Distribution of stars in three Magellanic Clouds star clusters NGC 1754, NGC 2005, NGC 2019

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Abstract. In this contribution we present our investigation of a sample of Large Magellanic Cloud star clusters. This galaxy is the closest neighbour of the Milky Way. In our sample we selected three clusters with similar ages of 10 Gyr, namely NGC 1754, NGC 2005 and NGC 2019. We construct the radial profiles of the clusters, derive structural parameters and study the distribution of the stars within the clusters through the variation of the core radius with magnitude of the stars. Indication of stellar stratification is found in NGC 1754 and NGC 2005.
Key words: LMC, star clusters, individually: NGC 1754, NGC 2005, NGC 2019

Introduction

The Large Magellanic Cloud (LMC) is known to host a variety of star clusters different in age, shape, multiplicity, some young, still forming and embedded in gas and some very old ones; some are spherical and others elliptical in shape and a large number of binary cluster candidates. The mechanisms of formation of the LMC clusters and their dynamical evolution are still subjects to investigation. The dynamical models predict that after the cluster is formed the low-mass stars are being given energy from the massive stars via two-body encounters (Lightman & Shapiro 1978; Spitzer 1987; Meylan & Heggie 1997). Eventually some of the low-mass stars escape the cluster's gravitational bound. The massive stars, on the other hand, sink towards the cluster's centre. The more massive a star is, the more it will sink. This is the expected outcome of the dynamical evolution of a star cluster after a relaxation time, as the Maxwellian distribution of the velocities is achieved. During the dynamical evolution of a star cluster stellar segregation (or stratification) is expected - the most massive stars distributed in the central regions, and the less massive stars distributed in the outer regions. So the spatial distribution of massive stars is showing a central concentration with a core radius much smaller than that of the less massive stars. Another possibility is that the massive stars are born in the cluster's centre - primordial mass segregation (Bonnell & Davies 1998). In this case the massive stars are located at the central regions from the beginning and the massive stars central concentration is displayed before relaxation time. We use the resolving capabilities of the Hubble Space Telescope (HST) to investigate the stellar stratification in three LMC clusters.

1 Studied clusters

The three studied clusters are old, metal-poor and populous. NGC 2005 and NGC 2019 are located in the inner parts of LMC, thus the field contribution from the host galaxy is significant. NGC 1754 is located in the outskirts of LMC and is less affected by field stars contamination than the other two. All three studied clusters are listed as possible post-core-collapsed by Mackey & Gilmore (2003) from surface brightness profiles. Literature values are listed in Table 1. The V magnitudes and $B-V$ colours are from Bica et al. (1996, 1999). Age is from Frogel et al. (1990). Metallicity $[Fe/H]$ is from Olsen et al. (1998). Half-light r_h and tidal radius r_t of the King-model cluster fit is from the catalogue of McLaughlin & van der Marel (2005).

Table 1. Literature data for the studied clusters.

Cluster Name	V	B-V	Age	[Fe/H]	r_h	r_t
NGC 1754	11.57	0.75	10 Gyr	-1.42	11.2	142.9
NGC 2005	11.57	0.73	10 Gyr	-1.35	8.65	98.8
NGC 2019	10.86	0.76	10 Gyr	-1.23	9.72	121.6

2 Photometry

In this study we use archival data from the WFPC2 on-board the Hubble Space Telescope (available on http://archive.stsci.edu/hst/). The images were taken for HST proposal ID 5916.

Table 2. List of observations used.

Cluster Name	Filter	Exptime	Filter	Exptime
NGC 1754	F555W	3x500, 2x20	F814W	2x600, 2x20
NGC 2005	F555W	3x500, 2x20	F814W	3x600, 3x20
NGC 2019	F555W	3x500, 2x20	F814W	3x600, 3x20

We obtained calibrated files from the archive which were processed prior downloading by the standard STScI pipeline and calibrated using the latest WFPC2 calibrations (bad-pixel, bias and flat field correction). The photometry was performed simultaneously on the calibrated images with HSTphot (Dolphin 2000). During photometry extensive completeness tests were performed. Representative photometric uncertainties are indicated on the CMDs of Fig. 1.

3 CMD

The three LMC star clusters are well evolved. Stars brighter than $V = 23$ are evolved beyond the Main Sequence. At the distance of the LMC ($M-m = 18.5$) this corresponds to $M_V = 4.5$, or roughly stars more massive than $0.8M_{\odot}$ have left the Main Sequence. The photometry of all three clusters reaches very faint stars down to 26-th magnitude in V. Stars fainter than $V = 25$ are most affected by incompleteness and this is why we do not consider them in the analysis. The CMDs are shown on Fig. 1.

4 Structural parameters

We construct the Radial Density Profiles (RDPs) by counting stars in concentric rings around the cluster centre. This number is corrected for the incompleteness of the stars and divided by the area of the ring. The resulting density profiles with radius r are fitted with a King profile (King 1962)

$$f(r) = f_{0K} \left(\frac{1}{\sqrt{1+(r/r_c)^2}} - \frac{1}{\sqrt{1+(r_t/r_c)^2}} \right)^2 + f_b \ , \qquad (1)$$

where f_{0K} is the central density, r_c and r_t are the core and tidal radius, respectively, and f_b is the background. We construct the RDPs for several ranges of magnitude, fit those profiles and derive the core radii of every subsample of the cluster. Thus we can study the variation of the core radius with magnitude. This is a method commonly used to search for mass-segregation in star clusters (Brandl et al. 1996, de Grijs et al. 2002).

Table 3. Structural parameters derived from King-like model fitting, f_{0K} is the central density, r_c is the core radius and r_t is the tidal radius.

Cluster Name	$f_{0K} \times 10^3$ (arcmin^{-2})	r_c (arcsec)	r_t (arcsec)
NGC 1754	42.9 ± 5.9	11.7 ± 2.1	98.5 ± 39.8
NGC 2005	29.7 ± 5.2	15.1 ± 3.3	56.0 ± 7.9
NGC 2019	47.9 ± 2.9	11.0 ± 0.9	62.9 ± 5.6

5 Stellar segregation

When we consider stars in groups, the faint stars (shown with red circle) have core radii approximately twice as large as the bright stars (shown with blue circle). The green circle marks the core radius derived for the cluster considering all magnitudes. If we look at the variation of the core radius with magnitude in NGC 1754 (Fig. 1 top-right) the stellar distribution varies with magnitude – brighter stars are more centrally distributed, an indication of stellar segregation, possibly of dynamical origin.

The variation of the core radius with magnitude in NGC 2005 shows a trend – increasing with increasing magnitude, and the groups of bright and faint stars support it (see Fig. 1 centre-right). The first and last data points are outliers, but this is not unexpected. The profile for the brightest stars with $16 < V < 17$ suffers from low-number statistics and the uncertainties of the

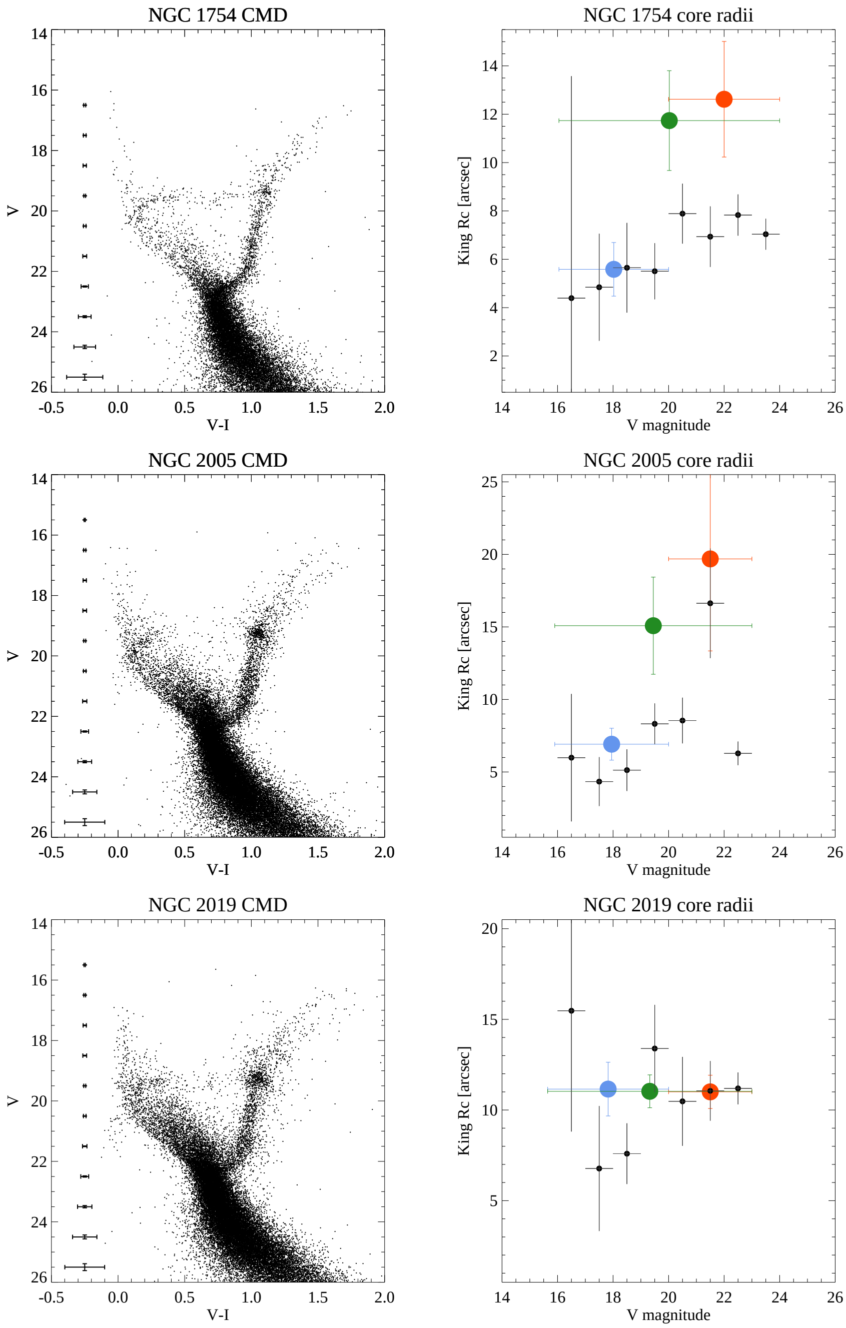

Fig. 1. (left) CMDs of the studied clusters; (right) stellar segregation diagnostics diagrams, core radius from model fitting is on y-axis, magnitude of the stars is on the x-axis.

derived parameters are larger (indicated with the error bars in the right figures on Fig. 1). The faintest stars with $22 < V < 23$, on the other hand are more affected by crowding and incompleteness, which distort the profile making it steeper with small core radius.

The profiles of NGC 2019 are very smooth but they are similar for all magnitudes (Fig. 1 bottom-right). This is the reason there is no significant variation of the derived core radius with magnitude.

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