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Research Note

Galactic Distribution of the Oldest Open Clusters

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Summary. The oldest known open clusters are found to be strongly concentrated in the outer part of the galactic disk. It is suggested that the relatively high survival rate of clusters in the outer disk might possibly be due to the fact that such objects suffer relatively few disruptive encounters with giant molecular clouds which are mainly located in the inner disk of the Galaxy.

Key words: open clusters – cluster disruption

1. Introduction

Old open clusters provide information on the dynamical evolution of star clusters and on the history of the galactic disk. In recent years a wealth of new data has become available on old clusters in the form of both theoretical evolutionary tracks and accurate colour magnitude diagrams. It therefore seemed worthwhile to collect available information on clusters of various ages to see what information they might be able to provide on the rate at which open clusters are destroyed and on factors that favour their survival.

2. Data on Nearby Clusters

A relatively complete list of clusters within 750 pc of the Sun has recently been published by Mermilliod (1980). These data, which include information on the earliest spectral type observed in each cluster, may be used to calculate the frequency with which clusters of differing ages occur in the solar neighbourhood[1]. An earlier investigation of the same problem is by Wielen (1971).

Table 1 gives the age distribution of the 63 nearby clusters listed by Mermilliod. The adopted ages were derived from the spectral type versus mass relation of Schmidt-Kaler (1965) and from the mass versus main sequence age relation

$$\tau_{ms}(\text{years}) = 8.86\ 10^9\ (\mathcal{M}/\mathcal{M}_\odot)^{-2.45} \tag{1}$$

given by Hills (1978). Also listed in Table 1 is the frequency distribution (normalized to B0–B4) that would have been expected if clusters form at a uniform rate and if all open clusters that ever existed survived to the present day. These data show that under the above assumptions less than one per cent of all clusters near the Sun survive for a period comparable to the age of the Galaxy. The results given in Table 1 strengthen and confirm earlier discussions of the age distribution of open clusters by van den Bergh (1957) and by Oort (1958). Since so few old clusters survive, the space distribution of those that do, must provide significant clues on the processes that affect the survival or destruction of open clusters.

Table 1. Observed and predicted numbers of open clusters within 750 pc

Sp	Age (10^9 yr)	N (obs)	N (pred)
O5 - O9	< 0.01	1	1.3
B0 - B4	0.01 - 0.11	13	13
B5 - B9	0.11 - 0.51	29	52
A0 - A4	0.5 - 1.3	14	104
A5 - A9	1.3 - 2.4	2	143
F0 -	> 2.4	4	~ 1000*

* For an assumed disk age of 1×10^{10} yr

3. Space Distribution of Old Clusters

A compilation of information on the 20 open clusters, for which relatively high quality colour-magnitude diagrams give ages in excess of $1.0\ 10^9$ yr, is given in Table 2. These data were determined from fits of published colour magnitude diagrams to isochrones published by Ciardullo and Demarque (1977, 1979). For several clusters with poor observational data the distances were determined by assuming $M_v = +0.7$ and $(B-V)_0 = 1.0$ for the giant branch clump. Needless to say the data in this table are subject to a number of ill-defined selection effects related to such factors as cluster distance, galactic absorption and probably even the north/south asymmetry in the terrestrial distribution of astronomers. Nevertheless the compilation of data in Table 2 exhibits some trends which are so clear-cut that they cannot be entirely due to selection effects.

Perhaps the most striking characteristic of the clusters listed in Table 2 is that they are, in the mean, located so far from the galactic plane. For the 11 oldest clusters with ages $T > 3.0\ 10^9$ yr $\langle|z|\rangle = 576$ pc. The increase of $\langle|z|\rangle$ with cluster age is dramati-

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1 In very sparse clusters such age determinations may lead to an overestimate of the cluster age because the main sequence might not be populated all the way up to the turnoff point

Table 2. The 20 oldest known open clusters

Cluster name	Age (10^9 yr)	ℓ	b	d (kpc)	z (pc)	Z*
N 6791	7.0:	70.0	11.0	4.6	872	.015:
Melotte 66	6.5	259.6	-14.3	4.0	-983	.007
N 188	6.0	122.8	22.5	1.7	635	.015
N 2420	3.8	198.1	19.7	2.3	772	.007
N 2243	3.8	230.5	3.6	4.0	250	.005
N 2141	3.8:	198.1	-5.8	4.0	-402	.007:
N 2682 (M67)	3.5	215.6	31.7	0.8	417	.015
N 2506	3.2	230.6	9.9	2.8	474	.007
N 2158	3.2	186.6	1.8	4.2	131	.007
N 2204	3.1	226.0	-16.1	4.0	-1104	.007
N 6819	3.0	74.0	8.5	2.0	295	.015
IC 4651	2.4	340.1	-7.9	0.8	-114	.015
N 3680	2.3	286.8	16.9	0.9	253	.015
N 752	2.0	137.2	-23.4	0.4	-158	.015
N 7789	2.0	115.2	-9.4	1.8	-171	.015
N 6939	1.8	95.9	12.3	1.3	268	.015
N 2360	1.5	229.8	-1.4	0.9	-22	.015
IC 166	1.5:	129.5	0.0	6.3	0	.015
N 6940	1.1	69.9	-7.2	1.0	-131	.015
N 1245	1.1	146.6	-8.9	3.3	-512	.015

* metallicity assumed for age computation

Table 3. Mean distance of clusters from the galactic plane*

Age (10^9 yr)	<|z|> (pc)	n clusters
0.01 - 0.11	63	13
0.11 - 0.51	63	29
0.5 - 1.3	70	14
1.0 - 3.0	148	9
> 3.0	576	11

* From Table 2 and Mermilliod (1980).

Table 4. Galactic longitude distribution of clusters with $T>1\ 10^9$ yr

Distance from galactic centre	All clusters	Clusters |b| > 10°
0° - 60°, 300° - 360°	1	0
60 - 120 , 240 - 300	8	5
120 - 180 , 180 - 240	11	4

Table 5. Galactic longitude distribution of the oldest clusters with $T>3\ 10^9$ yr

Distance from galactic centre	No. clusters
0° - 60°, 300° - 360°	0
60° - 120 , 240 - 300	2
120 - 180 , 180 - 240	8

cally illustrated by the data collected in Table 3. Clearly large $|z|$ implies high survival probability for galactic open clusters or longevity implies large $|z|$.

The fact that old clusters are preferentially located far from the galactic plane was first noticed by van den Bergh (1958) for the 4 old open clusters which were known at that time. This phenomenon might be due to any one of several effects. Clusters located far from the plane are relatively immune to energy pumping by close encounters with interstellar clouds (Spitzer, 1958) which leads to expansion and ultimately to cluster disruption. Wielen (1971, 1977) suggests that initial mass is the primary factor affecting longevity of a cluster, and that old clusters, as well as old field stars are found preferentially far from the galactic plane because of orbital diffusion. Larson (1979) showed that stellar velocity dispersion increases with size of the region considered, and suggests that old stars *originate* in a larger volume of space. This would again account for older clusters being found preferentially far from the galactic plane.

An additional characteristic of old open clusters, which does not seem to have been noticed before, is (see Table 2) that such objects are strongly concentrated towards the galactic anti-centre. Table 4 shows that this trend persists for clusters with $|b|>10°$ for which the distribution is not strongly affected by interstellar absorption. The data in Table 5 show that this concentration towards the anti-centre is particularly strong[2] for the oldest known clusters with $T>3.0\ 10^9$ yr. We note in passing that this preference of old open clusters for the outer part of the galactic disk contrasts with that of globular clusters (Shapley, 1918) which are concentrated towards the galactic centre. Furthermore there is reason to believe that the *formation* rate of disk clusters should also be greatest in the inner part of the Galaxy where both the density of gas and stars is higher than it is towards the anti-centre.

Unless the data in Tables 4 and 5 are affected by the well-known perversity of small number statistics it follows that some factor in the outer disk strongly favours the longevity of open clusters. The observation (Solomon and Sanders, 1979) that giant molecular clouds are mainly located interior to the Sun suggests that cluster destruction by the Spitzer (1958)[3] mechanism will be least efficient in the outermost part of the Galaxy. It follows that if this disruption mechanism is significant, most surviving old open clusters should be seen towards the anti-centre.

An additional (but probably less important) factor favouring the survival of clusters in the anti-centre direction is that clusters formed in the warped (Kerr, 1969) outer part of the galactic

2 A Kolmogorov-Smirnov goodness of fit test shows that deviations from a uniform distribution in the galactocentric distances $|l-l_0|$ are significant at the $\sim 98\%$ level

3 Large Molecular clouds have an average size of ~ 40 pc (Solomon et al., 1979) and space velocities ~ 10 km s^{-1} so that the effective time $T_{\rm pass}$ during which a cluster passes such a cloud is $\sim 4\ 10^6$ yr. Old clusters have $\mathscr{M}_c \sim 10^3\ \mathscr{M}_\odot$, $V_{\rm rms} \sim 1$ km s^{-1} and core diameters ~ 5 pc so that the crossing time $T_{\rm cr} \sim 5\ 10^6$ yr. It follows that $T_{\rm pass} \sim T_{\rm cr}$, i.e. the impulsive approximation used by Spitzer remains marginally valid. From the calculations by Spitzer (1958) it is seen that the rate at which clusters gain energy by encounters with interstellar clouds is greater if the interstellar medium consists of a few massive clouds than it is if it consists of many low mass clouds. For mean cloud densities $\varrho \alpha \mathscr{M}^0$, $\mathscr{M}^{1/2}$, and $\mathscr{M}$ respectively it is found that the rate of energy gain $dU/dt \alpha \mathscr{M}^{1/3}$, $\mathscr{M}^{2/3}$, and $\mathscr{M}$. It is concluded that giant molecular clouds, which have large values of $\mathscr{M}$, are probably the most effective agents for destroying old open clusters

hydrogen disk might spend most of their lives at relatively large $|z|$ distances. This will reduce the frequency with which such clusters encounter massive interstellar clouds near the galactic plane. Finally, clusters formed with a fixed velocity dispersion will reach higher values of $|z|$ in the outer part of the Galaxy than they will near the Sun. For a galactic mass model with $V_{\odot}=250$ km s^{-1} and $\tilde{\omega}_{\odot}=9$ kpc derived by Clutton-Brock et al. (1977) a cluster with $\dot{z}=50$ km s^{-1} will reach $z=0.85$ kpc, 1.4 kpc, and 2.6 kpc at values of $\tilde{\omega}=9$, 11, and 13 kpc respectively (Innanen, 1979).

In summary it is concluded that giant molecular clouds may have decimated the population of old open clusters in the central part of the Galaxy. Furthermore survival of clusters in the outer disk might have been assisted by formation at relatively large $|z|$ values and by the shallowness of the outer disk potential well. On the other hand if the total lifetime of a cluster is mainly dependent on its initial mass, as Wielen (1971) suggests, it is more difficult to understand why old clusters would be found preferentially in the outer parts of the galactic disk.

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