AGE DISTRIBUTION OF OPEN CLUSTERS AS A FUNCTION OF THEIR LINEAR DIAMETER AND AGE-DEPENDENCE OF CLUSTER MASSES

A. K. PANDEY, B. C. BHATT, and H. S. MAHRA
Uttar Pradesh State Observatory, Manora Peak, Naini Tal, India

(Received 21 August, 1986)

Abstract. From the well-observed data of star clusters, the age distribution of galactic clusters is obtianed as a function of their linear diameter and it is concluded that the observed age distribution of clusters for different linear diameter intervals within 1500 pc, is not seriously affected by the selection effects. If we assume that the rate of formation of clusters is constant, the lifetimes $\tau_{1/2}$ of the clusters for different linear diameter intervals have been obtained and it is found that the clusters with a linear diameter in the range 0–1.9 pc have longer lifetimes than the clusters having linear diameters larger than 2.0 pc.

Total masses of 57 clusters have been obtained using the catalogues of Piskunov (1983) and Myakutin *et al.* (1984). A study of age-dependence of cluster masses, based on the total masses of the clusters obtained in the present study and the cluster masses given by Bruch and Sanders (1983) and Lynga (1983b), shows that there is a decreasing trend in the total mass with the age, however, there is an increasing trend after the age of about 10^8 yr. It is also concluded that the initial rate of formation of rich clusters was relatively higher than the present rate of formation.

1. Introduction

Open clusters represent a large range in age from very young to the age of the Galaxy. Therefore, the study of these objects plays an important role in the studies of our Galaxy. The most important point in favour of the study of galactic clusters is that almost all relevant quantities are more accurately measurable for clusters as compared to single stars. Since the parameters such as age, total mass, linear diameter are known for a significant number of galactic clusters, therefore, it is possible to have statistical study of open clusters based on these parameters.

The analysis of the observed galactic clusters indicates that the number of clusters decreases with the age (Wielen, 1971a; Janes and Adler, 1982; Lynga, 1982a; Pandey and Mahra, 1986), which has been attributed to a process of dynamical dissolution of clusters. Since all the earlier studies related to the lifetimes of clusters based on the observed parameters, were carried out without considering the linear diameter of the galactic clusters, therefore, it was considered worthwhile to carry out a study of age distribution of galactic clusters as a function of their linear diameters. Wielen (1971b, 1975, 1985) obtained the lifetime of open clusters theoretically and it has been shown that a star cluster has longest lifetime for a median radius of about 0.5 pc.

A number of correlation studies among the various parameters have been made by Lynga (1982b, 1983a, 1985). Lynga (1985) has discussed that, if only bound clusters are considered, there is a quite clear correlation between the ages and masses fo clusters and the younger clusters have higher masses. Furthermore, Lynga (1983a) has reported

Astrophysics and Space Science **129** (1987) 293–302.

that there is lack of trend in the age-dependence of cluster masses and some possible reasons for this have been discussed by him. However, we feel that the inaccuracy in the determination of cluster masses by converting the cluster masses given by Buscombe to Bruch and Sanders's system, using the mean linear relation between the two determinations (Lynga, 1983a), may be the additional possible reason for the lack of trend in the age-dependence of cluster masses. Therefore, on the basis of the presently available more reliable and homogeneous data of cluster masses and ages, we have investigated the correlation between these parameters of the clusters.

2. Observational Data and Age Statistics

Lynga (1983b) has prepared a computer-based catalogue of open clusters with their distances, ages, linear diameters and other relevant information. Our present study is based on the available data for the clusters given in this catalogue because it contains the most consistent material presently available for the galactic clusters.

The observed age distributions of clusters for Trumpler's different richness classes have been obtained by Pandey and Mahra (1986) and it is found that the rich clusters have longer lifetimes than the poor clusters. However, Wielen (1971b) has shown that the evaporation time mainly depends on three parameters of a cluster; (i) its median radius R, (ii) its total mass $\mathfrak{M}$, and (iii) its total numbers of stars N. Since $\mathfrak{M}$ and N for galactic clusters are strongly correlated (van Altena, 1966), therefore, the age distribution of clusters shall depend both upon the number of stars N in the cluster and the median radius R. In light of these findings it seems necessary to study the age distribution of clusters as a function of their linear diameters for different richness classes of the clusters. However, sufficient observed data is not available to divide the clusters according to different richness classes for such studies. The presently available observed cluster data have been used for a statistical study of the age distribution of clusters having $N \leq 100$, for various linear diameter intervals. The observed data for rich clusters – i.e., clusters having $N > 100$ – is not sufficient to make any significant statistical study of age distribution of these clusters for various linear diameter intervals.

In Table I, we have given the age distributions of clusters having stars $N \leq 100$ for different linear diameter intervals and it is found that the age distribution of the galactic clusters for different linear diameter intervals in the distance ranges $0 < r \leq 1000$ pc and $1000 < r \leq 1500$ pc do not differ systematically. This statement was also checked with the help of Kolmogorov–Smirnov test which revealed an insignificant difference between the two distributions of the galactic clusters. Since the age distribution of the clusters in the distance range $r \leq 1500$ pc does not seem to be seriously affected by the selection effects, therefore, in the present study we have considered all the clusters within $r \leq 1500$ pc. However, we have omitted the clusters younger than 10^7 yr to avoid the inclusion of associations.

The resulting frequency $\nu(\tau) = \Delta n / \Delta \tau$ of clusters within $r \leq 1500$ pc as a function of age τ for various diameter intervals, has been given in Table II.

TABLE I

Age distribution of clusters within $r \leq 1500$ pc, for different linear diameter intervals

Linear diameter interval (pc)	Distance range (pc)	No. of clusters Δn in the interval of log age (τ)					
		7.0–7.59	7.6–7.99	8.0–8.39	8.4–8.79	8.8–9.19	9.2–9.59
0–1.9	0–1000	3	4	4	2	2	2
	1001–1500	5	5	5	2	1	0
	0–1500	8	9	9	4	3	2
2.0–2.9	0–1000	6	3	5	6	3	1
	1001–1500	4	7	2	1	0	0
	0–1500	10	10	7	7	3	1
3.0–3.9	0–1000	4	4	2	1	2	0
	1001–1500	3	4	3	1	1	0
	0–1500	7	8	5	2	3	0
4.0–4.9	0–1000	1	1	1	2	1	0
	1001–1500	1	1	0	0	0	0
	0–1500	2	2	1	2	1	0
5.0–5.9	0–1000	1	1	3	2	0	0
	1001–1500	0	0	1	1	0	0
	0–1500	1	1	4	3	0	0
6.0–7.9	0–1000	1	2	1	1	0	0
	1001–1500	3	0	0	1	0	0
	0–1500	4	2	1	2	0	0

TABLE II

$\nu(\tau) = \Delta n/\Delta\tau$, for clusters within $r \leq 1500$ pc

Linear diameter interval (pc)	$\nu(\tau)$ in the interval of log age (τ)					
	7.0–7.59	7.6–7.99	8.0–8.39	8.4–8.79	8.8–9.19	9.2–9.59
0.0–1.9	26.7	15.0	6.0	1.1	0.32	0.08
2.0–2.9	33.3	16.7	4.7	1.8	0.32	0.04
3.0–3.9	23.3	13.3	3.3	0.5	0.32	–
4.0–4.9	6.7	3.3	0.7	0.5	0.11	–
5.0–5.9	3.3	1.7	2.7	0.8	–	–
6.0–7.9	13.3	3.3	0.7	0.5	–	–

3. Total Lifetimes

The total lifetime of a cluster is the period between its formation and its total disintegration. The age distributions of galactic clusters for various linear diameter intervals have been statistically deduced from the observed frequency $\nu(\tau)$ of the clusters. The percentage of clusters, $P(\tau)$, which will reach the age τ has been obtained using the relation (Wielen, 1971a)

$$\nu(\tau) = \nu(0)P(\tau),$$

where $\nu(0)$ is the initial frequency of the clusters. The relations between $P(\tau)$ and age τ for different linear diameter intervals have been plotted in Figure 1.

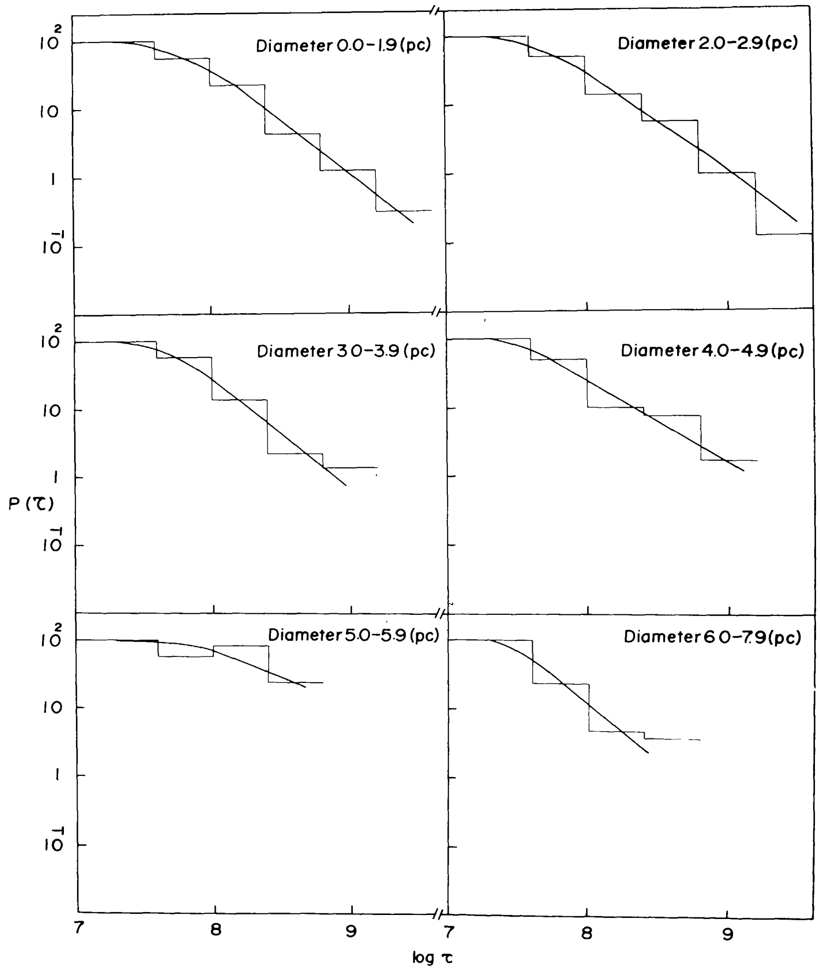

Fig. 1. The relation between $P(\tau)$ and age (τ) for different linear diameter intervals.

TABLE III

Lifetime as a function of linear diameter

Linear diameter intervals (pc)	$\log \tau_{1/2}$
0.0–1.9	7.85
2.0–2.9	7.80
3.0–3.9	7.80
4.0–4.9	7.75
5.0–5.9	8.20
6.0–7.9	7.60

The lifetime $\tau_{1/2}$ in which 50% of the clusters in the sample shall be disintegrated, have been obtained for different linear diameter intervals and these are given in Table III. The lifetime $\tau_{1/2}$ for the linear diameter interval 5.0–5.9 pc comes out to be exceptionally high probably due to insufficient cluster data for this diameter interval. The relation between lifetime $\tau_{1/2}$ and linear diameter of the clusters is shown in Figure 2 and we conclude that the lifetimes of clusters decreases systematically with their linear diameters. The clusters with a linear diameter in the range 0–1.9 pc have longer lifetimes than the clusters having a diameter larger than 2.0 pc. Our conclusions are qualitatively in agreement with the theoretical findings of Wielen (1971b, 1975, 1985).

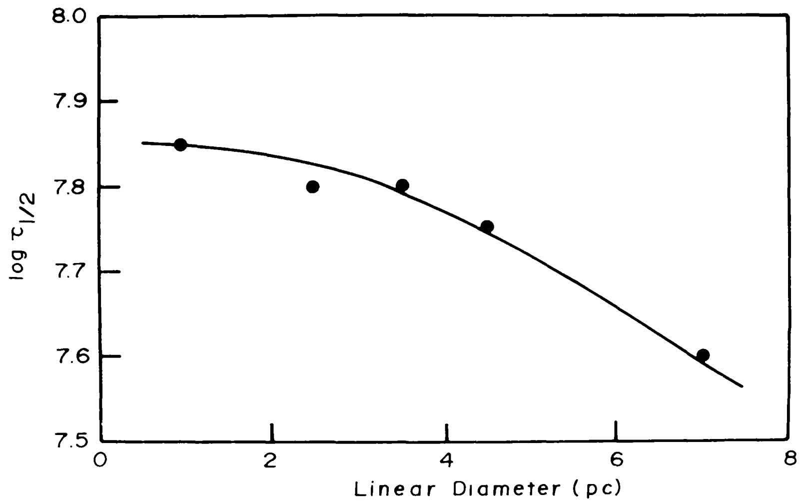

Fig. 2. The relation between lifetimes $\tau_{1/2}$ and linear diameter intervals. Lifetime $\tau_{1/2}$ for the diameter interval 5.0–5.9 is not shown in the figure (see text).

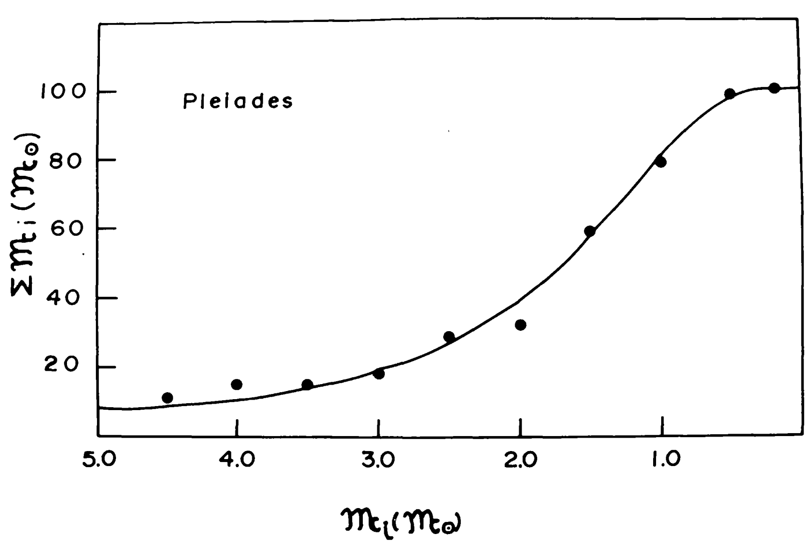

Fig. 3. Dependence of $\Sigma\, \mathfrak{M}_i$ over $\mathfrak{M}_i$ for Pleiades cluster.

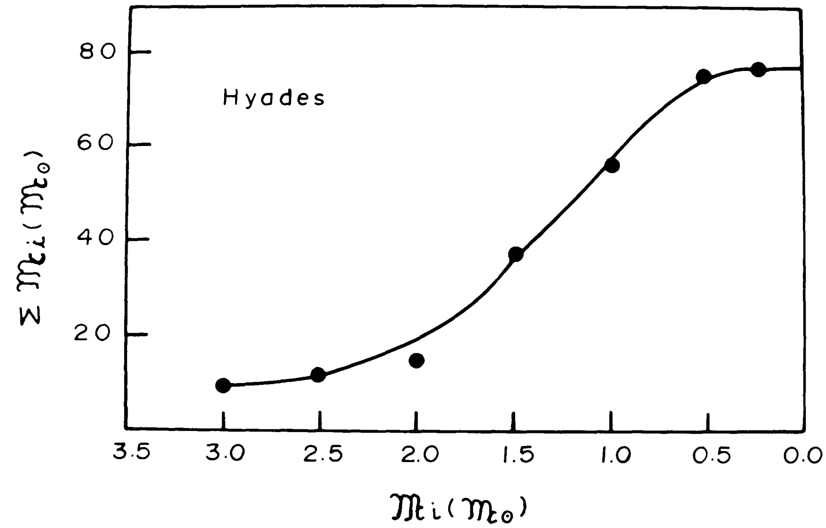

Fig. 4. Dependence of $\Sigma\,\mathfrak{M}_i$ over $\mathfrak{M}_i$ for Hyades cluster.

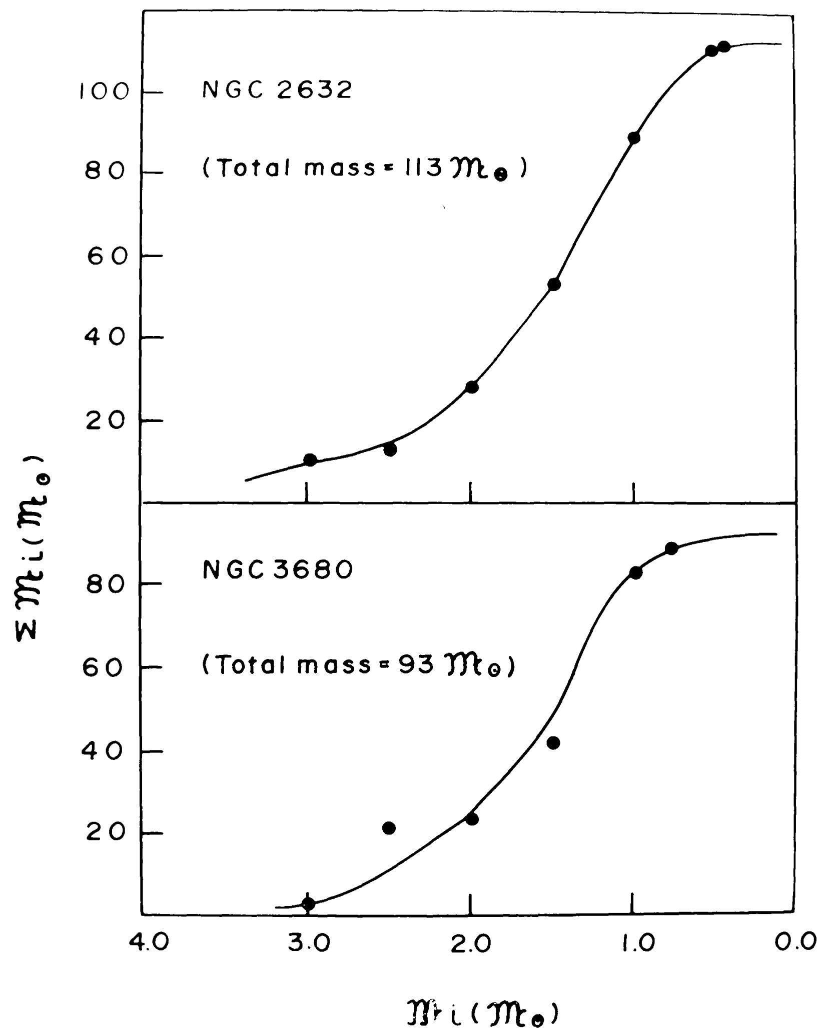

Fig. 5. Examples of determination of total cluster masses.

4. Determination of Total Mass

We have taken the total masses of clusters given by Bruch and Sanders (1983) and Lynga (1983b). We have also obtained the total masses of 57 open clusters using the catalogues of Piskunov (1983) and Myakutin *et al.* (1984). The ages of clusters were taken from the catalogue of Lynga (1983b). The catalogues of Piskunov (1983) and Myakutin *et al.* (1984) provide the masses of individual star members in each cluster.

TABLE IV

Total cluster masses obtained from the catalogue of Piskunov (1983)

Cluster	Log mass ($\mathfrak{M}_\odot$)	Cluster	Log mass ($\mathfrak{M}_\odot$)	Cluster	Log mass ($\mathfrak{M}_\odot$)
NGC 129	2.27	NGC 5617	2.59	NGC 7788	1.95
NGC 188	2.32	NGC 6025	2.19	NGC 7790	2.05
NGC 1039	1.99	NGC 6134	2.31	IC 1369	2.14
NGC 1912	2.31	NGC 6208	2.26	IC 1805	2.81
NGC 1960	2.18	NGC 6613	2.05	IC 2391	1.86
NGC 2099	2.69	NGC 6633	2.17	IC 2581	2.70
NGC 2264	2.30	NGC 6705	2.60	IC 2602	1.99
NGC 2516	2.23	NGC 6716	1.60	IC 4651	2.17
NGC 2527	1.71	NGC 6811	2.48	IC 4665	1.86
NGC 2546	2.41	NGC 6866	2.74	Pleiades	2.00
NGC 2567	1.98	NGC 6939	2.53	Hyades	1.89
NGC 2571	2.32	NGC 7062	1.97	Cr 185	1.70
NGC 2632	2.05	NGC 7092	1.63	Hogg 17	1.86
NGC 2682	2.67	NGC 7209	1.80	Pismis-1	1.65
NGC 3680	1.97	NGC 7243	1.95		
NGC 5460	2.05	NGC 7380	2.68		

TABLE V

Total cluster masses obtained from the catalogue of Myakutin *et al.* (1984)

Cluster	Log mass ($\mathfrak{M}_\odot$)
NGC 654	2.47
NGC 1778	2.08
NGC 2169	1.90
NGC 2264	2.45
NGC 2539	2.44
NGC 6530	2.67
NGC 6611	2.72
NGC 6823	2.73
NGC 6913	2.58
IC 1805	2.63
TR-1	2.04

The total mass of a cluster can be determined by summing up the individual masses of all the member stars. Therefore, the total mass of a cluster can be expressed as

$$\mathfrak{M} = \sum_i \mathfrak{M}_i ,$$

where $\mathfrak{M}_i$ is the mass of the ith member of the cluster.

It is not possible to observe the faint members of the cluster due to the presence of stellar background and the limiting magnitude in the photometry. However, low-mass completeness is not considered to be a significant factor in the total mass determination of open clusters, because the number of low-mass stars would have to be extremely high for a significant change in the determination of cluster masses (Bruch and Sanders, 1983).

In order to estimate the contribution of the faint members to the total mass of a cluster we have plotted the dependence of $\Sigma\,\mathfrak{M}_i$ over $\mathfrak{M}_i$ in Figures 3 and 4 for Pleiades and Hyades clusters, respectively, and it is concluded that the mass $\Sigma\,\mathfrak{M}_i$ of the cluster increases with the inclusion of lower mass member stars and does not change significantly with the inclusion of the cluster members of lowest masses. The total masses of the clusters, for which the asymptotic constancy could be extrapolated have been obtained by extrapolation. Examples of determination of the total mass using this method, are shown in Figure 5. The clusters for which it was not possible to extrapolate the asymptotic constancy, have not been included for the total mass determination. The total masses of the clusters thus obtained, using the catalogue of Piskunov (1983) and Myakutin *et al.* (1984), are given in Tables IV and V, respectively.

A comparison of the total masses of the clusters obtained by us using the catalogues

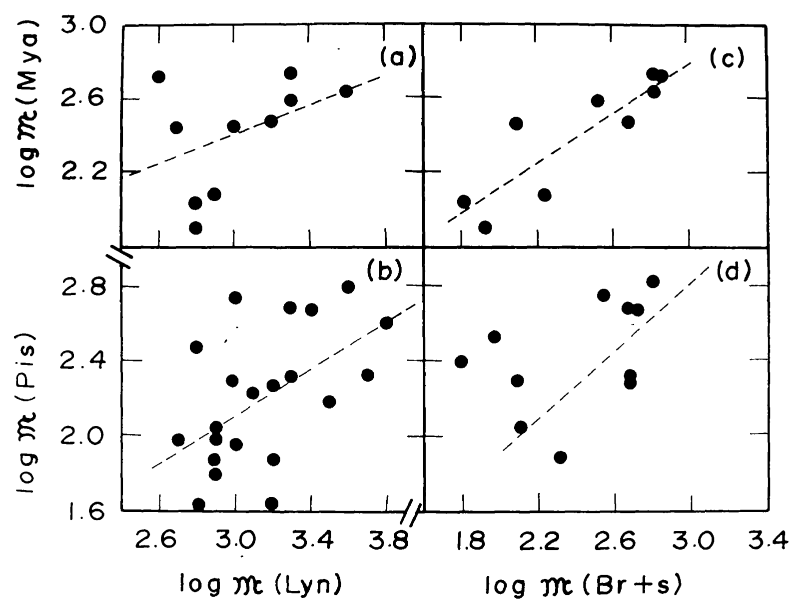

Fig. 6. Comparison of total masses of the clusters obtained in the present study using the catalogues of Myakutin *et al.* (1984) (Mya) and Piskunov (1983) (Pis), with the total masses given by Lynga (1983) (Lyn), (a) and (b), and Bruch and Sanders (1983) (Br + S) (c) and (d).

of Piskunov (1983) and Myakutin *et al.* (1984), with the total masses given by Bruch and Sanders (1983) and Lynga (1983b) is shown in Figure 6 and it is apparent that the total masses of the same clusters obtained by different authors differ significantly and non-systematically. Therefore, in Figure 7 we have plotted the age-dependence of cluster

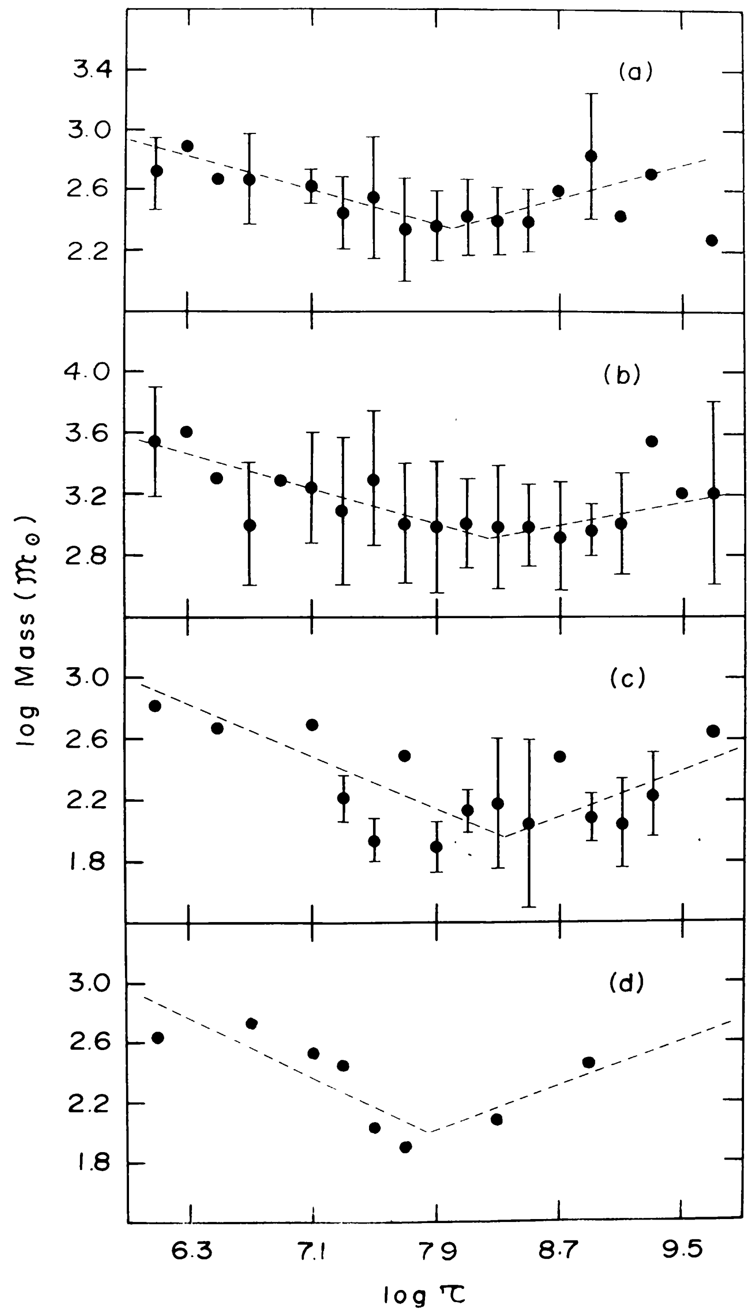

Fig. 7. Age-dependence of cluster masses. The cluster masses taken from Bruch and Sanders (1983) (a), Lynga (1983b) (b), Piskunov (1983) (c), and Myakutin *et al.* (d). The trend of the age-dependence of cluster masses is shown by dashed lines. The error bars shown in the figure correspond to $\pm\sigma$ in the determination of mean total masses for different age intervals.

masses based on total masses of clusters obtianed by different authors, separately. In this figure we have plotted the mean total masses of the clusters for different age intervals against log age. The mean total masses have been plotted to reduce the scatter in the diagram and to show the mean trend in the age-dependence of the cluster masses.

From Figure 7 it is concluded that the younger clusters have higher masses and there is a decreasing trend in the total masses of the clusters with age, however, there is an increasing trend after the age of about 10^8 yr. The above-mentioned trend in age-dependence of cluster masses is almost same in all the four plots shown in Figure 7. The observed trend in the age-dependence of cluster masses can be explained on the basis that the younger clusters have relatively larger number of stars of heavier masses and, therefore, the total mass of the younger clusters is relatively higher than the older clusters. The increasing trend with age after $\sim 10^8$ yr may be due to the fact that the rich clusters have longer lives, and the relative frequency of rich clusters increases with age after 10^8 yr. Consequently the total masses of the clusters having ages greater than 10^8 yr show an increasing trend after an age of about 10^8 yr. It is also concluded that the initial rate of formation of rich clusters was relatively higher than the present rate of formation. From Figure 7 we have also estimated that the total mass of the clusters is minimum at an age of about 10^8 yr which approximately corresponds to the lifetime $\tau_{1/2}$ obtained for clusters of all richness classes (Pandey and Mahra, 1986). It is also estimated that the total masses of the clusters decrease by a factor of ~ 5 within a time interval of about 10^8 yr.

Acknowledgements

The authors are thankful to Drs Ram Sagar and A. E. Piskunov for useful discussions.

References

Bruch, A. and Sanders, W. L.: 1983, *Astron. Astrophys.* **121**, 237.
Janes, K. and Adler, D.: 1982, *Astrophys. J. Suppl.* **49**, 425.
Lynga, G.: 1982a, *Report from the Observatory of Lund*, No. 18, p. 68.
Lynga, G.: 1982b, *Astron. Astrophys.* **109**, 213.
Lynga, G.: 1983a, in J. Ruprecht and J. Palouš (eds.), 'Star Clusters and Associations and Their Relation to the Evolution of the Galaxy', *Publ. Astron. Inst. Czech. Acad. Sci.*, No. 56, p. 292.
Lynga, G.: 1983b, *Catalogue of Open Cluster Data* (3rd ed.), Stellar Data Centre Observatoire de Strasbourg, France.
Lynga, G.: 1985, in H. V. Woerden, R. J. Allen, and W. B. Burton (eds.), 'The Milky Way Galaxy', *IAU Symp.* **106**, 133.
Myakutin, V. S., Sagar, Ram, and Joshi, U. C.: 1984, *Catalogue of Masses and Ages of Stars in Twelve Open Clusters*, Stellar Data Centre, Observatoire de Strasbourg, France.
Pandey, A. K. and Mahra, H. S.: 1986, *Astrophys. Space Sci.* **126**, 167.
Piskunov, A. E.: 1983, *Catalogue of Masses and Ages of Stars in 68 Open Clusters*, Stellar Data Centre, Observatoire de Strasbourg, France.
van Altena, W. F.: 1966, *Astron. J.* **71**, 482.
Wielen, R.: 1971a, *Astron. Astrophys.* **13**, 309.
Wielen, R.: 1971b, *Astrophys. Space Sci.* **13**, 300.
Wielen, R.: 1975, in A. Hayli (ed.), 'Dynamics of Stellar Systems', *IAU Symp.* **69**, 119.
Wielen, R.: 1985, in J. Goodman and P. Hut (eds.), 'Dynamics of Star Clusters', *IAU Symp.* **113**, 449.