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Integrated Luminosity Distribution of Galactic Open Clusters

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Abstract. The integrated magnitudes of 221 Galactic open clusters have been used to derive the luminosity function. The completeness of the data has also been discussed. In the luminosity distribution the maximum frequency of clusters occurs near $I(M_v) = -3\overset{m}{.}5$, and some plausible reasons for a sharp cut-off at $I(M_v) = -2\overset{m}{.}0$ have been discussed. It is concluded that the paucity of the clusters fainter than $I(M_v) = -2\overset{m}{.}0$ is not purely due to selection effects. The surface density of the clusters for different magnitude intervals has been obtained using the completeness radius estimated from the log N–log d plots. A relation between $I(M_v)$ and surface density has been obtained which yields a steeper slope than that obtained by van den Bergh & Lafontaine (1984).

Key words: open clusters—integrated magnitudes—luminosity distribution

1. Introduction

In recent years young objects such as the Galactic open clusters have created much interest in deriving information on different modalities of stellar birth and evolution because the young open clusters offer an almost unique opportunity to look at the process of ongoing star formation. The luminosity function in the Galaxy, derived from the integrated parameters of the open clusters could be compared with the luminosity function derived from the integrated aperture photometry of clusters in other galaxies. Mermilliod (1980) has suggested that open clusters in the Galaxy have a luminosity function that rises steeply towards fainter magnitudes. From the luminosity distribution of open clusters based on the integrated parameters obtained by Sagar, Joshi & Sinvhal (1983), van den Bergh & Lafontaine (1984) have concluded that for brighter clusters the observed cluster frequency decreases with increasing luminosity and a sharp cut-off at $I(M_v) = -2\overset{m}{.}0$ is probably due to selection effects. However, the clusters fainter than $I(M_v) = -2\overset{m}{.}0$ are generally older clusters having ages around 10^9 yr (*cf.* Pandey *et al.* 1989). The clusters disrupt because they continuously lose stars by escape processes and thus the observed integrated luminosities of older clusters are due to the remaining low mass stars which are beyond the main sequence phase (Spassova & Baev 1985). The clusters of fainter magnitudes at large distances may not have been observed, therefore, the completeness of the available cluster data also needs to be examined. In view of the above discussions, we have derived the luminosity distribution from the integrated parameters of a larger sample of open clusters to study their formation and evolutionary history.

2. The data

Sagar, Joshi & Sinvhal (1983) and Pandey *et al.* (1989) have derived the integrated parameters of open clusters using similar methods. The integrated absolute magnitude, $I(M_v)$ values for 221 open clusters are based on the published *UBV* photometry and for which membership data based on proper motion or on photometry are available. The integrated absolute magnitude of these clusters ranges from $I(M_v)=-9^m\!.11$ (NGC 884) to $I(M_v)=1^m\!.95$ (NGC 2482). The distances and the ages of these clusters have been taken from the catalogue of Lyngå (1987).

It is necessary to ensure that the sample of open clusters is reliably complete so that the usefulness of statistical studies of the main characteristic parameters of the Galactic open clusters as a system is established and their utility for comparison with clusters in other galaxies is ascertained. The possible source of incompleteness arises from the fact that the fainter the cluster, the harder it is to detect it. Thus the probability of detection of an open cluster would depend on its absolute magnitude and distance. We have plotted the integrated absolute magnitude against the distance modulus, of the observed clusters in Fig. 1 which shows that fainter clusters at large distances have not been discovered. However, the data seems to be complete up to $(m-M)=11^m\!.5$. It is also interesting to note that clusters brighter than $I(M_v)<-6^m\!.0$ have not been observed within a distance of 1.0 kpc. It is found that nearly 92 per cent of the clusters brighter than $I(M_v)=-5^m\!.0$ are young clusters having ages less than 10^8 yr and all clusters fainter than $I(M_v)=-2^m\!.0$ are older.

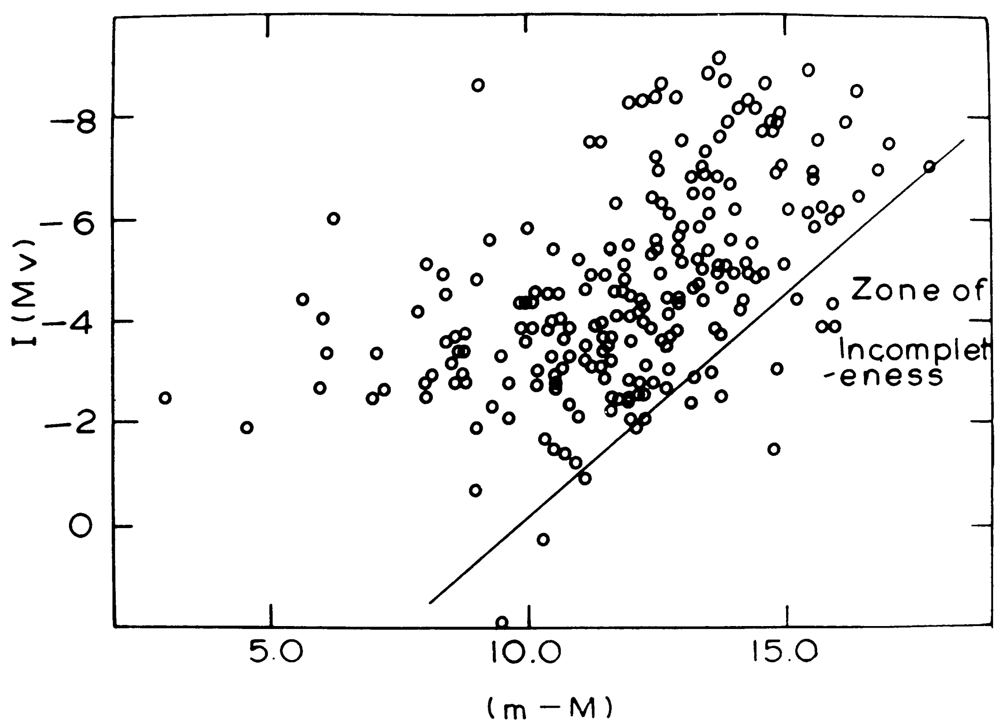

Figure 1. The plots of integrated magnitudes, $I(M_v)$ against distance modulus $(m-M)$ of the clusters. The zone of incompleteness is shown beyond the solid line.

3. Cluster luminosity distribution

The integrated absolute magnitude distribution of the 221 open clusters is shown in Fig. 2. The distribution of clusters within 2.0 kpc of the Sun is also shown in the figure. The observed cluster frequency decreases with increasing luminosity with a maximum frequency near $I(M_v) = -3^m.5$, and a sharp cut-off at $I(M_v) = -2^m.0$ for both the samples. Van den Bergh & Lafontaine (1984) have also derived the luminosity function from the integrated magnitudes of 142 open clusters using the data of Sagar *et al.* (1983) and concluded that the sharp cut-off at $I(M_v) = -2^m.0$ is probably due to selection effects.

The observed distribution of open clusters fainter than $I(M_v) = -2^m.0$ may not be entirely due to selection effects. There may be some physical causes of the cut-off at $I(M_v) = -2^m.0$. It is important to consider the limiting number of stars to form a cluster because if a multiple-star system with five components is also defined as a cluster then one can expect that the number of clusters fainter than $I(M_v) = -2^m.0$ could be large. Although the star formation efficiency is maximum in the low mass molecular clouds ($M \sim 100\, M_\odot$) (Pandey, Paliwal & Mahra 1990) it is also true that low mass clouds can generate poor clusters only. The lifetime of star clusters depends on richness of the clusters (Pandey & Mahra 1986; Janes & Adler 1982). Poor clusters have short lifetime as compared to the rich ones and very poor clusters (say 5 to 10 stars only) will be disrupted on a very small time scale and consequently it seems that these will not contribute in any way to the statistics at the fainter limits.

If one ascribes a minimum number of stars to any cluster, the $I(M_v)$ cannot be fainter than a given value, which depends on the number of giants among the cluster members. If the cluster has no giants, then its integrated magnitude will depend on the number of mainsequence stars, their mass range and ages, since the absolute magnitude at the turn-off depends on the age. The $I(M_v)$ and number of stars in the

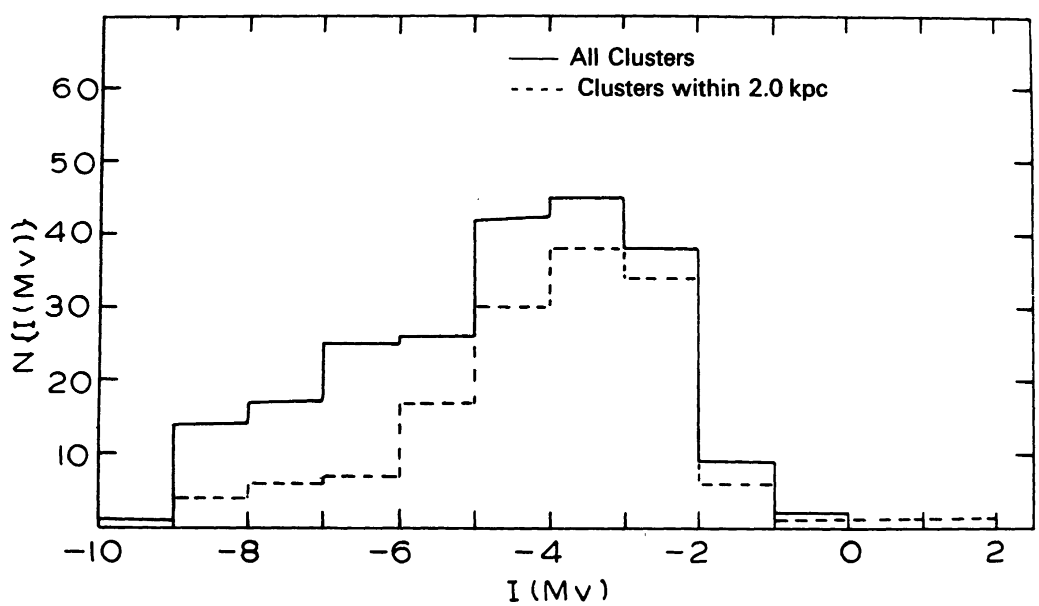

Figure 2. The luminosity distribution of all 221 clusters. The histograms shown by dotted line represent the distribution for clusters within 2.0 kpc of the Sun.

cluster having main-sequence stars only, have been plotted in Fig. 3 which does not show any dependence. Red giants may not be present in poor clusters younger than the Hyades due to the statistical uncertainties of small numbers. Thus these clusters are among the fainter ones in integrated magnitudes. But the clusters older than the Hyades (log $t \sim 9.0$) have generally giants which have a strong influence on the integrated magnitude and the contribution of the mainsequence stars diminishes.

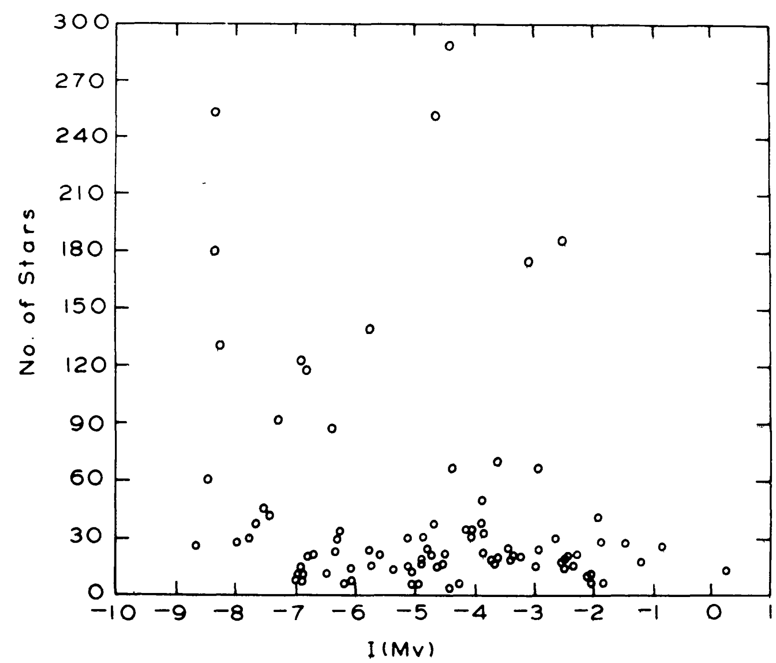

Figure 3. The integrated magnitudes against the number of stars in the clusters having mainsequence stars only.

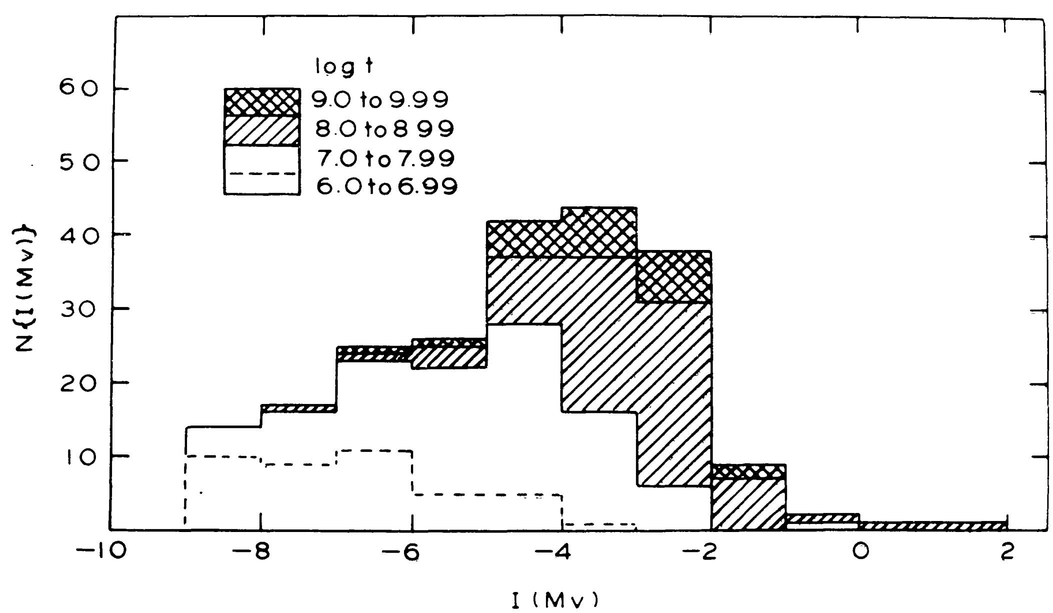

Figure 4. The histograms of the luminosity distribution for the clusters of different age groups.

The luminosity distribution for different age groups has been plotted in Fig. 4. All the young clusters and the majority of older clusters have magnitudes brighter than $I(M_v) = -2^m.0$.

The clusters fainter than $I(M_v) = -2^m.0$ have longer ages, generally of the order of 10^9 yr (*cf.* Pandey *et al.* 1989). At this stage the disruption of the clusters is expected to be prompt and only those clusters having higher masses would survive (Pandey, Bhatt & Mahra 1987), which are probably brighter than $I(M_v) = -2^m.0$, simply because of the existence of a number of red giants in these clusters.

4. Surface density

The distance and the number of open clusters observed are nearly correlated, however, the observations of distant clusters are highly selective towards more luminous objects. We have estimated the completeness of the data for different magnitude intervals by considering $\log N \propto \log d$ (where N is cumulative number of clusters, d is the distance). Fig. 5 shows the plots of log N against log d for different magnitude intervals and the solid line represents the line of completeness. A cut-off radius of the data has been estimated and values are tabulated in Table 1 for each magnitude interval.

The surface density of open clusters in the galactic plane, σ, has been obtained using the relation

$$\sigma = N/\pi d^2, \tag{1}$$

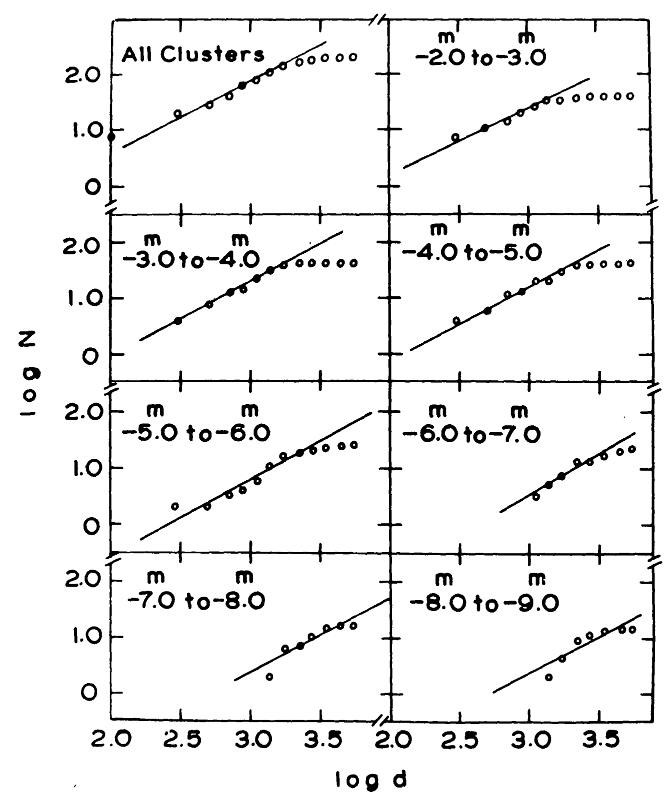

Figure 5. The log N against log d plots for different integrated magnitude intervals. The solid line shows the line of completeness fit.

Table 1. Completeness radius and surface density for the different magnitude intervals.

$I(M_v)$ interval (mag)		Total number of clusters	Clusters within 2.0 kpc	Completeness radius, d (kpc)	Number of clusters within d (N)	Surface density, σ (cluster/kpc^2)
2	1	1	1	—	—	—
1	0	1	1	—	—	—
0	−1	2	1	—	—	—
−1	−2	8	6	—	—	—
−2	−3	38	34	1.6	31	3.85
−3	−4	45	38	2.0	38	3.02
−4	−5	42	30	2.0	30	2.39
−5	−6	26	17	2.0	17	1.35
−6	−7	25	7	4.0	18	0.36
−7	−8	17	6	5.0	15	0.19
−8	−9	14	4	5.0	14	0.18
−9	−10	1	0	—	—	—

where, N is number of open clusters observed within the completeness radius d, for each magnitude interval. The cluster population N and the surface density have also been tabulated in Table 1 for different magnitude intervals. A relation between the cluster surface density, σ, and $I(M_v)$ for the clusters brighter than $I(M_v) = -2^m\!.0$ is represented by the equation

$$\log \sigma(I(M_v)) = (0.26 \pm 0.03) I(M_v) + (1.27 \pm 0.15). \quad (2)$$

This equation represents the estimated surface density and integrated magnitude relation obtained from our sample. Extrapolation of this equation to higher luminosities, and assuming that the Galactic disc has an area of 500 kpc^2, yields approximately 10 clusters with $I(M_v) = -11^m\!.0$ and about 5 with $I(M_v) = -9^m\!.5$ within 5.0 kpc of the Sun, whereas, the earlier work of van den Bergh & Lafontaine (1984) yields a much higher value, i.e. 10^2 clusters and about 35 clusters, respectively. A comparison of the present work with that of van den Bergh & Lafontaine (1984), reveals that the sample used in the present work towards the fainter end of the luminosity distribution is significantly better. Thus it seems that the present approach to the luminosity distribution yields a better result. It is important to note that the slope of Equation (2) is steeper than the slope obtained by van den Bergh & Lafontaine (1984). Finally it seems that the observed luminosity function differs from the luminosity function based on theoretical models which predict a steeper slope.

5. Conclusions

From the above discussions the following conclusions are drawn:

1) The completeness of the data sample has been discussed and it is concluded that the fainter clusters at large distances are not observed. However, the data seems to be complete up to $(m - M) = 11^m\!.5$ which corresponds to a distance of 2.0 kpc which also

comes from the completeness fit of the log N v/s log d plot for all the clusters. In the data sample nearly 92 per cent of the clusters brighter than $I(M_v) = -5\overset{m}{.}0$ are young clusters having ages less than 10^8 yr.

2) The integrated luminosity distribution of 221 open clusters and the distribution of open clusters within 2.0 kpc of the Sun are almost identical. These distributions show the scarcity of the number of clusters fainter than $I(M_v) = -2\overset{m}{.}0$ which may be due to a higher disruption rate at older ages and possibility of higher number of rich massive older clusters having generally giants. Consequently these will have strong influence on the integrated magnitude contributing towards the brighter side of the luminosity distribution.

3) The surface density of the open clusters within different integrated magnitude intervals has been obtained using the completeness radius estimated from the log N v/s log d plots for different magnitude intervals. The surface density for the clusters brighter than $-2\overset{m}{.}0$ may be represented as

$$\log \sigma(I(M_v)) = 0.26\, I(M_v) + 1.27.$$

This equation has a steeper slope than the slope obtained by van den Bergh & Lafontaine (1984). However, an even steeper slope is expected on the basis of the theoretical models.

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