The chemical composition of the Small Magellanic Cloud *

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The Small Magellanic Cloud is a close, irregular galaxy that has experienced a complex star formation history due to the strong interactions occurred both with the Large Magellanic Cloud and the Galaxy. Despite its importance, the chemical composition of its stellar populations older than ~1-2 Gyr is still poorly investigated. I present the first results of a spectroscopic survey of ~200 Small Magellanic Cloud giant stars performed with FLAMES@VLT. The derived metallicity distribution peaks at [Fe/H] ~0.9–1.0 dex, with a secondary peak at [Fe/H] ~0.6 dex. All these stars show [α/Fe] abundance ratios that are solar or mildly enhanced (~+0.1 dex). Also, three metal-poor stars (with [Fe/H] ~–2.5 dex and enhanced [α/Fe] ratios compatible with those of the Galactic Halo) have been detected in the outskirts of the SMC: these giants are the most metal-poor stars discovered so far in the Magellanic Clouds.

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1 Introduction

In the last decade, the advent of the high-resolution spectrographs mounted on 8-10 m class telescopes (i.e. VLT, Keck, Subaru) has allowed us to investigate the chemical composition of individual Red Giant Branch (RGB) stars in the Local Group, extending our knowledge in galactic environments outside our Galaxy. Detailed chemical abundances analysis for old (>1-2 Gyr) stellar populations are available for the Sagittarius remnant (Sbordone et al. 2007), for the Large Magellanic Cloud (LMC, Pompeia et al. 2008, Mucciarelli et al. 2012) and for some isolated nearby dwarf galaxies (Shetrone et al. 2001, Shetrone et al. 2003, Letarte et al. 2010, Lemasle et al. 2012). Despite its proximity (~60 kpc), the chemical composition of the Small Magellanic Cloud (SMC) is still poorly known, without available studies based on high-resolution spectroscopy concerning its old stellar populations. This irregular galaxy is characterized by a relevant and ongoing star-formation activity. The SMC has experienced a complex and violent star formation history, because it is gravitationally bound with the LMC and the Milky Way, forming a triple system. The mutual tidal interactions occurring among these three galaxies have probably triggered the main star formation episodes in the Magellanic Clouds (see for instance Bekki & Chiba 2005). Thus, the study of the chemical composition of the stars in the SMC is a gold-mine of information to understand the chemical enrichment history of irregular galaxies characterized by tidal interactions and matter exchanges.

Currently, our knowledge of the chemical composition of the stars in the SMC is based on high-resolution spectroscopy of supergiant stars (Spite et al. 1989a, Spite et al. 1989b, Hill et al. 1997, Luck et al. 1998, Venn 1999), thus sampling only the youngest (<200 Myr) stellar populations, and on low-resolution spectroscopy through the Ca II triplet (Carrera et al. 2008), providing metallicities for stellar populations older than ~1 Gyr but without information about the individual elements. In this contribution, I discuss the preliminary results of a spectroscopic survey of the SMC giant stars performed with the ESO spectrograph FLAMES with the final aim to provide a global and deep comprehension of the chemical enrichment history of this galaxy.

2 Observations

High-resolution spectra have been acquired with the multi-object facilities FLAMES (Pasquini et al. 2000) mounted at the UT2 of the Very Large Telescope during 4 nights of observations. Three SMC fields have been selected around three different globular clusters, thus to observe both cluster stars (with the UVES fibers, Lapenna et al., in prep.) and the surrounding field stars (with the GIRAFFE fibers, discussed here, Mucciarelli et al., in prep.). The three targets globular clusters have been selected in order to sample different regions of the SMC and different ages: (i) NGC 419, an intermediate-age cluster (~1-2 Gyr) in the innermost region of the SMC, (ii) NGC 339, an external cluster with an age of ~5-6 Gyr, and (iii) NGC 121, the unique old (~11 Gyr) SMC globular cluster, located in the outskirts of the SMC.

* based on observations obtained at Paranal ESO Observatory with the FLAMES facility.
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Two GIRAFFE gratings (namely HR11 and HR13) have been secured for all the targets, allowing to measure Fe and α-elements (O, Mg, Si, Ca and Ti) and other key-elements (like Na, Ni and Ba). The targets have been selected in the bright portion of the RGB, by using the near-infrared SOFI@NTT photometry (Mucciarelli et al. 2009) for the regions close to the cluster (within a radius of \( \sim 2.5 \) arcmin from the cluster center) and the 2MASS photometry for the outermost regions.

The dataset includes a total of 214 giant stars, members of the SMC field according to their radial velocities; this is the largest dataset of high-resolution spectra for SMC field stars collected so far.

3 Analysis

Atmospherical parameters have been derived from the photometry, combining the near-infrared SOFI+2MASS colors with the optical colors provided by the Magellanic Photometric Survey (Zaritsky et al. 2002). The traditional method of the equivalent widths (EWS) has been adopted to infer the chemical abundances of the investigated elements. EWS of unblended lines have been measured with the automatic code DAOSPEC (Stetson & Pancino 2008) and the abundances derived by using the package GALA (Mucciarelli et al. 2013), coupled with the last generation of ATLAS 9 model atmospheres (Castelli & Kurucz 2004). Spectral synthesis (through a \( \chi^2 \)-minimization between the observed spectrum and a grid of suitable synthetic spectra computed with the code SYNTH) has been used only for O (to take into account the blending of the forbidden O I line at 6300.3 \( \text{Å} \) with a close Ni I transition).

4 Results

4.1 The metallicity distribution

Fig. 1 shows the metallicity distribution of the entire sample, ranging from \([\text{Fe/H}] \sim -2.6\) dex to \([\text{Fe/H}] \sim -0.4\) dex. We can distinguish three main features in the SMC metallicity distribution:

1. a mean peak at \([\text{Fe/H}] \sim -0.9\)–\(-1.0\) dex, that we can consider as the typical metallicity of the old stellar populations in the SMC. This metallicity is consistent with those observed in the old globular clusters NGC 121 and NGC 339, suggesting that these stars formed during the first \(~5\) Gyr of the evolution of the SMC. This scenario seems to be in agreement with the star formation history of the SMC derived by Harris & Zaritsky 2004 where approximately 50\% of the SMC stars formed in early epochs (at ages \( >8 \) Gyr ago);

2. a secondary peak at \([\text{Fe/H}] \sim -0.6\) dex, probably linked to the star formation burst occurring in the last few Gyr and due to the tidal capture of the SMC by the LMC (Bekki & Chiba 2005). This burst is also responsible of the formation of some intermediate-age SMC globular clusters (like NGC 419) and of the metal-rich ([Fe/H]= \(-0.5\) dex) population observed in the metallicity distribution of the LMC (Lapenna et al. 2012);

3. a metal-poor tail, including three giants in the field of NGC 121, with \([\text{Fe/H}] \sim -2.5\) dex. This is the first discovery of metal-poor ([Fe/H]<\(-2.0\) dex) field stars in the Magellanic Clouds (in fact, the most metal-poor field star known so far in the Magellanic Clouds is a LMC giant with \([\text{Fe/H}] = -1.74\) dex, see Pompeia et al. 2008). Fig. 1 shows the comparison between the spectra taken with the HR13 setup of one of these metal-poor stars and a giant with the typical metallicity of the SMC.

Our survey confirms, for the first time through the analysis of a large sample of high-resolution spectra, that the bulk of the old stellar populations in the SMC has a metallicity lower than that observed in the LMC, where the dominant population has \([\text{Fe/H}] \sim -0.5\) dex (Lapenna et al. 2012). The derived metallicity distribution nicely matches with the scenario proposed by Harris & Zaritsky 2004 for the chemical enrichment history of the SMC: the bulk of the stars formed in the first bursts of star formation or in the following long quiescent period with a low star formation efficiency (until about \(3\) Gyr ago) should show low-metallicity ([Fe/H]<\(-1\) dex), with a following increase of the metallicity (reaching \([\text{Fe/H}] \sim -0.4\) dex) due to the recent bursts of star formation (and linked to the past close encounter of the SMC with the LMC and the Milky Way).
Fig. 2 Comparison between the spectra of two SMC giant stars observed with the FLAMES-GIRAFFE HR13 setup, with similar atmospheric parameters and different metallicity, namely [Fe/H]=−1.02 dex (upper panel) and [Fe/H]=−2.44 dex (lower panel).

4.2 α-elements

The [α/Fe] ratio represents a powerful diagnostic to investigate the relative role played by Type II Supernovae (main producers of α-elements) and Type Ia Supernovae (main producers of Fe) in the chemical enrichment process. Indeed, there is time delay between the explosion of Type II Supernovae, occurring since the onset of the star formation event, and Type Ia Supernovae, which happen later on (Greggio 2005).

Fig. 3 Behavior of the average [α/Fe] abundance ratio (obtained by averaging O, Mg, Si, Ca and Ti abundances) as a function of [Fe/H] for the SMC giant stars observed with FLAMES-GIRAFFE (red circles), in comparison with the abundance ratios obtained for stars in the Milky Way stars (small grey circles, Edvardsson et al. 1993, Gratton et al. 2003, Reddy et al. 2003, Barklem et al. 2005, Reddy et al. 2006), in the LMC (green triangles, Lapenna et al. 2012), and dwarf spheroidal galaxies of the Local Group (blue squares, Shetrone et al. 2001, Shetrone et al. 2003, Sbordone et al. 2007, Letarte et al. 2010, Lemasle et al. 2012).

5 Conclusions

In this contribution, I have discussed the first results (about the metallicity distribution and the α-elements abundances) of a spectroscopic campaign performed with FLAMES@VLT to investigate the chemistry of the SMC giant stars. These results allow for the first time to have a global picture of the chemical composition of the SMC.
stellar populations older than $\sim$1-2 Gyr, providing a valuable tool to understand the chemical enrichment history of this galaxy, in particular in light of the mutual interactions among the LMC, SMC and the Milky Way. Finally, the discovery of the most metal-poor giant stars observed so far in the Magellanic Clouds opens a new perspective in the study of these irregular galaxies, allowing to shed new light on the early epochs of star formation of the SMC.

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