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Open clusters with proper motions fully separatedfrom the field stars using Gaia DR2

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ABSTRACT
The study of open star clusters makes us understand a lot about the composition and construction of the Milky Way Galaxy. Thanks to the Gaia DR2 database that helps us to get the genetic members of star clusters using their proper motions and parallaxes, and estimating their physical properties in a very accurate way. This study aims to detect the reasons that make clusters (within 2 kpc) have proper motions completely separated from the background field stars. We studied a large sample of open stellar clusters taken from Dias's catalogue and drew the vector point diagrams using the astrometric data of Gaia DR2. By visual inspection, we specified 108 objects as separated clusters and 377 ones as melted clusters. We studied their mean parameters in the four galactic quadrants of the Milky Way Galaxy.

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1. Introduction

Open star clusters (OCs) are one of the most important tracers of the galactic structure and are often found on the galactic disk. Studying the distribution of such objects shows us the shape of our Galaxy. OCs are not only useful tracers of the Galaxy structure but also interesting targets in their own right. One of the important things in studying open clusters is to investigate the formation and evolution of stars in the Milky Way Galaxy. In addition, OCs are significant in stellar evolution studies because member stars of a cluster are born from the same molecular cloud. Therefore, they have similar ages, distances, and chemical compositions but vary in stellar mass (Maurya and Joshi 2020). Our vantage point within the Galaxy's disc helps us to see some of the finer structures in the solar neighbourhood in great detail, but it limits our view of the disk's three-dimensional configuration on a broader scale, (Cantat-Gaudin et al. 2018). Estimating distances to OCs as well as studying their distribution is needed to reconstruct the overall shape of the Galaxy. (Perren et al. 2020) use galactic open clusters as probes for the formation and evolution of the Milky Way disc.

In the literature, about 4000 objects are currently known that can be regarded as galactic star clusters of various types (Kharchenko et al. 2013). Although most stars in the Milky Way Galaxy are observed in isolation, it is believed that most of them form in clustered environments and spend at least a short amount of time gravitationally bound with their brothers embedded in their molecular cloud (Anders et al. 2019). The latest recent version of the Dias catalogue lists about 2200 objects, most of them located within 2 kpc of the Sun. Many of the recent studies have a lot of detected new clusters that need confirmation (Tadross 2018; Tadross and Hendy 2021). This study aims to investigate the vector point diagrams of a large sample of OCs using visual inspection, specifying the clusters that have separated proper motions and the others that have the same motion of the background field. And study their mean parameters in the four galactic quadrants of the Milky Way Galaxy. The paper is organised as follows: Gaia space telescope is presented in Section 2. The data reduction is presented in Section 3. Finally, the results and conclusions are depicted in Section 4.

2. The *Gaia* space telescope

The space telescope Gaia was launched at the end of 2013 and located 1.5 million kilometres from Earth at the L2 Lagrangian point. Gaia data release DR2 database is available on the Gaia Archive website (*http://www.cosmos.esa.int/gaia*). The results of the query are available in different formats, but we used CSV (Comma Separated Values) because the resulting table can be loaded in a spreadsheet. DR2 is a high-precision database containing 1.7 billion sources in the astrometric parameters of coordinates, proper motions, and parallaxes (α, δ, μ_α cos δ, μ_δ, π). Furthermore, magnitudes for over 1.38 billion sources in three photometric filters (*G, GBP and GRP*) with magnitudes down to 20.5 where (*GBP*) is the blue photometry value, and (*GRP*) is the red photometry value (Gaia et al. 2018). Gaia data release 2 was released on

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25 April 2018. For sources G < 15 mag, the parallax uncertainties are in the range of 0.04 mas, and proper motion are up to 0.06 mas/yr. For sources G = 17 mag, the parallax uncertainties are in the range of 0.1 mas and proper motion of 0.2 mas/yr. At G = 20 mag, the corresponding values 0.7 mas and 1.2 mas/yr for parallax and proper motion, respectively. G_{BP} and G_{RP} magnitudes with precisions varying from a few milli-mag at the bright G < 13 mag end to around 200 milli-mag at G = 20 mag. The Gaia DR2 catalogue is essentially complete between G = 12–17 mag. Near very bright sources, and at the faint end (G > 19 mag) of the survey, the photometric measurements from the G_{BP} and G_{RP} photometers suffer from an insufficiently accurate background estimation from nearby sources. According to (Lindegren et al. 2018), we should shift all the parallax values by adding 0.03 mas to their values. In addition, RUWE, which is the value for a renormalised unit weight error indicates how well the source matches the single-star model; RUWE should be ≤1.4.

3. Data reductions

Using *TOPCAT*, the interactive graphical viewer and editor for tabular data, which is a Tool for Operations on Catalogues and Tables. We compiled a list of 485 clusters among 2167 clusters listed in the Dias catalogue (DAML), (*https://wilton.unif ei.edu.br/ocdb/)*. By downloading the astrometric data from the Gaia DR2 survey service, located at the centres of the clusters with radii covered all the clusters regions, up to 20 arcmin. The vector point diagram (VPD) of the proper motion in right ascension (μ_α) and declination (μ_δ) is plotted for all the clusters under study. The VPD is the most important diagram that should be done as a first step in studying an open cluster to see if it was melted in or separated from the background field stars. This visual inspection of VPDs is a very important process that we can use with *TOPCAT*.

Often the VPD includes two condensed groups of stars, the larger one indicates the background field stars and the smaller one refers to the most cluster members. However, VPD makes us know what kind of cluster we deal with. When the cluster's stars appear to be fully separated from the background field, then we called it a separated cluster. Isolating the membership, in that case, is very easy and more precise, see the example of the left-hand panel of Figure 1. When the cluster's stars appear to be melted in the background field stars, then its VPD includes one large condensed group only, and we called it a melted cluster. Isolating the membership, in that case, is very difficult, so it maybe needs to apply a membership probability method, for example, Hendy and Tadross (2021), (Bisht et al. 2019 & 2020), Cantat-Gaudin et al. (2018), Kharchenko et al. (2004), (Chen et al. 2004), see the example of the right-hand panel of Figure 1.

For a separated cluster, the small high-density area is chosen as a subset of the most probable members of that cluster, which often have similar astrometrical properties. While another subset is taken at the large high-density area as a sample of the field stars. We always found that the first subset represents the co-moving stars of the cluster, that is the stars that move together with the same speed and the same direction in the sky compared to the background field ones (which have different speeds and directions), as shown in the left-hand panel of Figure 2. On the contrary, for a melted cluster, the co-moving stars have the same direction as the field stars do, as shown in the right-hand panel of Figure 2. On the other hand, the (G vs. Plx) diagrams for the two clusters show that the separated cluster NGC 2287 has obviously prominent members, as shown in the left-hand panel of Figure 3. While the member

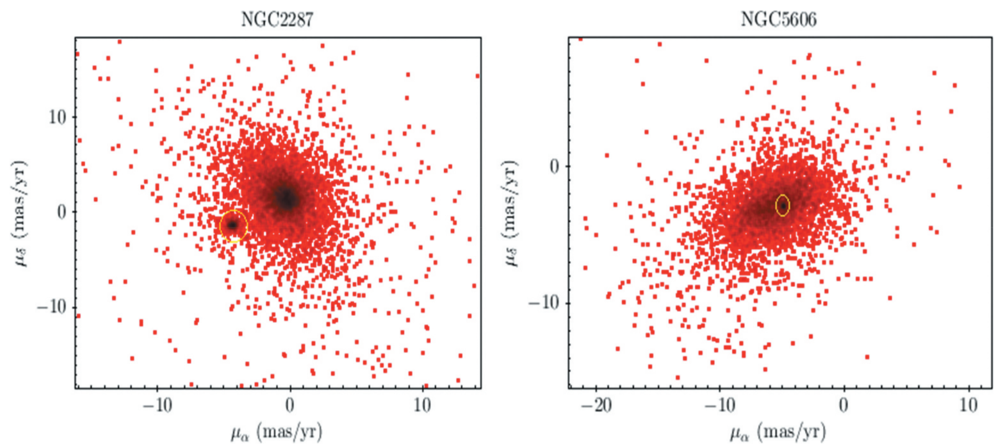

Figure 1. The left-hand panel is an example of a fully separated cluster from field stars, while the right-hand panel is an example of a melted cluster in the background field stars.

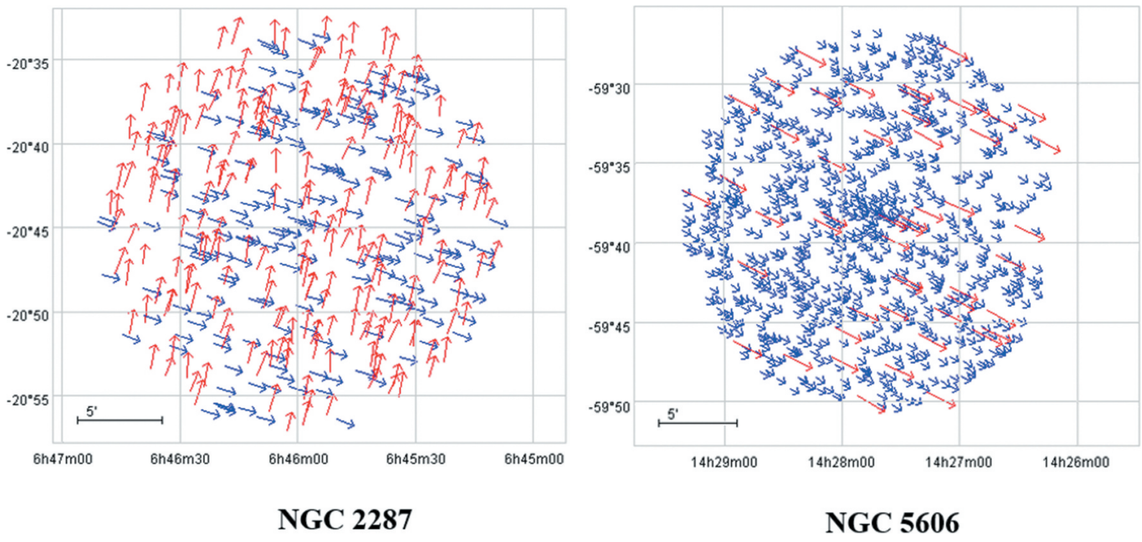

Figure 2. The left-hand panel represents the co-moving stars of the separated cluster NGC 2287, where the member stars (blue arrows) have a direction different from the field ones (red arrows). While the right-hand panel represents the co-moving stars of the melted cluster NGC 5606, which have the same direction as the field stars do.

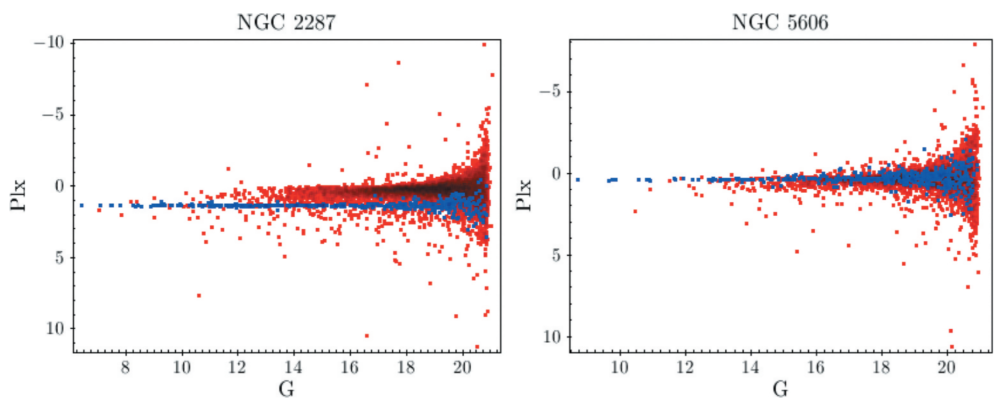

Figure 3. The relation of G mag vs. Parallax for the separated cluster NGC 2287 (left-hand panel), and for the melted cluster NGC 5606 (right-hand panel). We found that the member stars (blue points) are fully separated from the field ones (red points) for NGC 2287, while they are melted in the field for NGC 5606.

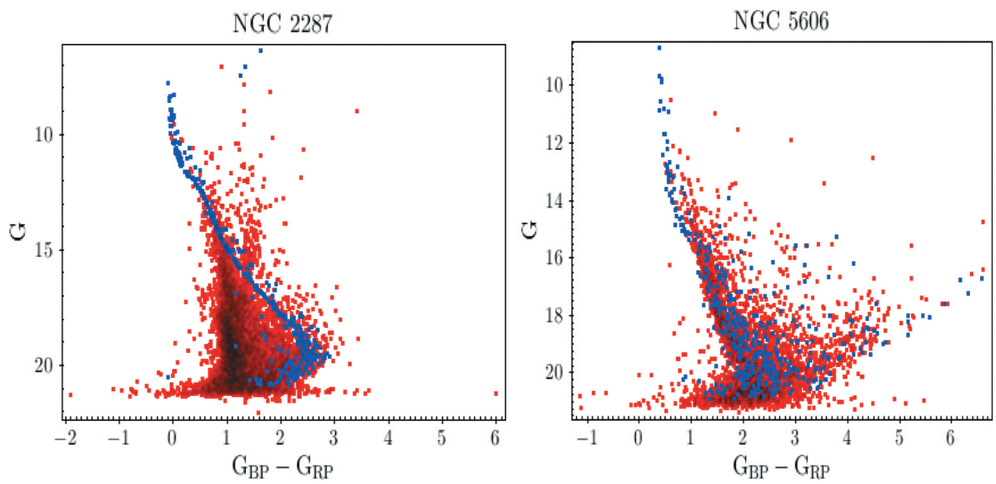

Figure 4. The left-hand panel represents the CMD of the separated cluster NGC 2287, where the member stars (blue points) are fully separated from the field ones (red points). While the right-hand panel represents the CMD of the melted cluster NGC 5606, where the member stars (blue points) are dissolved in the field ones (red points).

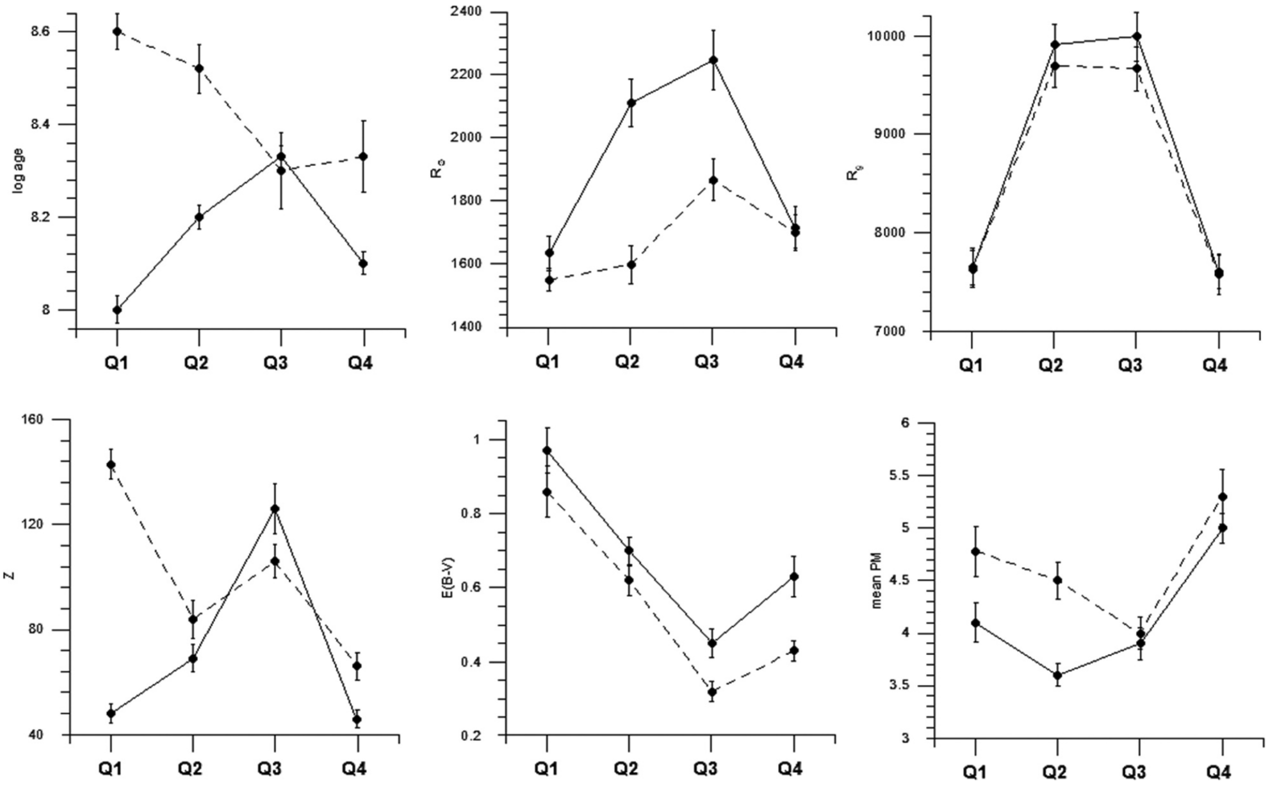

Figure 5. The statistical mean values of the melted and separated clusters in the four galactic quadrants of the Galaxy. The dashed lines represent the separated clusters, while the solid lines represent the melted clusters. The error bars represent the standard deviations of each parameter for each galactic quadrant of the Galaxy.

stars of the melted cluster NGC 5606 appear to have dissolved, members into the field's stars, as shown in the right-hand panel of Figure 3. The colour-magnitude diagram (CMD) shows that the member stars of NGC 2287 are fully separated from the field ones, as shown in the left-hand panel of Figure 4. While the CMD of the melted cluster NGC 5606 shows that the member stars are dissolved in the field ones, as shown in the right-hand panel of Figure 4. Therefore, we can easily specify the fully separated clusters (108 objects) and the other melted ones (377 objects).

4. Results and conclusions

Using the visual inspection of VPDs (μ_α vs μ_δ), 485 OCs have been selected randomly among 2167 OCs listed in the Dias Catalogue. We designated 108 OCs with the proper motion completely separated from the field stars, and 377 OCs with the proper motions that melted into the field. The clusters that have separate proper motions from the field are very simple to investigate than those that have melted proper motions. Their members are easily specified as co-moving stars, which have the same speed and direction in the sky, as shown in Figure 2. They are very prominent in the (G vs. Plx) diagram, as shown in Figure 3, and have an explicit curve in the CMD, as shown in Figure 4. Studying these two kinds of clusters in the four galactic quadrants of the Milky Way Galaxy, we found that the separated OCs are older, closer, and have proper motions greater than those of melted ones. In addition, the separated OCs are found far from the galactic disk than those of the melted ones.

Some statistical processes have been applied to the two kind of clusters on the four galactic quadrants of the Milky Way Galaxy, as explained in Table 1. The mean values of ages, distances, colour excess; and proper

Table 1. *The mean values and the standard deviations of the main parameters in each* galactic quadrants of the Milky Way Galaxy.

Parameter			Log age		Distance		Rgc		|Z|		E(B-V)		PM	
#	OCs	N	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Q1	S	6	8.6	0.4	1549	613	7633	746	143	115	0.86	0.69	4.8	2.6
	M	46	8.0	1.0	1634	676	7655	737	48	71	0.97	0.61	4.1	3.8
Q2	S	31	8.5	0.5	1597	990	9701	881	84	145	0.62	0.40	4.5	2.0
	M	114	8.2	0.8	2112	942	9913	803	69	105	0.70	0.36	3.6	2.2
Q3	S	32	8.3	0.8	1867	1090	9666	903	106	127	0.32	0.28	4.0	1.7
	M	81	8.3	0.8	2247	1180	9992	973	126	189	0.45	0.39	4.0	3.1
Q4	S	23	8.3	0.8	1700	932	7582	816	66	103	0.43	0.28	5.3	2.9
	M	89	8.1	0.8	1751	815	7605	684	46	72	0.63	0.54	5.0	2.8

motions are plotted as shown in Figure 5. The error bars represent the standard deviations of the mean value of each parameter at each quadrant of the Galaxy. We infer that the mean age of the separated clusters is older than those of the melted ones; approximately the same in the third quadrant of the Galaxy. The mean distances from the Sun and rather from the galactic centre indicate that the separated clusters are closer than the melted ones in all the galactic quadrants. Hence, their proper motions are found greater than the melted clusters, but they are almost equal in the third quadrant of the Galaxy. And logically, the melted clusters are found closer to the Galactic disk, in which they are more reddened than separated ones in all the galactic quadrants of the Galaxy. Noticed that the third quadrant of the Galaxy (Q3) has special cases in ages and the distance from the galactic disk (Z). We concluded that they may affect the Galactic warp in the third quadrant of the Milky Way Galaxy, Hidayat et al. (2019).

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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