Identification warp and flare milky way’s disk in the third galactic quadrant

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Abstract. Milky Way's disk has a feature called warp and flare. Warp is a bending phenomenon of the galactic disk. This feature is noticeable in the first and third galactic quadrant. Meanwhile, flare define as the increment of galactic disk scale high depends on galactocentric distance. Galactic disk tracers (dust, gaseous, and stars) can be used to explain the presence of both structures. The reddening of 10 young open clusters (OC) and 2985 early-type (OB) stars chosen in this work. Both components predicted to represent the galactic disk component where the warp and flare occurred. The Milky Way Star Cluster (MWSC) catalogue used to select the open clusters initial parameters. Then, we used proper motion data from GAIA DR2 combined with photometric data from Two Micron All Sky Survey (2MASS) catalogue to determine the open cluster membership and reddening. The open cluster memberships are selected using scatter algorithm. Then, the JHKs photometric data used to build the Two Colour Diagram (TCD) and Colour-Magnitude Diagram (CMD). We selected the reddening of OB stars data from Tycho 2 catalogue. The result is an increment of colour excess depends on galactocentric distance. This distribution could indicate the presence of warp and flare of the Milky Way's disk.

Keywords: flare milky way and third galactic quadrant

1. Introduction
Warp define as bending phenomenon which is observed in the young population of galactic disk components such as stars, dust, and gaseous [1, 2]. The observation of Hydrogen Neutral (HI) emission from M33 revealed the structures of warp in another galaxy [3]. They found an anomaly of this data and make a hypothesis it came from the bending of the galactic plane. Further studies showed that the warp was detected in many spiral galaxies [4].

The Milky Way’s galactic disks bend to the North Galactic Pole (NGP) and South Galactic Pole (SGP) in the first and third galactic quadrant, respectively [5]. Meanwhile, the star counts from Two Micron All Sky Survey (2MASS) catalogue constrain the warp started at 8.4 kpc from the centre of Milky Way. Therefore, the presence of the warp structure is one of an interesting problem in galactic structure study. The warp structure of Milky Way's disk accompanied by a structure named Flare. Flare define as the increment of galactic disk scale height depends on galactocentric distance [6]. In this work, we want to confirm the presence of both structures in Milky Way’s disk. In section 2 we describe the data used in this work. Then we explain our method in section 3. At the end of this work, we describe our result concerning the presence of the warp and flare structure in Milky Way’s disk.
2. Data
To support the goals of this work, the initial parameter of young OCs taken from the Milky Way Star Clusters (MWSC) catalogue [7]. 10 OCs located within longitudes $220^\circ < l < 240^\circ$ and $-15^\circ < l < 15^\circ$. Furthermore, we combined GAIA DR2 and 2MASS catalogue of stars that located in selected MWSC cluster’s area. We describe the region as a circle with a radius ($r$ and data) twice cluster's radius ($r2$). We picked the data which has relative error of parallax, proper motion RA (pmra) and proper motion declination (pmdec) less than 15%, and the photometric quality is “AAA”. These criteria are used to minimize the uncertainty of kinematics and the photometric component of data.

| Name         | RA (deg) | dec (deg) | l (deg) | b (deg) | r2 (deg) | $r_{\text{data}}$ (deg) | pmra (mas yr$^{-1}$) | pmdec (mas yr$^{-1}$) | pm error (mas yr$^{-1}$) | Distant ce Modul us | E(J-H) | Distant ce (pc) |
|--------------|----------|-----------|---------|---------|----------|-------------------------|---------------------|----------------------|----------------------|---------------------|--------|----------------|
| NGC_2287     | 101.51   | -20.74    | 231.01  | -10.44  | 0.44     | 0.88                    | -3.33               | -0.75                | 0.2                  | 9.45                | 0.02   | 769            |
| NGC_2437     | 115.45   | -14.81    | 231.85  | -4.07   | 0.57     | 1.14                    | -3.05               | 0.38                 | 0.09                 | 10.74               | 0.05   | 1375           |
| NGC_2383     | 111.17   | -20.94    | 235.26  | -2.46   | 0.12     | 0.25                    | -6.84               | 2.83                 | 0.63                 | 11.16               | 0.07   | 1655           |
| NGC_2384     | 111.28   | -21.02    | 235.38  | -2.40   | 0.16     | 0.33                    | -6.44               | 3.29                 | 0.42                 | 11.71               | 0.13   | 2074           |
| NGC_2421     | 114.06   | -20.61    | 236.27  | 0.07    | 0.16     | 0.32                    | -2.92               | 4.81                 | 0.3                  | 11.84               | 0.15   | 2178           |
| DBSB_10      | 113.86   | -22.39    | 237.73  | -0.96   | 0.12     | 0.25                    | -5.2                | 1.33                 | 0.49                 | 12                  | 0.12   | 2362           |
| ASCC_32      | 105.52   | -26.56    | 237.94  | -9.61   | 0.32     | 0.65                    | -2.33               | 4.25                 | 0.35                 | 9.45                | 0.02   | 767            |
| NGC_2362     | 109.68   | -24.96    | 238.18  | -5.55   | 0.26     | 0.52                    | -2.6                | 2.34                 | 0.32                 | 10.74               | 0.05   | 1375           |
| Trumpler_7   | 111.82   | -23.96    | 238.21  | -3.35   | 0.18     | 0.36                    | -4.1                | 4.19                 | 0.28                 | 11.2                | 0.1    | 1659           |
| NGC_2455     | 117.26   | -21.29    | 238.34  | 2.32    | 0.14     | 0.28                    | -5.55               | 3.2                  | 0.36                 | 11.2                | 0.03   | 1711           |

In addition, we collected colour excess of 2985 early-type star (OB) from the Tycho 2 catalogue [8]. The OB stars position selected correspond to the galactic longitude of the OCs and another two regions as a complement.

3. Methodology
Tracing the warp signature from young open clusters (OC) is quite challenging due to OC’s membership problems. The determination of clusters member in a specific area is necessary to find the intrinsic properties of OCs. As we know that the OC’s member shares a similar age, metallicity, reddening, and proper motions. We used this description as the first assumption of our works.

3.1. Scatter Algorithm
Scatter Algorithm describe as an algorithm which constructs density maps based on spatial distribution of the stars [9]. In this work, we would like to implement the density maps concept in open clusters proper motion area. First, we need to create a grid of the proper motion area. Then, we measure the density of each grid based on the presence of a star in the grid area and its surrounding. The main constant of this method is smoothing length ($h$), describes as the minimum distance of stars from the centre of the grid. If the stars located inside this range, it will contribute to the density of the designated grid.

\[
h = \left( \frac{2}{\sqrt{N_{\text{tot}}}} \right)^2 s
\]

\[
s = \frac{2}{N_{\text{tot}}(N_{\text{tot}}-1)} \sum_{n=1}^{N_{\text{tot}}-1} \sum_{m=n+1}^{N_{\text{tot}}} \left[ ((x_n - x_m)^2 + (y_n - y_m)^2)^{\frac{1}{2}} \right]
\]
The contribution of each star calculated by,

\[ W(r) = \frac{3(h-r)}{\pi h^4} \text{ for } r < h \]  
\[ W(r) = 0 \text{ for } r > h \]  

with \( r^2 = (x-x_n)^2 + (y-y_n)^2 \).

After we build the density map of the OC’s area, we determine the OC’s member as the stars located inside the circle with a radius of \( h \). The centre of the circle is the location with the highest density in density maps.

\textbf{Figure 1.} Left side showing the density maps of OCs in proper motion area. Right side showing the distribution of member stars in the equatorial plane.

\textbf{3.2. Zero Age Main Sequences (ZAMs) Fitting}

The selected member of OCs which share similar proper motion properties plotted in CMD and TCD diagrams. We perform the fitting by eye method with ZAMs data to derive the colour excess and distance modulus of OCs. The ZAMs for 2MASS near-infrared photometry taken from the previous works [10]. Ratio of reddening \( \frac{A_J}{A_V} = 0.276 \), \( \frac{A_H}{A_V} = 0.176 \) [11], and \( \frac{A_Ks}{A_V} = 0.118 \) [12]. We calculated that \( A_J = 0.669852 \) \( E(J-H) \) and \( E(J-H)/E(H-Ks) = 1.724 \).

\[ d = 10^{\frac{\mu_{J} + 5}{5}} \]  

The distance of OCs calculated using equation (5) and we derived the error of each components. The data must fit as shown in figure 2.
4. Result and Discussion

In this work, we derived the colour excess $E(J-H)$ and distance modulus for constructing the graph of colour excess depend on galactocentric distance for 10 OCs. The determination of both parameters is challenging because as seen in figure 1, the spatial distribution of OC’s member could not be determined as the clusters of stars directly. We need the information of its intrinsic parameter, such as proper motion, to decide the probable member of OCs. After selecting the member, we can see the OC’s main sequences in figure 2. It makes the fitting by eye procedure are done more clearly for OC’s members. The results of the OC’s parameter determination procedure summarized in table 3. The centre of proper motion constant is inconsistent with the MWSC catalogue. Meanwhile, the distances modulus, distances, and colour excess $E(J-H)$ meet a good agreement with the catalogue.

Table 2. The result of density based method and ZAMs fitting.

| Name    | pmra   | pmdec  | h     | Mod_fit | E(J-H)_fit | Distance_fit (pc) |
|---------|--------|--------|-------|---------|------------|------------------|
| NGC_2287 | -4.320 | -1.380 | 0.355 | 9.106 ± 0.058 | 0.012 ± 0.001 | 660.029 ± 88.117 |
| NGC_2437 | -3.840 | 0.420  | 0.249 | 10.756 ± 0.074 | 0.060 ± 0.003 | 1390.186 ± 236.591 |
| NGC_2383 | -1.620 | 1.920  | 0.222 | 11.378 ± 0.054 | 0.072 ± 0.004 | 1844.505 ± 229.286 |
| NGC_2384 | -1.620 | 1.920  | 0.225 | 11.989 ± 0.037 | 0.106 ± 0.006 | 2418.589 ± 205.440 |
| NGC_2421 | -3.120 | 3.120  | 0.230 | 11.667 ± 0.047 | 0.092 ± 0.008 | 2094.008 ± 228.637 |
| DBSB_10  | -1.620 | 1.560  | 0.280 | 11.933 ± 0.038 | 0.131 ± 0.005 | 2339.385 ± 208.062 |
| ASCC_32  | -3.240 | 3.480  | 0.361 | 9.411 ± 0.081 | 0.056 ± 0.005 | 749.513 ± 139.598 |
| NGC_2362 | -2.820 | 2.940  | 0.278 | 10.67 ± 0.062 | 0.076 ± 0.003 | 1334.853 ± 191.954 |
| Trumpler_7 | -2.520 | 3.360  | 0.246 | 11.311 ± 0.043 | 0.104 ± 0.006 | 1771.046 ± 175.684 |
| NGC_2455 | -2.760 | 2.700  | 0.261 | 11.222 ± 0.044 | 0.044 ± 0.004 | 1731.770 ± 175.003 |

If we construct the OCs and OB stars position in the cartesian galactic plane, we can see the plot in figure 3. We used the position of the Sun $x_0 = 8.3\, kpc$, $y_0 = 0\, kpc$, and $z_0 = 0.016\, kpc$ [13]. The number of OCs and OB stars in $z$ negative relatively higher than $z$ positive. It could be the first indication that the galactic disk components are following the warp in the third galactic quadrant that dominated in South Galactic Pole (SGP) directions.
Figure 3. Position of OCs and OB in cartesian galactic plane. The size of blue circle represents the amount of colour excess J-H. Orange circle is the Sun position and the star represent the open clusters.

To clarify the existence of warp and flare structure, we construct the change of colour excess depend on galactocentric distance in figure 4. Generally, the colour excess of OCs and OB stars is higher below the galactic plane. The colour excess can represent the amount of dust in our galaxy that dominated below the galactic plane which indicate the presence of warp. Meanwhile, the value of E(J-H) in NGP directions that still increasing depend on the galactocentric distance which represent the structure of flare. The result of this work related to the previous study which found that the warp occurred in the third galactic quadrant [14]. For $238^\circ < l < 239^\circ$, this region has a higher amount of E(J-H) and could associate with the Canis Major over density in area of $l \approx 240^\circ$. Furthermore, the area of distance from 8.5 – 9 kpc show that the density of OB stars is higher in all longitude directions. This can be an indication of the existence of another structure called Gloud Belt.

Figure 4. The change of colour excess depends on galactocentric distance of OCs and OB stars in 7 galactic longitude directions. The x axis is the distance of OCs and OB stars from our Sun. The y axis is the amount of colour excess E(J-H) for both components.
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