Star clusters: basic galactic building blocks
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Metallicity analysis of an SMC cluster sample using CaII-triplet spectroscopy

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Abstract. The metallicities of 15 Small Magellanic Cloud (SMC) clusters are determined from the Calcium II-triplet lines in spectra obtained using the FORS2 multi-object spectrograph on the *VLT* (Paranal, Chile). The metallicity distribution, metallicity gradient and age–metallicity relationship in the SMC are determined and analyzed using new and literature data for these and other, previously studied SMC objects. Only the main results regarding these topics are presented and discussed.

Keywords. galaxies: star clusters, techniques: spectroscopic

1. Introduction

We have obtained near-infrared spectra covering the CaII-triplet (CaT) lines for a large number of stars associated with 15 Small Magellanic Cloud (SMC) clusters using *VLT*/FORS2. We have targeted clusters that cover as large a range in ages as possible so as to sample the age–metallicity relation over a wide baseline. We also attempted to select clusters that were in relatively uncrowded fields and that were spread around the galaxy to cover as wide an area and radial range as possible to search for any global effects such as gradients. Spectrocopic targets were chosen based on the instrumental color–magnitude diagram (CMD), assigning highest priority to stars lying along the apparent cluster giant branch. We used slits that were $1''$ wide and $8''$ long. In all fields, we obtained a single 900 s exposure with a typical seeing of less than $1''$. Pixels were binned 2×2, yielding a plate scale of $0.25''$ pixel^{-1}. The spectra have a dispersion of ~ 0.85 Å pixel^{-1} with a characteristic rms scatter of ~ 0.06 Å, and cover a range of ~ 1600 Å in the CaT region. Signal-to-noise ratios ranged from ~ 10 to ~ 70 pixel^{-1}.

2. Radial velocities, equivalent widths and metallicities

To measure the radial velocities (RVs) of our program stars, we performed cross correlations between their spectra and the spectra of 32 bright Milky Way open and globular cluster template giants using IRAF tasks. We used the template stars of Cole *et al.* (2004), who observed these stars with a setup very similar to ours. Typical RV errors are 7.5 km s^{-1}.

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Table 1. Derived SMC cluster properties.

Cluster	N	[Fe/H] (dex)	$\sigma_{[Fe/H]}$ (dex)	a (°)
BS 121	5	−0.66	0.07	1.496
HW 47	4	−0.92	0.04	3.502
HW 84	4	−0.91	0.05	5.513
HW 86	4	−0.61	0.06	7.345
L 4	9	−1.08	0.04	3.265
L 5	5	−1.25	0.05	3.092
L 6	7	−1.24	0.03	3.124
L 7	7	−0.76	0.06	2.888
L 17	8	−0.84	0.03	1.718
L 19	7	−0.87	0.03	1.564
L 27	7	−1.14	0.06	1.392
L 106	7	−0.88	0.06	7.877
L 108	6	−1.05	0.05	4.460
L 110	9	−1.03	0.05	5.323
L 111	8	−0.82	0.03	7.830

To measure equivalent widths, we used a previously written FORTRAN program (see Cole *et al.* 2004 for details), following the procedure of Armandroff & Zinn (1988). To derive the metallicities of our entire cluster sample, we adopted the Cole *et al.* (2004) relationship (see Parisi *et al.* 2009 for more details). Our estimate of the total metallicity error per star ranges from 0.09 to 0.35 dex, with a mean of 0.17 dex.

Cluster members were selected using a combination of their positions relative to the cluster center and their location in the CMD, abundances and RVs (see Parisi *et al.* 2009). We used these cluster members to calculate the mean metallicity of our cluster sample. We determine mean cluster metallicities to 0.05 dex (random error), from a mean of 6.4 members per cluster. The results are given in Table 1, together with the semi-major axis, a (see Section 3). Metallicity errors correspond to the standard error of the mean (s.e.m.).

3. Metallicity results

The metallicity distribution (MD), metallicity gradient and age–metallicity relation (AMR) are investigated, combining our clusters with those observed by Da Costa & Hatzidimitriou (1998) and Glatt *et al.* (2008) (also using the CaT) and one cluster with a detailed, high-resolution metallicity to compile a sample of 25 clusters on a homogeneous metallicity scale.

We derive a mean metallicity for our CaT sample of −0.94 dex, with a standard deviation $\sigma = 0.19$ dex, while for the full sample these values become −0.96 and 0.19 dex, respectively. The mean values are in very good agreement with each other and the global mean value of −1 dex found by Carrera *et al.* (2008) from CaT spectra of a large number of field giants. The MD is shown in Figure 1 (left top panel), in which we also show the MD for Large Magellanic Cloud (LMC) clusters derived by Grocholski *et al.* (2006) in our CaT study (left bottom panel). The SMC clusters fall in a rather small metallicity range of < 0.8 dex, from −0.6 to −1.4 dex, and are concentrated in the 0.5 dex range from −0.75 to −1.25 dex. This is unlike the LMC clusters, which cover ~ 2 dex in metallicity (Grocholski *et al.* 2006), with higher and lower metallicities than found in their SMC counterparts. The broad characteristics of the MD of the Magellanic

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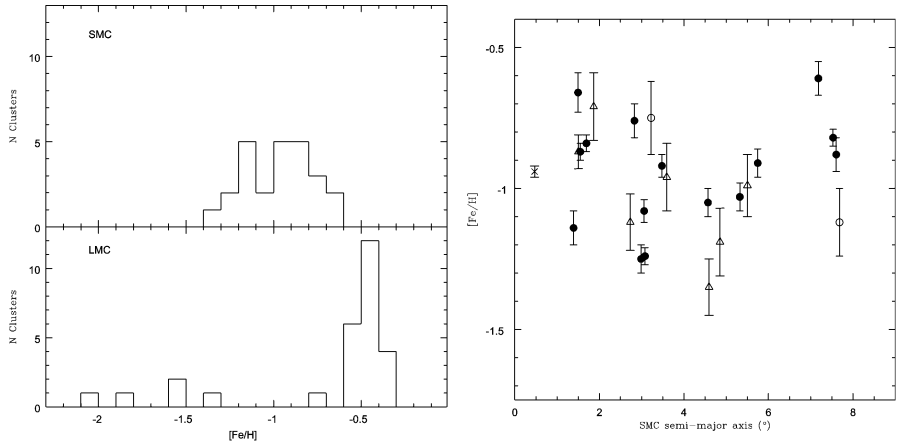

Figure 1. *(left)* Metallicity distribution (MD) of SMC clusters *(top panel)*: 15 from the present work, six from Da Costa & Hatzidimitriou (1998), three from Glatt *et al.* (2008) and NGC 330 Gonzalez & Wallerstein (1999). The histogram in the bottom panel corresponds to the MD for LMC clusters derived from our CaT investigation (Grocholski *et al.* 2006). *(right)* Metallicity versus projected radius (semi-major axis a) for the SMC clusters. Open circles represent clusters from Da Costa & Hatzidimitriou (1998) and triangles represent clusters from Glatt *et al.* (2008). Clusters from our CaT sample are represented by filled circles. NGC 330 is shown by a cross. No clear trend is evident.

Cloud cluster systems have been known for some time. Da Costa (1991) noted that (sic) "The LMC managed to make metals but no clusters during the age gap while the SMC managed to make clusters but no metals". These curious facts are now even more evident and corroborated in much greater detail than known at that time, but their explanation remains as mysterious. There is a suggestion for bimodality in the MD, with peaks at [Fe/H] ~ -0.9 and -1.15 dex, but more clusters are needed to corroborate this result.

In the right panel of Figure 1 we plot metallicity versus the semi-major axis a value for our cluster sample and for the full sample. The parameter a is the semi-major axis that an ellipse would have if it were centered on the SMC center, aligned with the bar, had a b/a ratio of 1/2 and one point of its trajectory coincided with the cluster position. No clear trend is evident. Dividing our sample at 4°, as did Piatti *et al.* (2007a,b), we find for the 15 inner clusters a mean metallicity and standard deviation of -0.94 and 0.19, respectively, while the 10 outer clusters have -1.00 and 0.21. The difference is not significant. To check to see if this could possibly be due to an inverse age-gradient effect, we also checked the mean ages of the two divisions. The inner clusters are 3.1 (1.9) Gyr and the outer clusters 4.4 (3.4) Gyr old. Thus, this cannot be the cause of a lack of an observed metallicity gradient. We conclude that any true metallicity gradient in the SMC cluster system must be relatively weak. Additional data are required to ascertain the existence and strength of any gradient. If the gradient is indeed minimal, Zaritsky *et al.* (1994)'s suggestion that a strong bar weakens any disk gradient is a viable explanation.

The AMR (Figure 2) shows evidence for three phases: a very early (> 11 Gyr) phase in which the metallicity reached ~ -1.2 dex, a long intermediate phase from ~ 10 to 3 Gyr ago, in which the metallicity only slightly increased although a number of clusters formed, and a final phase from 3 to 1 Gyr ago, in which the rate of enrichment was substantially faster. We find good overall agreement with the model of Pagel & Tautvaišienė (1998; solid line), which assumes a burst of star formation at 4 Gyr. A hybrid infall + outflow model of Carrera (2005; long-dashed line) also fits the data reasonably well. The simple

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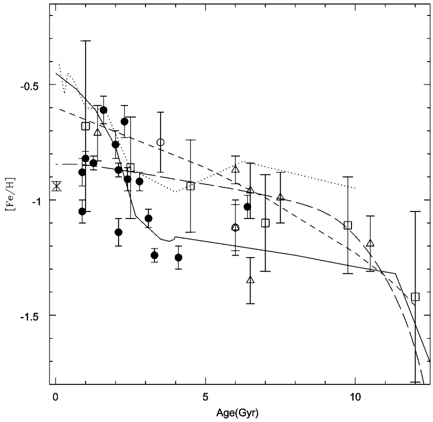

Figure 2. Age–metallicity relation. Symbols are the same as in Figure 1. The mean metallicity in six age bins calculated by Carrera *et al.* (2008) is also shown (squares). Lines are explained in the text (Section 3).

closed-box model of Da Costa & Hatzidimitriou (1998; short-dashed line) yields a much poorer fit and the AMR derived by Harris & Zaritsky (2004; dotted line) is significantly offset to higher metallicities for intermediate-age clusters. A number of different lines of evidence point to the likelihood of a burst in the SMC star- and cluster-formation intensity about 3 Gyr ago. The cause of such a burst is currently a source of much speculation. The suggestion by Bekki *et al.* (2004) that it is due to a close passage of the SMC and LMC is intriguing but requires better knowledge of their orbits, especially proper motions, to be definitively tested.

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