We used the model white dwarf photometry of Holberg & Bergeron (2006) to predict the UKIDSS colours of likely α per white dwarfs. These predictions informed our selection criteria. We selected all blue objects between RA of 42 and 58 degrees, and dec of 40 and 55 degrees from the UKIDSS GCS (Figure 1; Lawrence et al. 2007) with Z > 15.0, J <= 19.25. The upper limits on the J magnitude is a conservative limit based on τ=120Myr, m-M=6.27 and E_{B-V}=0.1 (van Leeuwen 2009). These criteria resulted in the selection of over 2000 objects which were then cross-matched with the SuperCosmos Sky Survey (Hambly et al. 2001) within 2". The cross-matched sample was then further selected by proper motion, requesting 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. We then performed an additional cut to remove 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 were then left with 26 objects, which was thinned down to 14 after examining the blend flags on the Supercosmos data and the images.

To accurately measure their effective temperatures and surface gravities, reliably assess their cluster membership status and estimate their initial and final masses, we obtained low resolution optical spectroscopy of the 11 brightest candidates using the Intermediate dispersion Spectrograph and Imaging System (ISIS) on the William Herschel Telescope on La Palma.

The data were reduced using IRAF as detailed in Dobbie et al. (2006).

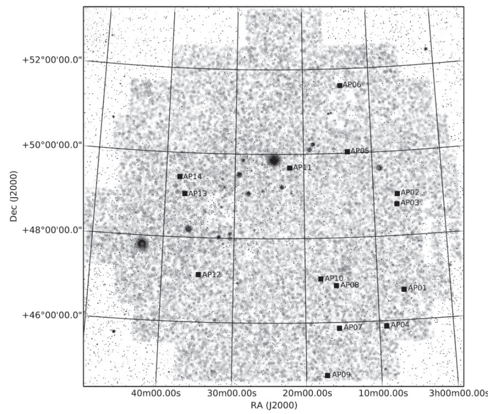

Figure 1. The area surveyed in α Per. Candidate white dwarfs are marked.

3. Determination of White Dwarf Parameters

After the data were reduced it became clear that 7 of the white dwarfs were DA white dwarfs, 3 were DB white dwarfs and one object was an sdB star. As we did in Casewell et al. (2009), the spectra were compared to the predictions of white dwarf model atmospheres using the spectral fitting programme FITS2B (Napiwotzki et al. 2004). For the DA white dwarfs, the same grid of pure hydrogen model spectra was used as in Casewell et al. (2009) and 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. The DB white dwarfs were fit using models from Koester (2010) combined with a cubic polynomial. The results can be seen in Table 1.

As in our earlier work (e.g. Casewell et al. 2009), we have utilised a grid of evolutionary models based on a mixed CO core composition and a thick H surface layer (Fontaine et al. 2001) to estimate the mass and cooling time of each DA white dwarf from our measurements of effective temperature and surface gravity (see Table 1). The same models, but with a thin H surface layer were used for the DB white dwarfs. Cubic splines have been used to interpolate between the points within these grids. The lifetime of the progenitor star of each white dwarf 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 (Table 1), it is clear that only two objects have cooling times that are less than the cluster age, AP04 and AP07. The rest are much older, and are likely to be field objects.

To constrain the mass of the progenitor star for these two 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. The initial and final masses of AP04 and AP07 are plotted on the IFMR in Figure 2. It can be seen that these objects sit much lower than the bulk of the objects, and as they are not especially high mass white dwarfs, it is unlikely that they are cluster members, although analysis of the radial velocities will prove this conclusively.

Table 1. The measured effective temperatures, log g, and cooling ages for the 11 white dwarfs.

Name	T_{eff} K	log g dex	Cooling age Myr
AP01	26804±190	8.48±0.03	172.48±25.88
AP02	14138±116	8.35±0.02	406.25±52.95
AP04	35138±295	7.89±0.05	5.19±0.42
AP05	15182±109	7.84±0.02	145.81±20.04
AP07	24409±145	7.99±0.02	24.52±4.06
AP09	12582±140	8.40±0.02	607.38±79.96
AP10	16180±190	8.03±0.09	174.93±17.64
AP11	15850±80	8.09±0.04	203.62±19.20
AP12	13858±315	7.93±0.05	299.67±37.06
AP13	16760±205	8.12±0.09	177.69±17.51

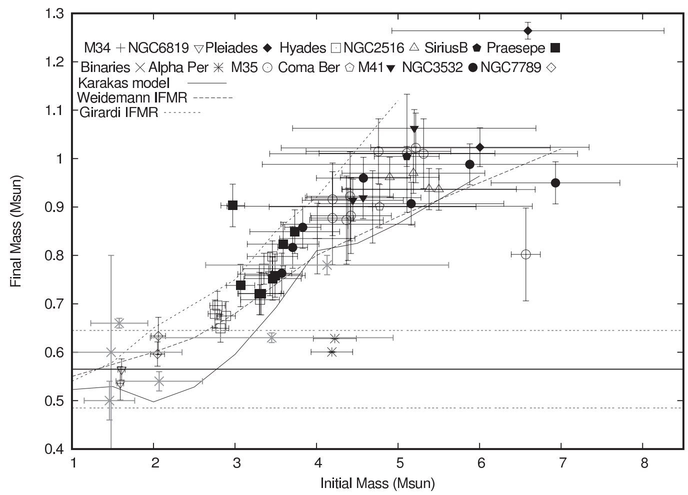

Figure 2. The IFMR of the available cluster and wide binaries data showing the position of the two α Per candidate members. The dashed black line is the semi-empirical Weidemann (2000) IFMR, the thick solid line is the IFMR as given by the Girardi et al. (2000) models and the grey dot-dashed line is the initial mass-core mass at the first thermal pulse relation from Karakas, Lattanzio, & Pols (2002). The peak in the field white dwarf mass distribution (thin solid line) and $\pm 1\sigma$ is represented by the thin dotted lines. The plotted white dwarfs are from Weidemann (1987, 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); Williams et al. (2009).

4. Conclusions

We have discovered 14 white dwarf candidate cluster members of α Per. Spectroscopy of 11 of these objects proved that 10 were indeed white dwarfs, but analysis of their cooling times and masses shows that all are unlikely to be members of the cluster.

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