BAAA, Vol. 58, 2016
P. Benaglia, D. D. Carpintero, R. Gamen & M. Lares, eds.
Asociación Argentina de Astronomía
Boletín de artículos científicos

Generating a Magellanic star cluster catalog with ASteCA

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Resumen / Un número creciente de herramientas de software se está empleando desde hace unos años para el tratamiento automatizado o semiautomatizado de datos astronómicos. Las principales ventajas de la utilización de tales herramientas sobre un análisis estándar a ojo incluyen: velocidad (en particular para grandes bases de datos), homogeneidad, reproducibilidad y precisión. Al mismo tiempo, permiten un estudio estadísticamente correcto de las incertidumbres asociadas con el análisis, en contraste con los errores establecidos manualmente, o la práctica aún generalizada de simplemente no asignar errores.
Presentamos un catálogo compuesto por 210 cúmulos estelares ubicados en las Nubes Mayor y Menor de Magallanes, observados con fotometría CT_1 en el sistema de Washington. Los parámetros fundamentales de los cúmulos fueron estimados mediante un proceso homogéneo, automatizado y completamente autónomo, a través del paquete de análisis de cúmulos *Automated Stellar Cluster Analysis* (ASteCA). Nuestros resultados son comparados con dos tipos de estudios sobre estos cúmulos: uno donde la fotometría es la misma, y otro donde el sistema fotométrico es distinto del usado por ASteCA.

Abstract / An increasing number of software tools have been employed in the recent years for the automated or semi-automated processing of astronomical data. The main advantages of using these tools over a standard by-eye analysis include: speed (particularly for large databases), homogeneity, reproducibility, and precision. At the same time, they enable a statistically correct study of the uncertainties associated with the analysis, in contrast with manually set errors, or the still widespread practice of simply not assigning errors.
We present a catalog comprising 210 star clusters located in the Large and Small Magellanic Clouds, observed with Washington CT_1 photometry. Their fundamental parameters were estimated through an homogeneous, automatized and completely unassisted process, via the Automated Stellar Cluster Analysis package (ASteCA). Our results are compared with two types of studies on these clusters: one where the photometry is the same, and another where the photometric system is different than that employed by ASteCA.

Keywords / catalogs — galaxies: star clusters: general — galaxies: Magellanic Clouds

1. Introduction

In a recent article (Perren et al., 2015) we presented ASteCA*, a new package for the automatic analysis of star clusters. The package is still in the development process, but it can already be applied on clusters with observations in at least two passbands of the supported photometric systems. One of the major advantages of using this tool, is the possibility of performing a valid error analysis on the obtained parameter values. In these type of studies, uncertainties are normally either manually estimated or simply not given.

We run ASteCA on 210 observed clusters (OCs) from the Magellanic Clouds, and here present a comparison of the obtained results with those taken from twenty-five published studies.

2. Clusters database

The entire set of OCs in our sample, 150 Large Maguellanic Cloud (LMC) and 60 Small Maguellanic Cloud(SMC) clusters, was observed through the CT_1 Washington photometric system (Canterna, 1976).

All fundamental cluster parameters (metallicity, age, distance, reddening, binary fraction, and total initial mass) are simultaneously obtained by ASteCA to prevent the introduction of biases via their known correlations. The binary fraction was the only parameter that we fixed to a value of 0.5 for all the OCs. We did this to avoid introducing an unnecessary number of degrees of freedom into the analysis. The rest of the parameters were allowed to vary within appropriate ranges.

The OCs' parameters are estimated automatically by the code, starting from center coordinates and a radius value assigned to the cluster region. A decontamination algorithm is applied to assign membership probabilities to stars within the OC region. This aims at preventing field stars located at the foreground/background of the cluster from disrupting the fundamental parameters finding process. As was shown in Perren et al. (2015) this algorithm works very well even for highly contaminated OCs, although becomes less accurate when the number of field stars within the OC region is more than twice than that of actual members.

*http://asteca.github.io/

The code handles the obtention of an OC's fundamental parameters via a minimum likelihood analysis, performed on a large set of synthetic clusters (SCs). The only restrictions imposed on ASteCA are the allowed ranges of variation for each parameter, and the steps between each valid parameter value within that range. As the ranges increase in size and the steps are made smaller, the number of possible solutions (i.e.: combinations of parameter values that produce a unique SC) increases. In our study, the number of solutions/SCs that the code could assign to each of the OCs was approximately 1.8×10^7.

The quality of the match between the OC and the set of SCs is assessed applying the Poisson likelihood rate developed in Dolphin (2002). A genetic algorithm takes care of finding the minimum likelihood value or best match, between the OC and the SCs.

Finally, a bootstrap process assigns errors to each derived parameter in a statistically valid way. This requires the OC versus SC matching to be re-run several times and thus is rather expensive timewise.

3. Results

3.1. Comparison with the literature

We compare the final parameters obtained by the code with the values presented in 18 published articles where each of the OCs in our sample was studied. These articles (hereafter referred to as the "literature") used the same Washington CT_1 photometry datasets as those used in the present work.

In Fig. 1 we show the distribution of values obtained by ASteCA for the fundamental parameters metallicity, age, extinction, and true distance modulus, compared with the values assigned in the literature (masses are not given in the latter). The metallicity is dispersed around the identity line, with slightly larger values derived by the code for both galaxies. On average ASteCA assigns metallicity values in excess of 0.2 dex compared to their literature counterparts. The largest difference, $\Delta\,[\mathrm{Fe/H}] > 1$, is found for two SCM clusters.

A concentration around $[\mathrm{Fe/H}] = -0.4$ and $[\mathrm{Fe/H}] = -0.8$ can be seen for the LMC/SMC clusters, respectively. This result is expected as these are the known present-day metallicities of both Clouds. Overall the metal content determined by the code, albeit somewhat larger, is in good agreement with the literature.

The age assignment depends strongly on the correct identification of an OC's turnoff point. In cases of heavy field star contamination or very few members, this task can easily produce incorrect solutions (specially if done by eye). Despite this constraint, the age parameter shows the closest agreement with literature values, presenting a noticeable dispersion mostly for OCs younger than $\log(\mathrm{age/yr}) = 8$.

There are eight clusters for which the difference in age found by the code is larger than $\Delta \log(\mathrm{age/yr}) = 0.5$, all but one of these have smaller age values assigned by ASteCA.

As can be seen in Fig. 1 extinction values differ for the LMC and the SMC, with considerably larger values

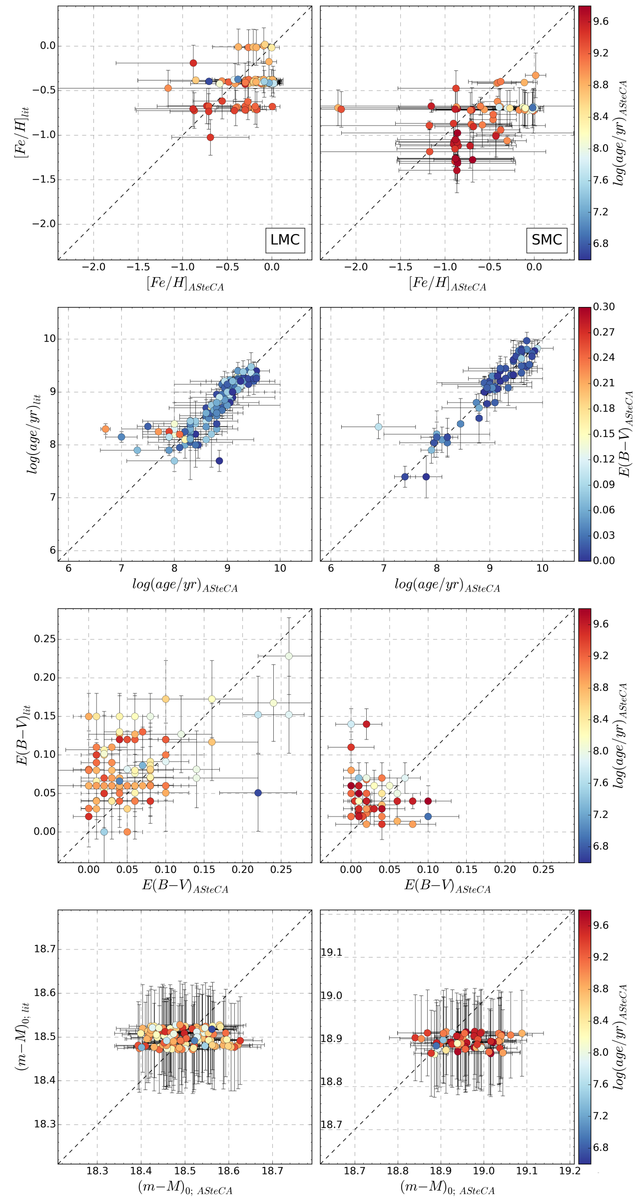

Figure 1: Left column: metallicity, age, extinction and true distance modulus values in the literature versus the ones found by ASteCA, for the LMC OCs. The colors coding corresponds to the colorbar to the right. Right column: idem for the SMC.

found for the former. Almost all OCs in both galaxies have reddening estimations that differ within 0.1 mag from the literature values.

The distance moduli used in the literature are fixed to 18.5 and 18.9 for the LMC/SMC respectively. We let the code assign values in an interval of ± 0.1 mag around the values 18.5 and 18.96, taken from de Grijs et al. (2014) and de Grijs & Bono (2015) for the LMC/SMC. The distances obtained by ASteCA are rather uniformly spread within this range, with an associated uncertainty of up to 0.07 mag.

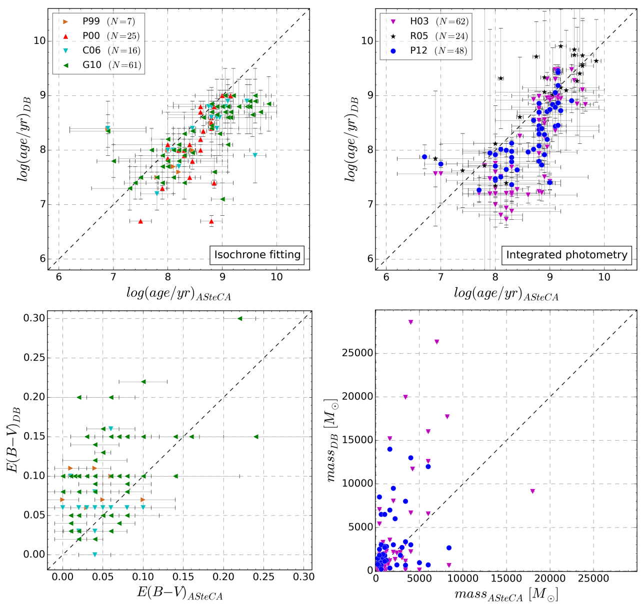

Figure 2: Top: comparison of ages ASTECA vs. databases; isochrone fitting to the left and integrated photometry to the right. Bottom: left, extinction distribution for those databases that provided this parameter. Right, mass distribution for those databases that provided this parameter.

3.2. Comparison with databases

Our results are also compared with those taken from seven articles, for those clusters that could be cross-matched in each of them, hereafter referred to as the "databases": Pietrzynski & Udalski (1999, P99), Pietrzynski & Udalski (2000, P00), Chiosi et al. (2006, C06), Glatt et al. (2010, G10), Hunter et al. (2003, H03), Rafelski & Zaritsky (2005, R05), Popescu et al. (2012, P12). These databases were generated combining two to four of the $UBVRI$ passbands, depending on the article, which means that the photometric system employed is different from the one used in this work.

The first four databases applied a by-eye isochrone fitting method to estimate ages and extinction, and the last three used integrated photometry. The distribution of ages, extinction and mass for those clusters that could be cross-matched in each database, are shown in Fig. 2.

Both methods (Fig. 2, top) assign lower age values on average to the analyzed clusters, an effect that is more pronounced in the integrated photometry analysis. This is somewhat expected since this method is known to be less accurate. In particular the ages estimated from integrated photometry can be easily biased by the presence of a few bright field stars, skewing the results towards smaller values.

The isochrone analysis also shows smaller age estimates when compared with ASTECA values. These discrepancies can be explained by known biases in these databases. P00 for example uses a fixed distance modulus of 18.24 mag for the LMC. de Grijs & Anders (2006) estimate that had they used a value of 18.5 mag, their ages would have been $\log(\mathrm{age/yr}) \approx 0.3$ smaller.

C06 use a mean metal content of $[\mathrm{Fe/H}] = -0.4$ which is larger than the usual -0.8 value used for the SMC. Given the negative correlation between the age and the metallicity, this certainly contributes to its smaller age values. In the case of the G10 database, the $\Delta \log(\mathrm{age/yr}) \approx 0.5$ offset found here is entirely consistent with the results previously obtained by Piatti et al. (2014, 2015). This is most likely the result of G10 not applying a proper decontamination algorithm previous to its isochrone fitting process.

The extinction comparison diagram (Fig. 2, bottom left panel) shows that the databases assign on average larger values than ASTECA, which again due to the negative correlation with the age, contributes to the smaller values given to this parameter.

The masses (Fig. 2, bottom right panel) are only derived by two integrated photometry databases and thus contain significant error. Below $M \approx 5000$ M$_\odot$ the values obtained by ASTECA show a reasonable agreement with those taken from H03 and P12. Beyond that value both articles assign much larger values than the ones found by the code.

4. Summary

We showed how the ASTECA package allows the automatic (unassisted) determination of the fundamental parameters of a star cluster. The results of this analysis demonstrate that the assigned values are in good agreement with studies that used the same Washington photometry. Studies that used different photometric systems were also compared and while the discrepancy is larger, it can be explained by effects outside the code.

The ASTECA package is thus shown to be capable of operating on large databases of observed clusters producing reasonable estimations of their properties, along with a necessary statistically valid error analysis.

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