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The chemical composition of the intermediate-age globular clusters in the Large Magellanic Cloud

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Abstract. We present the chemical abundance analysis of a sample of 27 red giant stars located in 4 popolous intermediate-age globular clusters in the Large Magellanic Cloud, namely NGC 1651, 1783, 1978 and 2173. This analysis is based on high-resolution (R∼47000) spectra obtained with the UVES@VLT spectrograph. For each cluster we derived up to 20 abundance ratios sampling the main chemical elemental groups, namely light odd-Z, α, iron-peak and neutron-capture elements.
All the analysed abundance patterns behave similarly in the 4 clusters and also show negligible star-to-star scatter within each cluster. We find [Fe/H]=-0.30±0.03, -0.35±0.02, -0.38±0.02 and -0.51±0.03 dex for NGC 1651, 1783, 1978 and 2173, respectively.

Key words. Stars: abundances – Stars: atmospheres – Galaxy: globular clusters –

1. Introduction

The Large Magellanic Cloud (LMC) is the nearest galaxy with a present-day star-formation activity and it represents a unique laboratory for the study of stellar populations. Its globular cluster (GC) system show a wide distribution of ages (Searle, Wilkinson, & Bagnuolo 1980; Elson & Fall 1988; Geisler et al. 1997), metallicities (Sagar & Pandey 1989; Olszewski et al. 1991) and integrated colors (van den Bergh 1981; Persson et al. 1983). In particular, we can distinguish three main stellar populations: an old and metal poor population (∼13 Gyr, i.e. Brocato et al. 1996; Olsen et al. 1998), the analogous of the Galactic halo GCs, an intermediate-age population (∼1-3 Gyr, Gallart et al. 2003; Ferraro et al. 2004; Mucciarelli et al. 2006, 2007a) and a young population, with clusters younger than 1 Gyr (Fischer et al. 1998; Brocato et al. 2003). Curious enough, is the lack of objects with ages in the ≈3-10 Gyr range, the so-called Age Gap (Rich et al. 2001; Mackey et al. 2006). The most recent theoretical investigations (Bekki & Chiba 2005) has shown that the main episodes of star formation in the LMC can be related to the close encounters with the

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Small Magellanic Cloud, which could be also responsible for the formation of the off-center Bar and the age distribution of the LMC GC system.

The LMC GCs are also ideal tracers of the chemical evolution of their host galaxy, recording in their abundance patterns the level of enrichment in the galactic environment at the time of their formation. However, our knowledge of the chemical abundances of the LMC GCs is still very sparse and uncertain. Most of the information still rely on photometric (see e.g. Dirsch et al. 2000) or low-resolution spectroscopy (see e.g. Olszewski et al. 1991; Grocholski et al. 2006).

Despite the new generation of 8-meter class telescopes, detailed chemical informations about the LMC clusters from high-resolution spectra are limited to a few stars in a few clusters (Hill et al. 2000; Johnson et al. 2006). They result insufficient to draw a global picture of the chemical properties of these objects and to constrain the timescales of the chemical enrichment.

2. The global project

We started a long-term photometric and spectroscopic project with the ultimate goal of constructing an homogeneous age-metallicity scale for the LMC clusters. In doing this, we make use of the latest generation of imagers and multi-object spectrographs in order to perform an appropriate study of their stellar population, age, metal content and structural parameters. From our high-quality, near-infrared photometric database of 33 LCM clusters (Ferraro et al. 2004; Mucciarelli et al. 2006) by using the near-infrared camera SOFI@NTT (ESO), we extracted a sub-sample of 10 LMC pillar clusters. The detailed chemical analysis of these spectra provides crucial information about:

- the iron content [Fe/H] [1] for each template cluster in order to define a new, homogeneous metallicity scale based on high-resolution spectra;
- the chemical abundances for several elements (light Z-odd, α, iron-peak, neutron capture elements) in order to study the contributor of Supernovae II, Ia and AGB stars to the chemical enrichment;
- the overall metallicity [M/H], as obtained by combining iron and α-element abundances (see i.e. Salaris et al. 1993). This quantity is crucial to derive reliable ages.

In the following, we describe the chemical analysis of 4 intermediate-age LMC clusters (namely NGC 1651, NGC 1783, NGC 1978 and NGC 2173).

[1] We adopt the usual spectroscopic notation: [A]=log$(A)_{star}$-log$(A)_{\odot}$ for each element abundance A; log(A) is the abundance by number of the element A in the standard scale where log(H)=12.

3. The chemical analysis

The observations were performed by using the multi-object spectrograph FLAMES (Pasquini et al. 2002), mounted at the Kueyen 8 m-telescope of the ESO Very Large Telescope on Cerro Paranal (Chile). We used FLAMES in the UVES+GIRAFFE/MEDUSA combined mode for a total of 8 UVES and 132 MEDUSA fibres. The UVES set-up (RED ARM, centered at 5800 $\AA$) provides a wavelength coverage of 4800-6800 $\AA$ and R$\sim$40000. The typical S/N of these spectra is of ~40. Fig. 1 shows a portion of the spectrum of the target star NGC 2173-4 with indicated the main spectral features.

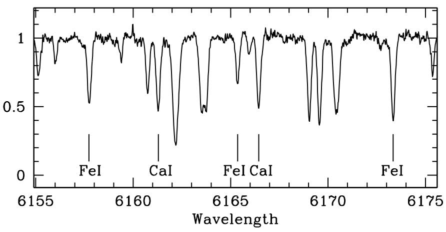

Fig. 1. A portion of the spectrum of the star NGC 2173-4 with indicated some spectral features.

The analysis of the observed spectra and the computation of the chemical abundances for Fe and other important elements was performed by using the ROSA package (Gratton

1988), that includes an automatic routine to measure the line equivalent widths. Only for the oxygen abundance, the analysis was performed by using the spectral synthesis, in order to model the oxygen forbidden line at $\lambda 6300.31 \mathring{A}$ and taking into account the contribution of a very close Ni transition.

4. Results

The 4 analyzed clusters result metal-rich, with a very little star-to-star scatter. We find [Fe/H]= -0.30±0.04 (σ=0.07), -0.35±0.03 (σ=0.06), -0.38±0.03 (σ=0.07) and -0.51±0.04 dex (σ=0.07) for NGC 1651, 1783, 1978 and 2173 respectively, in well agreement with the previous determinations by Olszewski et al. (1991) and Grocholski et al. (2006).

All the clusters show a depletion of [Na/Fe] (<-0.1 dex) and [Al/Fe] (<-0.3 dex); a similar deficiency of [Na/Fe] has been observed also in the LMC disk stars by Pompeia et al. (2006). For comparison, the Milky Way thin disk (that includes mainly metal-rich and intermediate-age stars) shows a roughly solar value for these two abundance ratios (Reddy et al. 2003). The production of these two elements is linked to SN II, because the main production sites are C and Ne burning, respectively. The Na and Al yields are metallicity-dependent, depending on the neutron excess and increase as the metallicity increases. Lower abundances for these elements can indicate that the environment, where these globulars formed, has been enriched from the ejecta of low-metallicity SN II.

Fig. 2 plots the average value of each [α/Fe] ratios for the 4 target clusters as a function of the iron content. The abundance ratios for other intermediate-age, metal-rich populations, namely the LMC disk (Pompeia et al. 2006), the LMC clusters (Hill et al. 2000), the Milky Way thin disk (Reddy et al. 2003) and the Sagittarius dwarf spheroidal (Bonifacio et al. 2000; Monaco et al. 2005, 2007; Sbordone et al. 2007) are also reported for comparison. Typically, the [α/Fe] turns out to be roughly solar, with a mild enhancement of [Mg/Fe](~0.10 dex). These intermediate-age, metal-rich LMC clusters with solar [α/Fe] abundance ratios reflect the standard chemical evolution scenario with a inter-stellar medium also enriched by SN Ia.

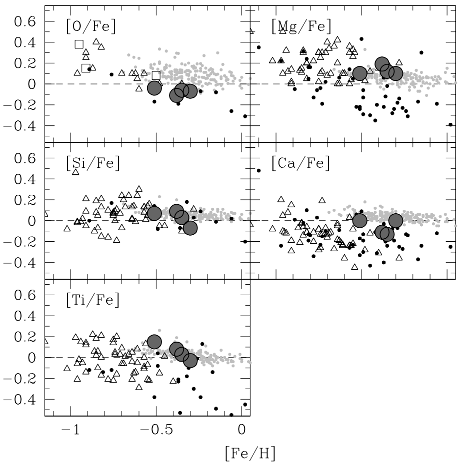

Fig. 2. The trend of the [α/Fe] (O, Mg, Si, Ca and Ti) as a function of [Fe/H] for the four analyzed LMC clusters (big grey points) and in comparison with the previous determination for the LMC field by Pompeia et al. (2006) (empty triangles), the LMC clusters (empty squares) by Hill et al. (2000), the Milky Way thin disk (little grey points) by Reddy et al. (2003) and Sagittarius (little black points) by Bonifacio et al. (2000), Monaco et al. (2005), Monaco et al. (2007), and Sbordone et al. (2007).

The bulk of the iron-peak elements are mainly produced by the SN Ia, from intermediate-mass stars located in single (or double) degenerate binary systems. All the measured iron-peak elements are nearly solar, in well agreement with the behaviour observed in the LMC disk and in the Milky Way thin disk. This result suggests that the iron-peak production well tracks that of iron.

The behaviour of s-process elements in these LMC clusters appears to be dichotomic, with a deficiency for the light s-elements (Y and Zr) and an enhanced pattern of the heavy ones (Ba, La and Nd), with the only exception of Ce, that evidence a solar ratio (see Fig. 3). The [Ba/Y] ratio represents a powerful diagnostics of the relative contribution of the heavy s-elements to the light ones. In our sample [Ba/Y] results enhanced of ~0.9-1 dex: similar values have been observed also in the LMC field (Pompeia et al. 2006) and in Sagittarius remnant (Sbordone et al. 2007) but not in the Milky Way, where the [Ba/Y] ratio appears to be solar (or even sub-solar).

Indeed, theoretical models (Travaglio et al. 2004) suggest that the AGB yields could be metallicity-dependent. In particular, the heavy-s elements have the maximum production at lower metallicities than the maximum production of light-s ones. This finding could explain the high [Ba/Y] ratio, suggesting that he main contribution derives from low-metallicity AGB population. This abundance pattern represents one of the most clear-cut signatures of the different chemical evolution of the LMC with respect the Milky Way.

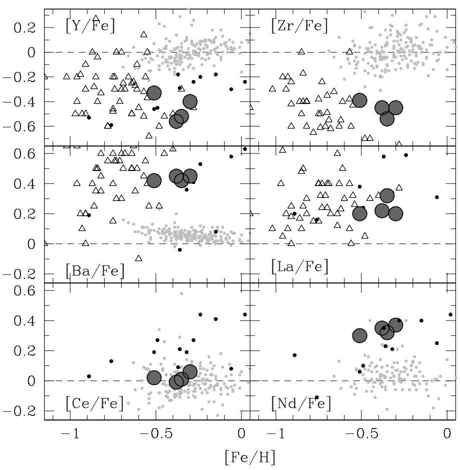

Fig. 3. The trend of the light ([Y/Fe] and [Zr/Fe]) and heavy ([Ba/Fe], [La/Fe], [Ce/Fe] and [Nd/Fe]) s-process elements as a function of [Fe/H] for the four analyzed LMC clusters (same symbols and references of Fig. 2)

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