Search for an Intrinsic Metallicity Spread in Old Globular Clusters of the Large Magellanic Cloud

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Abstract

We report for the first time on the magnitude of the intrinsic [Fe/H] spread among 10 old globular clusters (GCs) of the Large Magellanic Cloud (LMC). Such spreads are merely observed in approximately 5% of the Milky Way GCs and recently gained more attention in theoretical models of GC evolution. We derived metallicities with a typical precision of 0.05 dex \( \leq \sigma_{\text{Fe/H}} \leq 0.20 \) dex for an average of 14 red giant branch stars per GC from Strömgren photometry. The respective, metallicity-sensitive indices have been calibrated to precise and accurate high-dispersion spectroscopy. For all clusters, we found null [Fe/H] spreads with a typical uncertainty of 0.04 dex, with the possible exception of NGC 1786 that shows an intrinsic dispersion of 0.07 ± 0.04 dex. The mean, observed standard deviation of the derived metallicities for nearly 40% of our GC sample amounted to smaller than 0.05 dex. At present, we cannot exclude the fact that the remaining GCs also have intrinsic Fe-abundance variations in excess of 0.05 dex, but in order to significantly detect those, the measurement errors on individual [Fe/H]-values would need to be lowered to the 0.03–0.07 dex level. These findings suggest, along with those from ages and light element abundances, that the LMC GCs studied here are similar to the majority of Galactic GCs.

Key words: galaxies: individual (LMC) – galaxies: star clusters: general – techniques: photometric

1. Introduction

Only eight out of 156 Galactic globular clusters (GCs) listed in the Harris (1996, 2010 version) catalog have recently been classified as “anomalous” objects, because their intrinsic [Fe/H] dispersions are >0.05 dex (Johnson et al. 2015; Marino et al. 2015). From this perspective, anomalies in the iron content would not appear to be the most frequent manifestation of the GC multiple population (MP) formation, as recently reviewed by Bastian & Lardo (2018).

Among the 15 known Large Magellanic Cloud (LMC) old GCs, only NGC 1754, 2210, and 2257 have been searched for anomalies in their metallicities by Mucciarelli et al. (2009), who concluded from [Fe/H] values of five to seven stars per GC that they exhibit quite homogeneous iron abundances (intrinsic spread \( \sim 0.02–0.04 \) dex) despite the observed occurrence of light element variations such as an Na–O anticorrelation. Therefore, they show very similar properties to the vast majority of Galactic GCs.

From a theoretical point of view, different models have recently proposed distinct scenarios to describe abundance anomalies in a variety of chemical elements in massive clusters harboring MPs. For instance, Bekki & Tsujimoto’s (2016) model is based on merger events, while that of Bailin & Stinson (2016) used supernovae enrichment and asymptotic giant branch (AGB) star ejecta, while Gieles et al. (2018) proposed a concurrent formation of GCs and supermassive stars, among others. These models have been mainly stimulated by observational findings of (anti)correlations between chemical abundances of certain light elements (e.g., Na–O, Mg–Al, Mg–Si, Si–Zn; Osborn 1971; Cohen 1978; Carretta et al. 2009; Gratton et al. 2012; Hanke et al. 2017) and bimodalities in CN and CH that trace light element variations (e.g., Kayser et al. 2008; Martell & Grebel 2010, and references therein). Some of the models also propose mechanisms to obtain intrinsic [Fe/H] spreads \( >0.05 \) dex. For instance, Gavagnin et al.’s (2016) model used merger events, while that of Bailin (2016) is based on feedback from core-collapse supernovae. Recently, Lim et al. (2017) found that GCs with large intrinsic [Fe/H] spreads also show a positive CN–CH correlation.

In this work, we report on the magnitude of the intrinsic [Fe/H] spread for a sample of nine old LMC GCs and in ESO 121-SC03, which lies in the LMC’s GC age gap (9 Gyr, Bica et al. 1998; Mackey et al. 2006). As far as we are aware, this is the largest sample of LMC GCs—assumed to have MPs but not confirmed as yet—analyzed in order to search for internal metallicity variations. In Section 2, we describe the observational material and precision and accuracy of our photometry. Section 3 deals with the estimation of individual metallicities for carefully selected cluster red giant branch (RGB) stars, while in Section 4 we analyze and discuss our results.

2. Observational Data Sets

We made use of publicly available images of 10 LMC GCs obtained through the Strömgren \( vby \) filters with the SOAR Optical Imager (SOI) mounted on the 4.1 m Southern Astrophysical Research (SOAR) telescope (program SO2008B-0917, PI: G. Pietrzyński). The images (field of view = 5′/25 × 5′/25, pixel scale = 0″154/pix) were obtained from exposures of 350–500, 140–300, and 90–180 s in the \( v, b, \) and \( y \) filters, respectively, under excellent atmospheric conditions (FWHM \( \sim 0″6 \)). We processed the images, along with the respective calibration images, following the SOI pipeline.5 Stellar photometry on the individual images was obtained using the DAOPHOT package (Stetson et al. 1990). We first derived a quadratically varying point-spread function (PSF) by using two sets of stars selected interactively, one with \( \sim 100 \)
and another with the brightest \(\sim 40\) stars. The smaller group was used to build a preliminary PSF, which was in turn used to clean the larger PSF sample. The resulting PSF was applied to all the identified stars in an image, which were then subtracted from it in order to identify fainter stars, and to run again ALLSTAR on the enlarged star sample. We iterated the loop three times. Finally, we kept only sources with \(\chi < 2\), [SHARPNESS] < 0.5, and DAOPHOT photometric errors smaller than 0.01 mag.

To standardize the PSF photometry, we first measured instrumental magnitudes of 5–10 standard stars observed twice per night, thus covering an airmass range between 1.1 and 2.1. Then, we fitted the transformation equations given by the expressions

\[
\begin{align*}
  v &= v_1 + V_{\text{std}} + v_2 \times X_i + v_3 \times (b - y)_{\text{std}} + v_4 \times m_{1\text{std}}, \\
  b &= b_1 + V_{\text{std}} + b_2 \times X_i + b_3 \times (b - y)_{\text{std}}, \\
  y &= y_1 + V_{\text{std}} + y_2 \times X_i + y_3 \times (b - y)_{\text{std}},
\end{align*}
\]

where \(v_i, b_i, \text{ and } y_i\) are the \(i\)th fitted coefficients, and \(X\) represents the effective airmass. Table 1 shows the resulting coefficients obtained using the IRAF:FITPARAMS routine.

The quality of our photometry was first examined in order to obtain robust estimates of the photometric errors. To do this, we performed artificial star tests by using the stand-alone ADDSTAR program in the DAOPHOT package (Stetson et al. 1990) to add synthetic stars, generated bearing in mind the color and magnitude distributions of the stars in the color–magnitude diagram (CMD) as well as the cluster radial stellar density profile. We added a number of stars equivalent to \(\sim 5\%) of the measured stars in order to avoid in the synthetic images significantly more crowding than in the original images. On the other hand, to avoid small number statistics in the artificial star analysis, we created 1000 different images for each original one. We used the option of entering the number of photons per ADU in order to properly add the Poisson noise to the star images.

We then repeated the same steps to obtain the photometry of the synthetic images as described above, i.e., performing three passes with the DAOPHOT/ALLSTAR routines. The photometric errors were derived from the magnitude difference between the output and input data of the added synthetic stars using the DAOMATCH and DAOMASTER tasks. We found that this difference resulted in being typically equal to zero and in all the cases smaller than 0.003 mag. The respective rms errors were adopted as the photometric errors. Figure 1 illustrates the behavior of these errors as a function of the distance from the cluster center and of the magnitude. For clarity, we only show two different magnitude levels, namely \(V = 16.5\) mag and 18.5 mag, respectively. These magnitudes roughly correspond to the upper and lower limits of the cluster RGBs used in this work (see Figure 2).

### Table 1

| Filter | Coef1 | Coef2 | Coef3 | Coef4 | rms |
|--------|-------|-------|-------|-------|-----|
| 2008 Dec. 18: NGC 2257, ESO 121-SC3 | | | | | |
| \(v\) | 1.122 ± 0.007 | 0.295 ± 0.005 | 1.995 ± 0.048 | 1.026 ± 0.061 | 0.002 |
| \(b\) | 0.942 ± 0.014 | 0.177 ± 0.009 | 0.946 ± 0.014 | ... | 0.008 |
| \(y\) | 0.932 ± 0.015 | 0.122 ± 0.009 | −0.005 ± 0.016 | ... | 0.010 |
| 2008 Dec. 19: NGC 1754, 1786, 1835, 1898, 2005, 2019, 2210 | | | | | |
| \(v\) | 1.096 ± 0.015 | 0.286 ± 0.009 | 2.004 ± 0.030 | 1.117 ± 0.038 | 0.010 |
| \(b\) | 0.916 ± 0.013 | 0.169 ± 0.007 | 0.999 ± 0.011 | ... | 0.010 |
| \(y\) | 0.939 ± 0.019 | 0.107 ± 0.010 | 0.018 ± 0.015 | ... | 0.016 |
| 2009 Jun. 16: NGC 1841 | | | | | |
| \(v\) | 1.005 ± 0.004 | 0.290 ± 0.009 | 2.034 ± 0.032 | 0.914 ± 0.028 | 0.007 |
| \(b\) | 1.014 ± 0.007 | 0.170 ± 0.007 | 0.939 ± 0.018 | ... | 0.011 |
| \(y\) | 1.005 ± 0.004 | 0.120 ± 0.010 | −0.046 ± 0.011 | ... | 0.007 |

### 3. Metallicity Estimates

We used the \(m_1\) versus \(b - y\), \(m_1\) versus \(v - y\), \(V\) versus \(b - y\), and \(V\) versus \(v - y\) diagrams as discriminators between giant, subgiant, and dwarf stars (thus weeding out foreground stars) to select RGB stars in stellar populations (Faria et al. 2007; Árnadóttir et al. 2010; Calamida et al. 2012, 2014). We contrained our search to RGB stars located inside the cluster radii estimated by Piatti & Mackey (2018), and brighter than the respective cluster horizontal branch in the \(V\) versus \(b - y\) CMD, where the RGBs are narrower and least contaminated by field stars (Frank et al. 2015). Indeed, we only kept stars within a strip of \(\pm 0.05\) mag in \(b - y\) from the cluster RGB ridge lines, assumed the \(b - y\) color to be mainly a temperature effective indicator with less metallicity sensitivity (Crawford & Mandewewala 1976). We also discarded any star lying inside the RGB strips whose [Fe/H] value departs significantly (more than 3 times the observed dispersion) from the readily visible cluster metallicity distributions. In addition, by using different field regions of equal cluster areas, distributed around the clusters, we found that the number of field stars that fall inside the RGB strips is smaller than 10% with respect to the total number of adopted cluster members. Figure 2 shows all the measured stars inside the cluster radius, those located far from the cluster region for an equal cluster area, and the selected RGB stars drawn with black, orange and red filled circles, respectively.

By using the semiempirical calibration by Calamida et al. (2007), we estimated individual metallicities ([Fe/H]) from the reddening corrected metallicity index\(^5\) \(m_{10}\), in turn based on the stars’ \((v - y)_{9}\) colors. The uncertainty were calculated from propagation of all the involved errors, i.e., those of the

\(^5\) Using the standard definition \(m_{1} = (v - b) - (b - y)\).
calibration and those of our photometry, as follows:

\[ m_{10} = \alpha + \beta \text{[Fe/H]} + \gamma (v-y)_0 + \delta \text{[Fe/H]} (v-y)_0, \]

where \( \alpha = -0.309, \beta = -0.090 \pm 0.002, \gamma = 0.521 \pm 0.001, \) and \( \delta = 0.159 \pm 0.001 \), respectively. Then, per standard error propagation,

\[
\sigma([Fe/H])^2 = \left( \frac{\partial [Fe/H]}{\partial \alpha} \sigma(\alpha) \right)^2 + \left( \frac{\partial [Fe/H]}{\partial \beta} \sigma(\beta) \right)^2 + \left( \frac{\partial [Fe/H]}{\partial \gamma} \sigma(\gamma) \right)^2 + \left( \frac{\partial [Fe/H]}{\partial \delta} \sigma(\delta) \right)^2 \\
+ \left( \frac{\partial [Fe/H]}{\partial m_{10}} \sigma(m_{10}) \right)^2 + \left( \frac{\partial [Fe/H]}{\partial (v-y)_0} \sigma((v-y)_0) \right)^2 \\
= \left( \frac{0.002 [Fe/H]}{c} \right)^2 + \left( \frac{0.001 (v-y)_0}{c} \right)^2 + \left( \frac{0.001 [Fe/H] (v-y)_0}{c} \right)^2 + \left( \frac{\sigma(m_{10})}{c} \right)^2 \\
+ \left( \frac{-0.521 c - 0.159 (m_{10} + 0.309 - 0.521 (v-y)_0) \sigma((v-y)_0)}{c^2} \right)^2,
\]

where \( c = -0.090 + 0.159 (v-y)_0 \), and \( \sigma(m_{10}) \) and \( \sigma((v-y)_0) \) are the photometric errors in \( m_{10} \) and \( (v-y)_0 \), respectively, according to the position of the stars with respect to the cluster’s center (see Figure 1). We note that \( m_{10} \) and \( (v-y)_0 \) depend on the \( vby \) magnitudes of each star, in the sense that the fainter a star, the larger its errors. They also depend on the position of the star with respect to the cluster center, because of crowding effects. Typically, stars located in the outer regions have smaller magnitude errors as compared with those of the same magnitudes placed at the cluster center. We derived them as follows:

\[
(v-y)_0 = v - y - 1.67 \times 0.74E(B-V),
\]

\[
\sigma((v-y)_0)^2 = \sigma(v)^2 + \sigma(y)^2 + (1.67 \times 0.74 \sigma(E(B-V)))^2
\]
and

\[ m_{10} = (v - b) - (b - y) + 0.33 \times 0.74 E(B - V), \]

\[ \sigma(m_{10})^2 = \sigma(v)^2 + 4\sigma(b)^2 + \sigma(y)^2 \]

\[ + (0.33 \times 0.74 \sigma(E(B - V)))^2, \]

where the reddening laws, \( E(X)/E(B - V) \), are those given by Crawford & Mandewewala (1976). We obtained the cluster reddening values from the NASA/IPAC Extragalactic Data base\(^6\) (NED; see Table 2). The resulting [Fe/H] values and their errors are plotted in the bottom right panels of Figure 2.

3.1. Intrinsic Dispersions

We next determined the mean and dispersion of each cluster’s Fe-abundance by employing a maximum likelihood approach, similar to the method detailed in Frank et al. (2015). The relevance lies in accounting for each individual star’s measurement errors, which could artificially inflate the dispersion if ignored. We optimized the probability \( \mathcal{L} \) that a given ensemble of stars with metallicities [Fe/H], and metallicity errors \( \sigma_i \) are drawn from a population with mean

\(^6\) http://ned.ipac.caltech.edu/. NED is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.
Fe-abundance \langle [Fe/H] \rangle and intrinsic dispersion $W$ (e.g., Walker et al. 2006; Koch et al. 2018), as follows:

$$
\mathcal{L} = N \prod_{i=1}^{N} (2\pi\sigma_i^2 + W^2)^{-\frac{1}{2}} \\
\times \exp \left( -\frac{(\langle [Fe/H]_i \rangle - \langle [Fe/H] \rangle)^2}{\sigma_i^2 + W^2} \right),
$$

where the errors on the mean and dispersion were computed from the respective covariance matrices. We note that this approach assumes that the error distribution is Gaussian, which is adopted here because of the limited number of stars (see Frank et al. 2015). The last columns of Table 2 list the mean metallicity, the intrinsic dispersion, and the number of stars used for each cluster. As far as we are aware, these comprise the largest sample of LMC GCs with metallicities put on an homogeneous scale. Here, we note the remarkably tight correlation between the spectroscopic and Strömgren-based metallicities, attesting to the validity of the calibrations over a broad metallicity- and color-range (see Figure 3). Moreover, although the CN absorption band at $\lambda$4142 Å is near the effective wavelength of the $v$ filter, our metallicities appear to also be driven by Fe abundances, as the index $m_1$ was calibrated by Calamida et al. (2007) as a photometric proxy for the iron abundance. Nevertheless, we cannot rule out that they could also reflect CN variations (Lim et al. 2017).
Here, the metallicity distribution function $p$ of the contaminants was drawn from the observed Strömgren-metallicity distribution of LMC field stars of Cole et al. (2000). This was done exemplary for NGC 1786, the only object in our sample that shows a hint of a significant intrinsic spread. As a result, even fractions as high as >90% will leave the result significant at the $1\sigma$ level.

Second, we removed stars from the NGC 1786 sample at random in a jackknife manner, recomputing the mean and dispersion as before. As a result, even upon rejection of three stars (amounting to 20% of the entire sample) as if they were foreground contaminants, did not alter the measured, non-negligible intrinsic dispersion and maintained the significance of the result. As for the other GCs with null dispersions, their results also remained unaffected, yielding the low-to-zeros values as before.

### 3.2. Foreground Contamination

Our measured intrinsic dispersion values are not expected to be affected by field star contamination, since the LMC field stellar population has more metal-rich mean metallicities (e.g., Cole et al. 2000; Pompéia et al. 2008; Van der Swaelmen et al. 2013; Piatti & Geisler 2013), and Milky Way (MW) stars placed along the cluster RGB sequences are expected to be negligible across the relatively small cluster areas ($r \lesssim 1.5$ Piatti & Mackey 2018).

We show in the $\sigma$[Fe/H] versus [Fe/H] plots of Figure 2 every measured field star located in the observed cluster areas, and distributed outside the adopted cluster RGB strips (black circles). For comparison, we also included field stars from regions outside the cluster areas (orange circles). As can be seen, these do not visibly widen the metallicity range of the selected stars. We note that field RGB stars younger than the GCs have [Fe/H] > −1.0 dex (Cole et al. 2005; Piatti & Geisler 2013) and are placed along GC RBGs with [Fe/H] > −1.0 dex, depending on their ages (Geisler et al. 2003; Ordoñez & Sarajedini 2015).

In order to assess the influence of LMC field star contaminants on our measurements, we expanded the above likelihood estimator by adding a fraction $f$ of foreground stars (Koch et al. 2007):

$$
\mathcal{L} = \prod_{i=1}^{N} \left( 1 - f \right) \left( 2\pi \left( \sigma_{i}^{2} + W^{2} \right) \right)^{-\frac{1}{2}}
\times \exp \left( -\frac{\left( \text{[Fe/H]}_{i} - \left< \text{[Fe/H]} \right> \right)^{2}}{\sigma_{i}^{2} + W^{2}} \right),
+f p(\text{[Fe/H]})
$$

Here, the metallicity distribution function $p(\text{[Fe/H]})$ of the contaminants was drawn from the observed Strömgren-metallicity distribution of LMC field stars of Cole et al. (2000).
average lower by merely 0.02 dex, so that the inclusion of a minor contamination (one to two stars per GC) in our presumed RGB samples, would not lead to a significant inflation of the intrinsic dispersion if they were misclassified as RGB stars.

However, we note that, being warmer and less massive than RGB stars, AGB stars have metallicities that should follow different relations from the Calamida et al. (2007) calibration that was used here; this is also due to the different strength of the molecular bands, with weaker CN- and CH-bands. Ideally, the AGB contamination should be weeded out by using the index $c_1 = (u - v) - (v - b)$ that is sensitive to stellar evolutionary stage (Árnadóttir et al. 2010), but this is inhibited by the lack of any $u$-band observations for our LMC targets.

### 4. Analysis and Discussion

The resulting dispersions reveal that 9 of the 10 LMC GCs studied here show metallicity spreads consistent with zero within the respective errors, as is the case for most of the MW GCs. One possible exception is NGC 1786, at $W = 0.07 \pm 0.04$ dex. The posteriori likelihood distribution for its mean metallicity and intrinsic dispersion is shown in Figure 4. We note that all of our results include a thorough consideration of all errors propagated through the calibration for each star, giving a realistic account of the, non-necessarily symmetric, error distribution.

In order to obtain $W$ values larger than 0.05 dex, errors of the individual metallicities of our selected stars would need to be smaller than 0.04 dex (NGC 1754), 0.10 dex (NGC 1786), 0.03 dex (NGC 1835), 0.07 dex (NGC 1841), 0.03 dex (NGC 1898), and 0.06 dex (NGC 2005), respectively. For the remaining GCs, the standard deviation of the derived [Fe/H] values is smaller than 0.05 dex, so that we discarded those GCs as possible candidates for Fe-abundance anomalies. They represent 40% of the whole analyzed sample. The estimated upper limits in the [Fe/H] uncertainties put a demanding constraint on the precision of [Fe/H] estimates. Indeed, by using only NGC 1786's stars with a tighter error constraint $\sigma_{\text{err}}$[Fe/H] < 0.10 dex, we derived $W = 0.07 \pm 0.04$ dex ($N = 8$). For other GCs, we did not reach the

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**Table 2**

| ID     | $E(B-V)_{\text{Bess}}$ (mag) | Age (Gyr) | References | $\text{[Fe/H]}$ | Ref. | $\text{[Fe/H]}$ | $W$ (dex) | $N$ |
|--------|-------------------------------|-----------|------------|----------------|------|----------------|----------|-----|
| NGC 1754 | 0.07                          | 12.96     | 2          | $-1.50 \pm 0.10$ | 4.5  | $-1.54 \pm 0.02$ | 0.00 ± 0.05 | 14  |
| NGC 1786 | 0.07                          | 12.30     | 7          | $-1.75 \pm 0.10$ | 1.45 | $-1.80 \pm 0.03$ | 0.05 ± 0.03 | 15  |
| NGC 1835 | 0.14                          | 13.37     | 2          | $-1.72 \pm 0.10$ | 4.5  | $-1.74 \pm 0.03$ | 0.00 ± 0.03 | 16  |
| NGC 1841 | 0.14                          | 12.57     | 2          | $-2.02 \pm 0.10$ | 4.5  | $-2.10 \pm 0.03$ | 0.00 ± 0.02 | 15  |
| NGC 1898 | 0.07                          | 13.50     | 7          | $-1.32 \pm 0.10$ | 4.56 | $-1.32 \pm 0.02$ | 0.00 ± 0.03 | 16  |
| NGC 2005 | 0.07                          | 13.17     | 2          | $-1.74 \pm 0.10$ | 4.56 | $-1.32 \pm 0.02$ | 0.00 ± 0.03 | 16  |
| NGC 2019 | 0.07                          | 16.20     | 2          | $-1.56 \pm 0.10$ | 4.56 | $-1.79 \pm 0.04$ | 0.00 ± 0.05 | 18  |
| NGC 2210 | 0.10                          | 10.43     | 2          | $-1.55 \pm 0.10$ | 1.2  | $-1.61 \pm 0.02$ | 0.00 ± 0.04 | 9   |
| NGC 2257 | 0.05                          | 11.54     | 2          | $-1.77 \pm 0.10$ | 1.42 | $-1.80 \pm 0.05$ | 0.00 ± 0.06 | 11  |
| ESO 121-SC3 | 0.04                      | 8.50      | 7          | $-1.05 \pm 0.20$ | 3.50 | $-1.05 \pm 0.04$ | 0.00 ± 0.05 | 5   |

**Notes.**

* Errors taken from the standard deviation of $E(B-V)$ values of the selected stars are <0.01 mag.

**References.** (1) Mucciarelli et al. (2009); (2) Wagner-Kaiser et al. (2018); (3) Bica et al. (1998); (4) Suntzeff et al. (1992); (5) Beasley et al. (2002); (6) Johnson et al. (2006); (7) Piatti et al. (2009).
expected metallicity uncertainties, which could be attempted to be obtained from high S/N, high-dispersion spectroscopy. As far as we are aware, there is no study showing the existence of MPs among the LMC’s old GC population from their CMDs (see Milone et al. 2009), although three of them display the giveaway light element abundance signatures such as a Na–O anticorrelation. In fact, as equivalents of MW GCs, they are assumed to harbor MPs, and there is an acceptable synchronicity between their ages (Wagner-Kaiser et al. 2017) and the abundances of some light chemical elements (Mucciarelli et al. 2010), and overlap of their mass and age to relaxation-time ratio ranges (Piatti & Mackey 2018). As far as the [Fe/H]-spread is concerned, the eight MW GCs with Fe-abundance variations larger than 0.05 dex represent nearly 5% of the whole GC population. If such a small percentage was applicable to the LMC GC population, we should find no more than one GC with such a metallicity spread, in agreement with our findings for NGC 1786 (at a significance of ~1.7σ).

This work represents the first attempt to measure the iron abundance variation in most of the LMC GCs so far. We were motivated by the fact that Fe-abundance variations are found among some MW GCs and by the increasing number of theoretical models that predict the presence of such chemical inhomogeneities. We used on average 14 selected RGB stars per cluster and obtained [Fe/H] values with uncertainties smaller than 0.20 dex, and nearly comparable accuracy to that derived from high-dispersion spectroscopy for some of the brightest stars. We tightly reproduced their generally accepted spectroscopic metallicity scale and found no hint—for except for NGC 1786—for a metallicity spread. This outcome supports the fact that LMC GCs share chemical abundance patterns similar to those seen in many of their Galactic counterparts, as has been suggested from the comparative, high-resolution abundance measurements in the LMC GCs (Mucciarelli et al. 2010; Bastian & Lardo 2018).

Based on observations obtained at the SOAR telescope, which is a joint project of the Ministério da Ciência, Tecnologia, Inovações e Comunicações (MCTIC) do Brasil, the U.S. National Optical Astronomy Observatory (NOAO), the University of North Carolina at Chapel Hill (UNC), and Michigan State University (MSU). A.K. gratefully acknowledges support from the German Research Foundation (DFG) via Sonderforschungsbereich SFB 881 (“The Milky Way System,” subproject A08). We thank C.I. Johnson and A. Mucciarelli for useful comments. We thank the referee for the thorough reading of the manuscript and timely suggestions to improve it.

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