The simplest way to get a cluster’s parameters in the Gaia era (Dolidze 41)

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Abstract The astro-photometric parameters of the open star cluster Dolidze 41, which located in the constellation of Cygnus, have been investigated using the Gaia-ESO DR2 large Survey merging with the near Infrared Two Micron All Sky Survey 2MASS database. The radial density distribution (limited, core and tidal radii), color-magnitude diagrams, the galactocentric coordinates, distances, color excess, and age of Dolidze 41 are presented. Thanks to Gaia DR2 astrometry, which help us to define the membership of the cluster stars easily. The luminosity & mass functions, the entire luminosity & mass, and the repose time of the cluster have been estimated as well.

Key words: (Galaxy:) open clusters and associations: individual (Dolidze 41) – Photometry: Color-Magnitude Diagram – astrometry – Stars: luminosity function, mass function – Astronomical data bases: miscellaneous.

1 INTRODUCTION

One of the foremost necessary constituents in studying the structure and evolution of the Milky Way system are star clusters. Known stellar clusters comprise about 160 globular clusters and about 3000 open clusters [Kharchenko et al. 2013] if we extrapolate the solar vicinity to the whole disc, we may reach about 100,000 open clusters [Bragaglia 2018] Many of such objects are newly discovered and need photometric investigations, as well as confirmation of their physical nature. We believe that most of them will be detected and investigated in the Gaia DR2 era. The name GAIA was originally derived as an acronym for Global Astrometric Interferometer for Astrophysics. This reflected the optical technique of interferometry that was originally planned for use on the spacecraft. While the working method evolved during studies and the acronym is no longer applicable; however, the name GAIA remained to provide continuity with the project. It is the backbone in the science program of the European Space Operations (ESO), which launched on 19 December 2013, and situated 1.5 million km from Earth. The spacecraft GAIA monitored each of its target objects about 70 times to a magnitude of G = 20 over a period of five years to study the precise position and motion of each one. The Gaia DR2 was released on 25 April 2018 for 1.7 billion exquisite precision sources in astrometric five-parameter solutions of coordinates, proper motions in right ascension and declination, and parallaxes (\(\alpha, \delta, \mu_\alpha \cos \delta, \mu_\delta, \pi\)). In addition, magnitudes in three photometric filters \((G, G_{BP}, G_{RP})\) for more than 1.3 billion sources [Gaia Collaboration et al. 2018] Gaia Archive is available through the web page [http://www.cosmos.esa.int/gaia](http://www.cosmos.esa.int/gaia).

With the help of the Virtual Observatory tool TOPCAT and ALADIN we could use the cross-matched data of Gaia DR2 and the 2MASS surveys to compile a useful photometrical data to investigate Dolidze 41 [Bonnarel et al. 2000, Taylor 2005] The current work could be a part of our continued series whose goal
is to get the most astrophysical properties of newly, antecedently unstudied and/or poorly studied open clusters utilizing the foremost newly databases [Tadross 2008a, 2008b, 2009a, 2009b, Tadross 2011]. The most important aspect of using Gaia DR2 with the 2MASS surveys lies in the positions, parallax and proper motions for the cluster’s stars, which makes the member candidates can be easily determined.

J2000.0 coordinates of Dolidze 41 are $\alpha = 20^h 18^m 49^s$, $\delta = +37^\circ 45' 00''$, $\ell = 75.707^\circ$ & $b = 0.9925^\circ$ in the Cygnus constellation with a roughly angular size of 12 arcmin as shown in Fig. 1. Kazlauskas et al. 2014 and Dias et al. 2014 mentioned some few astrometric information about the cluster. No real photometric data has been published for Dolidze 41 to date except the study of Tadross & Nasser 2010 hereafter TN (2010). In the present work, we re-study Dolidze 41 in the light of Gaia DR2 database. The near-infrared JHK photometry of the 2MASS catalog of [Skrutskie et al. 2006] is also used to estimate and confirm the most main properties of the cluster.

This paper is arranged as follows: The target data is presented in Section 2. The radial density profile is described in Section 3. Color-Magnitude Diagrams are presented in Section 4. Luminosity -mass functions and the dynamical status of the cluster are discussed in Section 5. Finally, the conclusion of the present study is given in Section 6.

2 TARGET DATA

Using (TOPCAT), 12,625 sources were downloaded from Gaia DR2 database service within a size of 10 arcmin located at the center of the cluster. While, 6,097 near-infrared sources were downloaded from 2MASS database service [Skrutskie et al. 2006] for the same area of the cluster. Both data were cross-matched, getting 5,570 sources, which contains all the datum we need. Of the Gaia DR2-2MASS cross-matched sources, a subset of 480 stars around the cluster center were selected as co-moving stars (the stars who travel together in the same direction through space) with halo-like background field [Bragaglia 2018] as shown in Fig. 2. For those co-moving stars, the mean values and the standard deviations of $\mu_\alpha \cos \delta$, and $\mu_\delta$ were found to be -2.95 ± 0.14 mas/yr and -4.68 ± 0.14 mas/yr respectively, as shown in Fig. 3. Stars are considered cluster’s member candidates if its 3$\sigma$ parallax error lies within the cluster mean parallax of 0.23 ± 0.06 mas; located in the ranging of 0.1 mas < $\pi$ < 0.4 mas. Those stars were selected to be the cluster’s member candidates, which have almost the same speed and direction in the sky with respect to the fore/background field ones, and at the same time located within the limited size of the cluster, see Fig. 4.

3 RADIAL DENSITY PROFILE

The radius determination is one of the most important fundamental properties of the cluster. To determine the cluster’s limited radius and core radius, the radial surface density of the stars $\rho(r)$ should be achieved firstly. In this context, the stars inside Dolidze 41 area are counted in concentric rings outwards from the cluster center with equal increment radius of 0.1 arcmin. Fig. 5 shows the radial density profile of the cluster, where the mean stellar density in each ring is plotted against the corresponding average radius. The cluster limited border is taken at the point, which comprises the entire cluster area and arrives at a sufficient stability with the background field density, i.e. at that point where the cluster stars dissolved in the background field; for more details see [Tadross 2011]. Applying the empirical King’s Model [1966] the density function $\rho(r)$ is represented as:

$$\rho(r) = f_{bg} + \frac{f_0}{1 + (r/r_c)^2}$$  \hspace{1cm} (1)

where $f_{bg}$, $f_0$, and $r_c$ are background, central densities of the stars in the cluster and the core radius of the cluster respectively. The angular limited radius is found to be 6.6 arcmin ($\sim$ 8.8 pc), while the core radius $r_c = 1.8$ arcmin ($\sim$ 2.4 pc). The concentration parameter of Peterson & King [1975] $C = \log(R_{lim}/R_c)$ ≈ 0.6.
4 COLOUR-MAGNITUDE DIAGRAMS

The Color-Magnitude Diagrams (CMDs) of the cluster Dolidze 41 have been constructed using the Gaia DR2 bandpass $G\sim(BP-RP)$ as shown in the left hand panel of Fig. 6, while the middle and right hand panels show the CMDs of 2MASS bandpass $J\sim(J-H)$ & $K\sim(J-K)$. Isochrones concerning to Gaia data were obtained from CMD 3.0 form of different ages and metallicities at (http://stev.oapd.inaf.it/cgi-bin/cmd3.0). All diagrams fitted to the solar theoretical isochrones of Marigo et al. 2017. The 2MASS dataset has the benefits of being homogenized all sky and covering near infrared wavelengths $J$ (1.25 $\mu$m), $H$ (1.65 $\mu$m) and $K_{s}$ (2.16 $\mu$m), wherever young clusters can be observed in their nebulous environments. Isochrone fitting was started using some guesses of ages and metallicities ranges for the cluster. However, we used the photometric systems with solar metallicity, because most open cluster studies based on isochrones fitting of solar metallicity $Z = 0.0152$ Caffau et al. 2009, 2011 for simplicity and comparing Steffl et al. 2018. Best fitted isochrones were then used to estimate the parameters of Dolidze 41.

In Fig. 6 the blue dots refer to the co-moving stars in the cluster’s area, located within the ranging parallax of the cluster (0.1 mas $< \pi < 0.4$ mas) and proper motion errors $\leq 10\%$. While the red dots refer to the stars with higher proper motion errors. The cyan dots refer to the fore/background field stars in the cluster region. The age of the cluster is found to be 200 $\pm$ 10 Myr. The intrinsic distance modulus $(m - M)_{0} = 13.3 \pm 0.1$ mag, which corresponds a distance of 4625 $\pm$ 210 pc. The $JHK$ photometric color excess $E(J-H)$ and $E(J-K)$ are found to be 0.35 and 0.55 mag respectively, which corresponds to an optical reddening of $E(B-V) = 0.54$ mag. Correspondingly, the linear diameter, the distance from galactic center $R_{g}$, the distance from the galactic plane $Z_{\odot}$, and the distances $X_{\odot}$ & $Y_{\odot}$ from the Sun on the galactic plane are found to be 17.7 pc, 8.5 Kpc, 80 pc, 1140 pc & 4480 pc respectively; for more details about the calculations, see Tadross 2011.

5 LUMINOSITY, MASS FUNCTIONS, AND THE DYNAMICAL STATUS

The open cluster represents of hundreds of stars having identical ages and compositions but different masses. The luminosity and mass functions (LF & MF) depended principally on the determination of the membership of the cluster. Here, the cluster’s member candidates are the co-moving stars located within the cluster’s area, at intervals the ranging of the cluster’s parallax, and proper motion errors $\leq 10\%$. Consequently, a number of 480 stars in the cluster region are counted inside the limit diameter of 17.7 pc.

The stars have been counted in terms of the absolute magnitude $M_{G}$ after applying the distance modulus derived above. The magnitude bin interval are taken to be $\Delta M_{G} = 0.50$ mag. The magnitude bin intervals are elect to incorporate an affordable number of stars in every bin for the most effective potential statistics of the LF and MF. To convert the star absolute magnitude to luminosity and mass, we used the theoretical tables of evolutionary tracks of Marigo et al. 2017 of the same cluster’s age. From the LF of Dolidze 41, we can infer that more massive stars are more centrally concentrated whereas the peak value lies at fainter magnitude bin of $G \approx 18.0$ mag, i.e. $M_{G} \approx 4.7$ mag. The luminosity function has been created as shown in Fig. 7 (the gray histogram). In this context, the entire luminosity of the cluster is found to be $\sim -4.3$ mag. The LF and MF are correlative to each other according to the well-known mass-luminosity relation. Therefore, the mass function distribution has been created as shown in Fig. 7 (the blue dotes), whereas the red line refers the initial mass function IMF slope, which can be obtained from the subsequent equation:

$$
\frac{dN}{dM} \propto M^{-\alpha}
$$

(2)

where $\frac{dN}{dM}$ is the number of stars in the mass interval $[M$(M+M+dM)] and $\alpha$ is the slope of the relation ($\Gamma = -2.3\pm0.24$), which indicates that the estimated masses of Dolidze 41 lie in the range of 0.08 $M_{\odot} < m < 0.5 M_{\odot}$ according to Salpeter 1955. We calculated the overall mass of the cluster by integrating the masses of the members Sharma et al. 2006, which is found to be 640 $M_{\odot}$.
Table 1 Comparisons between the previous and present results.

| Parameter                  | TN (2010)       | Present work       |
|----------------------------|-----------------|-------------------|
| pm α cos δ                 | --              | -2.95 ± 0.14 mas/yr. |
| pm δ                       | --              | -4.68 ± 0.14 mas/yr. |
| Parallax                   | --              | 0.23 ± 0.06 mas    |
| Age                        | 400 Myr.        | 200 Myr.           |
| Metal abundance            | 0.019           | 0.0152             |
| E(B – V)                   | 0.53 mag.       | 0.54 mag.          |
| R*,                       | 3.25            | 3.1                |
| Intrinsic Modulus          | 12.20 mag.      | 13.30 ± 0.10 mag.  |
| Distance                   | 1763 pc.        | 4625 ± 210 pc.     |
| Limited radius             | 5.0′            | 6.6′ (8.8 pc.)     |
| Core radius                | --              | 1.8′ (2.4 pc)      |
| Tidal radius               | --              | 12.6 pc.           |
| Membership                 | --              | 480 stars          |
| R_o                        | 8.2 kpc.        | 8.5 kpc.           |
| X_⊙                        | -435 pc.        | 1140 pc.           |
| Y_⊙                        | 1708 pc.        | 4480 pc.           |
| Z_⊙                        | 31 pc.          | 80 pc.             |
| Total luminosity           | --              | -4.3 mag.          |
| IMF slope                  | --              | Γ = -2.3 ± 0.24    |
| Total mass                 | --              | ≈ 640 M⊙ (minimum) |
| Repose time                | --              | < 40 Myr.          |
| c                          | --              | ≈ 0.6              |
| τ                          | --              | ≈ 6.0              |

Knowing the overall mass of the cluster, and applying the equation of [Jeffries et al. 2001](https://www.cosmos.esa.int/web/gaia/dpac/consortium), the tidal radius can be given as:

\[
R_t = 1.46(M_c)^{1/3},
\]  

where \(R_t\) and \(M_c\) are the tidal radius and the overall mass of the cluster respectively. \(R_t\) is calculated to be 12.6 pc.

Following [Spitzer & Hart 1971](https://www.cosmos.esa.int/web/gaia/dpac/consortium), the dynamical repose time \(T_R\) is obtained from the relation:

\[
T_R = \frac{8.9 \times 10^5 \sqrt{N} \times R_h^{1.5}}{\sqrt{m \times log(0.4N)}},
\]

where \(N\) is the number of the cluster members, \(R_h\) is the radius containing half of the cluster mass in parsecs, and \(m\) is the average mass of the cluster in solar unit, assuming that \(R_h\) equals half of the cluster radius. Then, the repose time is found to be less than 40 Myr. The dynamical evolution parameter \(\tau = Age/T_R \approx 6.0\), which means that the cluster Dolidze 41 is indeed dynamically relaxed.

6 CONCLUSIONS

The open cluster Dolidze 41 is poorly studied objet, the only photometric study, which found in the literature was carried out by TN 2010 using 2MASS database. According our analysis for refining the fundamental parameters of Dolidze 41 in the GAIA era, we presented a real astro-photometric study here, which is somewhat different from the previous TN 2010 one. The present and previous results are summarized and compared in table 1.

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by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement. In addition, the present study makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. Virtual observatory tools like Topcat and Aladin have been used in the analysis.

References

Bonnarel, F., Fernique, P., Bienaymé, O., et al. 2000, aaps, 143, 33
Bragaglia, A. 2018, A&A, in the Gaia sky, Proceedings of the IAU Symposium, 330, 119
Caffau, E., Maiorca, E., Bonifacio, P., et al. 2009, A&A, 498, 877
Caffau, E., Ludwig, H., Steffen, M., et al. 2011, Solar Physics, 268 (2), 255
Dias, W., Monteiro, H., Caetano, T., et al. 2014, A&A, 564A, 79
Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2018, ArXiv e-prints [arXiv1804.09365]
Jeffries, R. D., Thurston, M. R., & Hambly, N. C. 2001, A&A, 375, 863
Kazlauskas, A., Šperauskas, J., Boyle, R. 2013, NewA 19, 34
Kharuchenko, N. V., Piskunov, A. E., Schilbach, E., Röser, S., & Scholz, R.-D. 2013, A&A, 558, A53
King, I. 1966, AJ, 71, 64
Marigo et al. 2017, ApJ, 835, 77
Peterson, C. and King, I. 1975, AJ, 80, 427
Salpeter, E. 1955, ApJ, 121, 161
Sharma, S., Pandey, A. K., Ogura, K., et al. 2006, AJ, 132, 1669
Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163
Spitzer, Lyman, Jr., Hart, Michael H. 1971, AJP, 164, 399
Steffi X., Yen, Reffert, S., Rser, S., et al. 2018, Astrometry and Astrophysics in the Gaia sky, Proceedings of IAU Symposium, 330, 281
Tadross, A. L. 2008a, NewA, 13, 370
Tadross, A. L. 2008b, MNRAS, 389, 285
Tadross, A. L. 2009a, NewA, 14, 200
Tadross, A. L. 2009b, Ap&SS, 323, 383
Tadross, A. & Nasser, M. 2010, ArXiv e-prints [2010arXiv1011.2934T]
Tadross, A. L. 2011, Journal of Korean Astronomical Society, 44, 1
Taylor, M. B. 2005, Astronomical Data Analysis Software and Systems XIV, 347, 29
Fig. 1 The image of Dolidze 41 as taken from ALADIN. $\alpha = 20^h\ 18^m\ 49^s$, $\delta = +37^\circ\ 45'\ 00''$, $\ell = 75.707^\circ$ & $b = 0.9925^\circ$. North is up, East to the left.
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Fig. 2 The left hand panel shows the proper motion diagram for Dolidze 41. The red crosses refer to the concentrated field with halo-like background field, while the blue dots show the stars with proper motion errors less than 10%. The white circle refers to the studied cluster’s area, in which 480 co-moving stars are located as shown in the zooming view of the right hand panel.

Fig. 3 The mean values of $\mu_{\alpha}\cos\delta$, and $\mu_{\delta}$ for the cluster member candidates, which are found to be $-2.95 \pm 0.14$ mas/yr and $-4.68 \pm 0.14$ mas/yr respectively.
Fig. 4 The left hand panel shows the magnified velocities of the cluster member candidates, i.e. the co-moving stars within the cluster area. They are located in the range of the parallax of $0.1 \text{ mas} < \pi < 0.4 \text{ mas}$, which presents in the right hand panel; the mean parallax $= 0.23 \pm 0.06 \text{ mas}$.

Fig. 5 The radial density profile of Dolidze 41. The model curve of King [1966] has been applied. The angular limited radius $R_{lim} = 0.11^\circ$ (6.6 arcmin, i.e. $\sim 8.8 \text{ pc}$). The core radius $r_c = 0.03^\circ$ (1.8 arcmin, i.e. $\sim 2.4 \text{ pc}$.)
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**Fig. 6** The CMDs of the cluster Dolidze 41; the blue dots refer to the co-moving stars in the cluster’s area; located within the ranging parallax of the cluster and the proper motion errors less than 10%. The red dots refer to the stars with higher proper motion errors. The cyan dots refer to the fore/background field stars around the cluster region. The left hand panel shows the CMD of Gaia DR2 bandpass $G \sim (BP-RP)$, while the middle and right hand panels show the CMDs of 2MASS bandpass $J \sim (J-H)$ & $K \sim (J-K)$. All diagrams fitted to the theoretical solar isochrones of Marigo [2017]. The intrinsic distance modulus is found to be $13.3 \pm 0.1$ mag, and the color excess values $E(J-H)$ & $E(J-K)$ are found to be $0.35$ & $0.55$ mag respectively. The age of the cluster is found to be $200 \pm 10$ Myr.
Fig. 7 The luminosity and mass functions of Dolidze 41. The gray histogram represents the luminosity distribution of the cluster, where the total luminosity is found to be $-4.3$ mag. The blue points refer to the mass distribution of the cluster, and the red line shows the linear fitting, where the initial mass function (IMF)-slope is found to be $-2.3 \pm 0.24$. 