Highlights of Spanish Astrophysics VIII, Proceedings of the XI Scientific Meeting of the Spanish Astronomical Society held on September 8–12, 2014, in Teruel, Spain. A. J. Cenarro, F. Figueras, C. Hernández-Monteagudo, J. Trujillo Bueno, and L. Valdivielso (eds.)

Age determination of open clusters with Gaia

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Abstract

Stellar clusters are optimal targets in the study of a variety of topics including the star formation process, stellar structure and evolution, dynamical interaction among stars, or the assembly and evolution of galaxies. In fact, most stars are formed in stellar clusters although most of them are dissolved in the first few Myr. Open clusters, which cover large ranges of ages and metallicities, are located in the Galactic disk and are crucial to investigate its formation and evolution. Therefore, the determination of cluster ages is crucial.
We investigate the accuracy in the determination of ages through isochrone fitting to color-magnitude diagrams from Gaia observations and for a set of open clusters covering a range of ages and distances. The Gaia Object Generator (GOG) has been used to simulate Gaia end-of-mission data of star members of open clusters. Open clusters are generated on a semi-empirical basis. The clusters are placed at positions on the sky where real clusters exist. Then, assuming the real cluster age, metallicity, mass, radius, distance, space velocities, and extinction of the cluster, simulated stars are generated using the Padova luminosity function simulator and assuming a lognormal IMF.

1 Introduction

The study of chemical composition of the stars and their age can provide a better understanding of the formation and evolution of the Galaxy and open clusters (OCs), located in the disk and covering a wide range of ages and metallicities, are ideal objects to attempt that. Their properties can be determined with smaller uncertainties than for field stars, since they are coeval group of stars at the same distance that have a homogeneous chemical composition. Besides, since they are relatively young objects, their radial position has not changed significantly since they were formed. Several attempts have been made to derive these two fundamental relations, but they are hampered by the lack of large and homogeneous high quality datasets.

However, the Gaia project by European Space Agency (ESA) will improve our knowledge about OCs in the next decade, by building a six dimensional (6-D) space with positions (2-D), parallaxes, proper motions (2-D) and spectra for most stars brighter than $G = 20$ and with an unprecedented precision. Actually, this space astrometric mission will provide accurate parallaxes allowing to determine distances with a precision better than 2% within 1.5 kpc. Unfortunately, the capability of Gaia to derive chemical composition is limited and detailed abundance determinations will be possible only for stars brighter than $G = 11$. For this reason, two on-ground surveys have been designed to complement the Gaia mission: Gaia-ESO (GES in the South) and OCCASO (Open Clusters Chemical Abundances from Spanish Observatories, in the North), both of them with the aim to determine detailed chemical abundances of stars of intermediate and old OCs.

This work is mainly focused on a subset of clusters from the OC Gaia Catalogue, simulated by GaiaSimu, a set of libraries containing the Gaia Universe Model and instrument models used by the Gaia Data Processing and Analysis Consortium (DPAC). There are ≈ 600 clusters in this catalogue and our subset picks up 13 of them, covering a wide range of ages, metallicities and galactocentric distances. Then, these clusters will be processed by the Gaia Object Generator (GOG) simulator developed by the UB team, aiming to reproduce how Gaia will see these objects. [1]

2 Open clusters simulations

2.1 Candidates from the OC Gaia Catalogue

Our subset of clusters from the OC Gaia Catalogue contains 13 clusters, covering a wide range of ages, metallicities and galactocentric distances, although this work is focused on intermediate and old OCs. Some of these clusters are also observed by the OCCASO and GES surveys, allowing the subsequent discussion about the determination of their chemical abundances. Figure 1 shows the schematic distribution of our subset of clusters in Cartesian coordinates.

2.2 Clusters through GaiaSimu

The OC Gaia Catalogue contains the basic parameters of the clusters that we want to reproduce, but we need to obtain some file with the true values associated to each star of a given cluster. This is the generation of the simulated clusters through GaiaSimu [13]. OCs are generated on a semi-empirical basis. The clusters are placed at positions on the sky where real clusters exist. Then, assuming the real cluster age, metallicity, mass, radius, distance, space velocities and extinction of the cluster, simulated stars are generated using the Padova luminosity function simulator [2] and assuming a lognormal Initial Mass Function (IMF) [3]. Stars are randomly distributed around the mean position on the sky following a Gaussian

[1]GOG is a simulator of the Gaia end of mission catalogue and it contains all of the currently available predicted error models for the Gaia satellite. For further information about GOG, [10].

[2]`http://stev.oapd.inaf.it/cgi-bin/cmd`

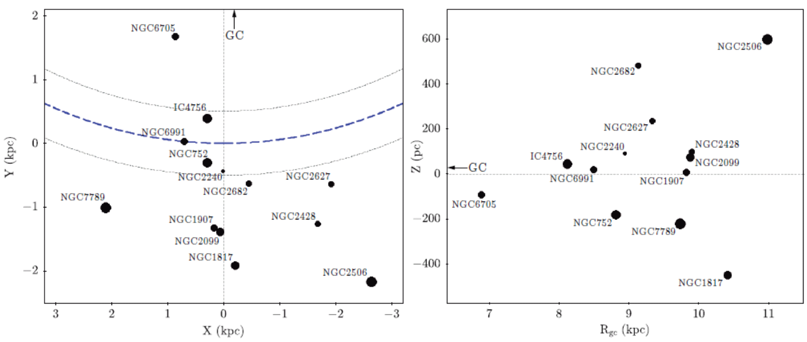


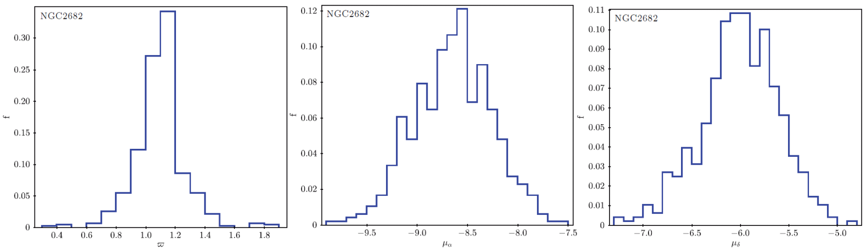
Figure 1: Schematic distribution of our subset of clusters in Cartesian coordinates ($X = d \sin l \cos b; Y = d \cos l \cos b; Z = d \sin b$), with the Sun at (0; 0; 0). The size of the points is proportional to the total mass of the cluster and the blue dashed line represents the solar orbit. Right panel: It has been assumed a value $Gc_{\odot} = 8.5$ kpc for the transformation tp R_{gc}.

distribution with a dispersion value corresponding to the core radius and the tidal radius used as a cut-off. Velocity of each star is computed using the sum of the velocity of the cluster plus a peculiar velocity randomly drawn from a 3D Gaussian. When the mean radial velocity is unknown, a mean of 10 km s^{-1} and a dispersion of individual stars of 1.6 km s^{-1} are assumed. The metallicity is assumed solar when it is lacking in the literature.

2.3 Clusters through GOG

Once the file from GaiaSimu with the true stellar values of the stars of a cluster is introduced in GOG, a first new file named UMStellar CLUSTERNAME.gbin.txt is generated. In this file, the true values of each member still remain intact (not affected by errors) but the photometric magnitudes are transformed in terms of Gaia passbands and then only members with G $<$ 20 survive. Recently, spectral energy distribution (SED) stellar libraries have been replaced by polynomial relationships [9] in order to transform Johnson-Cousins magnitudes and colors in terms of Gaia passbands. GOG also provides information about the true values of the absorption in the visual band and colors affected by extinction that GOG assigns to each star by using the three-dimensional dust map of Drimmel's extinction model from [6].

Finally, four other relevant files are generated by GOG, with the simulated values of photometry, astrometry and physical parameters, affected by errors. As a simulator of the Gaia end of mission catalogue and containing all of the currently available predicted error models for the Gaia satellite, GOG is capable to transform an input catalogue of true stellar properties into simulated Gaia observations including predicted observational effects and the instrumental capabilities.



(a) (b) (c)

Figure 2: Distribution of values of (a) parallax and proper motion in (b) right ascension and (c) declination for NGC2682.

3 Open clusters distance determination

As seen in previous section, astrometric data in Gaia is reliable. Figure 2 show the errors in parallax and proper motion for a relatively close cluster (NGC2682). Most of the measurements have an associated error below the 20% error.

Using only parallaxes to determine the distance to a given cluster is risky, some measurements may have huge uncertainties. So, even though the values can follow a Gaussian distribution, we prefer to compute a weighted mean.

Table 1: Weighted mean parallaxes and mean distances for each cluster, compared with the input values for the simulations (true values, last column). We get better results when short distances and large number of stars are combined (e.g. IC4756, NGC752).

Name	N (stars)	$< \varpi >$ (μas)	$< d >$ (pc)	d (pc)
IC4756	4980	2066.6 ± 0.3	483.89 ± 0.07	484
NGC1817	776	507.3 ± 0.7	1971 ± 3	1972
NGC1907	457	752.4 ± 0.7	1329.0 ± 1.3	1330
NGC2099	959	723.7 ± 0.7	1381.8 ± 1.3	1383
NGC2240	39	2223 ± 4	449.8 ± 0.7	450
NGC2428	122	476.0 ± 1.4	2101 ± 6	2100
NGC2506	2927	289.4 ± 0.7	3455 ± 8	3460
NGC2627	71	493.2 ± 1.7	2027 ± 7	2034
NGC2682	480	1104.2 ± 1.3	905.6 ± 1.0	908
NGC6705	298	531.2 ± 1.1	1883 ± 4	1877
NGC6991	615	1428.0 ± 0.7	700.3 ± 0.3	700
NGC752	6004	2184.3 ± 0.4	457.80 ± 0.08	458
NGC7789	3597	427.6 ± 0.5	2339 ± 3	2337

4 Open clusters age determination

A very important tool to derive ages in astronomy is the colour magnitude diagram, since a coeval population of stars occupies an specified curve in this diagram. We apply the method

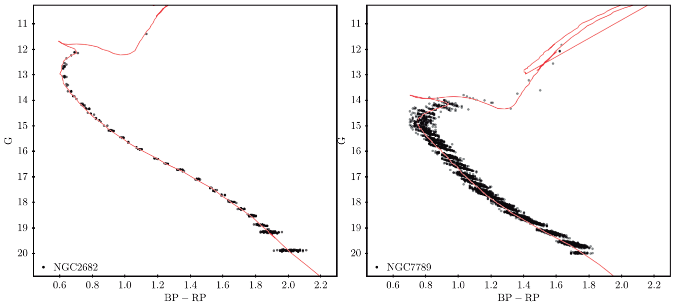


Figure 3: Colour magnitude diagrams for two intermediate OCs, NGC2099 (left) and NGC7789 (right), and the fit isochrone in terms of the Gaia passbands. Coefficients $< \varpi >$ and $< A_0 >$ has been extracted from the data whereas the metallicity is a free parameter

described in [7] to fit isochrones by the least-squares method and then, we will perform a Monte-Carlo simulation in order to derive the uncertainties associated. A set of PARSEC isochrones [1] can be downloaded from the Padova website [3], covering a wide range of ages and metallicities. The idea is to fit the best curve to the stars of a given cluster in a CMD in terms of Gaia passbands. So, we need to transform the fields of the files containing isochrones: Z, log(age/yr),M_V, M_I into these other ones: Z, log(age/yr), G, BP-RP. The near point estimator can be computed now to extract the distance from any star to a given isochrone. In fact, if the cluster has N stars and the isochrone has M points, then:

$$d_{ij}^2 = \left(\frac{G_i - G_j}{\sigma_{G_i}}\right)^2 + \left(\frac{(BP-RP)_i - (BP-RP)_j}{\sigma_{(BP-RP)}}\right)^2 \tag{1}$$

are the distances from a single star (i) to each point (j) of the isochrone. Then: $di \equiv MIN_{j=1,M(d_ij)}$ is the distance from that star to the nearest point of the isochrone. Finally, the fitting statistic Ψ (in analogy with conventional statistic χ^2) can be computed as follows:

$$\Psi^2 = \sum_{i=1}^{N} d_i^2 \tag{2}$$

which is a measure related with the distances of all stars to the isochrone.

Figure 3 shows two diagrams resulting from isochrone fittings in terms of Gaia pasbands.

5 Maximum likelihood for open cluster distance determination

An improved method for estimating distances to open clusters is presented and applied to Hipparcos data for the Pleiades and the Hyades [12]. Based on maximum likelihood estimation, the method combines parallax, position, apparent magnitude, colour, proper motion,

[3] `http://stev.oapd.inaf.it/cgi-bin/cmd`

and radial velocity information to estimate the parameters describing an open cluster precisely and without bias. Please, refer to [12] in order to have more details about this method.

6 Results and discussion

Astrometric data in Gaia is reliable, as seen in Section 2.3. So, we can think that real OC data provided by Gaia will show thinner CMDs easier to fit. However, field stars contamination has not been considered in this work. Once more, the good quality of the astrometric data in Gaia will be able to determine which stars belong to the cluster using proper motions and so on. Although better results can be provided to determine the distance of the clusters (maximum-likelihood in [12]) here we have shown that parallaxes in Gaia give impressive results for many known open clusters and allow to get distances up to 2-3 kpc with an error of a few parsecs.

Acknowledgments

This work was supported by the MINECO-FEDER through grant AYA2012-39551-C02-01 and ESP2013-48318-C2-1-R And the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement GREAT-ITN FP7 264895 and GENIUS FP7 - 606740.

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