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The 8 populations of Omega Centauri

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Abstract. We analyzed ∼450 stars beloging the SGB region of ω Centauri using high-resolution spectroscopy, in order identify the sub-populations that compose the cluster and to study the age dispersion and the age-metallicity relation. The accuracy of our measurements coupled with the age-sensitivity of the SGB, allowed us to identified up to 8 sub-population that are identified by their [Fe/H] value. Taking advantage of the age-sensitivity of the SGB we showed that, first of all, almost all sub-population have an age spread of at least 2 Gyrs. Then we obtainend an age-metallicity relation. The interpretation of the age-metallicity relation is not straightforward, but it is clear that the cluster (or what we can call its progenitor) was initially composed by two old populations, as old as the age of the Universe, but having different metallicity. The most metal poor had [Fe/H]∼-2.0, while the most metal rich had [Fe/H]∼-1.2. After that, at a first order, each one evolved chemically with iron that linearly increases with age.

Key words. Globular Clusters: general — Globular Clusters: individual(NGC 5139)

1. Introduction

Omega Centauri is a fascinating and enigmatic object: it appears to be a globular cluster (GC), but it has a very complex stellar population, and with its unusual mass ($M \sim 3 \times 10^6 M_\odot$) it has often been suggested to be the remains of a larger stellar system. Sollima et al. (2005) found at least 4 stellar populations on the sub-giant branch (SGB) at [Fe/H]=-1.7,-1.3,-1.0, and -0.6 dex based on CaT abundances. Villanova et al. (2007) identified photometrically at least five stellar populations in the SGB region, and spectroscopically three populations at [Fe/H]=-1.68, -1.37, and -1.14.

Two other studies tried to establish the number and iron content of the populations.The first was Calamida et al. (2009), based on Strömgren photometry of the red-giant branch (RGB). The authors found 6 peaks in the iron distribution at [Fe/H]=-1.73,-1.29,-1.05,-0.80,-0.42, and -0.07 dex. On the other hand Johnson & Pilachowski (2010), based on a large number of high resolution RGB spectra, identified four groups at [Fe/H]=-1.75,-1.50,-1.10,-0.75 dex. Recently Pancino et al. (2011) suggested also the presence of a very metal poor population, at [Fe/H]=-1.95.

We can see that the exact number an d metallicity of sub-populations is matter of great debate. Apart from this, the age-metallicity relation for these sub-populations is almost unknown.

To try and solve this problem, we collected a large spectroscopic database that covers the entire SGB of the central HST photometric field (see Villanova et al. 2007), where the position of a star depends strongly not only on the metallicity, but also on the age. In this way both age and metallicity can be used to disentangle and identify the sub-populations.

2. Observations and data analysis

Stars we obseved using FLAMES@VLT-+GIRAFFE facility, and reduced using the dedicated pipeline. The resulting spectra have a typical S/N ~20-40. Atmospheric parameters were obtained as in Villanova et al. (2007), i.e. we derived effective temperatures colors, adopting a reddening of $E(B-V) = 0.115$, the gravity $\log g$ was calculated from the elementary formula:

$$\log\left(\frac{g}{g_\odot}\right) = \log\left(\frac{M}{M_\odot}\right) + 4\log\left(\frac{T_{\rm eff}}{T_\odot}\right) - \log\left(\frac{L}{L_\odot}\right).$$

while the microturbulence velocity came from the relation:

$$v_{\rm t} = 2.22 - 0.322\log g.$$

Our [Fe/H] values were obtained from a comparison of each observed spectrum with five synthetic ones, calculated with different metal abundances. The random internal error is largely dominated by the noise of the spectra. Monte Carlo simulations gave an error of σ([Fe/H])=0.08 dex. Other sources of error can be neglected.

2.1. Results

We plotted the iron distribution of the entire sample in figure 1. The indentification of the subpopulations were done interactively in order to reproduce at the same time the entire sample, the single SGBs, and the results on the RGB from Marino et al. (2011). We could identify the following peaks plotted in Fig. 1: [Fe/H]=-2.00,-1.73,-1.56,-1.44,-1.29,-1.05,-0.78 and -0.46. Those at -1.56, -1.44, -1.29, and -0.46 are not as clear as the others, but their presence is confirmed when considering the single SGB branches separately and the comparison with Marino et al. (2011). In summary we can identify 8 sub-populations termed:

$$Pop_1 : [Fe/H] = -2.00$$

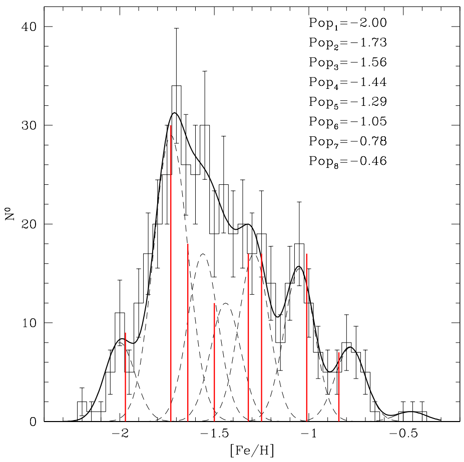

Fig. 1. [Fe/H] distribution of our entire sample. Each sub-population is represented by a gaussian (dashed line) and its mean metallicity is indicated. The continuous line is the convolution of the gaussian fitting the observational data. Red vertical lines are the result of the cluster analysys (see text).

$$Pop_2 : [Fe/H] = -1.73$$

$$Pop_3 : [Fe/H] = -1.56$$

$$Pop_4 : [Fe/H] = -1.44$$

$$Pop_5 : [Fe/H] = -1.29$$

$$Pop_6 : [Fe/H] = -1.05$$

$$Pop_7 : [Fe/H] = -0.78$$

$$Pop_8 : [Fe/H] = -0.46$$

In figure 1 each subpopulation was fitted with a gaussian (dashed line) having σ=0.08, that is our measurement error. We verified that a σ other than that gives a worse fit of the distributions, except for Pop_2, that requires σ=0.09, so we adopted this value for it. The continuous line is the summation of all the single gaussian.

In order to confirm the previous analisys and the number of groups we found, we performed a cluster analisys using the k-means test (Gratton et al. 2011). We found the following groups: [Fe/H]=-1.97, -1.73, -1.64, -1.50, -1.01, and -0.84 that correspond to Pop_1,Pop_2,Pop_3,Pop_4,Pop_6, and Pop_7. Pop_8

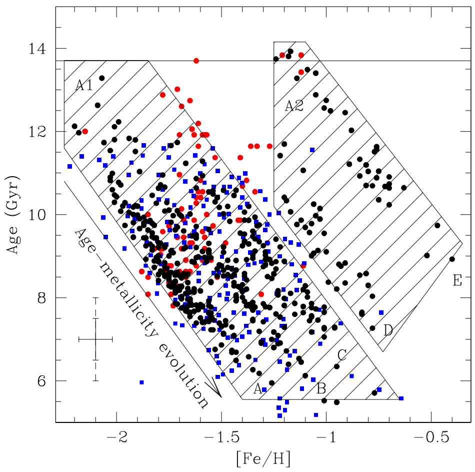

Fig. 2. The age-metallicity relation for ω Centauri. See text for more details.

was not found in this analysis because of the low number of stars it is made of, but we already proved in the previous section that it is visible as a well defined peak in the iron distribution histogram. In addition we found two other groups at [Fe/H]=-1.32 and -1.25 that correspond to our Pop$_5$. The result of the cluster analisys is reported in Fig. 1 as red vertical lines. The agreement with the populations we identified in the previous section is mostly good, with a difference that is at most of 0.08 dex in the worst case.

2.2. The age spread and the age-metallicity relation

After having determined the sub-populations that form the cluster and their distribution on the SGB, we can discuss the implication of the present results on the age spread that, according to Villanova et al. (2007), affects the cluster and that should be of the order of several Gyrs. For this purpose we estimated the range in magnitude each sub-population covers at the level of the SGB. Then we translated the magnitude spread into an age spread. All the populations turned out to have an age-spread of the order of 2 Gyrs or more with the exception of Pop$_8$ that shows no age spread. On the other hand Pop$_6$ and Pop$_7$ show a surprisingly large age-spread of 5÷7 Gyrs. So we conclude that **ω Centauri shows clear evidence of a significant age-spread, at least for some of its populations**.

The next step is to tranform all the information we have, i.e. the metallicity and magnitude of each stars, in an age-metallicity relation, taking adtvantage of the fact that the SGB is the place in the CMD most sensible to age effects. The aim is to transform the magnitude of each star into an age. However there are several effects to take into account. The most obvious one is the fact that stars of the same age but different metallicity have different magnitude, with the most metal rich being also the faintest. A further effect to take into account is due to the He content. We followed the prescrition by Joo & Lee (2013). Finally we have to consider the total CNO content. To investigate this point we considered the data by Marino et al. (2012), D'Orazi et al. (2011), and Villanova et al. 2012 (in preparation). The mean CNO content has a bilinear trend with no or negligible spread. Error on the final age is a function of the [Fe/H] difference between two stars. For targets of the same metallicity and, as a consequence, of the same He and CNO content, it is dominated by the error on the magnitude and [Fe/H] value. In this case a good estimation is σ_{age}=0.5 Gyr. For stars at the extremes of the [Fe/H] interval instead, also uncertainties on the He and CNO trends matter. In this case a good estimation for the error in σ_{age}=1.0 Gyr.

The final product of this procedure is the age-metallicity relation presented in Fig. 2. Our data (black points) appear to follow 5 well defined strips. This is not a real effect but a consequence of our target selection. Red points are the age-metallicity relation by Villanova et al. (2007), taken as reference. Blue points are the age-metallicity relation by Hilker et al. (2004).

The easiest first order way to interpret Fig. 2 is to devide our points in two shaded areas, one that follows the trend shown by metal poor stars (A1), and the other that follows the trend shown by metal rich stars (A2). In both cases the progenitor of each relation appear to be a quite old group of stars, that for A1 have

[Fe/H]~-2.0 and Age~12.5 Gyrs, while that for A2 have [Fe/H]~-1.2 and Age~13.5 Gyrs. Then in each area stars appear to evolve toward higher metallicities following the the arrow labeled with *Age-metallicity evolution*. To complete our interpretation, we have to notice also that, at a second order, each relations has an age spread of 2 Gyrs for a given [Fe/H] value, as discussed above.

At this point it is natural to postulate that ω Centauri is the result of the merging of two objects (drawf galaxies?), the first having the the oldest stars metal poor ([Fe/H]~-2.0), the second having the oldest stars more metal rich ([Fe/H]~-1.2).

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