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Towards an unbiased stellar census in open clusters using multi-wavelength photometry

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Abstract. We look for very low-mass members in open clusters with different ages placed at different distances. The main goal is to produce a reliable census of low-mass stars for each of the clusters and derive the Initial Mass Function. To achieve this, we combine deep optical and infrared photometry from our own observing runs and from different public databases. We also characterise the individual stellar parameters of our targets.

Key words. Stars: Low-mass stars – Galaxy: Open Clusters – Photometry

1. Introduction

A priori, a stellar association is an homogeneous group of stars, (generally) placed at roughly the same distance from us, and formed from the same molecular cloud. Our study is focused on young open clusters (OCs). Despite the fact that there are several very well studied associations (for instance the Pleiades, the Hyades, or M35, see Stauffer et al. (2007), Perryman et al. (1998), Barrado y Navascués et al. (2001), to name a few) several questions still remain open: the properties and evolution of low-mass objects, the cluster distances, lack of a time scale valid to characterise stellar ages over a wide range and in a homogeneous way, or the number of stars in each mass range (best known as Initial Mass Function or IMF for short). Gaia, the European Space Agency mission, will determine cluster distances and very accurate proper motions for a large amount of clusters, and will identify a significant number of low-mass cluster members. Even though additional data are needed to reach the low-mass regime in a large sample of OCs and try to answer the previous questions.

Our goal is to complement Gaia's result by looking for very low-mass members in a sample of open clusters, with several ages and distances located at different regions of the Galaxy. We will produce a reliable census for each cluster, focusing on the low-mass regime near the substellar frontier. In this paper we describe our project and the current status.

2. Objectives and sample

The targets of our study are young open clusters of different ages and environments. Photometric and spectroscopic data are used in the analysis, and in some cases astrometry measurements. Once the census is completed, we will study the IMFs, the structure of the clusters and, if possible, derive ages with different techniques.

The first step is set up a suitable sample of OCs ready for study. We select those OCs visible from the northern hemisphere, plus

NGC2451A and B, with distances and ages up to 500 pc and 500 Myr, respectively. The selection is made it using the Dias et al. (2002) catalogue. We retrieved a total of 12 targets with a variety of distances and ages ranging 190 pc to 400 pc and 20 Myr to 400 Myr. The exception is M36, located at about 1330 pc and an age of 25 Myr (see Table 1).

For each OC, we gathered all the available information: members and candidates from other works, distances, ages, radial velocities, $E(B-V)$, and metallicities. The WEBDA[1] database, SIMBAD (Egret et al. 1991) and Kharchenko et al. (2005), have been used for this task.

2.1. Photometry data

The photometric datasets are from optical (for example SDSS) to mid-infrared and varies for each cluster. Some bands are commons for all OCs (2MASS and WISE), whereas others are unique for each association. Photometric data not coming from public surveys has been reduced in the same way as DANCe project (Bouy et al. 2013).

Due to the variety of photometry, the lowest mass observed in each cluster is different. It is important to know how deep is the photometry in each band and the area in the sky covered by it, so we can construct the appropriate Colour Magnitude Diagrams (CMDs) and Colour Colour Diagrams (CCDs) to select candidates. An example is shown in Figure 1 that contains the mass range covered by each band in M39. In this case the potential minimum mass for a cluster member is roughly 0.061 $M_\odot$.

3. Selection of candidate members

First of all we have to recover previous members (if that is the case) and placed them in several CMDs. This gives us an idea of the sequence in the brighter regime. We consider as candidates those sources located above an isochrone, and no candidates those placed below it. We would like to point out that we weigh up the uncertainties in the photometry and keeping in mind the saturation, completeness and detection limits of each band.

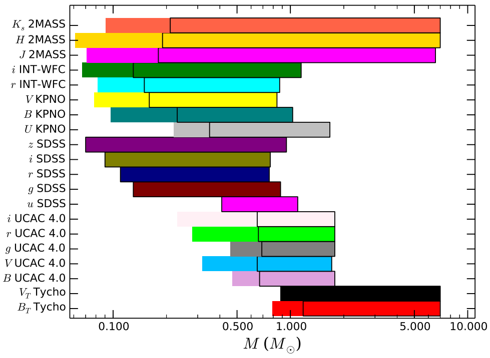

Fig. 1. The diagram shows the mass range covered for all photometric bands for the cluster M39. The saturation, completeness and limiting mass for each band have been calculated with the Lyon models (Allard et al. 2012) or Siess models (Siess et al. 2000). The black edge rectangles show the mass range coverages between saturation completeness assuming a distance of 303 pc, A_v = 0.064 mag an age of 280 Myr (van Leeuwen 2009).

The selection is made with the appropriate photometric filters for the BT-Settl (Allard et al. 2012) models and the Siess et al. (2000) evolutionary tracks. So the selection covers a wide range of masses. From all the ages recovered from the literature we choose the oldest one, and shift at the farthest distance considering the cluster reddening. The Spanish Virtual Observatory provides a Filter Profile Service[2], an useful tool to transform A_V into the absorption in an each specific photometric band.

The final selection has several categories of candidates: probable candidates -sources flagged as candidates in all CMDs-, probable no candidates -sources flagged as not candidates in at least one CMD-, possible candidates -sources flagged as members in the deepest CMDs and not detected in brighter ones-.

[1] http://www.univie.ac.at/webda/

[2] http://svo2.cab.inta-csic.es/theory/fps/index.php?mode=voservice

Table 1. Basic data for our sample of open clusters.

CLUSTER	RA J2000 (h m s)	Dec J2000 (d m s)	Distance (pc)	$E(B-V)$ / A_V (mag)	*logt* / Age (Myr)	Diameter (arcmin)	Photometry	*Gaia* Mass $M(M_\odot)$
NGC1960/M36	05 36 18	+34 08 24	1330	0.22 / 0.704	7.4/25	10	INT-WFC, *JKs*-KPNO	0.42
NGC 7058	21 21 53	+50 49 11	400	0.06 / 0.1932	8.35 /223	7	INT-WFC, *IZ*-CFHT12K, SDSS	0.17
Stock 23	03 16 11	+60 02 59	380	0.26 / 0.8372	7.51 / 32	29.0	INT-WFC	0.11
ASCC 127	23 08 24	+64 51 00	350	0.10 / 0.322	7.82 / 66	86.4	INT-WFC, SDSS	0.11
Stock 10	05 39 00	+37 56 00	380	0.07 / 0.2254	7.9 / 79	25	INT-WFC	0.085
ASCC 123	22 42 35	+54 15 35	250	0.10 / 0.322	8.41 / 257	153.6	INT-WFC, SDSS	0.13
NGC7092/M39	21 31 48	+48 26 00	326	0.013 / 0.04186	8.445/ 279	29.0	INT-WFC, *UBV*-KPNO	0.14
Platais 2	01 13 50	+32 01 42	201	0.05 / 0.161	8.6 / 398	336	SDSS	0.11
Herschel 1	07 47 02	+00 01 06	370	0.02 / 0.644	8.44 / 275	43.2	SDSS	0.19
NGC 2451 A	07 43 12	-38 24 00	189	0.01 / 0.0322	7.78 / 60	120	*BVI* *Ic*/*Iwp* ESO-WFI	0.059
NGC 2451 B	07 44 27	-37 40 00	302	0.055 / 0.176	7.648 / 44	180	*BVI* *Ic*/*Iwp* ESO-WFI	0.081
ASCC 20	05 28 44	+01 37 48	450	0.04 / 0.1284	7.35 / 22	90.0	SDSS	0.091

Note: For all OCs we also have retrieved photometry from the catalogues: Tycho-2, UCAC 4, 2MASS, and WISE. The last column is an estimation of the mass of the faintest object observed with *Gaia*, The mass has been calculated assuming distances, ages and A_v of the table for each cluster at magnitude $G = 20$ mag, -the stellar survey will be complete to magnitude $G = 20$ mag, (Sarro et al. 2013)- using BT-Settl models.

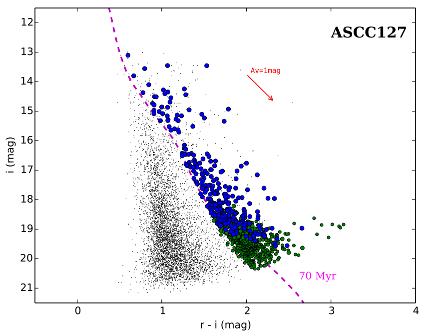

Fig. 2. The CMD (($r - i$), i) reaches the lowest mass in ASCC127, and it shows the final selection. Blue filled circles are probable candidates in all CMDs and CCDs, green points are possible candidates that are not detect in all CMDs/CCDs. The magenta dash-line is a 70 Myr isochrone (Allard et al. 2012) shifted at the distance and A_v of the cluster (see Table 1).

3.1. Stellar parameters

Our next step is to characterise the stellar parameters from our potential candidates, in particular bolometric luminosities (L_{bol}) and effective temperatures ($T_{\rm eff}$).

Deriving just L_{bol} and $T_{\rm eff}$ building a Spectral Energy Distribution (SED) is more robust than using one colour index. In this way, we eliminate the uncertainties in the luminosities that appear when bolometric corrections are used. Our multi-wavelength approach allows us to build reliable SEDs and use VOSA (Bayo et al. 2008) to obtain L_{bol} and $T_{\rm eff}$. In particular, since in several cases we have a significant number of datapoints covering a large range in wavelength, the errors in L_{bol} are very reduced. VOSA can also estimates masses and ages for each member using several grids of models (Allard et al. (2012), Siess et al. (2000)). We generate a Hertzsprung-Russell Diagram (HRD) and reject additional possible non-candidates with the values of $T_{\rm eff}$ and the

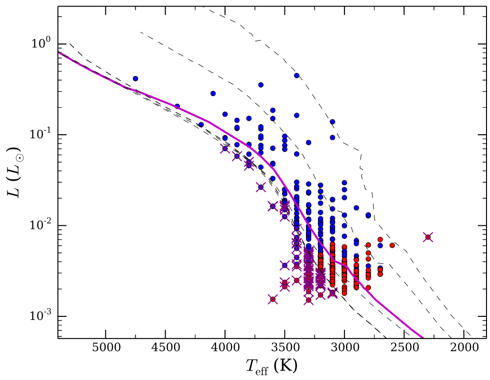

Fig. 3. HRD for ASCC127. Solid circles are the candidates: in blue those with photometric measurements in all bands, in red candidates with missing photometry. Dash-lines correspond to 1-10-100-1000-10000 Myr isochrones (Allard et al. 2012). The magenta line correspond to 100 Myr. The rejected members below the Main Sequence have over-imposed big magenta crosses.

L_{bol}. The HRD for ASCC127 with potential candidates is shown in Figure 3.

4. Future work

The current status of our project has been described. The multi-wavelength approach allows us to derive a reliable census down to low-mass candidates. Gaia will provide exact distances and proper motions of these clusters, although our survey is deeper and will complement those data.

In addition, we are implementing statistically robust selection methods (Sarro et al. 2014), following the same methodology as the DANCe project regarding the photometry -Bouy et al. (2013), Bouy et al. (2014) and Bouy et al. (2014)-. When it is feasible, we will also use proper motions, mainly to reject foreground objects. The subsequent step would be to derive IMFs and study the spatial distribution in a wide mass range and several environments. Different observing campaigns have been carried out to confirm candidates with spectroscopy and derive spectral types to estimate the loci of the lithium depletion boundary.

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