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Elemental abundances in RGB stars of the Large Magellanic Cloud

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Abstract. The present work is based on a high-resolution spectroscopic survey of two LMC fields located in the bar and the inner disc, observed at ESO/VLT with FLAMES/GIRAFFE. We confront the results in the LMC inner disc and bar fields and discuss their similarities/differences in the light of the origin of the LMC bar. Both fields show that the LMC has a SFH slower than the MW, resulting in a chemical evolution dominated by SNIa and metal-poor AGB winds. Chemical anomalies for Eu, Ba and La are detected in the most metal-rich field stars, as it has been before in LMC GC stars, and cannot be explained by canonical nucleosynthesis processes.

Key words. Stars: abundances - Galaxies: Magellanic Clouds - Galaxies: abundances - Galaxies: evolution

1. Introduction

Despite decades of intensive observational and theoretical works, we are still far from a complete and clear understanding of our close universe, the Milky Way (MW) and its neighbours. Among the satellites of the MW, the Small and the Large Magellanic Clouds (SMC, LMC) are of particular interest since it is the closest example of galaxies in gravitational (systems: SMC+LMC, SMC+LMC+MW) and chemical interactions (Magellanic Bridge between the clouds, made of stars and gas). The LMC is an almost face-on, gas-rich galaxy with regions of active stellar formation (distance: 50 kpc, Alves 2004, mass: 10^{10}M$_{\odot}$, van der Marel et al. 2002). The young population exhibits an irregular morphology, likely the stigmata of the very recent interaction with the SMC. The old and intermediate-age population are located within a regular disc and a prominent and luminous off-centre bar. The morphology of the LMC is not well understood and, in particular, we still do not know the origin and the true nature of the bar-like structure (dynamical bar driven by disc instabilities or new stellar population) (Subramaniam & Subramanian, 2009; Zaritsky, 2004; Bekki, 2009). Smecker-Hane et al. (2002) have derived from deep colour-magnitude diagram (CMD) the star formation histories (SFH) for field stars located in the LMC bar and the inner part of the LMC disc. They found that the LMC field stars do no exhibit an age gap, unlike the stars of the LMC globular clusters (GC), hence their usefulness to probe the epoch 3 to 13 Gyr (see also Cole et al., 2005). Moreover they show that the SFH of the bar and the inner disc were similar at old epochs (between 7 and 14 Gyr); but while the SFH of the inner disc has remained rather constant, the bar has experienced a dramatic increase of its SFH, 4 to 6 Gyr ago, corresponding to the epoch of the formation of the bar. This work aims at investigating the chemical history of and the relation between the bar and the disc via a detailed chemical analysis of Red Giant Branch (RGB) stars located in the bar and in the inner disc.

2. Data and methods

We obtained high resolution spectra ($R \sim 20,000$) for 113 LMC bar stars at VLT/ESO with the FLAMES/GIRAFFE multifibre spectrograph (Pasquini et al., 2002). This complements a similar dataset in the LMC disc, located at $\sim$ 2 kpc from the centre (Pompéia et al., 2008). We carried out the data reduction with the help of the ESO GIRAFFE pipeline (built upon the Geneva Giraffe pipeline described in Blecha et al., 2000) and with our own reduction routines: our reduced averaged spectra have a typical final SNR of around 25 for HR11, 40 for HR13 and 48 for HR14.

We derived the temperature T_{phot} from VIJHK photometry (Udalski et al., 1997, 2000; Szymanski, 2005) using photometric calibrations for giants (Ramírez & Meléndez, 2005a,b), the surface gravities $\log g$ using the Bayesian estimation algorithm of stellar parameters of da Silva et al. (2006), and the overall metallicity and the microturbulent velocity simultaneously by requiring that different Fe I lines of different equivalent widths (EW) give the same iron abundance [Fe I/H].

We used both EW and fitting of absorption profiles to derive abundances. We measured EW with DAOSPEC (Stetson & Pancino, 2008) and converted them into abundances. We computed synthetic spectra with *turbospectrum* (Alvarez & Plez, 1998), together with the grid of OSMARCS spherical model atmospheres (Gustafsson et al., 2008) and used a χ^2 minimisation to find the best fit abundance. We re-analysed (stellar parameters+abundances) the sample of LMC disc stars of (Pompéia et al., 2008), in exactly the same fashion to insure a homogeneous comparison of bar and disc fields and we used Arcturus as a reference star to determine the zero-point of our chemical abundances scale. The abundances we derived for Arcturus are in good agreement with the literature (Ramírez & Allende Prieto, 2011; Worley et al., 2009).

3. Results and discussion

In this section, we present the results for some key elements: O, Mg, (α elements), Ba, La and Eu (s- and r-elements). α-elements are used to track the epoch where SNeII drove the chemical evolution of the galaxy since at early epochs, α elements and iron are produced in massive stars interiors and are released to the ISM through type II supernovae (SNII) explosions (Burbidge et al., 1957) (α-plateau) while later, iron is mainly produced in type Ia supernovae (SNIa). Figure 1 shows the [α/Fe] trend (mean of O and Mg) for the LMC bar and disc stars, as well as that of the MW. We clearly see that compared to the MW, the LMC has deficient [α/Fe] for [Fe/H] ≥ -1.3 dex. Those low [α/Fe] ratios can be explained by a higher contribution of SNIa to the chemical enrichment of the LMC, compared to the MW. Unlike for the MW, we do not see a plateau until [Fe/H] ≈ -1.5 dex in the LMC trends; despite the paucity of data, we can suspect that the plateau pops up for [Fe/H] $\lessapprox -1.6$ dex. This indicates that the SFH has been slower in the LMC than in the MW.

Unlike the elements lighter than iron, the heavy elements are produced by neutron captures through s- and r-processes. While it is known that the s-process takes place in the envelopes of AGB stars (*e.g.*, Busso et al., 1999), the r-process can in principle take place in several sites (Qian, 2012), such as SNII (Wasserburg et al., 1996) or neutron stars (Freiburghaus et al., 1999). In Figure 1, we see that the LMC bar and disc Eu distributions agree very well: they both exhibit a constant [Eu/Fe] ≈ 0.5 dex for [Fe/H] ≤ -0.8 dex, then a decreasing trend with increasing metallicity. The LMC Eu distribution does not match that

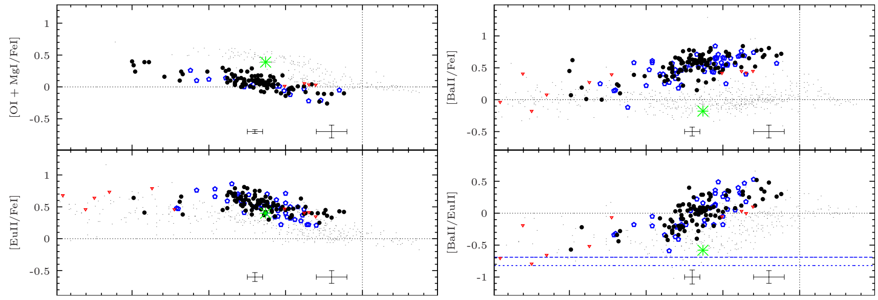

Fig. 1. Top left: [O I + Mg I/2Fe I] vs. [Fe I/H]. **Bottom left:** [Eu II/Fe I] vs. [Fe I/H]. **Top Right:** [Ba II/Fe I] vs. [Fe I/H]. **Bottom right:** [Ba II/Eu II] vs. [Fe I/H]. **Legend:** black filled circles: LMC bar (this work); blue open pentagons: LMC inner disc (this work); green asterisk: Arcturus (this work, data for median SNR); red downward triangle: LMC GC (Johnson et al., 2006; Mucciarelli et al., 2008, 2010); black tiny dots: MW thin and thick disc (Bensby et al., 2005; Reddy et al., 2003, 2006), halo (Fulbright, 2000; Stephens & Boesgaard, 2002; Reddy et al., 2006), MW data for Eu and La from Simmerer et al. (2004); Brewer & Carney (2006); blue dashed and dotted lines: [Ba_r/Eu_r] (Arlandini et al., 1999 and Sneden et al., 2008, respectively). Typical random (left) and systematic (right) error bars on both coordinates are provided for our LMC samples.

of the MW: while for the metal-poor stars the abundance ratios of the LMC and the MW halo overlap, for [Fe/H] ≥ -1 dex the LMC trend is above that of MW. This enhancement for metal-rich stars is not an artifact of our analysis since Arcturus has the expected Eu abundance (*i.e.* it falls in the MW thick disc): this is a chemical anomaly already noticed in LMC supergiant stars (Russell & Bessell, 1989; Hill et al., 1995) and LMC GC stars (Mucciarelli et al., 2008; Colucci et al., 2012) and its origin still remains unclear. However, recent work on CEMP-*r*/*s* by Allen et al. (2012) suggests that metal-poor AGB stars could have significant Eu production through *s*-process.

While the MW has constant solar [Ba/Fe] ratios (with a weak increase towards high metallicities), both LMC fields exhibit a dramatic increase of [Ba/Fe] with increasing metallicity. This indicates that the production of Ba and La has been much more efficient in the LMC than in the MW. To identify the process responsible for this high production, we examine [Ba/Eu]. We see that for LMC GC and field metal-poor stars (from -2. dex to -0.8 dex), [Ba/Eu] is constant and compatible (within uncertainties) with a pure *r*-process source (see Fig. 1). On the other hand, for [Fe/H] ≥ -0.8 dex, the increase of the LMC [Ba/Eu] is interpreted as the rise of a new source of Ba and La, *i.e.* the *s*-process. The differences between the LMC and the MW (the increase starts at lower metallicity, the LMC has higher ratios) suggest that the production of Ba by the *s*-process has been much more efficient in the LMC than in the MW, and thus it indicates that AGB stars played a stronger role in the chemical enrichment of the LMC compared to the MW. Furthermore, the LMC has lower [Y + Zr/Ba + La] ([1^{st} peak/2^{nd} peak]) than the MW, which shows that the AGB stars that contributed to the chemical enrichment were more metal-poor (Cristallo et al., 2011).

4. Conclusion

We found that the LMC had a chemical history different from that of the MW: the SFH of the LMC was slower and the chemical enrichment was dominated by SNIa (α trend) and AGB winds ([Ba/Eu] vs [Fe/H]). We found chemical anomalies in Eu compared to the Galactic trends, which probably indicate that Eu can be significantly produced by *s*-process. For these elements, the two LMC fields do not exhibit strong differences in their abundance patterns, except for the α, where a slightly larger scatter of [α/Fe] is observed for the bar for -0.8 dex $\leq$ [Fe/H] ≤ -0.5 dex. According to the age-metallicity relation (Cole et al., 2005), this metallicity range corresponds to the age range 2 Gyr to 6 Gyr ago, thus the suspected epoch of the bar formation and it can be understood in a scenario where a new population is formed (new burst of star formation).

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