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Recognizing new stellar clusters in the Magellanic System

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Abstract. The adventure of catching up with new stellar clusters in the Magellanic System has been recently fueled from the ongoing relatively deep and extensive photometric surveys. Particularly, the presence of stellar clusters in the periphery of the Magellanic Clouds and beyond is currently an exciting issue. We present here a review of recently discovered stellar clusters in the Magellanic System. Particularly, we focus on the use of a wealth of wide-field high-quality images released in advance from the Magellanic Stellar History (SMASH) survey. We conducted a sound search for new stellar cluster candidates using suitable kernel density estimators for appropriate ranges of radii and stellar densities. In addition, we used a functional relationship to account for the completeness of the SMASH field sample analysed that takes into account not only the number of fields observed but also their particular spatial distribution; the present sample statistically represents about 50 per cent of the whole SMASH survey. The relative small number of new stellar cluster candidates identified in this survey, most of them distributed in the outer regions of the Magellanic Clouds, might suggest that the lack of detection of a larger number of new cluster candidates beyond the main bodies of the MCs could likely be the outcome once the SMASH survey is completed.

Key words. techniques: photometric – galaxies: individual: LMC – Magellanic Clouds.

1. Introduction

Because of the implications of the interactions between the Magellanic Clouds (MCs) and between them with the Milky Way (MW), the search for new stellar clusters in the MW halo as well as along the stripped streams of gas in the MCs periphery has recently been renewed. Indeed, several new extended stellar systems have been discovered using the Dark Energy Camera (DECam) at the 4-m Blanco telescope at Cerro Tololo Inter-American Observatory (CTIO). Some of these objects resulted to be globular clusters (e.g., Kim et al., 2015; Martin et al., 2016), while others turned out to be dwarf galaxies (e.g. Martin et al., 2015; Drlica-Wagner et al., 2016).

Sitek et al. (2016) and Pieres et al. (2016) have searched for new stellar clusters in the outer disc of the Large Magellanic Cloud (LMC), separately. Sitek et al. (2016) used the Optical Gravitational Lensing Experiment (OGLE-IV, Udalski et al., 2015) to identify 226 new stellar cluster candidates, while Pieres et al. (2016) based their identification of 28 new cluster candidates on Dark Energy Survey

(DES, Abbott et al., 2016) data sets. Hence, the increasing number of new bona fide stellar aggregates in the outer regions of the LMC, particularly along the recently discovered Northern stellar stream (Mackey et al., 2016), has made the search for new objects in the MCs periphery an excited field of research.

The innermost regions of the MCs has also been the target of other searches, such as that performed by Piatti et al. (2016) in the South-West part of the Small Magellanic Cloud (SMC) bar, one of the densest and most reddened region of the galaxy. The authors had chosen that region as a pilot one to probe a new automatic code for seeking new stellar clusters. The results were really amazing, since the authors identified a number of new real objects which represents 55 per cent increase in the number of known stellar clusters within that relatively small area (36x36 square arcmin). This outcome pointed to the need of a more vigorous effort in order to build a statistically complete catalogue of genuine MCs stellar clusters.

Surprisingly enough is also de discovery of a loose cluster projected towards the LMC outer disc (d > 4^o, Piatti, 2016). According to its relatively position in the sky, the cluster is expected to be an intermediate-age object (1-3 Gyr) with a metallicity of [Fe/H] ~ -0.4 dex, which correspond to the values that a cluster would have if it followed the age-metallicity-position relationship for the LMC (Piatti & Geisler, 2013). However, the new discovered stellar cluster resulted to be relatively young (280 Myr), and with a metal content ([Fe/H] = -0.1 dex) that places it at the top of the most metal-rich LMC clusters. Even more striking is the derived distance ($\approx$ 60 kpc), which resulted to be nearly similar to the SMC distance. If the position of such an object is confirmed spectroscopically, then, we will be dealing with a inner disc LMC cluster that has been ejected from its birthplace or formed from stripped gas as a result of MCs interactions.

The campaign for searching new stellar clusters is not always straightforward. Not only an stellar overdensity have to be detected in the sky, but also further analysis are needed in order to confirm that we are dealing with a real physical system. In performing the recognition of stellar overdensities, imaging depth and spatial resolution play a very important role. Sometimes, relatively shallowed images and/or with a not appropriate spatial resolution have misled astronomers identifying as extended objects, for instance, a very bright star, a fluctuation of the field stellar density, etc. Indeed, Piatti & Bica (2012) and Piatti (2014) showed that there could be ~ 10-15 per cent of objects catalogued as clusters in the LMC and SMC that are not true aggregates.

2. A novel search

The DECam (CTIO) is nowadays one of the wide-field imagers (3 square degree FOV) that should allow us to reach any resolved stellar cluster in the MCs. Indeed, previous works have shown that $g \sim 24$ mag is reached with reasonable exposure times (e.g. Abbott et al., 2016). On the other hand, taking into account the MCs' distance and depth (45-70 kpc Wagner-Kaiser & Sarajedini, 2017), the main sequence turnoff (MSTO) of the farthest MCs old stellar cluster (13 Gyr) is observed at $g \sim$ 22.5 mag, thus resulting brighter than the limiting magnitude mentioned above. Note that old clusters also contain red giant branch stars. Young clusters should be much easier observed because of their brighter MSTOs. Therefore, if there were unidentified stellar clusters, they should be detected having the above condition on the magnitude limit satisfied.

Another important issue for a reliable and successful search of new stellar clusters is related to the stellar density map employed. Frequently, stellar density maps are built using bins of fixed size. However, histograms have shown to produce non-intrinsic distributions of the data sets they represent, because of the positions and sizes of the intervals used. For instance, Piatti (2010) found an enhanced formation episode of open clusters in the MW, once the clusters' ages in the catalogue of Dias et al. (2002) are properly sampled. He showed that the same data points produce very distinct age distributions if histograms with bins of different sizes are used instead.

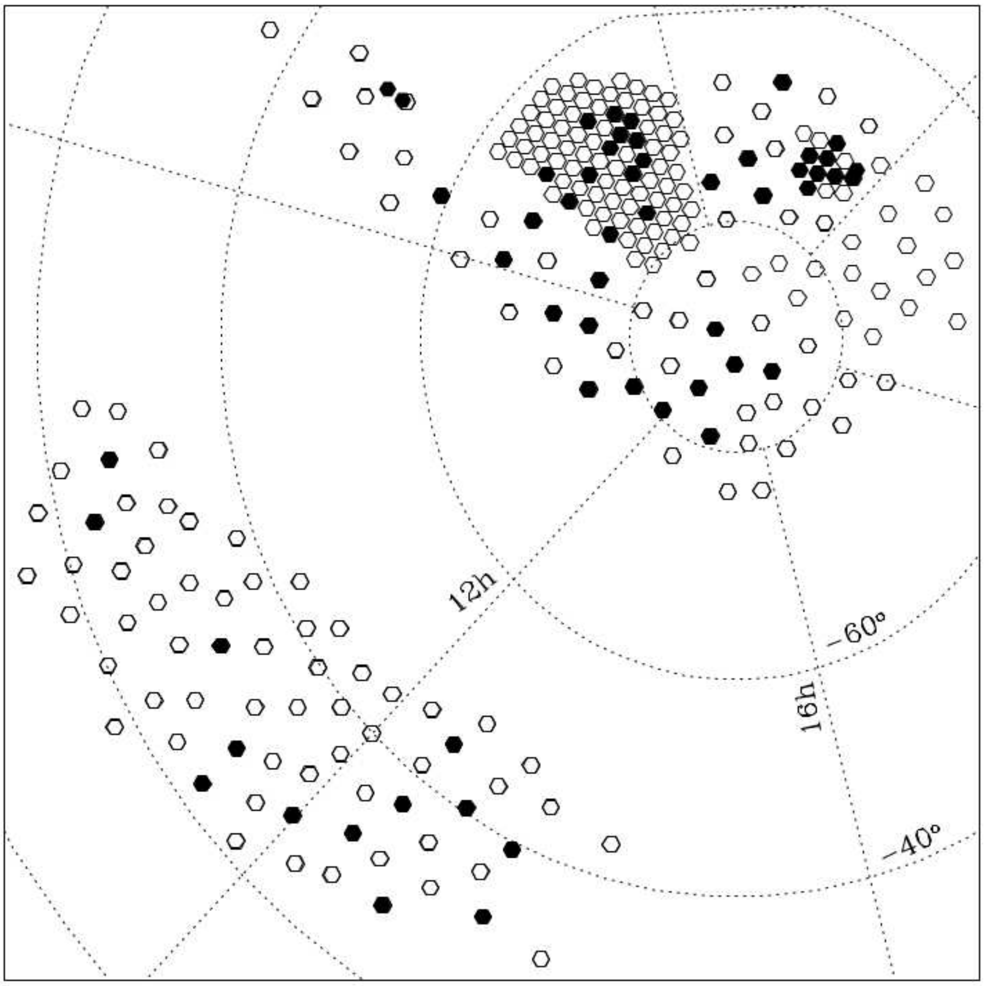

Fig. 1. Equal-area Hammer projection of the SMASH fields in Equatorial coordinates. Filled hexagons represent those analysed in this work.

An alternative tool to cope with this constrain consists in using kernel density estimators (KDEs) with appropriate kernel functions. The technique does not require of any interval where to count the number of stars, neither of boundary limits. It simply adjusts kernel functions to the data sets, thus producing smooth surfaces which much closer represent the intrinsic stellar density. Suitable kernel functions for stellar density maps are *gaussian* and *tophat*. KDE only needs that its bandwidth be a priori fixed. In this case, a suitable bandwidth is of the order of the smallest structures we want to detect, i.e., the smallest stellar cluster dimensions.

With these recipes in mind, we took advantage of the first 58 deep *g* MCs field images obtained with DECam by the Survey of the MAgellanic Stellar History (SMASH Nidever et al., 2015) that have been released through

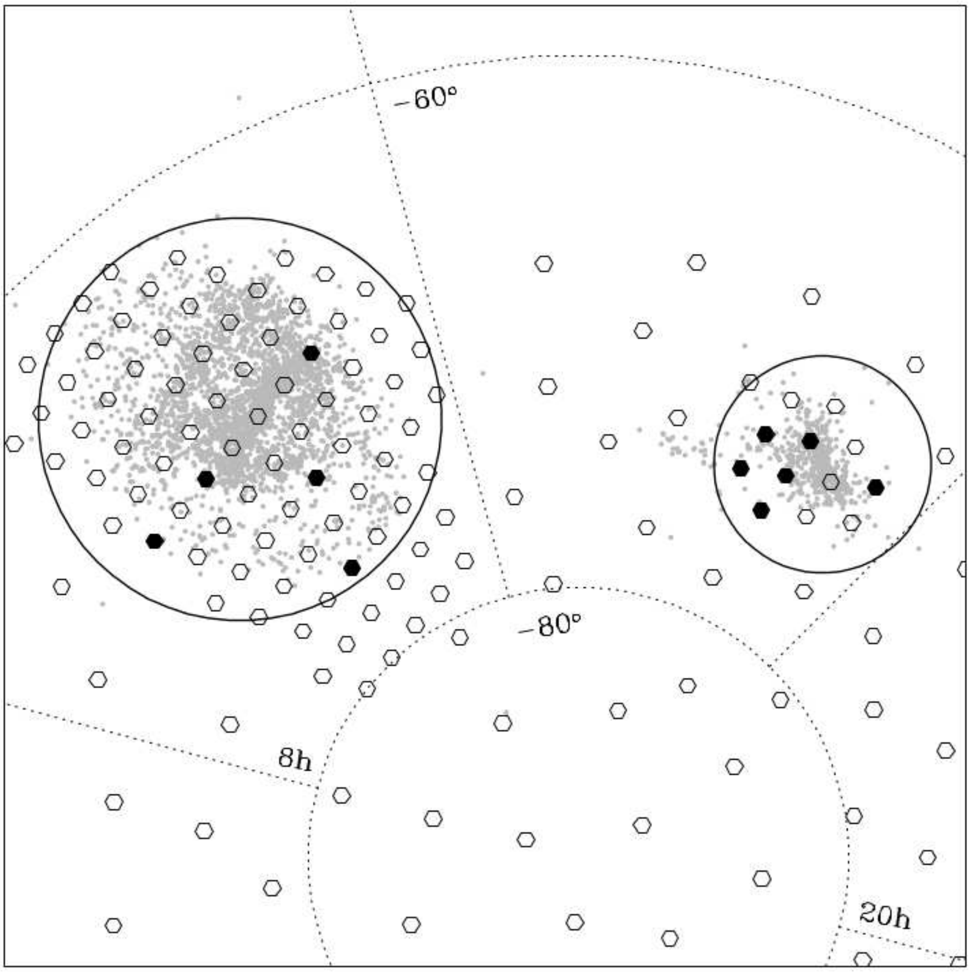

Fig. 2. Enlargement of Fig. 1 with the positions of stellar clusters in Bica et al. (2008)'s catalogue superimposed for comparison purposes. The SMASH fields where new stellar cluster candidates were identified are drawn with filled hexagons.

the National Optical Astronomy Observatory (NOAO) Science Data Management (SDM) Archives[1]. Fig. 1 depicts the complete sample of SMASH points, kindly provided by D. Nidever. Those plotted with filled symbols represent the fields released by SMD Archives. We first run a stand-alone version of DAOPHOT (Stetson et al., 1990) to identify stellar sources. In order to go as deep as possible and at the same time to avoid spurious sources (faint background galaxies, CCD cosmetic defects, etc), a threshold of 7 times the background noise above the mean background level was used. The search was performed by employing a series of AstroML routines (Vanderplas et al., 2012) with *gaussian* and *tophat* KDE functions.

The resultant number of identified stellar clusters: 533 known clusters, and 24 new can-

[1] `http://www.noao.edu/sdm/archives.php`

didates distributed in very few SMASH fields (see Fig. 2), suggests that a large number of new stellar clusters should not be expected to find out in the outskirts of the MCs. Although we surveyed nearly 1/3 of the whole SMASH field sample, and therefore more favourable findings could be expected once the survey is completed, our results are statistical significant as if half of the SMASH pointings had been used. This comes up when not only the ratio between the number of pointings used to the total number of SMASH fields, but also their spatial distribution throughout the whole area covered my SMASH is considered. Hence, the more homogeneously distributed the surveyed pointings, the more representative the findings obtained from them. In this case, the spatial distribution of the 58 studied MCs fields are at a 90-95 per cent level similar to that of the whole SMASH pointings, so that the statistical completeness reaches nearly 50 per cent, if the expression proposed by Piatti (2017) is used.

3. Concluding remarks

We briefly gave an overview of the recent breakthroughs about finding new stellar clusters in the MCs and their peripheries. Different approaches have been made by some astronomer groups, which have surveyed different MCs regions employing their own techniques. Although most of the results tend to suggest an increasing number of stellar clusters to populate these galaxies, some further analyses are required in order to firmly confirm their true nature. At the same time, it would be desirable to gather all the independent efforts in finding new stellar clusters into a catalogue constructed on an homogeneous basis. This will be widely helpful for improving our knowledge about the formation and evolution of the MCs stellar cluster population.

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