6. THE TOTAL BRIGHTNESS OF GALACTIC CLUSTERS

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For many generations astronomers have been fascinated by open clusters of stars, of which many are found close to the central plane of the Milky Way. Only in comparatively recent years, however, has it become possible to derive reasonably consistent distances for these stellar systems. The difficulty was that until techniques of photoelectric photometry in at least three colours were developed, there were no reliable estimates of the amount of interstellar absorption and reddening.

All extensive catalogues of clusters which were compiled prior to 1960 give rather unsatisfactory estimates of the distances and linear diameters of clusters. Most of these data were based on the assumption that all clusters have either the same linear diameter or the same luminosity function. From fitting the main sequence (and possibly also the giant branch) of the diagram of intrinsic colour and correct apparent magnitude for the stars in a cluster to the standard graph of colour and absolute magnitude for nearby stars with accurately determined parallaxes, Johnson and others have derived photometric distance moduli for more than 150 clusters. These are summarized in *Mount Stromlo Mimeogram* No. 6, where general references are also quoted. Becker (this volume, paper 3) indicates how this procedure can be made more exact with two colour-indices.

After the frequency distributions of stars with different intrinsic brightness were found to be different in typical clusters, Sandage and others showed that the clusters containing supergiants and hot blue stars are younger than those dominated by stars of the giant branch.

For some clusters containing stars brighter than the eighth magnitude, luminosity classifications of a few stars have been made from slit spectrograms. These data aid the analyst of photometric data to assign intrinsic colours, especially for giant and supergiant stars, but as yet the calibration of absolute magnitudes for supergiants is not completely consistent. Since it is difficult in practice to estimate the degree of evolution of hot stars above the main sequence, spectroscopic distance moduli for the brightest individual stars may give an underestimate of the distance for the cluster.

This paper will examine how one can estimate the intrinsic brightness of a cluster, mainly with photometric observations, and thus obtain its distance. The estimates of integrated apparent brightness, expressed on the scale of photographic magnitude by Lundmark and Collinder about 1930, were converted to absolute photographic magnitude for all clusters whose distance and interstellar reddening have been determined from photoelectric measures in three colours.

It would have been preferable to use integrated photoelectric magnitudes, but these are available for very few clusters, mainly in extragalactic systems such as the Magellanic Clouds and Messier 31. In the later section the significance of integrated colours, which have been measured for a few clusters with wide-field photometers, will be discussed.

The main characteristics of galactic clusters were examined by grouping their integrated absolute magnitudes in steps of $\Delta M = 1\cdot 5$, i.e. intervals of a factor 4 in total brightness from one group to the next. Except for the very brightest clusters, of which there are only a few representatives, the average absolute magnitude (M_B) for the brightest star in each cluster is very well correlated with the integrated
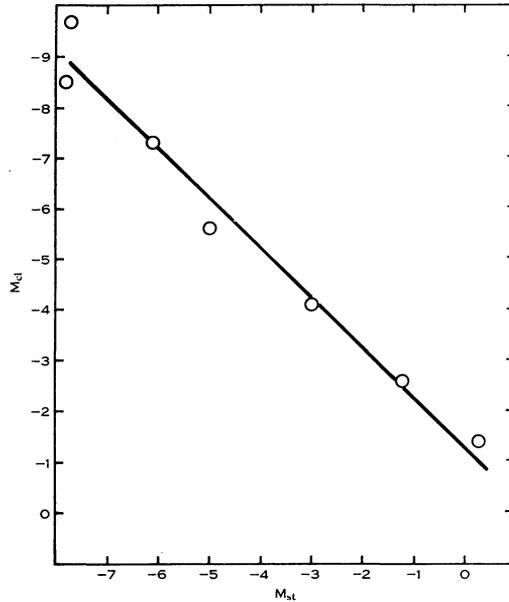
Fig. 1.—Mean relation between total brightness of cluster (ordinate) and absolute magnitude of brightest star.

TABLE 1

AVERAGED DATA FOR GROUPS OF CLUSTERS

$\bar{M}_{cl}$	$\bar{r} \pm$p.e. (n) (kpc)			$\bar{M}_{st} \pm$ p.e. (n)			$\bar{d} \pm$p.e. (pc)		$\log \bar{d}$
$-9\cdot7$	2·2	0·07	(4)	$-7\cdot7$	0·07	(3)	20	3	1·20
$-8\cdot5$	2·1	0·10	(10)	$-7\cdot8$	0·10	(9)	10	1·4	0·99
$-7\cdot3$	2·04	0·12	(21)	$-6\cdot1$	0·04	(18)	9	0·9	0·95
$-5\cdot6$	1·62	0·10	(34)	$-5\cdot0$	0·08	(26)	6·2	0·4	0·79
$-4\cdot1$	1·20	0·04	(48)	$-3\cdot0$	0·13	(24)	5·4	0·14	0·73
$-2\cdot6$	0·89	0·08	(27)	$-1\cdot2$	0·19	(15)	3·8	0·22	0·58
$-1\cdot4$	0·8	0·10	(13)	$+0\cdot3$	0·17	(6)	3·0	0·3	0·48

photographic absolute magnitude. The linear coefficient is $0\cdot755 \pm 0\cdot042$ (s.e.). In most clusters a single star, or else a small group of stars equally bright, contributes the majority of the light. Figure 1 and Table 1 indicate the mean relation.

Another significant correlation is found — that the average linear diameter declines monotonically with the total brightness for each group of clusters. The

equation of the linear relation in Figure 2 is $\log d = 0\cdot38 - 0\cdot080M$. However, a definite effect of selection is seen through the course of the average distances. For the most luminous clusters, the observational data may be nearly complete
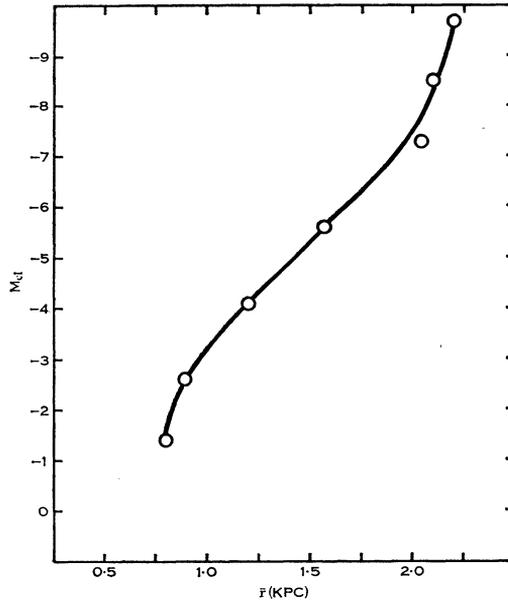
Fig. 2.—Observed relation between brightness of cluster and average distance.
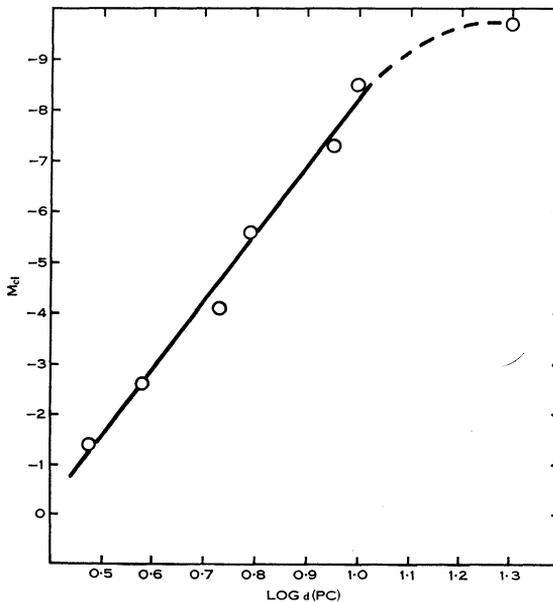
Fig. 3.—Mean linear diameters of clusters (abscissa), grouped according to total brightness.

within a sphere of radius 3 kpc around the Sun, but less luminous clusters have only been discovered and studied within about half that distance. (See Fig. 3.) No adjustment for background light has been attempted in this discussion.

It may be of some interest to note that the majority of very luminous clusters associated with emission nebulosity is found in the southern sky. On the other hand, information on the least luminous classes of cluster is as yet confined entirely to northern systems. Southern astronomers have recently made some headway with accurate photometric and spectroscopic studies of the brightest clusters, but have not such great reserves of instrumental facilities and manpower as have been built up in northern countries over many generations.

TABLE 2
BRIGHTEST STARS IN GALACTIC CLUSTERS

$\overline{M}_{cl}$	$\overline{M}_{st}$	Spectral Types of Brightest Stars
$-9\cdot7$	$-7\cdot7$	O8: (IC 2944), B1 Ia–0 (NGC 6231), B2 Ia (χ Per), A1 Ia (h Per)
$-8\cdot4$	$-7\cdot7$	O5f (2), O8f, B3 Ia, B6 Iab; A2 Ia, F0 Ia, G1 Ib
$-7\cdot3$	$-6\cdot1$	O5, O6 (3), O7 (2), O9 III, 09·5 Ia (2); B0 Ia (2), B0 Ib (3), B1 Ib, B2 Ia, B3 Ia, B3 Iab, B3 Ib, B5 Ib
$-5\cdot6$	$-5\cdot2$	O6 (2), O7 (2), O8, O9 Ib, O9 III; B0 Ia, B0 II, B0 III, B0 IV, B0 V, B1 Ia, B2 III, B9 Ib; F0 Ia, F5 Ia; K5 Ib; M1 Ib (II Sco)
$-4\cdot1$	$-3\cdot1$	B0 V (2), B1 IV, B2 IV, B3 III, B3 V (2), B7 III (Pleiades), B8 III; G8 III
$-2\cdot8$	$-1\cdot9$	B2 IV, B3 III, B5 III, B8 III; A7 III (Hyades); F0 III; K0 III (Praesepe)
$-1\cdot4$	$+0\cdot3$	B8 III, B9 III; F0 III (Coma); G8 III; K1 III

A few further points emerge from consideration of the MK luminosity classes of the brightest individual stars in each of 73 clusters, summarized in Table 2. In each cluster having the integrated absolute magnitude brighter than -8, the type of the brightest star is either Of or an early-type supergiant of class Ia. This survey confirms other evidence that the absolute visual magnitudes of Of stars are of the order -7.

For clusters in the next groups, with $-8 < M_{pg} < -5$, the characteristic types for the brightest individual stars are Ib supergiants and absorption-line O stars. For clusters with $-5 < M_{pg} < -2$, early B-type stars on the main sequence and late-type supergiants appear among the brightest stars. Only clusters in the intrinsically faintest group considered are dominated by stars of the giant branch.

The available evidence suggests that the youngest clusters, dominated by a single early Of-type star, are the most compact, with diameters of only a parsec or less, embedded in more extensive nebulosity. In a later stage of evolution there may be one or several B-type supergiants in a cluster for which 15 or 20 pc is a

typical diameter. Emission nebulae are not reported around clusters whose inte-
grated absolute magnitude is fainter than -5. (See Table 3.) Incidentally, the
brightest *globular* clusters, with absolute magnitudes around -9, have diameters
of 30 pc. Unfortunately, the individual diameters, especially of open clusters, are
comparatively uncertain, and could be improved only by very detailed studies of star
counts interpreted from measures of the fluctuating effect of interstellar absorption.

TABLE 3
DIAMETERS OF CLUSTERS AND NEBULOSITY

M_{cl}	NGC	d_{cl} (pc)	d_{neb} (pc)	Constellation
$-9\cdot8$	6231	10	150	Sco
$-9\cdot6$:	IC 2944	30	50	Car
$-8\cdot9$	3572	20	20	Car
$-8\cdot8$	6611	6	30	Ser
$-8\cdot3$	Cr 173	7	120	Vel
$-8\cdot2$:	Cr 228	10	100	Car
$-8\cdot1$	IC 1805	12	90	Cas
$-8\cdot0$	2244	12	50	Mon
$-7\cdot5$	1893/IC 410	18	25	Aur
$-7\cdot5$	2362	3	220	CMa
$-7\cdot3$	6193	8	50	Ara
$-7\cdot1$	IC 1848	14	30	Cas
$-7\cdot1$	2579	4	150	Pup
$-7\cdot1$	3293	6	30	Car
$-7\cdot0$	6514	14	14	Sgr
$-7\cdot0$	6523/6530	21	40	Sgr
$-6\cdot4$	7380	5	10	Cep
$-6\cdot3$	6383	2	40	Sgr
$-6\cdot1$	Cr 302	35	30	Sco
$-5\cdot7$	Cr 69	8	8	Ori
$-5\cdot7$	2264	7	7	Mon
$-5\cdot3$	2175	8	15	Gem

In an attempt to find a basis for interpreting the integrated colours for assoc-
iations of stars in the Magellanic Clouds, I have removed the colour excess, which had
been determined from photoelectric colour diagrams for galactic open clusters, from the
integrated $(P-V)$ and $(V-I)$ colours measured through a wide-field photometer
by Kron and his collaborators (see Table 4). Among the 28 clusters for which these
data have been published, the colours for more than half are characteristic of late
B- and early A-type stars on the main sequence. (Extension of this work to southern
systems would be highly desirable.) However, certain clusters, e.g. IC 1805 and NGC
1502, are conspicuously blue. Their colour-magnitude arrays show a section of the main
sequence for O, B, and A stars extending through an interval of 7 or 8 magnitudes.
In other words, the diagrams are characteristic of very young clusters, and corres-
pond generally to Trumpler's class 3 for their extensive range of stellar magnitudes.
On the other hand, examples of red galactic clusters are NGC 2682 and 7789 —

intrinsically faint, dominated by red giants which contribute most of the light. To these clusters Trumpler has assigned class 1, since so many of their stars have similar brightness. Presumably these are quite old stellar groups, whose more massive members are already burnt out.

TABLE 4
INTRINSIC INTEGRATED COLOURS OF CLUSTERS

NGC	M_B	$(B-V)_0$	$(V-I)_0$
869	$-9 \cdot 8$	$-0 \cdot 18$	$-0 \cdot 43$
884	$-9 \cdot 7$	$+0 \cdot 06$	$+0 \cdot 49$
663	$-8 \cdot 7$	$-0 \cdot 15$:	$+0 \cdot 20$
457	$-8 \cdot 6$	$+0 \cdot 08$	$+0 \cdot 01$
7790	$-7 \cdot 4$	$+0 \cdot 04$	$+0 \cdot 05$
1502	$-7 \cdot 2$	$-0 \cdot 31$	$-0 \cdot 50$
IC 1805	-7 :	$-0 \cdot 31$	$-0 \cdot 44$
581	$-6 \cdot 7$	$+0 \cdot 02$	$+0 \cdot 40$
7380	$-6 \cdot 4$	$-0 \cdot 22$	$-0 \cdot 32$
637	$-5 \cdot 9$	$-0 \cdot 06$	$-0 \cdot 22$
2099	$-5 \cdot 5$	$+0 \cdot 22$	$+0 \cdot 12$
1960	$-5 \cdot 0$	$-0 \cdot 16$	$-0 \cdot 28$
7789	$-5 \cdot 0$	$+0 \cdot 65$	$+0 \cdot 68$
1027	$-4 \cdot 7$	$+0 \cdot 09$	$+0 \cdot 02$
1912	$-4 \cdot 7$	$+0 \cdot 07$	$+0 \cdot 09$
559	$-4 \cdot 3$	$-0 \cdot 14$	$+0 \cdot 19$
1528	$-4 \cdot 3$	$+0 \cdot 05$	$+0 \cdot 09$
IC 4725	$-4 \cdot 2$	$+0 \cdot 21$	$+0 \cdot 35$
6940	$-3 \cdot 8$	$+0 \cdot 31$	$+0 \cdot 86$
7243	$-3 \cdot 8$	$-0 \cdot 15$	$-0 \cdot 28$
7209	$-3 \cdot 4$	$+0 \cdot 30$	$+0 \cdot 59$
6866	$-3 \cdot 1$	$+0 \cdot 26$	$+0 \cdot 20$
Tr 2	$-3 \cdot 1$	$+0 \cdot 06$	$+0 \cdot 40$
6633	$-2 \cdot 7$	$+0 \cdot 11$	$-0 \cdot 20$
2682	$-2 \cdot 4$	$+0 \cdot 69$	$+0 \cdot 63$
6811	$-2 \cdot 4$	$+0 \cdot 48$	$+0 \cdot 60$
7092	$-2 \cdot 0$	$-0 \cdot 03$	$-0 \cdot 24$
1662	$-1 \cdot 4$	$+0 \cdot 15$	$+0 \cdot 18$

The integrated intrinsic colours of several open clusters in the northern Milky Way, computed by Arp for paper 50 in this Symposium, agree well with Kron's observations. However, the agreement is not yet so satisfactory in published data relating to the Large Magellanic Cloud.

It is a pleasure to thank Mr. Charles Dickens for his assistance in preparing this paper and *Mount Stromlo Mimeogram* No. 6. Professor G. E. Kron has graciously permitted the use of some unpublished magnitudes for clusters.