Boletim da Sociedade Astronômica Brasileira, **35**, no. 1, 232-233

Dynamical state of open clusters projected onto the Galactic bulge

Maria Gabriela M. Gallo.[1], J. F. C. Santos Jr.[1], B. P. L. Ferreira[1], M. S. Angelo[2], & W. J. B. Corradi [3]

[1] DF-ICEx-UFMG e-mail: gabbsmacedo@ufmg.br, jsantos@fisica.ufmg.br, plfbernardo@gmail.com
[2] CEFET - MG e-mail: mateusangelo@cefetmg.br
[3] LNA e-mail: wbcorradi@lna.br

Abstract. The present work aims to study the dynamical state of 5 open clusters (ASCC88, NGC6231, NGC6405, NGC6400, Collinder 338) projected towards the bulge of the Milky Way through the determination of astrophysical parameters. In this preliminar analysis, the mass of the clusters was obtained using two different methods. The visible mass was estimated by adding up the stellar masses corresponding to the isochrone that best fits the cluster color-magnitude diagram.. The resulting astrophysical parameters from the isochrone fitting agree with literature values. The second method utilizes the integrated G magnitude and the age of the clusters.

Resumo. O presente trabalho tem como objetivo estudar o estado dinâmico de 5 aglomerados abertos (ASCC88, NGC6231, NGC6405, NGC6400, Collinder 338) projetados em direção ao bojo da Via Láctea através da determinação de parâmetros astrofísicos. Nessa análise preliminar, a massa dos aglomerados foi obtida utilizando dois métodos diferentes. A massa visível foi estimada somando as massas estelares correspondentes à isócrona que melhor se ajusta ao diagrama cor-magnitude do aglomerado. Os parâmetros astrofísicos resultantes do ajuste da isócrona concordam com os valores da literatura. O segundo método utiliza a magnitude G integrada e a idade dos aglomerados.

Keywords. Galaxy: open clusters

1. Introduction

A vast majority of stars form in groups or clusters, emerging from the gravitational contraction of molecular clouds that fragment, generating a stellar system with a mass distribution. The evolution of these clusters is linked to various processes involving stellar evolution and internal and external dynamic effects.

Star clusters, as self-gravitating systems that undergo structural changes over time, are inherently intriguing objects and a significant focus of study in the field of stellar populations.

This work addresses one of the fundamental problems in the study of star clusters, which is determining their dynamic state. This can be evaluated through the age, mass, and kinematics of their stars. The analysis involves identifying the cluster's member stars, deriving astrophysical parameters, and determining both the total photometric and dynamic masses.

2. Methodology

The following procedures were conducted for the 5 clusters under study: ASCC 88, Collinder 338, NGC6400, NGC6405, NGC6231.

2.1. Data extraction and preliminary analysis

Firstly data was extracted from the Gaia DR2 mission, and analyzed according to Ferreira et al. (2020), that involves the determination of mean values for central coordinates, parallax, proper motion, and visual radius of each cluster. The parameters were then refined through a program that utilizes parallax, proper motion, and coordinate histograms, and applies statistical techniques on a subsample containing only stars within the visual radius, with the information of all the initial parameters. The clusters' center and limiting radius were determined by constructing the radial density profile (RDP) and by calculating the centroids of the stars' coordinates.

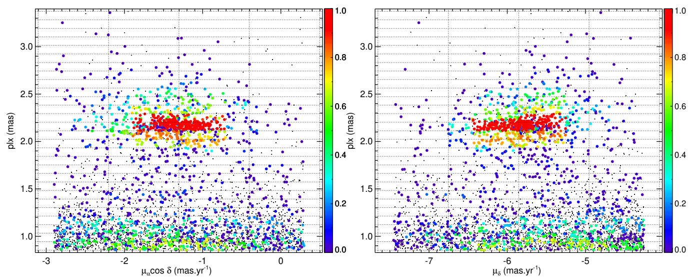

Figure 1. Parallax vs. proper motion for the cluster NGC6405. Color bars indicate the membersip probability.

2.2. Decontamination and astrophysical parameters

An astrometric decontamination program was employed (Angelo et al. 2019) to produce a list of member stars with their respective probabilities of belonging to the cluster, which was subsequently filtered to include stars with a minimum membership probability of 70%, as indicated by the color bar in Fig 1.

Cluster age, reddening, and distance were then derived by fitting a solar metallicity PARSEC isochrone (Bressan et al. 2012) to the decontaminated color-magnitude diagram (CMD). Fig. 2 exhibits the CMD of NGC6405 member stars, with the adjusted logt=7.8 isochrone.

2.3. Total mass

The total mass of the clusters was estimated using two methods.

2.3.1. Direct sum

The visible mass of the cluster ($\mathcal{M}_\mathcal{V}$) was calculated through the direct summation of its member stars' masses, with each star's mass being considered as that of the closest isochrone point, us-

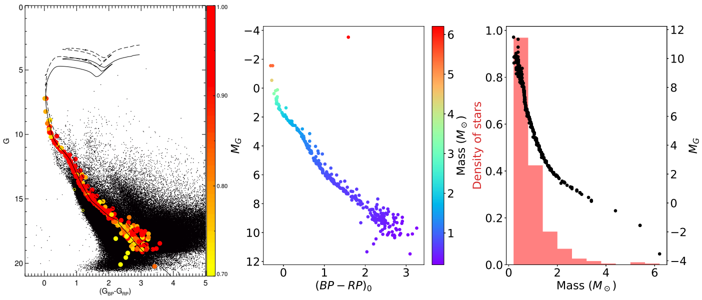

Figure 2. *Left:* Apparent CMD of NGC6405 field where member stars are marked by color symbols indicating membership probability (colorbar). The adjusted isochrone (continuous line) and the corresponding equal mass binary sequence (dashed line) is also shown. *Middle:* NGC6405 absolute CMD with the mass of each star represented by the color bar. *Right:* Histogram of the mass distribution of the cluster.

Table 1. Clusters parameters: mass calculates using integrated magnitude, visible mass, distance, age, number of members.

Cluster	$\mathcal{M}$ ($M_\odot$)	$\mathcal{M}_\mathcal{V}$ ($M_\odot$)	d (kpc)	log[t(yr)]	N
ASCC88	289.7	138.3	0.83	8.50	103
Collinder 338	78.9	70.3	0.64	8.20	53
NGC6400	367.7	236.1	1.00	8.35	161
NGC6405	311.1	310.1	0.42	7.80	318
NGC6231	1982.6	1689.1	1.26	7.00	774

ing interpolation routines and the k-nearest neighbors algorithm. Figure 2 shows the member stars on the CMD with their respective determined masses, followed by a histogram on the right, illustrating the cluster's mass distribution.

2.3.2. *Integrated magnitude*

The other method to derive the total mass of the cluster, described in Maia et al. (2014), uses the integrated absolute G magnitude (M_G) and age of the cluster:

$$\log \mathcal{M} = a + b \log t - 0.4(M_G - M_{G,\odot}) \qquad (1)$$

where $a = -6.09$, $b = 0.644$, $M_{G,\odot} = 4.67$, and M_G was calculated by summing the member stars fluxes.

3. Results

Table 1 presents the results of the mass obtained by both methods for the 5 studied clusters, along with the other determined parameters. The distance was calculated from the distance modulus obtained in the isochrone fitting.

As a star cluster moves farther away, the magnitudes of its stars at the lower end of the main sequence increase. Due to observational limits, more distant clusters will have fewer stars observed in this part of the CMD. Consequently, the visible mass of the cluster might be underestimated, as fainter and more distant stars may not be observed. Fig. 3 illustrates the relationship between the clusters' distance, age, and the stellar mass for G=16.5, the faintest magnitude where a significant number of members is observed in all clusters.

Fig. 4 shows age, number of members, and distance compared to Cantat-Gaudin et al. (2020).

4. Conclusions and perspectives

The masses calculated using the integrated magnitude are greater than the visible masses for all clusters in the sample. This difference may be partly explained by the hidden stellar content due to the observed stellar mass limit, as shown in Fig 3.

In the future, uncertainties of the astrophysical parameters and masses will be computed. A stellar mass function for the clusters will be constructed, following Kroupa (2001), to determine the mass using yet another method. Additionally, calculating the Virial mass of each system is necessary to establish an evolutionary scenario and determine whether the cluster is in dynamic equilibrium or undergoing dissolution, following Wright & Mamajek (2018).

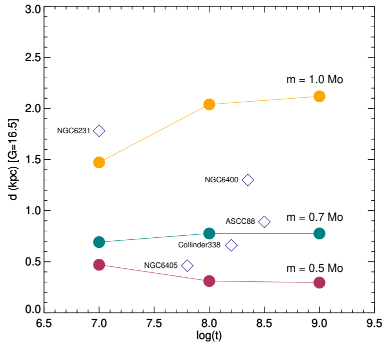

Figure 3. Theoretical limits of the lowest observable mass (G=16.5) based on the clusters' distance and age.

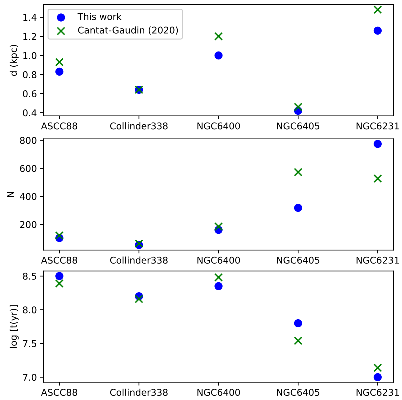

Figure 4. Comparison of parameters determined in this work with Cantat-Gaudin et al. (2020)

Acknowledgements. Capes, CNPq.

References

Angelo, M. S., Santos, J. F. C., Corradi, W. J. B., & Maia, F. F. S. 2019, A&A, 624, A8

Bressan, A., Marigo, P., Girardi, L., et al. 2012, MNRAS, 427, 127

Cantat-Gaudin, T., Anders, F., Castro-Ginard, A., et al. 2020, A&A, 640, A1

Ferreira, F. A., Corradi, W. J. B., Maia, F. F. S., Angelo, M. S., & Santos, J. F. C., J. 2020, MNRAS, 496, 2021

Kroupa, P. 2001, MNRAS, 322, 231

Maia, F. F. S., Piatti, A. E., & Santos, J. F. C. 2014, MNRAS, 437, 2005

Wright, N. J. & Mamajek, E. E. 2018, MNRAS, 476, 381