Star clusters: basic galactic building blocks
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Further developments in star cluster spectral libraries†

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Abstract. We present flux-calibrated integrated spectra in the optical spectral range of Galactic open clusters (GOCs) and Magellanic Cloud (MC) stellar clusters (SCs) obtained at *CASLEO* (Argentina). The SC parameters were derived using the equivalent-width (EW) method and the template-matching procedure by comparing the line strengths and continuum distribution of the cluster spectra with those of template spectra with known parameters. MC cluster reddening values were also estimated by interpolation between the available extinction maps. The derived ages for the GOCs range from 3 Myr to 4 Gyr, while those of the MC SCs vary from 3 Myr to 7 Gyr. $E(B-V)$ colour-excess values in the MCs appear to be all lower than 0.17 mag, while those of the GOCs range from 0.00 to 2.40 mag. The present data led us to upgrade the spectral libraries of reference spectra or templates of solar and MC metallicities.

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1. Introduction

It is well known that star clusters (SCs) are building blocks of galaxies, in the form of young associations, open and globular clusters. SCs are, in general, powerful tracers of

† The full poster (in pdf format) is available at
http://www.astro.iag.usp.br/~iaus266/Posters/pAhumada.pdf.

the formation and evolution of their parent galaxies. This work is an ongoing systematic spectroscopic survey of Galactic open clusters (GOCs) and Magellanic Cloud (MC) SCs. The main goal of this long-term study is to collect and analyse a large sample of SC integrated spectra with the aim of deriving their fundamental parameters and making them available as template spectra to complement previous spectral libraries.

2. Galactic open clusters

GOCs have always played a prominent role in the derivation of both the chemical and dynamical evolution of the Galactic disk. This is due to the fact that their fundamental parameters may be determined more easily and more accurately than those for isolated stars. However ∼50% of the 1787 OCs known to exist in the Milky Way (Dias *et al.* 2002) are unstudied. Integrated spectra of small-angular-size OCs have proved very useful tools in increasing the number of OCs studied and are a valuable means to provide independent information about reddenings, ages and, in some cases, metallicities. Several years ago, Bica & Alloin (1986a) published a pioneering study of integrated spectroscopy applied to composite stellar populations. Compact SCs are the most suitable objects to carry out integrated spectroscopic observations with a middle-sized telescope. Our sample was selected using the WEBDA database (Paunzen & Mermilliod 2009), where most of the selected OCs are compact clusters. On this basis, we have observed and studied 71 GOCs in the last 10 years by means of integrated spectroscopy. Table 1 shows the GOC sample (see the full electronic poster version).

3. Observations

All observations were carried out with the 2.15m telescope at the *Complejo Astronómico El Leoncito* (*CASLEO*, Argentina) during several runs. We employed a CCD camera with a chip of 1024×1024 pixels attached to a REOSC spectrograph (simple mode). The observations were performed by scanning the slit across the objects in the north–south direction. A grating of 300 grooves mm^{-1} was used. The spectral coverage was in the visible range: 3600–6800 Å, with an average dispersion in the observed region of ∼140 Å mm^{-1} (3.46 Å pix^{-1}). The slit width was 4.2″, which provided a resolution of ∼14 Å.

4. Reddening and age determination

Age and foreground-reddening values of the selected clusters were derived simultaneously by means of a template-matching method. This was done by achieving the best possible match between the continuum and the lines of the analysed cluster's integrated spectrum and those from a template of integrated spectra with known properties. To apply the template-matching method, a direct, reddening-independent age estimate was first obtained from the EWs of the Balmer absorption lines in each spectrum. This was done by interpolating the EW values from the age calibration of Bica & Alloin (1986b). Based on this age estimate, we selected, among the available template libraries, a subset of templates to compare with the observed spectrum. This selection allowed us to constrain our search of the most appropriate template, as those selected were within a certain age range. The next step was to determine the final age of the spectrum by varying reddening and template values until the best match of continuum, Balmer and metal lines to that of the best-fitting template was obtained. Results of the study of the full sample are shown in Table 1 (poster version), where the columns show the first

cluster designation, the derived $E(B-V)$ and the age adopted for the cluster, taking into account the Balmer lines and the template age.

5. GOC template libraries

Different authors, including Bica & Alloin (1986a), Bica (1988), Bonatto *et al.* (1995), Santos *et al.* (1995) and more recently Schiavon *et al.* (2005) struggled to create reference spectra of SCs in different spectral ranges and to define grids of composite stellar populations. Because SCs may be considered stellar population units of a given age and metallicity, their spectral properties have been used for stellar population synthesis and for the interpretation of galaxy spectra. We collected part of the OCs spectra presented here and averaged them into templates, together with previously available spectra of well-studied OCs, with a view of obtaining the highest possible signal-to-noise ratio and higher time resolution to study their integrated-light evolution (Piatti *et al.* 2002; Ahumada *et al.* 2007). Figure 1 shows the spectral evolution up to intermediate ages (Ia and Ib) of stellar populations with nearly solar metallicity. For the younger populations, we constructed different templates (Ya and Yb), considering the foreground, the mean (Ya2 and Yb2) and the internal reddening. At such young ages, luminous stars play an important role in the resulting slope of the continuum energy distribution, which was also taken into account (Y*–WR–SG).

6. Magellanic Cloud SCs

The study of extragalactic stellar systems provides relevant information about star-formation and chemical-enrichment histories of the host galaxies. Despite the multiple observational and theoretical projects undertaken in the past, our current knowledge of these processes is rather imcomplete, even for the galaxies in the Local Group. Therefore,

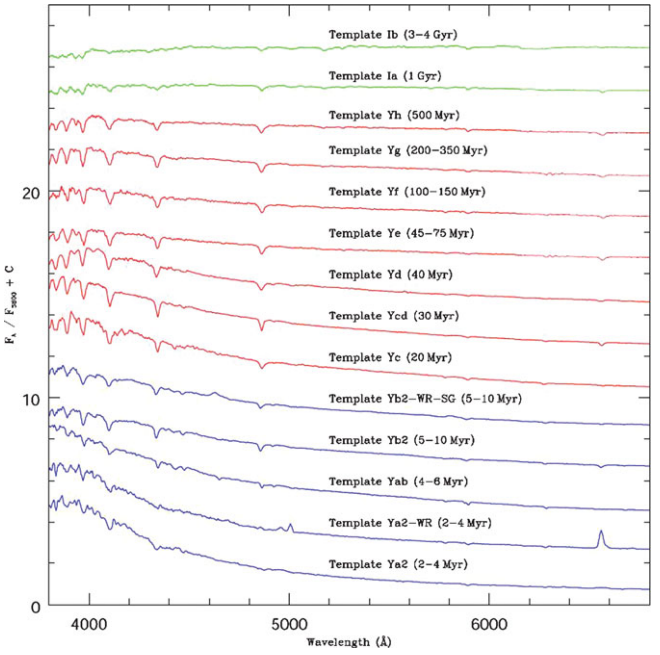

Figure 1. GOC template spectra for the young (Y) and intermediate (I) age groups.

the SCs of the MCs may furnish us with the ideal basis to conduct a detailed examination of these processes because of their proximity, richness and variety. One of the goals of the present study is to collect and analyse a large sample of MC SC spectra with the aim of studying the integrated-light properties of such metal-deficient clusters, deriving their fundamental parameters and making them available as template spectra which can complement previous subsolar-metallicity libraries. The main denomination of the 42 observed SMC SCs are shown in Table 2 (poster version). Some of the SCs are very-well-known objects and they were observed to have SMC template spectra at the ages of those clusters. Table 3 (poster version) shows the denomination of the 54 LMC SCs selected for this study. Most of the LMC clusters were classified as type II (30–70 Myr), according to Searle *et al.* (1980). In addition to using the template-matching method, we determined ages using diagnostic diagrams involving the sum of the EWs of selected spectral lines combined with the calibrations of age and metallicity by Santos & Piatti (2004). Based on the Burstein & Heiles (1982) maps we determined another $E(B-V)$ value, which turned out to be very similar to the one derived from the template matching method. $E(B-V)$ colour-excess values in the MCs appear all to be lower than 0.17 mag. Tables 2 and 3 show the ages determined for SMC and LMC SCs, respectively (poster version).

7. Future work

Among some previously defined consecutive spectral groups, we are working on defining new GOC template spectra with the aim to refine the spectral library of Piatti *et al.* (2002) and to improve its temporal resolution. The present MC data constitute part of the elements to enhance the spectral libraries at the metallicities of the SMC and LMC SCs. We are planning, in the near future, to extend the existing libraries to the near-infrared. We will also create new libraries for other metallicities, which will be very useful to study the stellar populations in more distant galaxies.

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