White Dwarfs in \( \omega \) Centauri: Preliminary Evidence

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Abstract. We present accurate and deep multiband B,R,H\(\alpha\) data for the globular cluster \( \omega \) Cen collected with the Advanced Camera for Surveys on HST. The photometric catalogue includes more than one million stars. By adopting severe selection criteria we identified more than 600 bona fide White Dwarfs (WDs). Empirical evidence suggests that a small sample of WDs are H\(\alpha\)-bright. The comparison between WD isochrones and observations shows a reasonable agreement at fainter magnitudes and a mismatch at the brighter ones.

1. Introduction

The Galactic Globular Cluster (GGC) \( \omega \) Cen is a fundamental laboratory to address several long-standing astrophysical problems. It is the most massive GGC (\( M = 5 \times 10^6 \, M_\odot \), Meylan et al. 1995) and the one that most clearly shows a well-defined spread in metallicity. According to recent estimates based on sizable samples of evolved red giant and sub-giant stars, the metallicity distribution shows three peaks around [Fe/H] = −1.7, −1.5, and −1.2 together with a tail of metal-rich stars approaching [Fe/H] \( \approx -0.5 \) (Norris et al. 1996; Hilker et al. 2004; Pancino 2004). During the last few years it has also been suggested that \( \omega \) Cen harbors multiple stellar populations (Lee et al. 1999) characterized by different ages (Ferraro et al. 2004; Hughes et al. 2004), helium abundances (Bedin et al. 2004; Norris 2004), and distances (Bedin et al. 2004; Freyhammer et al. 2004). From a kinematical point of view the properties of \( \omega \) Cen appear well-established: it moves along a high-eccentricity, retrograde orbit (Geyer et al. 1983), and shows differential rotation (Merritt et al. 1997). The occurrence of a tidal tail in \( \omega \) Cen was suggested by Leon et al. (2000) but questioned by Law et al. (2003) on the basis of 2MASS data. This problem has not been settled yet, because recent detailed N-body simulations of the tidal interaction between \( \omega \) Cen and the Galaxy do suggest the occurrence of extended tails (Chiba & Mizutani 2004). Current empirical and theoretical evidence do not allow us to establish whether \( \omega \) Cen is the core of a galaxy that was partially disrupted...
by the gravitational interaction with the Galaxy (Lee et al. 1999; Pancino 2004) or the aftermath of the merging of two GCs (Icke & Alcaino 1988).

Even though ω Cen presents several properties that need to be properly understood, its stellar content is a gold mine to investigate some open problems concerning the dependence on the metallicity. This applies not only to evolved stars such as RR Lyrae, hot HB stars, and the tip of the RG branch, but also to the different expected population(s) of white dwarfs. The search for WDs in GGCs has been quite successful, and several cooling sequences have already been identified (Hansen et al. 2002; Moehler et al. 2004, and references therein). The detection of WDs in ω Cen dates back to Ortolani & Rosino (1987) and to Elson et al. (1995) on the basis of ground-based and space (HST) data, respectively. In this paper, we present preliminary results concerning the identification of the WD cooling sequence in ω Cen on the basis of data collected with the Advanced Camera for Survey (ACS) on board HST, and publicly available on the HST archive.

2. Data Reduction and Color-Magnitude Diagrams

Current data were collected with nine pointings of the ACS camera across the center of the cluster. The 3 × 3 mosaic covers a field of view of ≈ 9′ × 9′. Four images per field have been acquired in three different bands, namely F435W, F625W, and F658N (hereinafter B, R, and Hα). Three deep (340s) and one shallow (8s, 12s) exposure were secured for the B and R-band, respectively, while the exposure time for the four Hα images was 440s. The nine fields were independently reduced with the DAOPHOTII/ALLFRAME package (Stetson 1994). An individual PSF has been extracted for each frame by adopting, on average, ≈200 bright isolated stars. The individual catalogues were rescaled to a common geometrical system with DAOMATCH/DAOMASTER. The final catalogue includes approximately 1.2×10^6 stars. The photometric calibration was performed in the Vega System (http://www.stsci.edu/hst/acs/documents). The same data set was adopted by Haggard et al. (2004) to identify the optical counterpart to a quiescent neutron star originally detected on X-ray data collected with Chandra.

Figure 1 shows the CMD of ω Cen in the B−R, B plane. Data plotted in this figure have been selected by using the ‘separation index’ sep introduced by Stetson et al. (2003). We adopted this parameter (sep ≥ 0.1) because crowding errors in the innermost regions of GGCs dominate the photometric errors. The WDs candidates have been selected among the objects with photometric errors in the three bands smaller than 0.2 mag. We end up with a sample of half a million cluster stars and roughly 600 WDs (thick points). To compare observed WDs with theoretical predictions we adopted the recent WD theoretical models computed by Prada Moroni & Straniero (2002). Predicted luminosities and effective temperatures have been transformed into the ACS bands by adopting the pure H atmosphere models kindly provided by Bergeron (private communication). The solid line plotted in Fig. 1 shows the WD isochrone for t=14 Gyr and Z=0.0001. We adopted the same distance modulus (DM=13.7) and cluster reddening (E(B-V)=0.12) adopted by Freyhammer et al. (2004). The extinction in the ACS bands was estimated using the Cardelli et al. (1989) rela-
Figure 1. Color-Magnitude Diagram, $B, B - R$, based on data collected with ACS@HST. The photometric catalogue was selected by assuming a separation index $sep \geq 0.1$. Thick points display WDs with photometric errors smaller than 0.2 mag. The solid line shows a WD isochrone for $t=14$ Gyr and $Z=0.0001$. See text for more details.

Theoretical and observational agreement appears to be at fainter magnitudes and cooler effective temperatures. However, we are faced with a substantial discrepancy in the bright region. At present it is not clear whether this mismatch is caused either by the assumed composition of the atmosphere models, or by the inner structure of the brightest WD models. More quantitative constraints do require a thorough comparison between theory and observations.

To further investigate the evolutionary properties of cluster WDs we plotted the same sample in the $H_\alpha - R, R$ plane (see Fig. 2).

This plane is generally adopted to detect stars with strong $H_\alpha$ emission, namely Cataclysmic Variables (CVs) or BY Draconis stars. The former group is characterized by flicker variations, while the latter group contains chromospherically active Main Sequence stars (dK,dM) with variability of the order of days caused by fast rotation. Recent photometric (Cool et al. 1998) and spectroscopic (Edmonds et al. 1999) measurements of a few blue stars in the GGC NGC6397 suggest that He WDs also show $H_\alpha$ emission, but they lack the flickering variations. Needless to say, that He WDs are excellent tracers of the dynamical properties of GGCs, since they are the aftermath of compact binary evolution (Taylor et al. 2001). Data plotted in Fig. 2 show that the WD sequence detected
Figure 2. Same as Fig. 1, but for $H\alpha$ and R-band photometry.

in the $B - R$, $B$ plane shows up also in this plane. The broadening in color when moving from $R \approx 22$ to $R \approx 24.5$ is mainly caused by photometric errors.

Figure 3. Intrinsic photometric error in $R$ (thin points) and $H\alpha$ (thick points) bands. Open circles mark WDs with $H\alpha - R \leq -0.2$, and $|\text{sharp}| \leq 0.1$. 
However, data plotted in this plane show quite clearly that a small sample of WDs are $H_\alpha$-bright. The identification of these objects is quite easy, since they show R magnitudes of the order of $R \approx 24 - 25$ but they appear systematically bluer than typical WDs. It is noteworthy that the identification of $H_\alpha$-bright WDs becomes more robust when moving toward bluer colors. In order to supply a more quantitative estimate of the photometric errors affecting current mean magnitudes, Fig. 3 shows the standard deviations for the R (thin points) and the $H_\alpha$ (thick points) mean magnitudes. To further improve the photometric characterization of $H_\alpha$-bright WDs we selected (open circles) the WDs with $H_\alpha - R \leq -0.2$ and $|\text{sharpness}| \leq 0.1$ (this parameter estimates the sharpness of the detected object). We end up with a sample of $\sim 70$ candidates. Data plotted in Fig. 3 show that typical errors for these objects range from less than 0.1 to $\sim 0.2$ mag when approaching the faintest limiting magnitude.

Finally, we plotted the entire sample of WDs in the $B - H_\alpha$, $B$ plane. Once again we found that a small sample appears to be systematically brighter in $H_\alpha$ (open circles), since they are redder than the bulk of the WDs and of the WD isochrone (solid line).

Current data indicate that a small sample of bonafide WDs are $H_\alpha$-bright. These objects do not appear to be located at a fixed color range in the $B - R$, $B$ plane. This evidence suggests that this phenomenon is not correlated with the
occurrence of a circumstellar envelope caused by pulsation properties of DA and DB pulsating WDs (Nitta et al. this conference).

Moreover, if independent photometric or spectroscopic measurements confirm that $H_\alpha$-bright WDs are truly He WDs, the size of the sample would pose a new puzzle concerning their origin. According to recent N-body simulations the occurrence of compact binaries is tightly connected with the dynamical evolution of the cluster and they should peak in post-core collapsed clusters, such as NGC6397. However, $\omega$ Cen presents a low central density.

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