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On the radial distribution of white dwarfs in the Galactic globular cluster ω Cen

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Abstract. We present deep and accurate photometry ($F435W$, $F625W$, $F658N$) of the Galactic Globular Cluster ω Cen collected with the Advanced Camera for Surveys (ACS) on board the Hubble Space Telescope (HST). We identified $\approx 6,500$ white dwarf (WD) candidates and compared their radial distribution with that of Main Sequence (MS) stars. We found a mild evidence that young WDs ($0.1 \lesssim t \lesssim 0.6$ Gyr) are less centrally concentrated when compared to MS stars in the magnitude range 25$\leq F435W \leq$26.5.

Key words. globular clusters: general — globular clusters: Omega Centauri

1. Introduction

The observation of white dwarfs (WDs) in Galactic Globular clusters (GGCs) presents some undisputed advantages: *1)* - They are located at the same distance and have approximately the same reddening. Moreover, the colors of WDs are, at all luminosities, systematically bluer than those of Main Sequence (MS) stars. This means that we can use a Color-Magnitude Diagram (CMD) instead of a color-color plane to identify cluster WDs. Therefore, WDs in GGCs are not affected by color degeneracy with MS stars such as field WDs (Hansen & Liebert 2003); *2)* - According to current evolutionary predictions in a GGC with an age of $\approx$ 12 Gyr and by assuming a Salpeter-like initial mass function ($\alpha = 2.35$) the number of WDs is three orders of magnitude larger than the number of Horizontal Branch (HB) stars (Brocato et al. 1999). This, together with the high stellar concentration of GGCs, implies that the expected local density of WDs in these

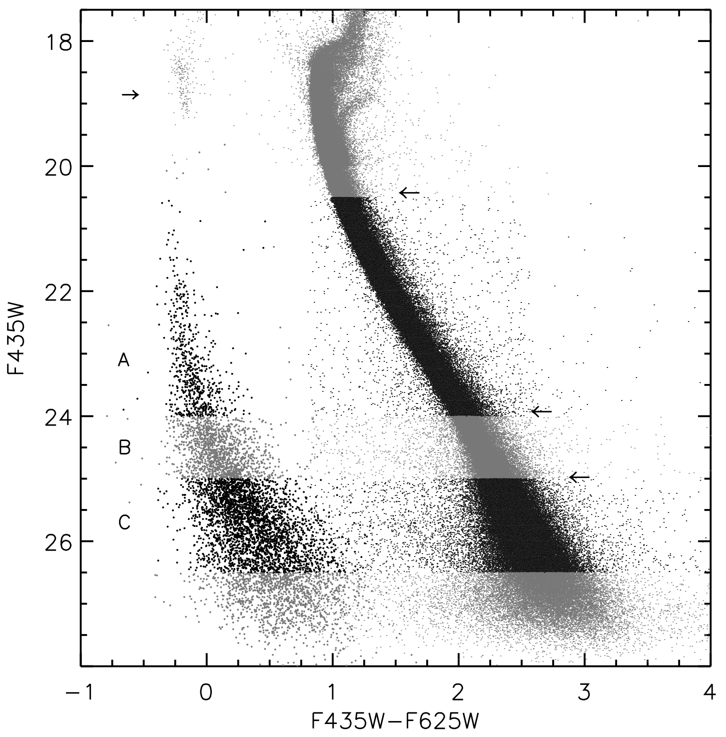

Fig. 1. *F435W*, *F435W* − *F625W* CMD based on deep images collected with ACS@HST and reduced with ROMAFOT for the WD cooling sequence and shallow and deep images reduced with ALLFRAME for the MS. The different grey levels indicate the WD and MS samples selected for the radial distributions. The right arrows mark the bright magnitude levels of the selected MS samples. The left arrow indicates the EHB stars. The letters mark the selections along the WD cooling sequence.

systems is several orders of magnitude higher than the local density in the Galactic field;
3) - We can trace back the evolutionary properties of the progenitors of cluster WDs, since both the chemical composition and the age of GGCs are well known (Kalirai et al. 2007). However, the observation of WDs in GGCs also presents a drawback: cluster WDs are faint stars and are severely affected by crowding problems. Therefore, both photometry and medium resolution spectroscopy are difficult even for 8m class telescopes (Moehler et al. 2004). In a previous investigation based on three out of nine pointings of the Advanced Camera for Surveys (ACS) on board the Hubble Space Telescope (HST), we have already addressed the properties of WDs in ω Cen (Monelli et al 2005, hereafter MO05). Furthermore, Calamida et al. (2007, hereafter CA07), based on eight out of the nine ACS pointings, identified $\approx 6,500$ WD candidates. They found that the ratio of WD and MS star counts is at least a factor of two larger than the ratio of CO-core WD cooling times and MS lifetimes. The presence of He-core WDs might explain the observed star counts, and the required fraction of He-core WDs ranges from 10% to 80%, depending on their mean mass. We now adopt our sample of WD candidates to investigate their radial distribution. Recent observations of WDs in M4 and NGC 6397 (Davis et al. 2006; 2007) showed that young WDs ($t \leq 1$ Gyr) are less centrally concentrated than either older WDs or progenitor MS stars. Davis et al. suggest that these WDs are born with a natal kick, starting their life with

a larger velocity dispersion when compared to the velocity of neighboring stars. Therefore, within a short time scale, the young WDs would acquire a more extended radial distribution. In order to explain this evidence, the authors suggest that these WDs have acquired a kick during their asymptotic giant branch phase caused by a slightly asymmetric mass loss (Spruit 1998; Heyl 2007).

2. Observations and data reduction

Multiband ($F435W$, $F625W$, $F658N$) photometric data collected with the ACS on board the HST were retrieved from the HST archive. The current data set includes eight out of the nine pointings located across the cluster center that have already been discussed by Castellani et al. (2007, see their Fig. 1). The central pointing of the 3×3 mosaic was omitted due to the severe crowding of the innermost regions. For each pointing four images in three different bands were acquired. The $F435W$- and $F625W$-band data consist of one shallow (8s) and three deep (340s each) exposures, while the $F658N$-band data consist of four exposures of 440s each per field. The raw frames were pre-reduced by the standard HST pipeline. The photometric catalogs (96) were rescaled to a common geometrical system with `DAOMATCH/DAOMASTER`, and the entire set of images was then re-reduced simultaneously with `DAOPHOT IV/ALLFRAME`. The final catalog includes more than one million stars having at least one measurement in two different photometric bands. The photometry was kept in the Vega system following the prescriptions suggested by Sirianni et al. (2005).

We then selected, from the final ALLFRAME catalog, all the stars systematically bluer than MS stars and fainter than extreme HB (EHB) stars ($F435W \lesssim 20$), ending up with a sample of $\approx 60{,}000$ stars. The photometry of these stars was performed once again using ROMAFOT (Buonanno & Iannicola 1989), but only for the deep exposures, namely three $F435W$, three $F625W$, and four $F658N$ images per pointing. Individual stars have been interactively checked in every image, and the WD candidates were measured either as isolated stars or together with neighbor stars in simultaneous joint solutions. Note that most of the neighbor stars located close to WD candidates are truly MS stars, i.e., they did not belong to the original sample of stars located on the blue side of the MS. A significant fraction of the originally selected detections turned out to be either cosmic rays or spurious detections close to saturated stars, or detections too faint to be reliably measured on individual images. Fig. 1 shows the $F435W$, $F435W - F625W$ CMD based on the ROMAFOT photometry for the refined sample of WD candidates and on the ALLFRAME photometry for the MS, the sub-giant branch and the EHB stars. Data plotted in this figure show that the cluster WD candidates ($\sim$ 6500) are distributed along a well defined star sequence fainter than EHB stars and systematically bluer than MS stars (MO05). To our knowledge this is the largest sample of cluster WD candidates ever detected (CA07).

3. Radial distributions

We adopted our sample of WD candidates to investigate the radial distribution of these stars in ω Cen . We selected WDs in three magnitude bins, namely $20.5 \leq F435W \leq 24$ (A, see Fig. 1), $24 \leq F435W \leq 25$ (B), and $25 \leq F435W \leq 26.5$ (C). In order to estimate the cooling times of these WD samples, we adopted a predicted cooling sequence for a CO-core and H-rich envelope WD ($M = 0.5M_{\odot}$) by Althaus, & Benvenuto (1998). The theoretical predictions were transformed into the observational plane by adopting the pure H atmosphere model computed by Koester, & Wolff (2000) and by Koester et al. (2005, for more details see CA07). The corresponding cooling times are: $t \lesssim 20$ Myr (A), $t \lesssim 120$ Myr (B), and $t \lesssim 570$ Myr (C).

In order to compare the radial distributions of WDs with those of MS stars, we selected MS stars in the same three magnitude bins (see Fig. 1). Note that the selection of MS stars is based on the ALLFRAME catalog, while the selection of WDs is based on the ROMAFOT catalog. For the former data set the complete-

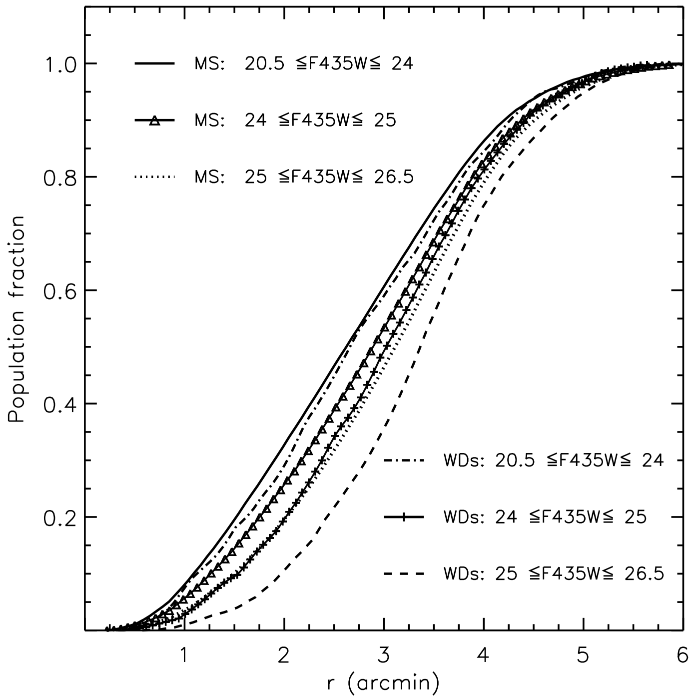

Fig. 2. Cumulative radial distributions of WD and MS stars. The different samples are shown with different lines labeled on the figure.

ness along the MS is ≈ 80% at $F435W = 24$. In order to have approximately the same completeness for WDs and MS stars, we compared the radial distributions of stars in the same magnitude bins.

Fig. 2 shows the six cumulative radial distributions. The WD and MS star radial distributions are in agreement, within the uncertainties, for the bright magnitude bin ($20.5 \leq F435W \leq 24$). On the other hand, the WD radial distribution appears to be less centrally concentrated compared to the MS profile in the case of the intermediate ($24 \leq F435W \leq 25$) and of the faint ($25 \leq F435W \leq 26.5$) magnitude bins. The difference between the three MS radial distributions could be due to completeness problems (the crowding would affect more the fainter stars) or to the presence of mass segregation. Ferraro et al. (2006), based on ACS@HST and WFI@2.2m photometric data of ω Cen , showed that the Blue Stragglers radial distribution do not differ from the red giant branch and HB distributions, up to a distance of 20' from the cluster center. This evidence would suggest that ω Cen is not a fully relaxed stellar system. However, the relaxation time at the core radius is $t_{r_c} \sim 5.4$ Gyr, much shorter that the cluster age ($t \approx 12 - 13$ Gyr), and some mass segregation should be observable. In order to assess if mass segregation is really present in ω Cen , we should first estimate the completeness along the MS up to $F435W \sim 26.5$. On the other hand, there is a mild evidence of a deficiency of WDs in the cluster center ($r \lesssim 6'$), as shown by the discrepancy between WD and MS star radial distributions in two magnitude bins (see Fig. 2).

4. Conclusions

We adopted our sample of ≈ 6,500 WD candidates to compare their radial distribution with that of MS stars. We selected WDs and MS stars in three $F435W$-band magnitude bins in order to have approximately the same completness level. We found a mild evidence that young WDs ($0.1 \lesssim t \lesssim 0.6$ Gyr) are less centrally concentrated when compared to MS stars in the magnitude range $25 \leq F435W \leq 26.5$. This evidence would support the results of Davis et al. (2006; 2007) who found that young WDs in NGC 6397 and M4 have an extended radial distribution when compared to the most massive MS stars in the clusters.

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