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Self-consistent physical parameters for MC clusters from CMD modelling: application to SMC clusters observed with the SOAR telescope

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Abstract. The Magellanic Clouds (MCs) present a rich system of stellar clusters that can be used to probe the dynamical and chemical evolution of these neighboring and interacting irregular galaxies. In particular, these stellar clusters (SCs) present combinations of age and metallicity that are not found for this class of objects in the Milky Way, being therefore very useful templates to test and to calibrate integrated light simple stellar population (SSP) models applied to unresolved distance galaxies. On its turn, the age and metallicity for a cluster can be determined spatially resolving its stars, by means of analysis of its colour-magnitude diagrams (CMDs). In this work we present our method to determine self-consistent physical parameters (age, metallicity, distance modulus and reddening) for a stellar cluster, from CMD modelling of relatively unstudied SCs in the Small Magellanic Cloud (SMC) imaged in the BVI filters with the 4.1 m SOAR telescope. Our preliminary results confirm our expectations from a previous integrated spectra and colour analysis: at least one of them (Lindsay 2) is an intermediate-age stellar cluster with $\sim$ 2.6 Gyr and [Fe/H] ~ -1.3, being therefore a new interesting witness regarding the reactivation of the star formation in the MCs in the last 4 Gyr.

Keywords. Magellanic Clouds, galaxies: star clusters, Hertzsprung-Russell diagram

1. Introduction

Stellar clusters (SCs) are useful tools to study the complex stellar content observed in nearby galaxies, as they may be modelled as simple stellar populations (SSP) of a fixed age and metallicity. In particular, the Magellanic Cloud (MC) SCs form a rich system ($>$ 3700 objects; Bica et al. 2008), therefore they can be used to test and to calibrate SSP models for combinations of age and metallicity that are not found in the Milky Way (Santos Jr. & Piatti 2004). Such information can be used to probe the dynamical and chemical evolution of these neighboring and interacting dwarf irregular galaxies.

The age distribution based on clusters is likely distinct from the star formation history (SFH) as inferred from field stars (Holtzman et al. 1999). More recently, Rafelski & Zaritsky (2005) analysed a sample of 195 clusters and shows that the populations of field stars are similar to the populations of SMC stars. The large period of quiescent star formation in the MCs between $\sim$ 4 and 10 Gyr (Harris & Zaritsky 2001, 2004) seems to be imprinted in the low number of populous SCs with these ages (Rich et al. 2000, 2001). Almost all of them are in the SMC as well (Mighell et al. 1998; Piatti et al. 2005, 2007).

In spite of that the SMC cluster system is comparatively much less studied than the LMC, e.g. Piatti et al. (2001) list only 16 SMC clusters with known ages and metallicities. A few more have been recently added by Piatti et al. (2005). Detailed CMDs for SMC clusters are still very scarce as well, which prevents more reliable age, metallicity and structural information from being derived for them.

Therefore we are studying SMC clusters by using photometry and CMD analysis, based on a combination of CMD modelling and statistical tools. The confirmation of some of these clusters as intermediate or old age ones will significantly improve the poor census in the age range corresponding to the age gap for the SMC clusters. Our sample data are for Lindsay 2, and Lindsay 72, for which preliminary estimates in the literature indicate ages of 3 to 8 Gyr and $\sim$ 200 Myr for Lindsay 72 (Chiosi et al. 2006), respectively. An age indication for Lindsay 2 was obtained from low resolution integrated spectra with the 1.5m telescopes at the ESO and LNA observed by us and based on integrated magnitudes and colours from Rafelski & Zaritsky (2005).

2. Method

In general the SC ages are determined by using subjective (often visual) isochrone fits in the CMDs (Sarajedini 1998; Rich et al. 2000, 2001), by assuming the other parameters within known ranges: metallicity, distance modulus and reddening. The [Fe/H] values are usually determined by spectroscopy of red giants (Ca II triplet; Grocholski et al. 2006, da Costa & Hatzidimitriou 1998, Kaiser et al. 2006).

However in this work we analyse the observed CMDs by applying the method developed by Kerber et al. (2002), Kerber & Santiago (2005) and Kerber, Santiago & Brocato (2007). This method is based on statistical comparisons between the observed CMD and a modelled CMD. The modelling assumes that the cluster is an SSP and uses as input the information on metallicity, age (given by a Padova isochrone; Girardi et al. 2002), intrinsic distance modulus $(m-M)_0$, reddening value $E(B-V)$, Mass Function slope α, and fraction of unresolved binaries $f_{\rm bin}$, and also photometric uncertainties and completeness. In order to proceed with the statistical correction for the field star contamination we take advantage of the outer regions of the SOI field images, not covered by the target SMC clusters. We applied the method explained in Kerber et al. (2002).

The models explore a grid of expected parameters for each cluster. So the best models are those that maximize the likelihood (Naylor & Jeffries 2006; Hernandez & Valls-Gabaud 2008), that can be defined as

$$\text{Likelihood} \sim \prod_{i=1}^{N_{obs}} p_{CMD,i} \sim \prod_{i=1}^{N_{obs}} N[V_i,(B-V)_i]$$

where $p_{CMD,i}$ is the probability for this model to generate a star in the position of the ith observed star, and $N[V_i,(B-V)_i]$ is the density of stars in this position, being the product done over all observed stars (see Figure 1).

3. SOAR/SOI data

Since 2006B we observe BVI images for SMC SCs using the SOAR Optical Imager (SOI) mounted in the 4.1 m Southern Astrophysical Research (SOAR) Telescope, with a seeing of $\sim$ 0.8 arcsec and a magnitude limit of V $\sim$ 23.

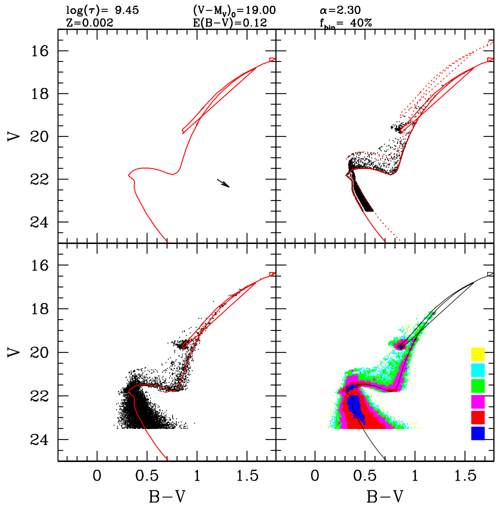

Figure 1. Example of CMD modelling. *Panel a*: adopted isochrone (age and Z) shifted by distance modulus and reddening. *Panel b*: the distribution of stars in accordance to the IMF and the fraction of binaries. *Panel c*: Introduction of photometric errors and incompleteness. *Panel d*: stars codded in colour in accordance to the density of points ($\sim p_{CMD,i}$) in the CMD in a logarithmic scale. The adopted input physical parameters are indicated in the figure.

Our reduction procedures were based on the SOAR/IRAF packages and the photometry procedures were based on the DAOPHOT/IRAF package (Stetson 1987). We performed aperture photometry and then we applied the point spread function (PSF) models of some bright and isolated field stars to all stars, in the B- and V-bands. We observed some of the Sharpee et al. (2002) standards stars in different air masses (X) and filters in order to correctly calibrate the magnitudes to the standard system of magnitudes. We achieved as dispersions from the fits: $\sigma_V \sim 0.09$ and $\sigma_{B-V} \sim 0.16$.

4. Results for Lindsay 2

Lindsay 2 is an intermediate-age SC with age $\sim$ 2.6 Gyr and [Fe/H] ~ -1.3 so this cluster is a new important object to trace the metallicity gradient in the SMC after the reactivation of the star formation in the last 4 Gyr.

Table 1. Result parameters for Lindsay 2 from our method.

	Z	[Fe/H]	$\log(\tau/\mathrm{yr})$	τ(Gyr)	$(m\text{-}M)_0$	E(B-V)
Modelling	0.0010	−1.30	9.42	2.6	18.99	0.02
uncertainties	+0.0010	+0.30	+0.07	+0.5	+0.10	+0.02
	−0.0006	−0.40	−0.07	−0.4	−0.10	−0.02

5. Conclusions & Perspectives

Using SOAR/SOI photometry we can objectively determine accurate and self-consistent physical parameters for SMC clusters by means of CMD modelling, as Lindsay 2 results show.

Soon we will combine results from analysis of V, $B-V$ and V, $V-I$ CMDs and we will also apply our method to Lindsay 72 and other far west SMC clusters that are

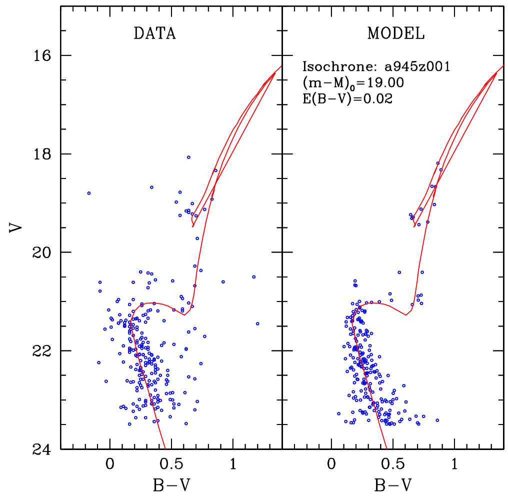

Figure 2. CMDs for Lindsay 2 from observations (left) and modelling (right) with a Padova isochrone fit.

suspect to be of intermediate or even old age. In case we confirm that, we would be able to combine our results with those of Crowl et al. (2001) and discuss the possibility that these clusters may be tidally stripped from the SMC into the Magellanic stream.

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