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Photometric metallicities of star clusters in the Large Magellanic Cloud

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Abstract. We derive photometric metallicities for a sample of 609 intermediate age and old LMC clusters from the slopes of their red giant branches in the K_s versus $(J - K_s)$ color-magnitude diagrams. Our cluster sample extends over the $\sim 40\,\mathrm{deg}^2$ area and covers the LMC bar and disk to a distance of $\sim \pm 2.5$ degrees from the bar. The derived cluster metallicity distribution spans a range of [Fe/H] from $+0.4$ to -2.2 and is similar to the metallicity distributions of field stars in the LMC bar and disk. While our preliminary analysis shows that cluster metallicity distributions in certain LMC bar and disk fields may be different, we find no compelling evidence for the global radial metallicity gradient as traced by star clusters in the LMC.

Keywords. Magellanic Clouds, galaxies: star clusters, galaxies: abundances

1. Introduction

Star clusters are powerful tools for studying chemical evolution history of the LMC. They are abundant in numbers and are distributed over large galactocentric distances and therefore sample well both the LMC bar and disk. However, only a small fraction out of 2769 LMC clusters listed in the catalogue of Bica et al. (2008) have reliable metallicity estimates obtained from either high resolution or infrared Ca II triplet spectroscopy (Olszewski et al. 1991; Hill et al. 2000; Ferraro et al. 2006; Grocholski et al. 2006; Johnson et al. 2006; Mucciarelli et al. 2008). While photometric metallicities are additionally available for a number of clusters (Bica et al. 1998; Dirsch et al. 2000; Kerber et al. 2007), the total number of LMC clusters with known metallicity estimates (i.e., spectroscopic + photometric) still remains low ($< 10\%$ of the known LMC cluster population).

To fill in this gap at least partially, in this work we derive photometric metallicities for a sample of 609 intermediate age and old LMC clusters ($> 1\,\mathrm{Gyr}$) from the slopes of their red giant branches (RGBs). The photometric data used for this purpose were taken from the catalog of recently accomplished SIRIUS JHK_s survey of the Magellanic Clouds (Kato et al. 2007). The large survey area ($\sim 40\,\mathrm{deg}^2$ in the LMC) and depth (10σ limiting magnitudes at $J \sim 19.2$, $H \sim 18.6$ and $K_s \sim 17.3\,\mathrm{mag}$) allow us to obtain photometric metallicity estimates of individual clusters located out to $\sim 2.5^\circ$ from the LMC bar and to investigate the distribution of cluster metallicities in the LMC bar and disk. Below we summarize preliminary results of this study.

2. A new RGB slope–metallicity relation

Metallicity estimates of individual clusters (see Sect. 3) were obtained from their RGBs slopes using a newly derived RGB slope–metallicity relation. This relation was obtained employing a sample of 12 well-studied LMC and SMC intermediate age clusters which

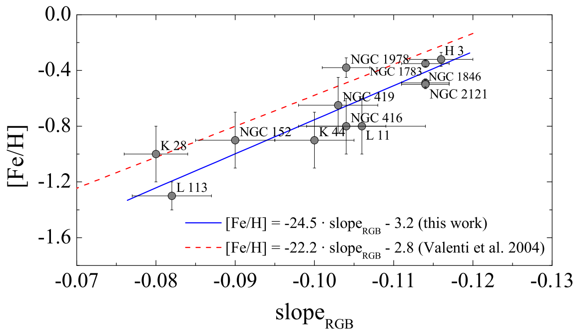

Figure 1. RGB slope- metallicity relation (solid line) derived as least square fit to the cluster slopes measured in the range $M_K = -2.0$ to -6.0 (dots with error bars). Relation of Valenti at al. (2004) that is based on Galactic globular clusters is shown as dashed line.

have well defined and well populated RGBs in the $K_s - (J - K_s)$ diagram (number of RGB stars brighter than $M_K = -2.0$ is $N_{\mathrm{RGB}} > 150$). All clusters have reliable age estimates derived from their main sequence turn-off point fitting and metallicities from the high resolution and/or infrared Ca II spectroscopy, together with $E(B - V)$ values available from photometry (all literature data). RGB slopes of individual clusters were obtained iteratively as linear least-square fits to the observed cluster CMDs in the range M_K -2.0 to -6.0. RGB stars used in the derivation of the RGB slope–metallicity relation were pre-selected to comply the following criteria:

• photometric uncertainty in all bands is $\sigma_{J,H,K_s} < 0.03$;

• parameters of the photometric procedure meet the following criteria: $|sharpness| \leqslant 0.5$, to ensure that the point source in a given photometric frame was neither more nor less extended than a typical stellar image: $\chi \leqslant 1.5$, $\leqslant 1$, and $\leqslant 0.8$ in J, H, and K_s, respectively, to ensure that the point spread function (PSF) was fitted accurately;

• no adjacent point-like sources detected within the FWHM of the PSF with a flux $> 10\%$ of the target star (see Kato et al. 2007 for details);

• RGB stars used in the slope derivations were limited to those that fall within $\pm 2\sigma_{(J-K_s)}$ from the best-fitting slope ($\sigma_{(J-K_s)}$ is photometric uncertainty in $(J - K_s)$).

The derived RGB slope–metallicity relation is:

$$[Fe/H] = -24.5(\pm 2.4) slope_{\mathrm{RGB}} - 3.2(\pm 0.3) \tag{2.1}$$

The new relation is similar to the one of Valenti et al. (2004) that was obtained employing a sample of Galactic globular clusters; the slopes of the two relations differ by $\sim 10\%$ only (Fig. 1). However, the difference in zero-points is significant: metallicities of LMC and SMC clusters inferred from the relation of Valenti et al. (2004) are up to 0.4 dex higher than those obtained from spectroscopy, while much better agreement is achieved if our RGB slope–metallicity relation is used instead (Kučinskas et al., in prep.).

3. Photometric metallicities of star clusters in the LMC

Metallicities of the LMC clusters were derived employing the following procedure:

• only stars within $1'$ radius from the cluster center (i.e., assumed to be cluster members) were used in the analysis (cluster coordinates from Bica et al. 2008); no statistical removal of the field stars was made;

• only clusters with sufficiently well defined red giant branches were used ($N_{\mathrm{RGB}} > 30$ stars; median $N_{\mathrm{RGB}} \sim 70$ stars);

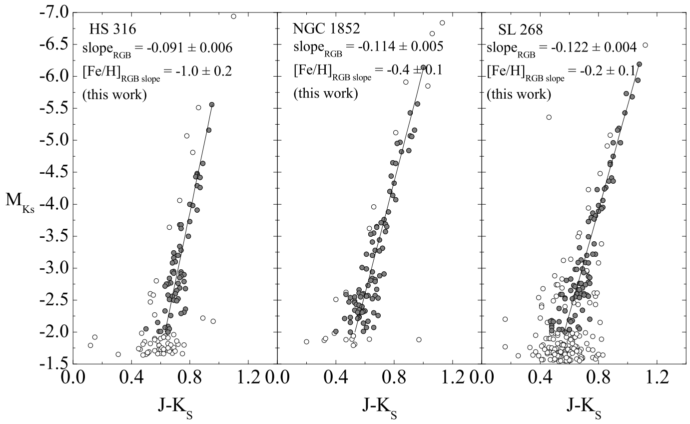

Figure 2. Observed RGBs of selected LMC clusters (circles). Filled circles are stars that were used to derive cluster RGB slope (solid lines) and metallicity (see text for details).

• RGB slopes of the resulting sample of 609 LMC clusters were derived employing the same procedure as used in the derivation of RGB slope–metallicity relation above (i.e., iterative linear least-square fitting to the observed RGBs in K_s vs. $(J-K_s)$ CMDs; RGB stars employed in the fitting procedure were limited to those that fall within $\pm 2\sigma_{(J-Ks)}$ range from the best-fitting slope). Similarly as in the derivation of the RGB slope–metallicity relation, only stars with best quality photometric data were employed. Sample fits of the RGB slopes are shown in Fig. 2;

• finally, cluster metallicities were obtained utilizing the RGB slope-metallicity relation derived above (Sect. 2). Typical (median) uncertainty of the photometric cluster metallicity estimate is ~ 0.3 dex.

Spatial distribution of the sample clusters in the LMC and their metallicity distributions are shown in Fig. 3. The distribution of cluster metallicities is slightly asymmetric and extends towards the lower metallicities (Fig. 3, right panel). The range of metallicities covered by clusters in our sample ([Fe/H] from $+0.4$ to -2.2) is similar to the metallicity range of field stars in the LMC disk (cf. Carrera et al. 2008). The median value of cluster metallicities in our sample is [Fe/H] ~ -0.5 which is comparable with the mean metallicities of the LMC bar and disk stars in the samples of Cole et al. (2005; [Fe/H] ~ -0.45) and Carrera et al. (2008; [Fe/H] ~ -0.5).

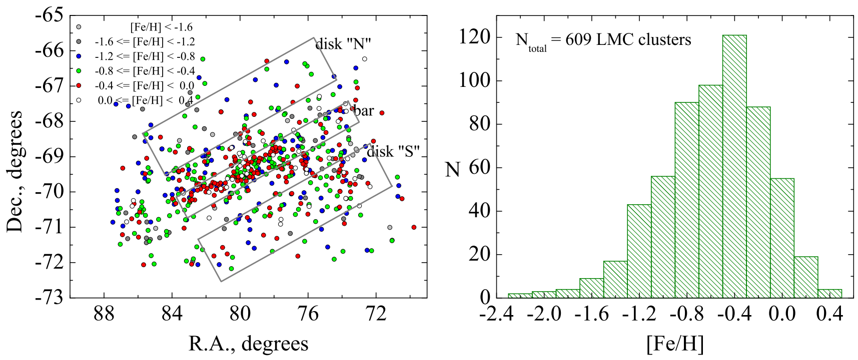

Figure 3. Left: spatial distribution of the studied LMC clusters. Fields in the LMC bar and disk where the distributions of cluster metallicities were studied in detail are marked as boxes. Right: metallicities of the intermediate age and old clusters in the LMC.

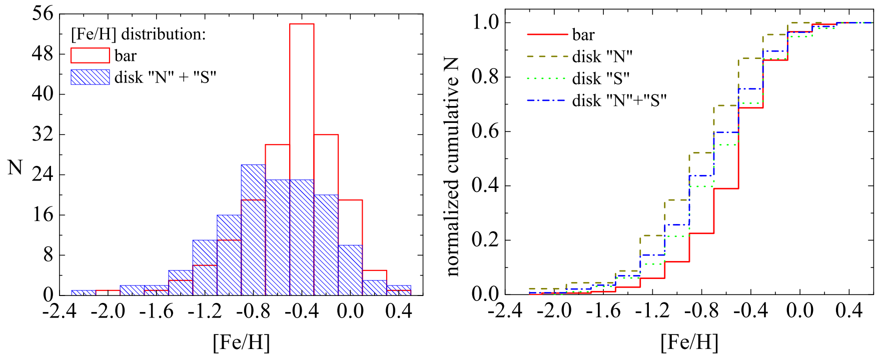

Figure 4. Left: metallicities of cluster in the LMC bar (contours) and disk (N+S) fields (dashed histogram). Right: cumulative distributions of cluster metallicities in the LMC bar field (solid line), two disk fields (dashed and dotted lines) and combined (N+S) disk field (dot-dashed line).

To investigate the differences between the cluster metallicities in the LMC bar and disk we selected clusters that belong to a field in the LMC bar (182 clusters) and two fields located $\sim 2^\circ$ to the north (46 clusters) and south (98 clusters) from the LMC bar (regions marked as boxes in Fig. 3, left panel). The distributions of cluster metallicities in these fields are shown in Fig. 4. The data hints that clusters in the disk fields may be somewhat more metal-poor than clusters in the LMC bar: the fraction of metal-rich clusters ([Fe/H] > -0.5) equals to ~ 0.6 and ~ 0.4 in the bar and combined (northern + southern) disk sub-samples, respectively.

Analysis of the cumulative distributions of cluster metallicities (Fig. 4, right panel), however, shows that statistical significance of the differences between the different fields is small. Kolmogorov-Smirnov test indicates that in case of the northern disk field these differences may be significant at the level of $\sim 95\%$; in all other cases the probability is much lower. We therefore conclude that our data does not provide a compelling evidence supporting the existence of a global metallicity gradient as traced by star clusters in the LMC.

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