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The Metallicity and Age Ranges in ω Centauri

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Abstract. We present a metallicity distribution and an age-metallicity relation for the globular cluster ω Centauri based on photometry and spectra of members at the Main Sequence Turnoff (MSTO) region of the color-magnitude diagram. The age-metallicity relation was determined by two independent methods. These preliminary results show that the formation of the cluster took place over an extended period of at least 4 Gyrs with the more metal-rich stars being younger. We find no metal-rich old or metal-poor young stars in our sample of 446 ω Cen members.

Key words. Globular Clusters, Omega Cen, Stellar Abundances

1. Introduction

ω Centauri is the largest globular cluster associated with our Galaxy and exhibits unusual properties for a classical globular cluster. It has a large abundance range in Fe (and Ca) and shows variations in all elements studied. It has been the subject of much research in the last few decades and was first recognized as "peculiar" by the photometric work of Woolley et al. (1966) and Cannon & Stobie (1973). An internal spread in metallicity was shown to exist from the spectroscopic work of Freeman & Rodgers (1975).

Extensive studies of the cluster have since progressed (eg. Norris & Da Costa 1995; Smith et al 1995; Norris, Freeman & Mighell 1996; Pancino 2000). These studies, however, have primarily concentrated on the red giants in the cluster as these are easier to obtain data for. There is evidence of an age range in ω Cen, from the abundance patterns of different elements, which show that enrichments have come from evolved stars (Lloyd Evans, 1977; and references above).

Using Strömgren photometry, Hughes & Wallerstein (2000) and Hilker & Richtler (2000) examined the metallicity distribution and determined ages for samples of stars near the turnoff region in ω Cen. Both of these studies concluded that the more metal-rich stars in the cluster were younger than the metal-poor ones, and there is an age range of several gigayears.

2. Observations and Reduction

Photometry for the cluster was obtained with the 1m telescope and CCD combination at

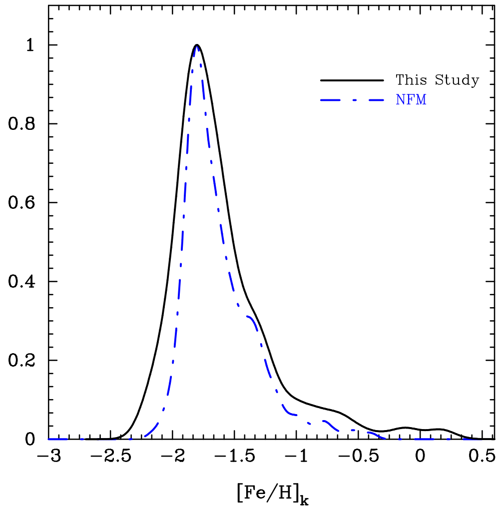

Fig. 1. The metallicity distribution of the main sequence sample (solid line). The dash-dot line shows the distribution from the red giant branch taken from Norris, Freeman & Mighell (1996).

Siding Spring Observatory, in the V and B bands. Ten fields (20×20 arcminutes) were taken and the samples were chosen to be within an annulus 15 to 25 arcminutes from the center of the cluster. Two regions were defined near the MSTO. The first was chosen to determine the metallicity range on the upper main sequence (18.04 < V < 18.51; 0.29 < B–V < 0.72) and observations were taken in May 1998 and April 1999. The second sample (17.25 < V < 18.5; 0.6 < B–V < 1.1) was defined to include the most metal-rich objects in that region, and also to optimally determine the age range for the cluster, since the age, metallicity degeneracy of the isochrones can best be broken at the turnoff region. The stars in this sample were observed in March 2002.

The samples were observed using the Two Degree Field Spectrograph (2dF) on the Anglo-Australian Telescope. This instrument has the capability of observing up to 400 objects at once. The 1200B gratings were employed and the spectra obtained covered the wavelength range $\lambda\lambda$3800–4600Å. They have a resolution of ~2.5Å FWHM and signal-to-noise ratio of ~30-50. A sample of ~450 radial velocity members at the MSTO region of ω Cen was obtained.

Metallicities were obtained for the ω Cen sample using the Ca II K line index and B–V color in the calibration developed by Beers et al (1999). These abundances are only accurate to ~0.2–0.3 dex due to the resolution and S/N of the data and the fact that the metallicity calibration does better at low metallicities than high ones. The metallicity distribution for the members is shown in Figure 1. The distribution found at the main-sequence is similar to that found for the red giant branch of the cluster.

To determine the age range in the cluster two methods were used. In both the Yonsei-Yale (Y^2) isochrones (Kim et al. 2002) were employed. These provided the greatest versatility in obtaining isochrones with large ranges in metallicity, alpha element abundance and age. The Y^2 isochrones can be constructed using two different color tables - the Green and the Lejeune. In this investigation the Green table was primarily used as it gave a better fit to the data at the MSTO region.

3. Results

The first method takes each individual star along with its metallicity and photometry and fits an isochrone to obtain the age. The errors in age were determined using the errors in metallicity (0.2–0.3 dex), photometry (0.03), and the error associated with using the Green table instead of the Lejeune one. In Figure 2*a* all the stars in our sample are plotted. The trend toward higher metallicities/lower ages is clear.

Table 1. Parameters for the synthetic CMDs calculated.

Model	[Fe/H]	Age	Correlation
a	-1.7	14.5	...
b	ω Cen	14.5	...
c	ω Cen	14.5 – 12.5	yes
d	ω Cen	14.5 – 10.5	yes
e	ω Cen	14.5 – 8.5	yes
f	ω Cen	14.5 – 12.5	no
g	ω Cen	14.5 – 10.5	no
h	ω Cen	14.5 – 8.5	no

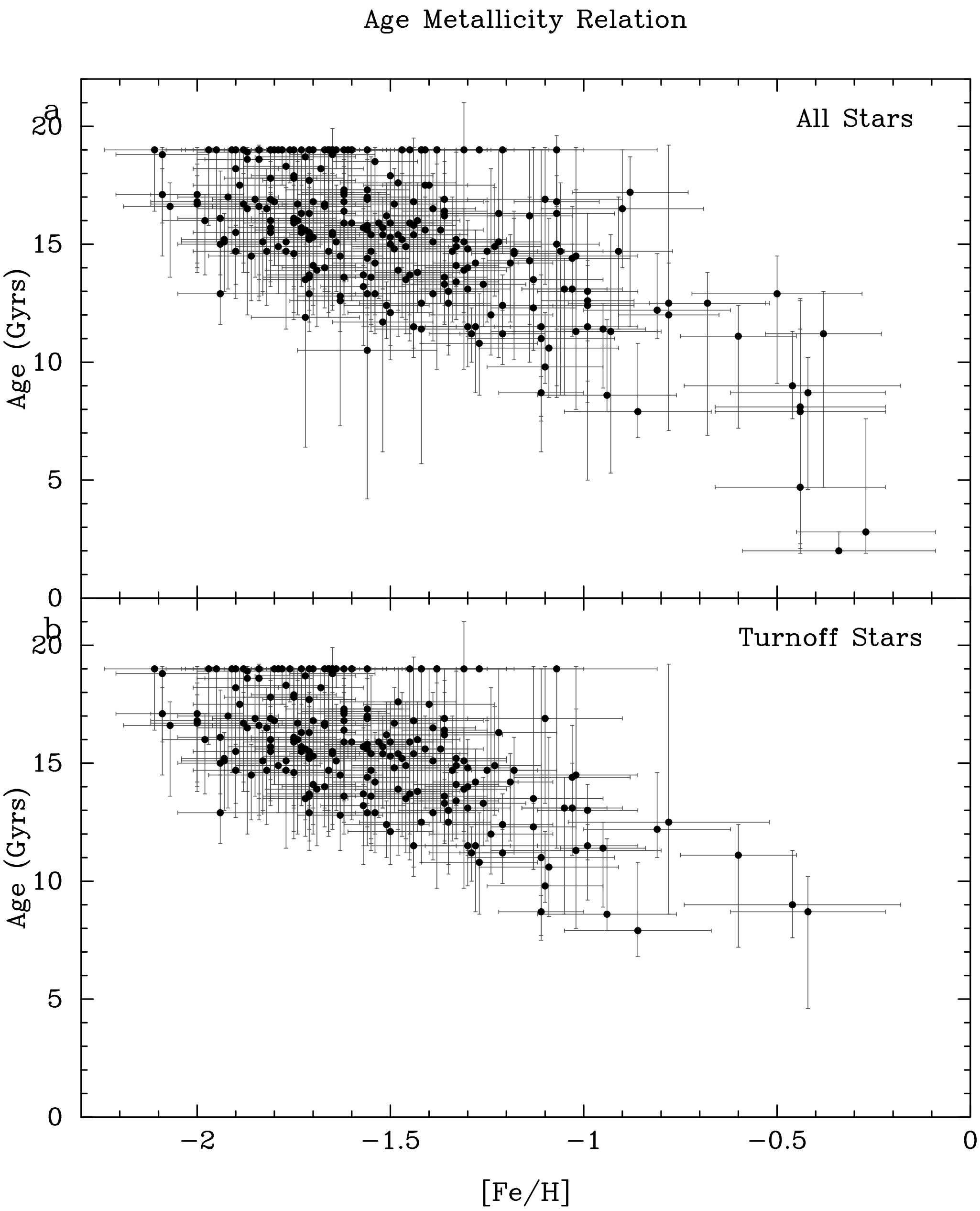

Fig. 2. Results using Method 1, where the stars are given individual ages based on their metallicity and photometry. Panel *a* shows all stars in the sample while panel *b* includes only those stars at the turnoff (V < 18) where the degeneracy of the age and metallicity can best be broken. The maximum age used is 19 Gyrs while the youngest is 2 Gyrs.

This is shown further in Figure 2*b* which plots only those stars at the turnoff region (V < 18), where the ages are more accurate. The age

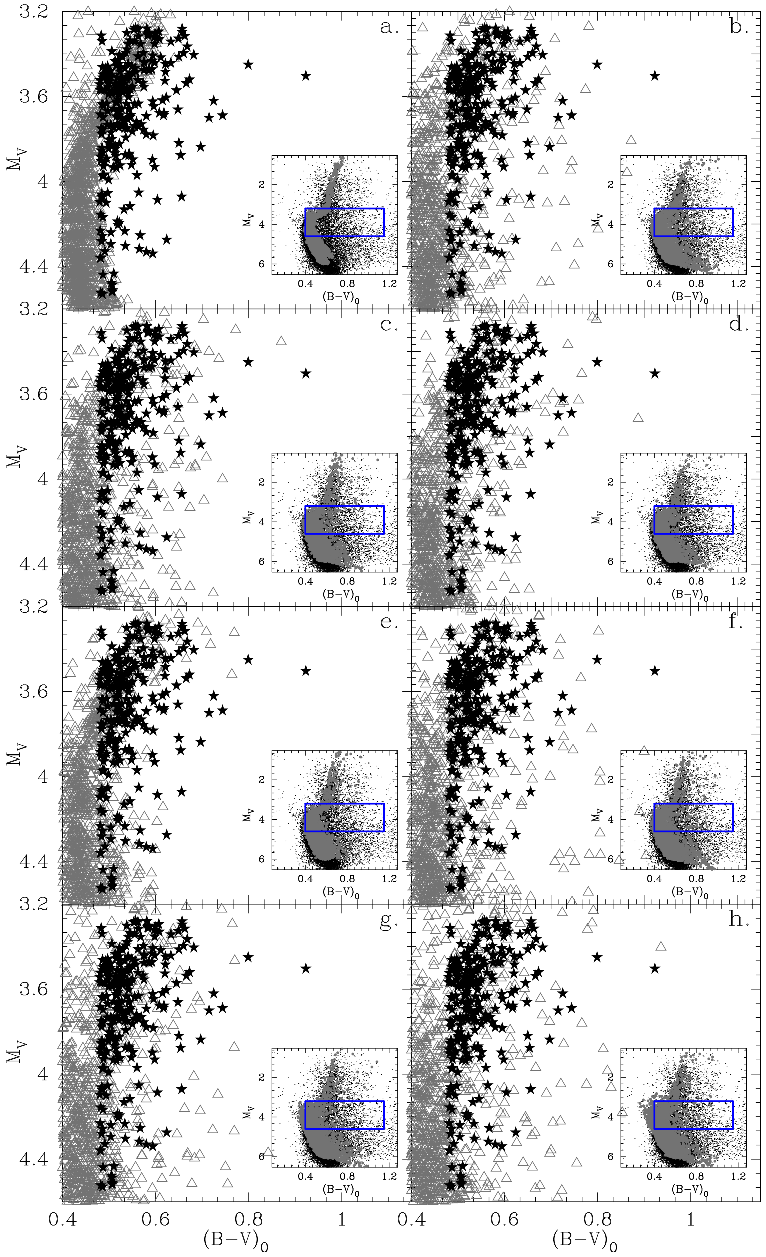

Fig. 3. Results from Method 2 where synthetic color-magnitude diagrams were constructed using model isochrones based on metallicities and ages described in the text and Table 1. The gray triangles represent the synthetic points, the black stars our sample. In this diagram only the 2002 sample is shown. The inset in each plot is the whole CMD for both the ω Cen field (black dots) and the synthetic (gray dots) photometry.

range found between the metallicities [Fe/H] = –1.7 and –0.6 is 5.5 ± 2.3 Gyrs.

The second method used was to construct synthetic populations of stars using theoretical isochrones. The models constructed varied in metallicity distribution and the ages of the stars. A correlation (or lack of) between metallicity and age was also incorporated. The models parameters are described in Table 1. In this table the metallicity heading describes the distribution used in the model. For Model *a* there is essentially no variation in metallicity while for the remaining models the MSTO ω Cen metallicity distribution was used. Age ranges of 0, 2, and 4 Gyrs were included. The final parameter in the models was whether a positive linear age-metallicity relation was enforced. If so, the higher age pertains to [Fe/H] = -1.7 and the lower age to [Fe/H] = -0.6. For models that do not have an age-metallicity relation, metallicities and ages were chosen independently. Therefore there could be old metal-rich stars and young metal-poor stars included. Binaries were also included in the simulation using the same mass function as single stars, and were assumed to represent 15% of the population of the cluster. These, however, did not have a significant effect on the results. The synthetic color-magnitude diagrams (CMDs) have then been qualitatively compared with that of our sample, as shown in Figure 3. In this diagram the grey triangles represent the models while the black stars are our 2002 sampleFrom this simple analysis it can be seen that the CMD that best matches our sample is Model *d* shown in Figure 3*d*. This model has the metallicity distribution of the cluster, and age spread of 4 Gyrs with an age-metallicity relation. Models without an age-metallicity correlation were rejected as they produce young metal-poor stars which are not found in the observations (seen in the inset CMDs which show the samples using larger ranges). Comparing this result with the one found in Method 1 we find agreement within the errors. A more quantitative analysis of Method 2 and comparison with Method 1 is underway.

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