MERGER CANDIDATES AMONG STAR CLUSTERS IN THE SMALL MAGELLANIC CLOUD

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Abstract

A new census of extended objects in the Small Magellanic Cloud reveals that about 13% of all star clusters (≈1200) take part in multiple groupings, which may include merging systems. In this work we present preliminary results on a project which aims at determining the fundamental properties of a sample of cluster merger candidates in different evolutionary phases as well as their structural characteristics. An initial sample of seven objects was observed in B and V with the SOAR 4-m telescope. Disturbances in the radial profile and dissimilarities in the CMDs of spatially selected regions are employed to recover signatures of the merging process. IC1612E/W and K50 show evidences of clusters in the process of merging and the pair NGC422/IC1641 seems to be in a capture process.

1 Introduction

The low-density medium of the Small Magellanic Cloud provides an environment that seems to favor the existence of binary clusters (BC) in the sense that a strong tidal field from a high-density medium would decouple a BC (or disrupt its components) during its orbit about the host galaxy while in a weak tidal field a BC would endure for many orbits and eventually merge into a single object (Innanem et al. 1972). In fact, while BC are rare or unreported in galaxies in general, in the Magellanic Clouds true BC (i.e., a gravitational bound system and not just a random line-up) seem to occur in great numbers (Bhatia & Hatzidimitriou 1988; Bhatia et al. 1991). Evidence of cluster binarity and mergers has been reported for both Clouds which are very rich in cluster pairs and multiplets (Dieball, Müller & Grebel 2002; Bica et al. 2008; Carvalho et al. 2008).

With the present study we intend to initiate a series of case studies of star cluster merger candidates in the Magellanic Clouds. We take advantage of SOAR's high quality B and V imaging of the star clusters and their surroundings to built stellar density profiles and colour-magnitude diagrams (CMDs). We determine cluster astrophysical parameters by fitting isochrones to the CMDs and examine fluctuations in the profile of template clusters and merger candidates in order to evaluate the merging process degree (if any) in a comparative way.

2 Observations

The SOAR optical imager (SOI) mounted in a bent-Cassegrain configuration to the 4.1-m SOAR telescope (Cerro Pachón, Chile) was employed to observe a sample of 7 merger candidates and 1 isolated template cluster for comparison purposes. Images in Bessel *BV* filters were obtained on the photometric night of 2007 November 11, using the SOI mini-mosaic of two E2V 2x4k CCDs (1 pixel = 15μm) to cover a 5.2x5.2 $(')^2$ field of view. The CCDs were binned to 2x2 pixels yielding a scale of 0.154$''$/pixel.

The average seeing was ∼0.95$''$ in *B* and ∼0.8$''$ in *V*. Two images in each filter were obtained, with single exposure times of 480 s in *B* and 195 s in *V*. Additional 30 s exposures were taken in both filters in order to not saturate bright stars. Only 30 s images have been obtained for NGC 121.

The sample cluster *V* images are shown in Fig. 1. All images correspond to extractions of the SOI frame.

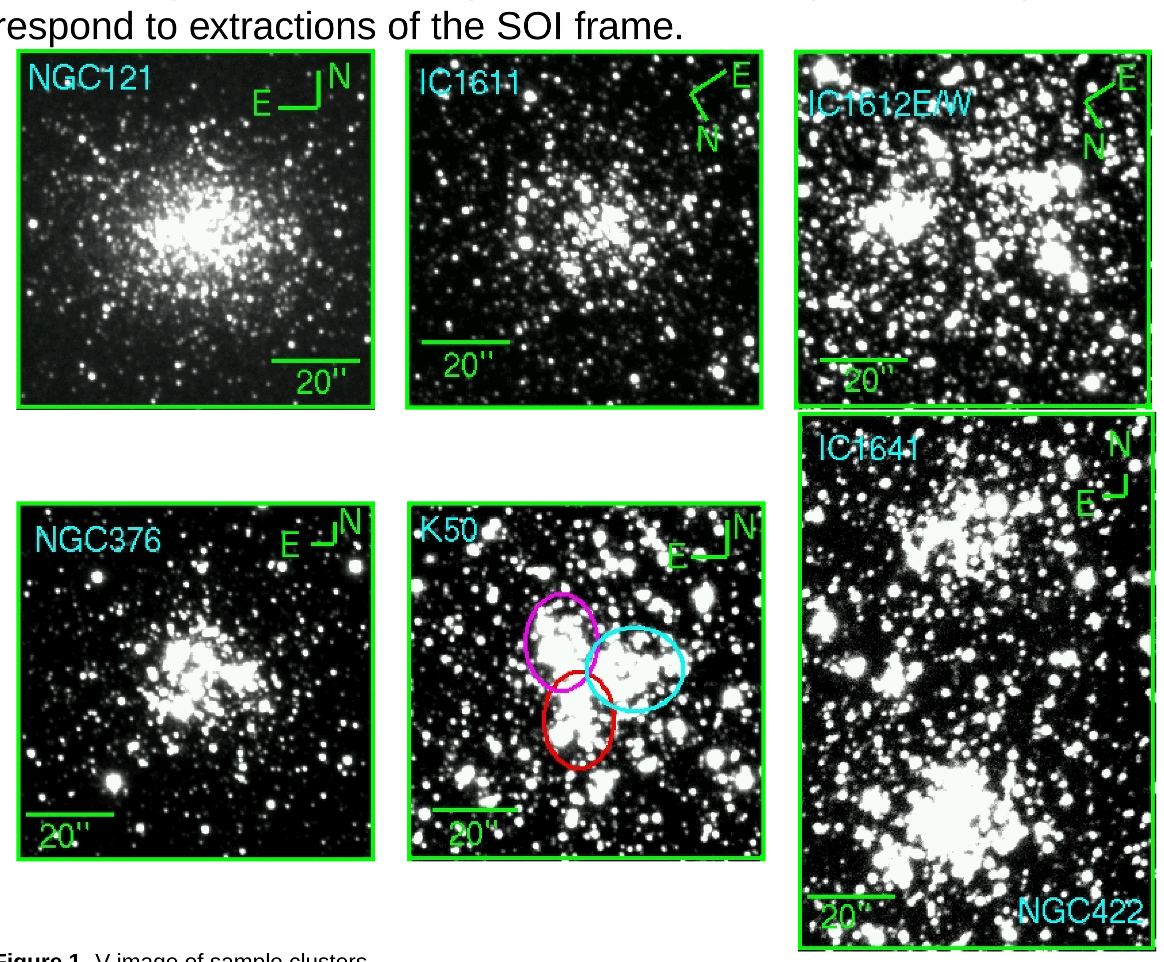


Figure 1. V image of sample clusters.

The CCD frames were reduced with IRAF software. DAOPHOT as implemented in IRAF was employed to perform point spread function (PSF) photometry with instrumental magnitudes obtained via ALLSTAR task. Only stars with photometric quality parameters $\chi < 3.0$ and -0.5$< sharp <$0.5 were kept in the final database. After photometric calibration, the magnitude errors achieved in *B* and *V* bands are smaller than 0.1 mag at mag=23 in the cluster central regions.

The merger candidates cluster sample is presented in Table 1 together with NGC 121, a well studied cluster that was included in the sample to serve as a comparison template of a single and isolated cluster for control analysis purposes.

Table 1. Cluster sample and derived parameters

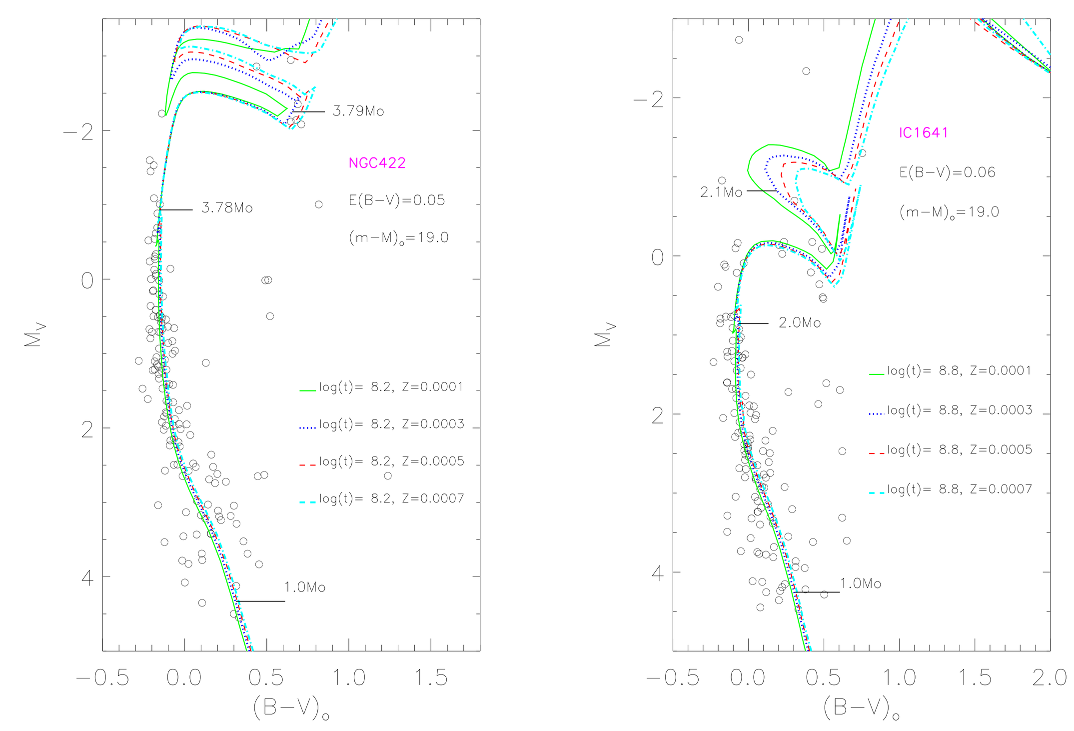
Cluster	α_{2000} (h:m:s)	δ_{2000} (° : ′ : ″)	E(B-V)^a	age (Gyr)	[Fe/H]	R$_c$ arcsec	R$_t$ arcsec
NGC121	0:26:47	-71:32:12	0.04 ± 0.01	12.6 ± 1.2	-1.68 ± 0.09	22 ± 12	133.1 ± 5.3
IC1611	0:59:48	-72:20:02	0.08 ± 0.01	0.133 ± 0.006	-1.07 ± 0.15	–	–
IC1612W=H86-186	0:59:57	-72:22:24	0.08 ± 0.01	0.038 ± 0.002	-0.29 ± 0.09	–	–
IC1612E =IC1612	1:00:01	-72:22:08	0.08 ± 0.01	0.133 ± 0.006	-0.50 ± 0.07	–	–
NGC376	1:03:53	-72:49:34	0.09 ± 0.02	0.024 ± 0.001	-0.29 ± 0.09	20 ± 15	71.5 ± 3.0
K50	1:04:36	-72:09:38	0.07 ± 0.01	0.0150 ± 0.0007	-0.75 ± 0.14	9.4 ± 6.1	149 ± 34
NGC422	1:09:25	-71:46:00	0.06 ± 0.01	0.150 ± 0.007	-1.68 ± 0.09	6.7 ± 5.5	111 ± 23
IC1641	1:09:39	-71:46:07	0.06 ± 0.01	0.60 ± 0.03	-1.68 ± 0.09	10.0 ± 5.8	206 ± 42

Note: ^{a} adopted average reddening according to Burstein & Heiles (1982) and Schlegel et al. (1998) maps.

3 CMDs and astrophysical parameters

We have obtained cluster parameters by fitting Padova isochrones (Girardi et al. 2002) to their *V* × (*B* – *V*) CMDs. In order to minimize the contamination of foreground/background stellar fields, a circular region defined by a visual radius covering the cluster central area was selected. The cluster centres were determined by fitting a gaussian to the star count distribution in both x and y pixel coordinates.

In Fig. 2 we show isochrone fittings to the CMDs of inner regions of selected clusters. The reddening was taken from H I (Burstein & Heiles 1982) and dust (Schlegel, Finkbeiner & Davis 1998) maps and kept fixed in the isochrone fitting process. The distance modulus was allowed to change within (*m-M*)$_\circ = 18.9 \pm 0.2$ (Westerlund 1997), where the uncertainty accounts for the SMC line-of-sight depth (Crowl et al. 2001). Then, for a given age and metallicity the best matching isochrone constrain the distance modulus. For all clusters in the sample good fittings were obtained for (*m-M*)$_\circ = 19.0 \pm 0.1$. Average age and metallicity corresponding to the best matching isochrones are then calculated with more weight to those isochrones which follow more closely the cluster evolutionary sequences. Table 1 presents the astrophysical parameters derived.



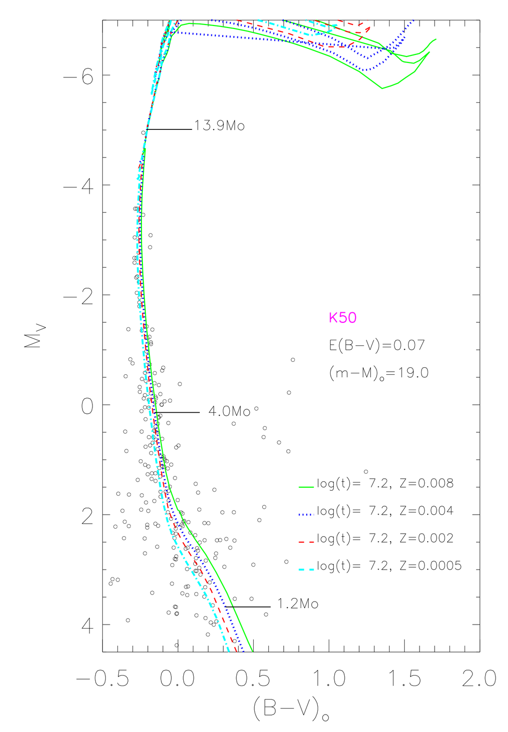


Figure 2. Isochrone fitting to the CMD inner region of selected clusters. Stars with photometric errors above 0.1 mag have been excluded. The data have been corrected for the best achieved values of reddening and distance modulus. The effect of different isochrone metallicities for the best fitted age is shown. Stellar masses in specific isochrone loci are indicated.

Our age determinations are in agreement with Pietrzynski & Udalski (1999) within the errors for the clusters in both OGLE survey and our sample (IC1611, NGC376, and K50). An exception is IC1612E, also in OGLE survey, which was found to be about 50 Myr older in the present work. Piatti et al. (2007) give ages for IC1611 and NGC376 that are also in agreement with our estimated ages. The same clusters present in the OGLE sample in common with our sample had their ages estimated by Chiosi et al. (2006), and again the only discrepancy was IC1612E, which suggests that our estimate may have a larger error than that indicated for this cluster.

As far as we know, the only age information on NGC422 and IC1641 is based on integrated light measurements. They are in the range 100 to 340 Myr for NGC422 (Piatti et al. 2005; Rafelski & Zaritsky 2005; González, Liu & Bruzual 2004) and for IC1641 (Piatti et al. 2005; Rafelski & Zaritsky 2005). In the case of NGC422 the lower limit is compatible with our age estimate, but in the case of IC1641, our method yields an older age.

4 Radial density profile and structural parameters

We built the radial density profile (RDP) for each merger candidate component by employing star counts in circular rings around the cluster centre. In order to get an optimized RDP, we limit the data to a threshold magnitude for which the difference between the cluster central density and the adjacent field density was maximum. All stars fainter than this threshold are then discarded from the analysis. We employ three-parameter (central density σ_0, core radius R_c and tidal radius R_t) King profiles (King 1966) to derive structural properties. The background was determined by fitting a constant to the outermost 4 rings, which was then subtracted from the overall stellar density and the King profile fitting was performed. Fig. 3 shows the RDPs of IC1612E and IC1612W, cases in which no fitting was possible, and Fig. 4 shows the RDP and the fitted profile for K50.

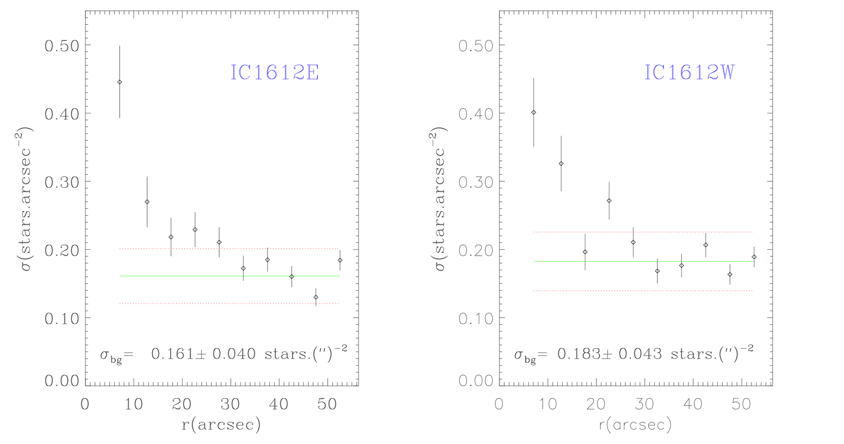


Figure 3. The RDPs with poissonian error bars for the probably interacting clusters IC1612E/W. It was not possible to fit a King model profile in either case.

The structural parameters are presented in Table 1. Note that it was not possible to fit a King model to IC1611 due to its extended halo, and to IC1612E and IC1612W, because of their disturbed profile.

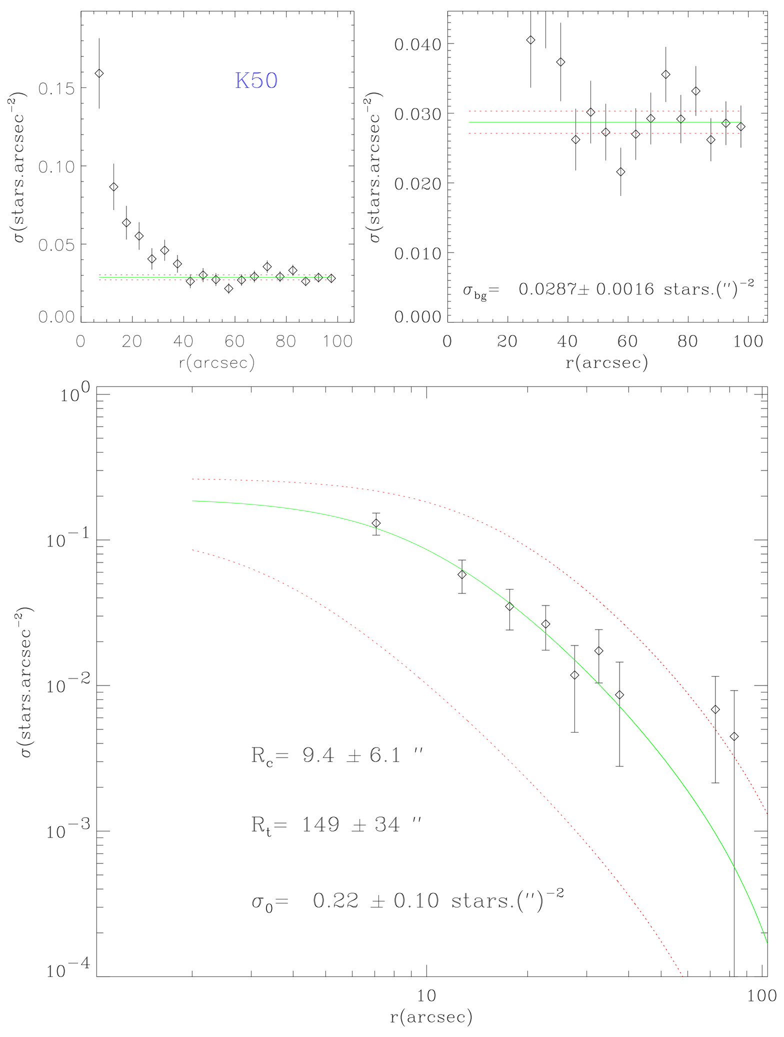


Figure 4. (a) RDP of K50; (b) Zoomed version of (a) where it is shown the fitted constant background; (c) The RDP in log scale with 3-parameter King profile fitting for which central density, core and tidal radii are indicated. 1σ dispersion for the fitting is indicated by dotted lines. The conversion scale is 1$''$=0.3 pc.

5 Discussion and perspectives

Because of a disturbed surface brightness profile as compared to Elson, Fall & Freeman (1987) models and isophotal analyses, Carvalho et al. (2008) classified K50 and NGC376 as mergers and the binary cluster IC1612E/W as an interacting system. Apart from a dip in the central density of NGC376 RDP, we did not find additional evidence for the system as a merger.

We explore further the stellar content of K50 by means of CMDs built for spatially selected regions. Fig. 5 shows these CMDs with corresponding areas marked in the cluster image. Only stars with photometric errors smaller than 0.05 mag in both bands were included in the CMDs. There is a lack of stars fainter than V≈19.5 (≈4.5 M$_\odot$) in the West part of the cluster with relation to the other parts. This difference in the stellar content suggests that interaction is taking place and corroborates the results of Carvalho et al. (2008).

NGC422/IC1641 are farther apart than IC1612E/W and have ages that differ by ≈450 Myr implying that, if they are interacting, a capture process occurred. As for K50, NGC422 and IC1641 show disturbances in their RDPs. IC1641, in particular, presents an extended halo, which could only be fitted by a King profile with a large tidal radius (see Table 1).

As a sequence of this study, we intend to build surface brightness profiles for the clusters in the sample with the same data and search for evidences of disturbances in their RDPs based on mass stratified profiles for the more populous clusters.

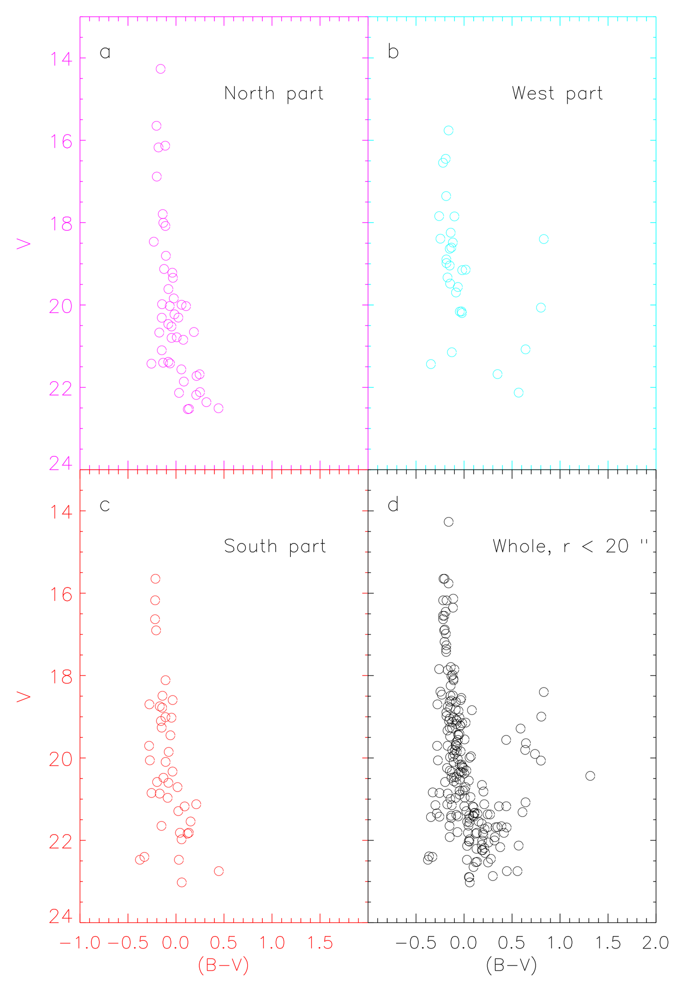


Figure 5. CMDs of K50 for spatially selected regions as indicated by the coloured ellipses in Fig. 1.

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