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Deprojecting the metallicity and age gradients for the Magellanic Clouds using star clusters

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Abstract. We compile the most reliable age, metallicity and distance determinations of well-studied stellar clusters from the Magellanic Clouds available, including the new results from the VISCACHA Survey. Using these benchmark clusters, we determine the age-metallicity relations of the two galaxies, the one of the LMC we show as an example, as well as the age and metallicity gradients of the LMC measuring the clusters' galactocentric distances using two different methods: On the one hand the standard deprojection based on the assumption that the clusters lie in the galaxy's main plane, and on the other hand using the distances as determined from their colour-magnitude diagrams. The results lead to an improved understanding of the formation and evolution of the Magellanic System, and allow to evaluate the validity of the standard deprojection method.

Resumo. Fizemos uma compilação das determinações mais confiáveis disponíveis de idades, metalicidades e distâncias de aglomerados estelares bem estudados das Nuvens de Magalhães, incluindo resultados novos do levantamento VISCACHA. Usando estes aglomerados de referência, determinamos as relações idade-metalicidade das duas galáxias, aquela da LMC mostramos como exemplo, assim como os gradientes de idade e metalicidade da LMC medindo as distâncias galactocêntricas dos aglomerados usando dois métodos diferentes: Por um lado a deprojeção padrão baseada na suposição, de que os aglomerados se encontram no plano principal da galáxia, e por outro lado usando as distâncias determinadas a partir dos seus diagramas cor-magnitude. Os resultados levam a um melhor entendimento das formação e evolução do Sistema Magellânico, e permitem avaliar a validade do método de deprojeção padrão.

Keywords. Magellanic Clouds – Galaxies: star clusters: general – Galaxies: structure

1. Introduction

The Small and Large Magellanic Clouds (SMC and LMC) represent ideal laboratories to test galaxy evolution models and probe 3D galactic structure, being among the galaxies closest to us. Whereas the LMC is known to have a prominent disk, the structure of the SMC is more complicated, very elongated in the direction of the line of sight, a possible disk would appear nearly edge-on (van der Marel et al. 2002). Star clusters can be used to trace the age and metallicity of the stellar content, and gradients of these properties, i. e. in the galacto-centric directions, can give us indications of the formation and evolution of the Magellanic System. These gradients are often estimated using a standard deprojection based on the assumption that the clusters lie in the galaxies' main planes (Palma et al. 2015). However, in the Magellanic Clouds it is possible to properly determine the distances to the star clusters from their colour-magnitude diagrams and calculate the gradients without making simplifying assumptions about their distribution.

2. Method

We compiled the most reliable age, metallicity and distance determinations of well-studied stellar clusters from the Magellanic Clouds available, determined by means of isochrone fitting on colour- magnitude diagrams, and red giant spectroscopy. We also include new results from the VISCACHA survey (VIsible Soar photometry of star Clusters in tApii and Coxi HuguA, Kerber et al. 2018). Typical errors on the distance moduli range from 0.03 to 0.15. Our sample contains 85 SMC clusters, and 111 LMC clusters. We then used the distance determinations to determine their distribution in three dimensions.
After that, we determined the galaxies' age-metallicity relations and age gradients and, for the LMC, the metallicity gradients along different galacto-centric directions: the traditional projection along the line of sight onto the galactic plane, a, the projection perpendicular to the galactic plane, $R_{\rm LMC}$, the distance to the plane, $Z_{\rm LMC}$, and the true galacto-centric distance, R. For the orientation of the LMC plane, we used a position angle of the line of nodes of 145° and an inclination to the plane of the sky of 35.8° (Palma et al. 2015). For objects in the galactic plane, $a = R_{\rm LMC} = R$.

3. Results

We compare the age-metallicity relations of our sample clusters with analytical chemical evolution models of the Clouds from Pagel & Tautvaišienė (1998). They agree remarkably well for the LMC, as can be ssen in Fig. 1, and within the standard deviation for the SMC (not shown).
We then determined the 3D distribution of our sample clusters, and their metallicity and age gradients.
In order to calculate the gradients, we subdivided our LMC cluster sample in two populations: an old one, with ages over 10 Gyr, corresponding to a galaxy "halo", and a younger, "disk" population. We determined [Fe/H] - and log(age) gradients for both populations individually, as can be seen in Fig. 2 (in red and

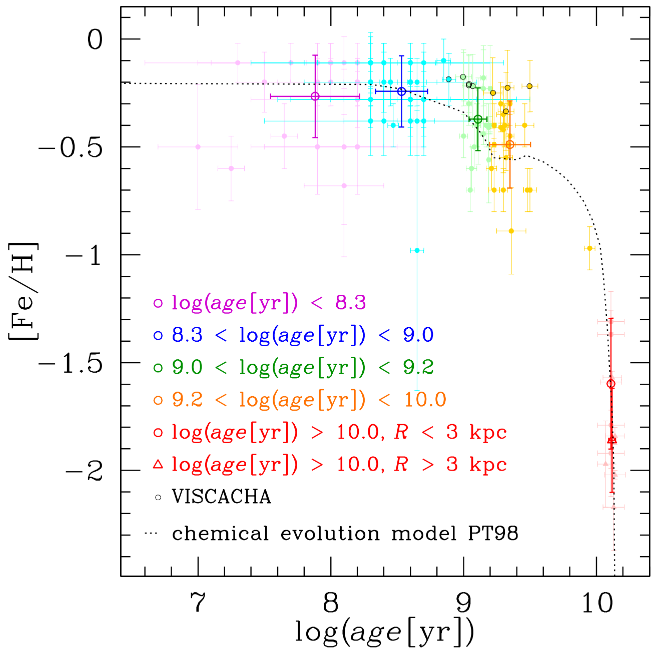

Figure 1. Age-metallicity relations of the Large Magellanic Cloud.

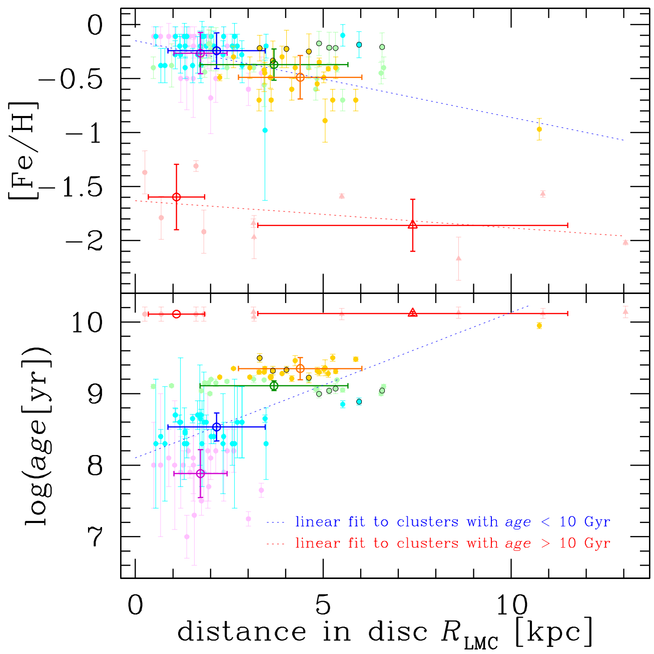

Figure 2. [Fe/H] and log(*age*) as projected perpendicularly onto the galaxy plane, the colours, symbols and error bars have the same meaning as in Fig. 1.

blue, respectively).
The cluster distributions and gradients in a and R_{LMC} are very similar, since they both represent projections onto the same plane, in similar directions, differing by 35.8°.
The younger population shows clear gradients in the usual senses, decreasing for [Fe/H] vs. R_{LMC} and increasing for log(*age*) vs. R_{LMC}. The old, "halo", population shows no significant gradients, as expected for a galaxy component that has had plenty of time to relax and seen several close encounters with the Galaxy and the SMC.

Table 1. gradients of LMC cluster metallicities and ages.

	∇[Fe/H] [dex/kpc]	∇[Fe/H] [dex/kpc]	∇log(*age*) [kpc^{-1}]
direction	< 10 Gyr	> 10 Gyr	< 10 Gyr
a	−0.052 ± 0.009	−0.022 ± 0.02	0.18 ± 0.03
R_{LMC}	−0.054 ± 0.01	−0.025 ± 0.02	0.20 ± 0.03
Z_{LMC}	−0.02 ± 0.02	0.14 ± 0.05	0.18 ± 0.06
R	−0.053 ± 0.01	−0.024 ± 0.02	0.21 ± 0.03

Perpendicular to the LMC plane, an age gradient can be seen in the young population but no metallicity gradient.
Surprisingly, calculating the clusters' true distances to the LMC center, R, did not yield significantly better results than using the projections a and R_{LMC}. It will be interesting to see if this result persists, when more and more precise distance determinations will be available.
Table 1 shows the numerical values of the different gradients determined in this work.

4. Conclusions & Perspectives

To our surprise, a true deprojection of the positions of LMC star clusters with age, metallicity and distance determinations did not yield any significant improvement for the calculation of age - and metallicity gradients in relation to the traditional "deprojection" method, based on the assumption, that all clusters lie in the galaxy's main plane. If this is due to the limited size of our sample (i. e. selection effects) can only be evaluated using a more complete sample.
As next steps, we will apply isochrone fits to 100 clusters of the VISCACHA survey of Magellanic Cloud star cluster CMDs, ∼ 60 in the LMC and ∼ 30 in the SMC plus another 10 + 30 that will be observed this semester, in order to increase the sample for both the SMC and LMC, and obtain more statistically significant results, find the galaxies' main planes by adjusting planes to the cluster positions, and compare our results to other works. This way we'll be able to make a revelant contribution to the discussion about the Clouds' formation and evolution.

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