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Structure and dynamical age of VISCACHA Magellanic Clouds peripheral star clusters

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Abstract. The Magellanic Clouds (MCs) constitute a pair of galaxies whose interaction is modulated by the Milky Way potential. Studies linking epochs of enhanced star formation with the Clouds mutual approximation reveal that the changing tidal field affects their stellar populations. Given this environment, star clusters that are located today at peripheral regions of the Clouds are also expected to be more susceptible to dynamical tidal effects than those located in internal regions. A preliminary analysis of the dynamical time scales of Magellanic Clouds' peripheral clusters from the VISCACHA survey is presented.

Resumo. As Nuvens de Magalhães (MCs) constituem um par de galáxias cuja interação é modulada pelo potencial da Via Láctea. Estudos que ligam épocas de maior formação estelar com a aproximação mútua das Nuvens revelam que a mudança do campo de maré afeta as suas populações estelares. Neste ambiente, espera-se que aglomerados de estrelas que estão hoje localizados em regiões periféricas das Nuvens sejam mais suscetíveis a efeitos dinâmicos de maré do que aqueles localizados em regiões internas. É apresentada uma análise preliminar das escalas de tempo dinâmicas dos aglomerados periféricos das Nuvens de Magalhães do levantamento VISCACHA.

Keywords. Galaxies: star clusters: general – Magellanic Clouds

1. Introduction

Star clusters are useful probes of the dynamical history of the Magellanic Clouds because through their colour-magnitude diagrams (CMDs) one can determine age, metallicity, distance and stellar mass distribution. Furthermore, structural parameters (core, half-mass and tidal radius) can be determined from the clusters' density and brightness profiles to reveal the spatial distribution of their stellar content, which is key to understand their evolution, dissolution, and the impact of external effects.

The VISCACHA survey (Maia et al. 2019) is an ongoing project which is based on SAMI@SOAR observations of MCs peripheral star clusters in BVI bands to produce a comprehensive database of homogeneous, deep and high quality photometry. The data analysis aims at deriving the clusters' astrophysical and structural properties. These data have been employed in the investigation of several relevant issues on the MCs: (i) position dependence of structural parameters, (ii) age-metallicity relations and radial gradients, (iii) 3D structure of the MCs+Bridge in contrast with results from field stars, (iv) star cluster formation history, (v) evolution and dissolution of star clusters, (vi) initial mass function for high and low mass clusters, (vii) extended main sequence turn-offs in intermediate-age clusters, (viii) combination with kinematical information to calculate orbits.

In the present study, total masses for 71 clusters from the VISCACHA Internal Data Release 1 (IDR1), with homogeneously determined fundamental parameters, were used to estimate their dynamical time scales and infer on the clusters' dynamical evolution. The present analysis complements Santos et al. (2020)'s study, which obtained masses from literature ages combined with derived structural parameters and integrated magnitudes. Fig. 1 shows the spatial distribution of the VISCACHA IDR1 cluster sample.

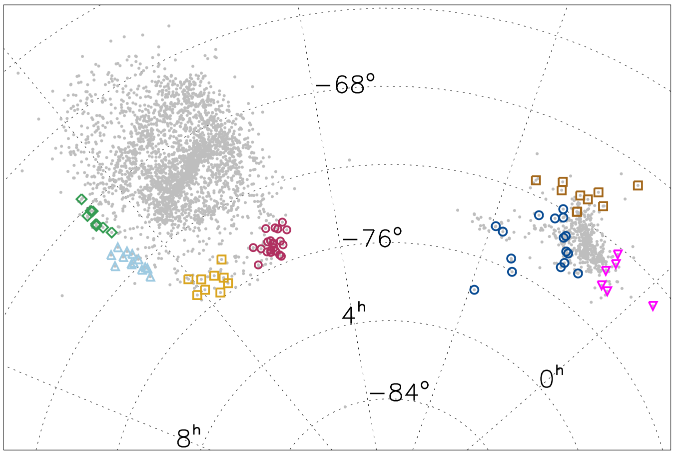

Figure 1. Projected spatial distribution of MCs star clusters (grey dots from Bica et al. 2008). The VISCACHA IDR1 observed clusters are represented by colored symbols discriminating different regions.

2. Methodology

2.1. Isochrone fittings: astrophysical parameters

Astrophysical parameters (age, metallicity, distance and reddening) were derived from visual fittings of PARSEC isochrones (Bressan et al. 2012) to the clusters' CMDs (Kerber 2022).

2.2. King model fittings to radial profiles: r_h and M_V

The structural parameters central stellar density, central surface brightness, core (r_c) and tidal (r_t) radius were obtained from King (1962) model fittings to the surface brightness (SB) and

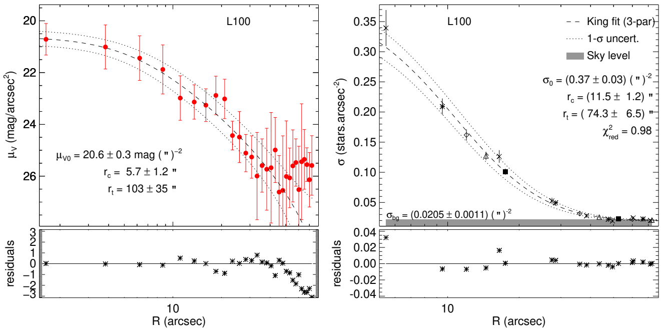

Figure 2. (*left*) King model fitting to the SBP; (*right*) King model fitting to the RDP.

radial number density (RD) profiles. To asccess profile uncertainties, eight sectors annular bins were used to build the SBP, while Poisson uncertainties of annular densities were employed for the RDP. Fig. 2 shows the SBP (left) and the RDP (right) for the SMC cluster Lindsay 100 together with the King model fittings. Because the RDP is uncertain due to crowding effects in the clusters' centers and the SBP presents large fluctuations in the clusters' outskirsts, the r_c was adopted from the SBP and the r_t from the RDP. The half-light radius (r_h) was derived from r_c and r_t and the integrated V magnitude was obtained by integrating the SBP (Santos et al. 2020). Fig. 3 (left) shows how the cluster sample is distributed in the plane M_V vs. r_h.

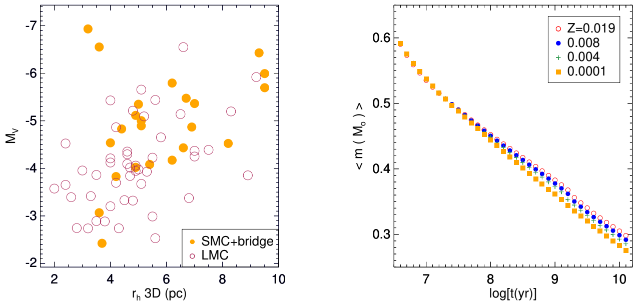

Figure 3. (*left*) Sample characterization according to r_h and M_V; (*right*) SSPs average stellar mass.

2.3. Simple stellar population models: from M_V and $\log t$ to $\mathcal{M}$

Masses for 71 clusters from VISCACHA internal data release 1 (IDR1) were obtained from simple stellar population (SSP) models with stars distributed according to a Kroupa (2001) mass function (Maia et al. 2014). The SSPs average stellar mass changes from 0.6 to 0.28 as the SSP age increases from 0.004 to 13 Gyr (Fig. 3, right).

The SSPs age (t) and integrated V magnitude (M_V) were used to determine the SSP mass ($\mathcal{M}$) through a fitting function (Maia et al. 2014):

$$\log \frac{\mathcal{M}}{M_\odot} = a + b\ \log\left[t(yr)\right] - 0.4(M_V - M_{V,\odot}) \quad (1)$$

where $M_{V,\odot} = 4.83$ and coefficients a and b depend on metallicity.

Therefore, from the measured age and integrated magnitude it is possible to obtain the clusters' mass using equation 1 with the estimated metallicity from isochrone fitting.

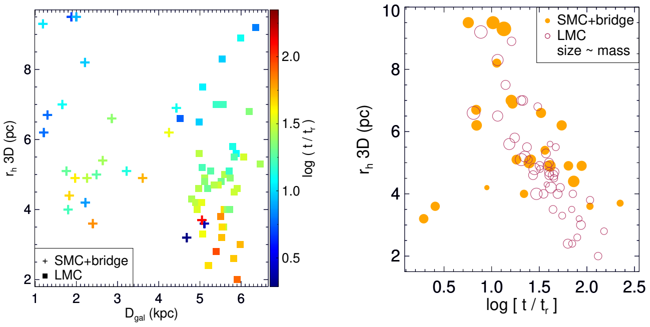

Figure 4. (*left*) Half-light radius distribution vs. MCs galactocentric distances with the color bar indicating the dynamical age; (*right*) Half-light radius vs. dynamical age, where the symbol sizes denote mass.

3. Results

3.1. Half-mass relaxation time and cluster internal dynamics

The half-light radius obtained from the radial profiles is considered here to be equal to the half-mass radius, an assumption that is satisfied if the mass/luminosity ratio is the same throughout the cluster. The half-mass relaxation time (t_r) is the time necessary to the interaction among stars redistribute significantly their velocities driving the system to virial equilibrium, when it looses memory of the initial state. In this case, t_r is evaluated at r_h and may be quantified, according to Heggie & Hut (2003), as:

$$t_r = 2.1 \times 10^5 \frac{\sqrt{\mathcal{M}(M_\odot)\ r_h(pc)^3}}{\langle m(M_\odot)\rangle \ln\left(0.11\mathcal{M}/\langle m\rangle\right)}\ \mathrm{yr} \quad (2)$$

The shorter the relaxation time compared to the cluster age, the more evolved the system, implying that the cluster dynamical age (t/t_r) is larger. It can be noted for our sample that this occurs regardless the galactocentric distance from the corresponding galaxy (D_{gal}): more evolved clusters tend to have smaller r_h and mass, which is compatible with progressive stellar mass loss (Fig. 4).

4. Conclusions and perspectives

The lack of a relation between r_h and D_{gal} suggests that the recent interaction between the Clouds, 150 Myr ago, have displaced the clusters from their original, undisturbed orbits.

Most clusters have $t_r < 150$ Myr and ages $> 10t_r$, suggesting that they could be underway towards Virial equilibrium with structural readjustment after the Clouds' last encounter.

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References

Bica E., Bonatto C., Dutra C. M., et al. 2008, MNRAS, 389, 678
Bressan A., Marigo P., Girardi L. et al. 2012, MNRAS, 427, 127
Heggie D., Hut P. 2003, The Gravitational Million - Body Problem: A Multidisciplinary Approach to Star Cluster Dynamics. CUP.
Kerber L. 2022, private comm.
King I. 1962, AJ, 67, 471
Kroupa P. 2001, MNRAS 322, 231
Maia F. F. S., Dias B., Santos Jr. J. F. C. et al. 2019, MNRAS, 484, 5702
Maia F. F. S., Piatti A. E., Santos Jr. J. F. C. et al. 2014, MNRAS, 437, 2005
Santos Jr. J. F. C., Maia F. F. S., Dias B. et al. 2020, MNRAS, 498, 205
Tokovinin A., Cantarutti R., Tighe R. et al. 2016, PASP, 128, 125003