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PRELIMINARY RESULTS ON THE DISTANCES, DIMENSIONS AND SPACE DISTRIBUTION OF OPEN STAR CLUSTERS

BY

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Although the observations of magnitudes and spectral types in open star clusters of the Milky Way undertaken by the writer are still far from being complete, it seemed of interest to utilize the data at present available for a preliminary investigation of the distances and diameters of these clusters and for a study of their space distribution.

1. Determination of the Distances of Clusters from Magnitudes and Spectral Types

The dimensions of most clusters are small compared with their distance from us. In any particular cluster we may thus assume that its members are at the same distance and that their absolute magnitudes M differ from their apparent magnitudes m by a constant:

$$m - M = 5 \log r - 5, \quad (1)$$

where r is the distance of the cluster in parsecs. Plotting the cluster members according to their apparent magnitudes and spectral types we obtain a diagram similar to the Hertzsprung-Russell diagram of giant and dwarf stars. Although the magnitude-spectral class diagrams of individual clusters vary considerably and although they are incomplete for the fainter stars, it is nearly always possible to decide which stars of a cluster belong to the giant or to the dwarf branch. In most clusters, moreover, only B and A type stars are observable and for these such separation is not necessary. If we assign to each cluster star the mean absolute magnitude corresponding to its spectral class and subtract it from the apparent magnitude, we obtain the distance r from formula (1).

The mean absolute magnitudes of the spectral subdivisions have been determined by various observers from trigonometric and moving cluster parallaxes or statistically from proper-motions. The values used are given in Table 1 and are mainly based on the determinations of Adams & Joy[1], Lundmark[2], Malmquist[3], and Hess[4]:

TABLE 1

Adopted Mean Absolute Magnitudes for Spectral Types

Spectral type	Mean absolute magnitude: Dwarf branch Vis.	Dwarf branch Phtgr.	Giants Vis.	Giants Phtgr.
O	−4.0	−4.3		
B0	−3.1	−3.4		
B1	−2.5	−2.8		
B2	−1.8	−2.1		
B3	−1.2	−1.4		
B5	−0.8	−1.0		
B8	−0.2	−0.3		
B9	+0.3	+0.3		
A0	+0.9	+0.9		
A2	+1.7	+1.7		
A3	+2.0	+2.1		
A5	+2.3	+2.5		
F0	+2.9	+3.2	+0.5	+0.9
F2	+3.2	+3.5		
F5	+3.6	+4.0	+0.5	+1.0
F8	+4.2	+4.7		
G0	+4.5	+5.1	+0.5	+1.2
G5	+5.0	+5.7	+0.5	+1.4
K0	+6.2	+7.0	+0.5	+1.6

[1] *Mount Wilson Contr.* Nos. 199, 244, 262.
[2] *Publ. A. S. P.* **34**, 150, 1922.
[3] *Meddel. Lund*, Ser. II, No. 32, 1924.
[4] *Seeliger Festschrift*, p. 265.

The application of this method for determining distances of clusters requires a knowledge of the spectral types and magnitudes for a number of stars in each cluster. Spectroscopic observations have so far been obtained for 57 clusters either with the 1-prism slit spectrograph attached to the 36-inch refractor for the brighter stars, or with the slitless quartz spectrograph attached to the Crossley reflector, or with both. In 43 other clusters, mostly situated too far south for observation from Mount Hamilton, the spectral types of some of the brighter stars are found in the *Henry Draper Catalogue*. This makes a total of 100 clusters for which spectroscopic data are available.

The photographic magnitudes of the stars in each cluster are being determined from photographs taken with a 4-inch Ross objective, comparing each cluster with the North Polar sequence as well as with several other clusters. From the comparisons so far measured and reduced preliminary results for the magnitudes in 38 clusters are available, most of which are based on the North Polar comparison alone. For 16 others we have accurate magnitude determinations by other observers, and in the remaining 46 clusters the magnitudes had to be taken from the *Henry Draper Catalogue*. As it is not possible *à priori* to decide which stars are physical members of the cluster and which are background stars, only the stars in the central part of each cluster, where the percentage of background stars is smallest, were used, and a few stars which did not fit into the giant or dwarf branch of the magnitude-spectral class diagram were omitted. As an illustration of the procedure followed, Table 2 gives the determination of the distance for the cluster N. G. C. 1960 (Messier 36). The first column contains the number of each star according to Hopmann's Catalog[5], the second the apparent photographic magnitude m (mean of Hopmann and Wallenquist[6]), the third the spectral type. The 13 brightest stars were observed with the 1-prism slit spectrograph, the others were classified on plates taken with the slitless quartz spectrograph. In the fourth column are found the mean absolute magnitudes M corresponding to the spectral type, taken from Table 1, and in the 5th, the differences m-M, which should be the same for all cluster members except for errors of observation and for the natural dispersion in absolute magnitude of the stars of a given spectral type. The 10 brightest stars (8.5–9.5) give a considerably smaller value for m-M than the 30 fainter ones. This fact is noted in most clusters in which the observations cover a large magnitude range. It indicates that the brightest cluster members as a rule are of abnormally high luminosity for their spectral class[7]. Some effect of this kind must, of course, be expected as a consequence of the natural luminosity dispersion in any particular spectral class. In Messier 36, for example, B3 and B4 are the spectral types of highest average luminosity and any stars of these types which are more luminous than the average must necessarily be among the

TABLE 2

DETERMINATION OF THE DISTANCE OF MESSIER 36

Star	App. phtg. magn. m	Spectr. type	Absolute magn. M	m-M	Corr.	Corr. m-M	Resid.
208a	8.5	B3s	−1.4	9.9	+1.0	10.9	−.2
258	8.6	B3s	−1.4	10.0	+1.0	11.0	−.1
313	8.8	B3	−1.4	10.2	+1.0	11.2	+.1
350	8.9	B4	−1.2	10.1	+1.0	11.1	.0
365	9.0	B4e	−1.2	10.2	+1.0	11.2	+.1
250	9.3	B3	−1.4	10.7	+ .5	11.2	+.1
162	9.3	B4	−1.2	10.5	+ .5	11.0	−.1
294	9.4	B5n	−1.0	10.4	+ .5	10.9	−.2
249	9.5	B3n	−1.4	10.9	+ .5	11.4	+.3
238	9.5	B4s	−1.2	10.7	+ .5	11.3	+.2
271	9.7	B4s	−1.2	10.9			−.2
120	9.8	B4	−1.2	11.0			−.1
173	10.1	B7n	− .5	10.6			−.5
156	10.4	B8	− .3	10.7			−.4
132	10.5	B9	+ .3	10.2			−.9
130	10.5	B9	+ .3	10.2			−.9
101	10.6	B8	− .3	10.9			−.2
197	10.7	B8	− .3	11.0			−.1
189	10.7	B6	− .8	11.5			+.4
206	10.7	B8	− .3	11.0			−.1
150	10.8	B8	− .3	11.1			.0
241	10.8	B8	− .3	11.1			.0
186	11.3	B9	+ .3	11.0			−.1
118	11.3	B9	+ .3	11.0			−.1
229	11.5	B9	+ .3	11.2			+.1
236	11.6	B9	+ .3	11.3			+.2
297	11.7	B9	+ .3	11.4			+.3
336	11.7	B9	+ .3	11.4			+.3
214	11.9	A0	+ .9	11.0			−.1
246	11.9	B9	+ .3	11.6			+.5
306	12.0	A0	+ .9	11.1			.0
225	12.2	A0	+ .9	11.3			+.2
324	12.2	A1	+1.3	10.9			−.2
199	12.3	A2	+1.7	10.6			−.5
310	12.3	B9	+ .3	12.0			+.9
233	12.3	A0	+ .9	11.4			+.3
232	12.5	A2	+1.7	10.8			−.3
286	12.7	A1	+1.3	11.4			+.3
305	12.7	A0	+ .9	11.8			+.7
235	13.2	A0	+ .9	12.3			+1.2
Mean of 10 brightest stars				10.36		11.12	
Mean of 30 fainter stars				11.12		11.12	

Mean of all stars: m-M = 11.1 = 5 log r − 5 ($p.$ $e.$ $\pm 0^m.2$)

Distance r = 1660 parsecs ($p.$ $e.$ ±10%)

[5] *Veröffentl. Bonn*, No. 19, 1924.

[6] *Meddel. Upsala*, No. 32, 1927.

[7] See *Publ. A. S. P.* **40**, 266, 1928.

brightest stars of the cluster. Such selection, however, accounts only for a part of the phenomenon referred to. Suppose we determine the distance of Messier 36 from the 30 fainter stars alone, and use this distance to compute the absolute magnitudes of the brighter stars. We find then that all stars of spectral types B3 and B4 in Messier 36 are on the average $0^m.8$ (resp. $0^m.5$) more luminous than the adopted mean magnitudes of Table 1. The upper end of the dwarf branch between B6 and B3 rises more sharply.

In different clusters this rise is not associated with any particular spectral type, otherwise it would require correction of the adopted mean absolute magnitudes of Table 1. But the rise nearly always occurs at the hottest spectral types present in the cluster or among its brightest members. In the cluster Messier 39 which does not contain any stars of hotter spectral type than A0, the rise takes place between A2 and A0, in the *Pleiades* between B9 and B5.

The abnormally high luminosity of the brightest cluster members is probably due to large mass; it was corrected for empirically by the addition of $+1^m.0$ to the *m-M* for the stars in the first half-magnitude interval and of $+0^m.5$ for the stars in the second half-magnitude interval. These corrections were applied for all clusters which contain mainly stars belonging to the dwarf branch; their omission would be a serious source of error in cases where only a few of the brightest cluster stars are available for the determination of the distance. At the fainter magnitude limit to which the observations extend, the selection due to dispersion in absolute magnitude was neglected. As this dispersion seems to be small in the dwarf branch, and as the observations generally cover a considerable magnitude range, the error thus committed will be small and is partly compensated by the correction applied to the brightest stars.

The mean of the corrected values of *m-M* is then taken and the distance in parsecs is computed according to formula (1). When many stars covering a considerable magnitude interval were observed, as in Messier 36, the probable error of the mean *m-M* should be of the order of $\pm 0^m.2$; this includes the uncertainty of the magnitude scale and of the adopted mean absolute magnitudes (Table 1). It corresponds to a *p. e.* of ±10% in the distance.

In Table 3 are collected the data referring to the determination of the distances and linear diameters of

TABLE 3

DISTANCES AND LINEAR DIAMETERS OF OPEN STAR CLUSTERS

NGC or I. C.	Other designations	Magnitude sp. class diagr.	Magnitude interval	Spectral types: Dwarf br.	Spectral types: G	*m-M*	Distance in parsecs: From sp. types: Obs.	Distance in parsecs: From sp. types: Corr.	Distance in parsecs: from diam.	Diameter in parsecs: D′	Diameter in parsecs: D″	$v'=\lg\frac{D'}{C'}$	$v''=\lg\frac{D''}{C''}$
436		1-2b	11m3-12m2	5 B5-B8		12.4	3000	1650	2290	5.2	2.9	−.02	−.14
457		1b	9.7-13.1	29 B2-A0		12.5	3200	1700	1260	11	6.0	+.25	+.13
581	M103	1-2b	9.2-14.4	25 B3-A2		12.3	2900	1600	2320	5.5	3.0	−.02	−.15
663		1b	8.9-13.7	42 B1-A0		12.7	3500	1800	2540	14	7.4	−.01	−.13
752		2f	8.8-12.2	39 F0-F8	12	7.9	380	340	450	5.0	4.5	−.20	−.12
869	*h* Per	1b	7.0-13.3	62 B1-A0		11.4	2200	1350	1300	19	12	+.05	+.01
884	χ Per	1-2b	8.3-13.7	40 B2-A0		11.9	2200	1350	1300	19	12	+.05	+.01
I. C. 1805		1-2o	8.5-13.8	33 O6-A1		12.8	3600	1850	1770	21	11	+.15	+.02
....	An. 2	2a	H. D.	5 A0-A5		*8.9*	*600*	*750*	650	*3.1*	*3.9*	*−.14*	*+.07*
1027		1-2b	9.8-13.7	32 B3-A2		12.1	2600	1500	1690	16	9.1	+.03	−.05
1039	M34	1b-a	8.0-13.7	64 B8-G0		8.6	520	440	460	4.5	3.8	−.09	−.02
....	Perseus	1-2b	3.0- 7.0	31 B1-B9		6.3	180	170	(148)	13	12	−.06	+.07
....	Pleiades	1b	2.8-11.5	127 B5-K0		6.0	160	150	(137)	5.6	5.3	−.06	+.04
1502		1b	7.3-13.9	27 B0-A2		12.0	2500	1450	1460	5.8	3.4	+.13	+.01
1528		1-2b-a	10.6-14.1	21 B8-A5		11.1	1650	1100	690	10	7.1	+.26	+.21
....	Taurus	2a	3.6- 8.1	63 A2-G7	4	2.9	37	37	(38)	4.3	4.3	−.13	−.01
1647		1b-a	8.8-12.7	31 B7-A7		9.5	800	630	580	8.1	6.4	+.01	+.04
1662		2a	H. D.	5 A0-A2		*9.3*	*730*	*860*	830	*3.0*	*3.5*	*−.15*	*+.04*
1746		2b-a	8.0-13.2	27 B5-A5	6	10.3	1150	850	890	13	9.9	−.06	−.02
1807		2a	H. D.	3 A	3	*8.6*	*530*	*670*	740	*2.2*	*2.8*	*−.27*	*−.03*
1912	M38	2b-a	8.3-11.7	27 B5-A4	5	10.2	1100	820	920	5.8	4.3	−.05	−.06
1960	M36	1b	8.5-13.2	40 B3-A2		11.1	1650	1100	860	7.7	5.1	+.15	+.11
1981		1b	H. D.	11 B0-A0		8.9	600	500	470	4.4	3.6	+.01	+.04
2099	M37	2a	10.9-12.4	22 B9-A5	15	10.8	1450	1000	630	10	6.9	+.20	+.19
2168	M35	1-2b	8.0-12.3	34 B4-A2		10.5	1250	910	770	11	7.7	+.09	+.08
2244	12 Mon	1-2o	6.6-13.8	30 O5-A2		11.7	2200	1350	1320	17	10	+.06	+.01
2264	S Mon	1o	4.7- 8.7	9 O8-B8		8.9	600	500	390	5.2	4.4	+.09	+.12
2281		*1a*	H. D.	4 A0		*9.0*	*630*	*780*	690	*2.8*	*3.4*	*−.16*	*+.05*

TABLE 3—(*Continued*)

NGC or I. C.	Other designations	Magnitude sp. class diagr.	Magnitude interval	Spectral types: Dwarf br.	Spectral types: *G*	*m–M*	Distance in parsecs: From sp. types: Obs.	Distance in parsecs: From sp. types: Corr.	Distance in parsecs: from diam.	Diameter in parsecs: *D′*	Diameter in parsecs: *D″*	*v′* = lg *D′*/*C′*	*v″* = lg *D″*/*C″*
2287	M41	2a	H. D.	20 A0	4	8.0	400	350	470	3.7	3.2	−.22	−.14
2323	M50	1b–a	H. D.	7 B8–A0		*9.0*	*630*	*780*	860	*3.0*	*3.6*	−.*26*	−.*04*
2353		1b	H. D.	7 B1–B9		*9.4*	*760*	*890*	690	*4.4*	*5.2*	−.10	+.*12*
2362	τ C Ma	1o	H. D.	3 O8–B8		*9.1*	*660*	*800*	1470	*1.3*	*1.6*	−.*50*	−.*27*
2422		1–2b	5.4–13.5	35 B3–F8		8.7	550	460	500	4.8	4.0	−.08	−.03
2437	M46	1a	10.1–11.2	11 B9–A1		9.8	910	710	610	7.2	5.6	+.05	+.06
2447		*2a*	H. D.	3 B9–A0	1	*9.3*	*730*	*860*	840	*3.8*	*4.5*	−.*22*	+.*01*
2451		1–2b	H. D.	11 B3–A0		7.5	320	290	280	3.5	3.1	−.07	+.01
2516		1–2b	H. D.	24 B3–A3		7.7	350	310	300	5.1	4.5	−.08	.00
2539		1–2a	9.3–13.6	28 A1–F2	6	10.1	1050	790	690	6.7	5.1	+.07	+.07
2546		1b	H. D.	16 B0–A0		8.9	600	500	340	7.8	6.5	+.11	+.16
2547		1b	H. D.	9 B3–A2		*8.7*	*550*	*690*	690	*2.7*	*3.4*	−.*20*	.00
2548		1–2a	8.4–11.5	29 A0–A5	3	8.6	530	440	500	4.7	3.9	−.12	−.06
2632	Praesepe	2a	6.3–10.7	53 B9–G2	9	6.0	160	150	(168)	4.2	4.0	−.17	−.09
I. C. 2391		1b	H. D.	15 B3–F2		6.2	175	160	260	2.3	2.2	−.27	−.20
I. C. 2395		1b	H. D.	14 B3–A2		8.5	500	430	580	2.9	2.5	−.17	−.13
....	An. 10	1b–a	H. D.	12 B8–A0		7.7	350	310	390	3.1	2.7	−.14	−.05
2682	M67	2–3a	10.4–14.5	74 B9–G0	12	9.2	690	560	920	3.6	2.9	−.25	−.22
3114		2a	H. D.	30 B9–A0	9	8.6	530	440	450	5.7	4.8	−.05	−.01
3228		1–2b–a	H. D.	12 B8–A0	1	8.8	580	480	520	3.4	2.8	−.08	−.03
3293		1b	H. D.	3 B0		*11.7*	*2200*	*1850*	2060	*5.1*	*4.3*	−.10	−.09
I. C. 2602		1–2b	H. D.	22 B0–A2		6.6	210	195	230	4.0	3.7	−.16	−.07
3532		2b–a	H. D.	117 B5–A3	12	8.3	460	400	300	7.3	6.3	+.05	+.11
3766		1 b	H. D.	5 B0–B8		*10.1*	*1050*	*1150*	1260	*3.7*	*4.0*	−.*22*	−.05
....	Coma Ber.	2a	4.8– 9.5	40 A0–G2	2	4.6	83	81	(39)	7.2	7.1	+.23	+.32
4755	κ Cru	*1–2b*	H. D.	3 B2–B3		*8.9*	*600*	*750*	1260	*2.1*	*2.6*	−.*47*	−.*23*
5316		*1–2b–a*	H. D.	2 B8–B9	2	*8.8*	*580*	*720*	1060	*1.9*	*2.3*	−.*35*	−.*15*
5460		1–2b–a	H. D.	12 B8–A0		8.9	600	500	430	6.1	5.1	+.03	+.07
5617		*2a*	H. D.	1 A0	4	*9.3*	*730*	*860*	1080	*3.0*	*3.5*	−.*31*	−.*10*
5662		1–2b–a	H. D.	11 B8–A0		9.2	690	560	780	3.0	2.5	−.15	−.13
5822		1–2b–a	H. D.	9 B8–A0	3	9.4	760	610	510	8.8	7.0	+.04	+.08
6025		1b	H. D.	5 B3–B8		*9.5*	*800*	*930*	1060	*2.6*	*3.0*	−.*22*	−.*04*
6087		1–2b	H. D.	9 B5–A0		*9.5*	*800*	*930*	840	*4.2*	*4.9*	−.*14*	+.*05*
6124		2b–a	H. D.	7 B8–A0	5	9.5	800	630	600	5.8	4.6	−.04	+.01
6231		1o	5.9– 8.0	9 Oa–B8		*9.9*	*960*	*1050*	940	*4.5*	*4.9*	−.*15*	+.*04*
....	An. 24	1o	H. D.	25 O5–B8		9.3	730	580	590	13	10	−.06	+.01
6242		1–2b	H. D.	4 B5–B8		*10.7*	*1400*	*1350*	1250	*4.5*	*4.4*	−.*09*	+.*04*
6322		1b	H. D.	3 B3–B5		*10.0*	*1000*	*1100*	1300	*2.6*	*2.9*	−.*22*	−.06
6405	M6	1–2b	6.8– 9.7	37 B5–A3		8.7	550	460	580	4.2	3.5	−.14	−.09
6416		2a	H. D.	2 A0	2	*9.1*	*660*	*800*	700	*4.3*	*5.1*	−.*14*	+.*06*
I. C. 4665		1–2b	6.4–11.4	22 B4–F5		7.8	360	320	230	5.2	4.7	+.09	+.15
6475	M7	1b	6.0– 9.5	30 B5–A3		7.1	260	240	275	3.8	3.5	−.16	−.06
6494	M23	2a	9.5–13.6	40 B9–F0	3	10.0	1000	760	560	7.8	5.9	+.09	+.12
6530		1o	6.0–12.9	25 O5–A1		11.0	1600	1100	1080	6.5	4.4	+.05	.00
6531	M21	1b	7.1–12.6	34 B0–A2		11.0	1600	1100	860	5.6	3.7	+.13	+.09
6611	M16	1o	8.6–13.3	24 O7–B8		13.4	4800	2200	1890	11	5.1	+.29	+.07
6613		1b	H. D.	3 B2–B3		*12.0*	*2500*	*2000*	1670	*5.1*	*4.1*	+.*08*	+.*09*
6633		1–2b–a	7.3–14.3	34 B6–G5	1	8.1	420	360	410	3.1	2.7	−.12	−.05
I. C. 4725	M25	2b	7.9–13.8	47 B4–A5		10.3	1150	850	1110	12	8.7	−.14	−.12
6645		2a	10.3–14.4	27 B9–A3	9	11.6	2100	1300	1160	7.9	4.9	+.10	+.04
I. C. 4756		2a	8.0–12.7	35 B9–F5	9	8.3	460	400	410	6.7	5.8	−.07	−.01
6694	M26	1–2b–a	11.1–13.5	16 B8–A2		12.2	2800	1550	1680	7.3	4.1	+.10	−.03
6705	M11	2b–a	11.3–14.1	55 B8–A2	27	11.7	2200	1350	1320	8.0	4.9	+.09	.00
6709		1–2b–a	9.4–13.7	37 B8–F0		10.5	1250	900	970	4.4	3.2	+.01	−.02
6716		1b	H. D.	3 B5–B8		*9.9*	*960*	*1050*	1460	*2.2*	*2.5*	−.*29*	−.*13*
6811		2a–f	11.0–14.5	37 A3–G0	8	9.8	910	710	1190	3.4	2.7	−.24	−.22
....	Mel 227	2a	H. D.	12 B9–A5	8	7.5	320	280	195	5.6	5.0	+.12	+.18
6866		2a	10.3–13.7	15 A2–F0	6	10.4	1200	880	1030	3.5	2.6	−.08	−.07
6871		1o	H. D.	5 O6–B1		*11.7*	*2200*	*1850*	1090	*16*	*13*	+.*15*	+.*23*
6882		1–2b–a	11.0–13.0	8 B7–A0		11.8	2300	1400	1290	5.3	3.2	+.10	+.02
6885		2–3a	5.9–13.5	7 B8–G0	11	9.2	690	560	700	4.4	3.6	−.13	−.10

TABLE 3—(*Concluded*)

NGC or I C.	Other designations	Magnitude sp. class diagr.	Magnitude interval	Spectral types: Dwarf br.	Spectral types: G	m–M	Distance in parsecs: From sp. types: Obs.	Distance in parsecs: From sp. types: Corr.	Distance in parsecs: from diam.	Diameter in parsecs: D′	Diameter in parsecs: D″	$v'=\lg\frac{D'}{C'}$	$v''=\lg\frac{D''}{C''}$
I. C. 4996		1b	8.4–13.1	11 B0–B7		13.0	4000	1950	1720	7.0	3.4	+.23	+.06
6913	M29	1b	9.7–12.8	9 B0–B5		13.1	4200	2000	2210	8.6	4.1	+.15	−.04
6939		3a	12.5–13.8	2 B8–B9	11	12.2	2800	1550	2060	6.5	3.6	.00	−.13
6940		2a	11.2–13.9	28 A2–F2	5	10.2	1100	820	780	8.3	6.2	+.02	+.02
7092	M39	1a	6.8–12.9	35 A0–G0		7.5	320	290	370	3.0	2.7	−.15	−.09
....	An. 37	1–2o	H. D.	4 O5–B8		*9.4*	*760*	*890*	650	*13*	*15*	*−.11*	*+.13*
7209		1–2a	8.9–11.3	16 A0–A5	2	9.2	690	560	585	4.0	3.3	−.03	−.01
7243		1b	8.3–13.2	29 B6–F0		10.0	1000	760	740	6.1	4.6	+.01	+.02
7380		1b	10.4–14.0	20 B0–A2		13.0	4000	1950	1720	10	5.1	+.22	+.06
7654	M52	1b–a	10.9–13.6	33 B7–A3		11.9	2400	1450	1270	9.0	5.4	+.14	+.04
7789		2–3a	11.3–12.6	7 B9–A4	10	11.1	1650	1100	1180	9.1	6.1	.00	−.02

NOTES.—*NGC* 6231: Spectral types and photographic magnitudes selected from Tables I and II of *H. C. O. Bull.* 846.

NGC 6882 and *NGC* 6885, see remark to Table 16.

NGC 6705. The observed distance (col. 8) is considerably larger than that (1250 parsecs) given in *L. O. B.* **12**, 14, 1925. This is partly due to slight changes in the mean absolute magnitudes here adopted but mostly to the addition of many fainter stars for which the spectral types are given by Lindblad (*Mt. Wilson Contr.* No. 228, 1922). The present result is in close agreement with Lindblad's determination.

100 open clusters; all data printed in italics are somewhat uncertain or less reliable. In the first column the number of the *New General Catalogue* of Dreyer[8] or of the *Index Catalogues*[9] is inserted and in the second column other designations of the cluster; among these *M* refers to Messier's list, *Mel.* to Melotte's Catalogue[10], *An.* to clusters not listed in any existing catalogue but for which the position is given in Table 16. The 4th column gives the magnitude interval of the stars observed with the spectrograph; an H. D. in this column indicates that the magnitudes and spectral types were taken from the *Henry Draper Catalogue.* The number of stars belonging to the main or dwarf branch and used for the determination of the distance is found in the 5th column together with the range of spectral types. The 6th column gives the corresponding number of red or yellow giant stars. Supergiants of types *F* to *M* have not been utilized, as their mean absolute magnitudes are too uncertain. The mean difference between the apparent and absolute magnitudes of the stars, in column 7, leads by means of formula 1 to the observed value of the distance *r* in parsecs (8th column). The accuracy of these distance results is necessarily uneven, depending on the number of stars used and on their range in magnitude and spectral type. Distances which are based on data taken from the *Henry Draper Catalogue* are as a rule less reliable, and if these are restricted to less than 10 stars the result is printed in italics to mark it as uncertain. For the remaining 76 clusters the probable error of the observed distances should lie between 10% and 20%.

[8] *Mem. R. A. S.* **49**, 1888.

[9] *Mem. R. A. S.* **51**, 185, 1895; **59**, 105, 1908.

[10] *Mem. R. A. S.* **60**, 175, 1915.

2. CHARACTER OF MAGNITUDE-SPECTRAL CLASS DIAGRAM

The 3rd column of Table 3 contains information concerning the character of the magnitude-spectral class diagram which is obtained by plotting the stars of a cluster according to their spectral types as abscissae and their apparent magnitudes as ordinates. In a former paper[11] attention has been drawn to the fact that the magnitude-spectral class diagrams of open star clusters differ considerably, although they always show some resemblance to the well known Hertzprung-Russell diagram of giant and dwarf stars. In some clusters the giant branch is entirely missing, and the dwarf branch extends unequally far in the direction of the hotter types. A simple classification was proposed which describes, by the combination of a number and a letter, the peculiar character of the magnitude-spectral class diagram of a cluster, and the 3rd column of Table 3 furnishes the class of each cluster on this system. The number is based on the relative frequency of yellow and red giant or supergiant stars. 1: means that the giant branch is entirely missing, all cluster stars belonging to the main branch from O to M. 2: a relatively small number of stars in the giant branch. 3: the majority of the more luminous stars are yellow or red giants. The letter following the number is that of the spectral type of highest temperature reached by the main branch. In addition to the four main types 1b, 1a, 2a, 2f illustrated in the former publication two others have been introduced: 1o for clusters containing O type stars, and 3a for clusters with many red or yellow giants, but very few A type stars. Intermediate steps are also indicated; 1–2 mostly referring to cases

[11] *Publ. A. S. P.* **37**, 307, 1925.

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TABLE 4

FREQUENCY OF DIFFERENT TYPES OF MAGNITUDE SPECTRAL CLASS DIAGRAMS

	o	b	b–a	a	a–f	f	
1	7	24	5	3			39
1–2	3	15	10	3			31
2		1	5	18	1	1	26
2–3				3			3
3				1			1
	10	40	20	28	1	1	100

in which it is doubtful whether the few yellow or red stars observed are physical members of the cluster.

Table 4 shows the frequency of the various types; the total number of clusters for which data are available being exactly 100, the numbers also express percentages. The most frequent types are 1b (*Pleiades*) and 2a (*Praesepe*), but there is also a well pronounced transition between them. Table 4 brings out plainly the peculiar feature in the distribution of these types, *i. e.*, a strong concentration along the diagonal from 1b to 2a. In other words open clusters which contain stars of highest temperature (types O and B) contain very few or no red or yellow giant stars (the few being generally supergiants); while clusters, in which types O and B are missing, most frequently contain an appreciable or even a considerable number of stars in the giant branch. The high percentage of clusters (50%) with O and B type stars is undoubtedly exaggerated by selection, as the great luminosity of these stars allows spectroscopic observations of very distant objects while only the nearer ones of type 2a are within reach of the spectroscope.

3. DETERMINATION OF LINEAR DIAMETERS (FIRST APPROXIMATION)

Unfortunately the list of clusters included in Table 3 is very incomplete and selective. Owing to more favorable observing conditions in summer and autumn the spectroscopic and photometric observations are more complete for objects in galactic longitudes 330° to 150°, while in the opposite hemisphere practically none of the fainter and more distant clusters have been investigated. A study of the general space distribution of open star clusters should be based on a more complete number of clusters, and for most of these an estimate of the distance can at present be obtained only from the apparent diameter. A careful investigation of the linear diameters of the 100 clusters of known distance was therefore undertaken primarily for the purpose of finding a method to determine the distance of a cluster from its diameter.

The apparent angular diameters found in the 9th column of Table 16 are means of the estimates of various observers, especially Bailey[12] and Melotte[10], to which the writer added a number of estimates made on cluster photographs or reproductions taken with various telescopes (Franklin-Adams Chart, Barnard's Milky Way Photographs[13], Isaac Roberts Photographs[14], Charts of Cordoba Photographs[15], plates taken with the 4-inch Ross Camera, with the Crossley Reflector or with the 30-inch refractor of the Allegheny Observatory). Estimates based on the appearance of a cluster only were utilized, as it is not important that the figures should give the extreme limit of each cluster system, but rather that they should measure the same feature for large and bright as for small and faint clusters. Such large and near clusters as the *Taurus* Cluster, *Coma Berenices*, *Pleiades*, etc. were examined on star charts or small scale photographs, taking special care to estimate their diameters by the same procedure that had to be applied to the small and faint clusters.

The linear diameter D in parsecs is then calculated from the apparent diameter d in minutes of arc and the distance r of the cluster by the formula

$$D = r \sin d = \frac{r}{3438} d \qquad (2)$$

and the result obtained with the observed distance r in the 8th column of Table 3 is given under D' in the 11th column. Even if we disregard the uncertain data (in italics) the observed linear diameters of the remaining 76 clusters show a rather wide range—from 2.3 to 21 parsecs. When we consider the great diversity in appearance and constitution of the open star clusters of the Milky Way it is *à priori* not surprising that these formations should also vary in dimensions. Some of these clusters like Messier 39 are groups of only a few dozen stars, others like *h Persei* contain several hundred or even a thousand members, and we could hardly expect each of these to occupy the same volume of space.

4. CLASSIFICATION OF CLUSTERS ACCORDING TO APPEARANCE

Our results undoubtedly discredit the assumption formerly made by some investigators, that all open clusters are nearly of the same dimensions, and that their angular diameters give a direct measure of their distances. At the same time, since clusters are more or less stable systems, it is likely that the dimensions

[12] *H. A.* **60**, 199, 1908.

[13] *Lick Obs. Publ.* **11**, and E. E. Barnard, *A Photographic Atlas of Selected Regions of the Milky Way*, 1927.

[14] Isaac Roberts: *A Selection of Photographs of Stars, Star Clusters and Nebulae.* Vol. I 1893, Vol. II 1899.

[15] *Cordoba Photographs*, by B. A. Gould, 1897.

of a cluster are governed by its gravitational potential and should therefore be related to its constitution. We evidently must restrict ourselves to the assumption that clusters of similar constitution have similar dimensions. To test this hypothesis the clusters were classified according to certain features which are characteristic of their constitution and which can be ascertained independently of their distances; such as the degree of central concentration of the stars, the range in luminosity of the members, and the number of stars contained in them. For each characteristic 3 or 4 subdivisions were made, designated by a number or a letter and the three characteristic figures were combined to a general symbol.

In the first place the clusters were divided into four main groups:

I. Detached clusters with strong central concentration.

II. Detached clusters with little central concentration.

III. Detached clusters with no noticeable concentration, in which the stars are more or less thinly but nearly uniformly scattered.

IV. Clusters not well detached but passing gradually into the environs, appearing like a star field condensation.

While the first three groups form a series with decreasing central concentration, the fourth defines a quite peculiar class and was added on the basis of the results of Table 3. The linear diameters in the 11th column of this table indicate a distinct group of clusters with abnormally large dimensions. A careful examination of these objects showed that they appear as a rule to be related to the surrounding star field, growing, so to speak, out of a larger star accumulation like a condensation. The double cluster in *Perseus* is a typical example, or the cluster NGC 1027 reproduced from Barnard's *Milky Way Atlas* in figure 6 of Plate I. Often we find in representatives of this group a small well defined densely crowded center (I. C. 1848) which might in itself be taken for a cluster, and occasionally several subsidiary centers of concentration are indicated. It must be admitted that it is sometimes difficult to decide from the appearance alone, whether a faint distant cluster belongs to the last group or to one of the three preceding ones.

In each of the four main groups three subdivisions were made according to the range in the brightness or luminosity of the cluster stars:

1. Most cluster stars nearly of the same apparent brightness (NGC 7789).
2. Medium range in the brightness of the stars.
3. Clusters composed of bright and faint stars; generally a few very bright and some moderately bright stars standing out from a host of fainter ones (*Pleiades*).

The most important distinction is perhaps that according to the number of members contained in a cluster, designated by the following letters:

p: Poor clusters with less than 50 stars.
m: Moderately rich clusters with 50–100 stars.
r: Rich clusters with more than 100 stars.

For most of the brighter clusters the number of stars was taken from the star counts of Raab[16]; for the others, rapid counts were made or estimates by comparison with brighter clusters, taking account of course, in all cases, of the star density of the background.

The classification of the cluster consists in a combination of the three characteristic symbols. Thus I3*m* designates a detached cluster with strong central concentration, composed of 50–100 bright and faint stars. A few clusters typical of the different groups and subdivisions are illustrated in plate I. Peculiarities of a cluster if very pronounced are further indicated by a capital letter added to the symbol: *E* for elongated, *U* for unsymmetrical, *N* for nebulosity involved in the cluster. The adopted classification of each cluster is found in Table 16, column 10.

5. Relation of Linear Diameter to Classification

Disregarding, at first, the second subdivision (according to range in luminosity of stars) the mean linear diameters were formed for the twelve subgroups of Table 5. Only the 76 clusters with best determined distances were used for this purpose. It may be assumed that the errors of the linear diameters D' (11th column, table 3) are proportional to their amount (percentage errors) since the same is true for the errors of the distance r and the apparent angular diameter d from which they are derived. The logarithms of the linear diameters are therefore approximately of the same accuracy, and the means of Table 5, accordingly, are geometrical, or logarithmic means.

TABLE 5

Mean Linear Diameters of Subgroups

Sub-group	Mean obs. diam. D′: Mean log D′	Mean D′	No. of Cl.	First approximation Comp. C′	Second approximation: Mean D′	Weight	Adopt C′
Ip	0.63	4.3	7	4.1	3.0	8.5	3.0
m	0.71	5.1	4	5.5	4.0	5.5	4.0
r	0.80	6.3	9	6.2	4.5	11.5	4.4
IIp	0.61	4.1	13	4.3	3.4	17.0	3.4
m	0.78	6.0	11	5.7	4.5	11.5	4.4
r	0.80	6.3	9	6.5	4.7	9.5	4.8
IIIp	0.80	6.3	6	6.0	4.3	6.5	4.5
m	0.86	7.2	5	8.0	5.9	5.0	5.9
r	1.00	10.0	2	9.0	6.9	2.0	6.5
IVp				11.1	13.2	0.5	7.9
m	1.18	15.1	7	14.9	9.9	7.0	10.3
r	1.22	16.6	3	16.8	11.3	3.5	11.3

[16] *Meddel. Lund.* Ser. II No. 28, 1922.

It is evident that in all of the four groups the mean diameter increases from the poor to the rich clusters, just as was expected. Some of the subgroups have very few representatives and their mean diameters are rather uncertain. In order to reduce the number of constants to be determined from the observational data, the assumption was made, that the rate of increase from poor to medium and rich clusters is the same in all four classes. The mean diameter of any subgroup G_g can then be represented as the product of two factors D_G and f_g, the first of which depends only on the group (G=I, II, III, IV) the second only on the qualification ($g=p$, m, r). To fix the absolute amount of these factors one of them can be assumed arbitrarily, and we set $f_m=1$. This reduces the number of constants to six: D_I, D_{II}, D_{III}, D_{IV}, the mean diameters of medium rich clusters of the four main groups, and f_p and f_r, the average ratios between the mean diameters of poor and medium rich clusters and between those of rich and medium rich clusters.

Every subgroup furnishes an equation of condition:

$$\text{Subgroup } G_g\text{: } \overline{\text{Mean } D'} = D_G f_g$$
$$\text{or } \overline{\log D'} = \log D_G + \log f_g$$

from which the six constants, or rather their logarithms, are easily determined by a least squares solution. The results are given in the second column of Tables 6 and 7, as first approximation D'_G and f'_g.

TABLE 6

Mean Diameters of Medium Rich Clusters of the Four Groups

Group	First approximation D'_G	First approximation No. of clusters	Second approximation D''_G	Second approximation No. of clusters
I	5.5	20	4.0	25.5
II	5.7	33	4.4	38.0
III	8.0	13	5.9	13.5
IV	14.9	10	10.3	11.0

TABLE 7

Relative Sizes of Poor, Medium Rich and Rich Clusters

Subdivision	First approximation f_g'	Second approximation f_g''	Average number of stars in cluster	Relative volume	Relative star density
p	0.75	0.77	35	0.45	78
m	1.00	1.00	75	1.00	75
r	1.13	1.11	200	1.36	147

The mean linear diameters C' of the 12 subgroups computed from the 6 constants D'_G and f'_g by the formula

$$C'_{Gg} = D'_G f_g'$$

are found in the 5th column of Table 5 and agree quite closely with the observed means in the third column. The residuals between the logarithms of observed cluster diameters D' (11th column of Table 3) and the logarithms of these computed mean diameters C':

$$v' = \log D' - \log C'$$

are given in the 13th column of the table.

6. Investigation of Systematic Errors

These residuals depend on the one hand on the correctness of our hypothesis that clusters of similar constitution have similar linear diameters everywhere in our stellar system and on the other hand on various sources of errors affecting our observational data (distance determinations, classification of clusters, estimates of angular diameter). If we hold fast to our hypothesis, which seems to have a high degree of probability, it becomes possible to investigate certain systematic errors of observation by means of the residuals v'.

In the first place we have to test the homogeneity of our distance determinations. According to the observational material used, we may divide these into 3 classes:

1st: Clusters with photometrically determined magnitudes, and spectral-types observed by the writer.

2nd: Clusters in which magnitudes and spectral types of more than 10 stars were available from the *Henry Draper Catalogue.*

3d: Uncertain distance determinations (given in italics in Table 3) based on the data of the *Henry Draper Catalogue* for only a few stars.

For each class the mean residual v' was formed and is given in Table 8; in the first approximation only clusters for which the observed distance r' is smaller than 1000 parsecs were used, as most of the clusters of the second and third class are relatively near.

TABLE 8

Systematic Errors of Distance Determinations

Class	Data	First approximation, clusters within 1000 p. s. Average v'	First approximation Number clusters	Second approximation, all clusters Average v''	Second approximation Number clusters
1	Tr	−.07	24	.00	58
2	H. D. C.	−.06	18	−.01	18
3	H. D. C.	−.24	18	−.01	24

The fact that all residuals are negative is due to the selection of relatively near clusters and to a dependence of the residuals on the distance (see Table 10). There is no appreciable systematic difference between the first two classes but the third, which had not been used in deriving the mean linear diameters of Tables 5–7, stands out by a large negative residual. For

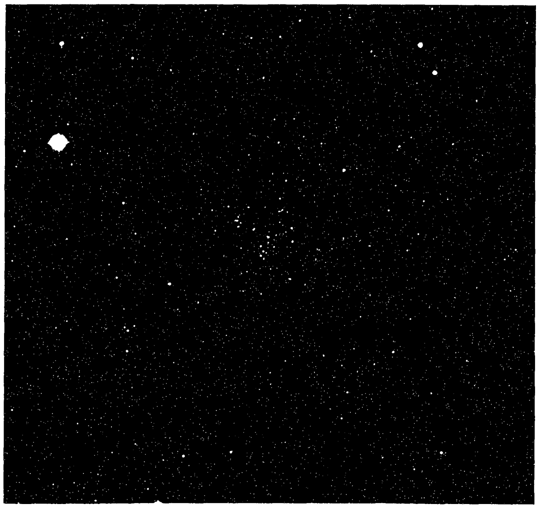
Fig. 1. NGC 6819, Class I2r.

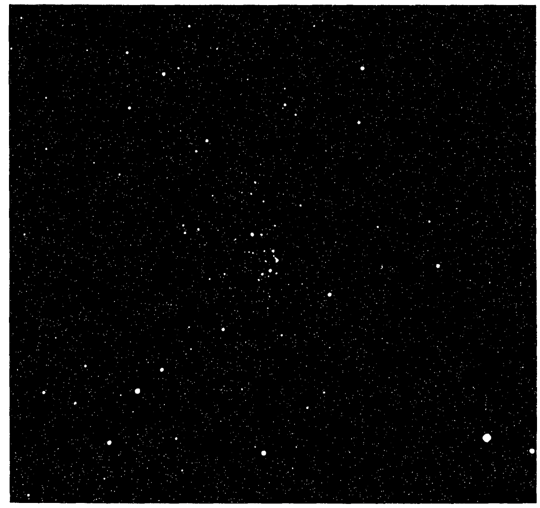
Fig. 2. NGC 2254, Class I2p.

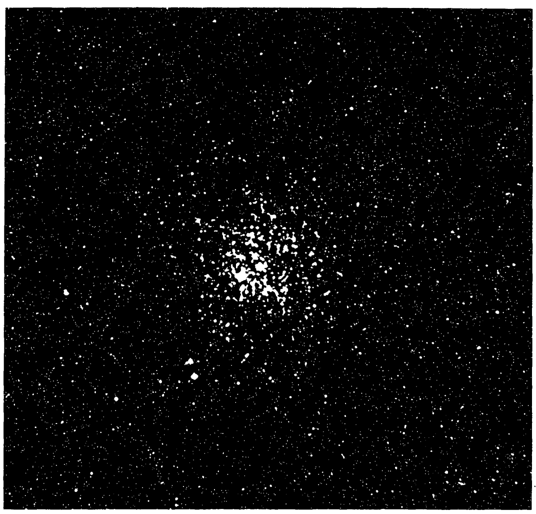
Fig. 3. NGC 6705, Class II2r.

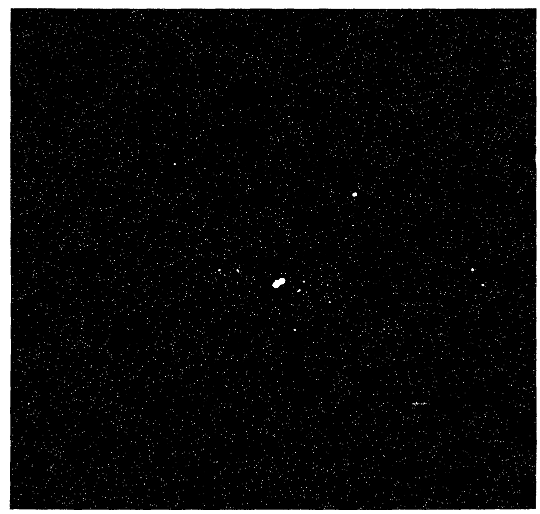
Fig. 4. NGC 1502, Class II3p.

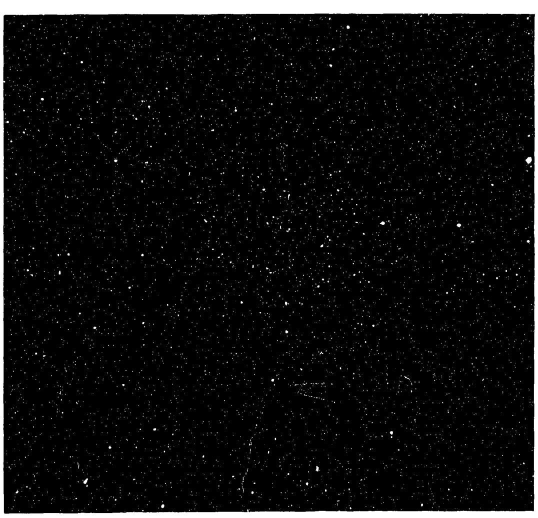
Fig. 5. NGC 7789, Class III1r.


Fig. 6. NGC 1027, Class IV3m.

TYPICAL OPEN CLUSTERS

clusters whose distances are based on the *Henry Draper Catalogue* data of a few stars the linear diameters come out systematically too small and we must conclude that the distances so derived are systematically too small compared with the much better determined distances of those of the other two classes. This is probably due to the combined effect of two causes; to the selection of stars with luminosity above the average and the omission of stars with luminosity below the average (see page 155-156) which is most serious when only a few of the brightest cluster stars were observed. In this case the empirical correction applied is probably insufficient. As the observed stars of these clusters are mostly fainter than 8th magnitude and mostly of types B and A0, the distance results will also be affected by certain systematic errors in the spectral type estimates of the *Henry Draper Catalogue*. It has been noticed that this catalogue has the tendency to attribute more advanced types to the fainter B type stars than result from well exposed slit-spectrograms. This is probably due to the poor visibility of the faint helium lines in under-exposed spectra. Many of the fainter A0 stars of the *Henry Draper Catalogue* show well defined helium lines on slit-spectrograms and should be classified as B9 or B8. Similarly, many of the fainter B8 stars would be classified B5–B7 on slit-spectrograms. The consequence is that in the clusters of the last class too low luminosities were attributed to the stars and the distances came out too small. An empirical correction of +0.18 was therefore added to the logarithm of the distances and linear diameters of the last class (which corresponds to multiplication by the factor 1.51) and after such correction they were included in the following discussions with half weight.

In studying the relation between the linear diameters of clusters and the classification of their constitution, we have made no use of the second subdivision according to the range in the luminosity of the cluster members. The average residuals v' of the three subdivisions are given in Table 9; no appreciable correlation between range in luminosity and linear diameters is indicated and our procedure appears well justified.

TABLE 9

DEPENDENCE OF LINEAR DIAMETERS ON RANGE IN LUMINOSITY

Sub-division	First approximation v'	First approximation Weight	Second approximation v''
1	−.02	9	−.01
2	.00	32.5	.00
3	.00	46.5	−.01

The clusters of Table 3 were then ordered according to the observed distance (column 8) and group means of the residuals taken. The latter are found in Table 10, column 3. They show a pronounced correlation with the distance of the cluster. For the nearer clusters the observed linear diameters D' are smaller than the average, for the distant clusters larger. The range in log D' is 0.28, which means that the linear diameters of the most distant clusters come out, on the average, nearly twice as large as those of the nearest ones. The following possible causes have to be considered in relation with this phenomenon:

TABLE 10

DEPENDENCE OF LINEAR DIAMETER ON DISTANCE

Observed distance in parsecs: Interval	Observed distance in parsecs: Mean	Average residual v'	Weight	Cl. with app. diam. 10′–20′: Mean d	Average v'	Weight	Cl. with app. diam. 20′–40′: Mean d	Average v'	Weight	True distance in parsecs Mean	Eff. of abs. A	Residual $v'-A$	Second approxim. Average v''
<500	294	−.09	20	20′	−.17	1	31′	−.14	5	266	−.09	.00	−.01
500–1000	730	−.05	26.5	16	−.10	8.5	29	−.02	15.5	594	−.04	−.01	−.02
1000–1500	1200	+.01	13.5	15	−.01	5.5	29	+.03	6	870	.00	+.01	+.01
1500–2000	1620	+.08	6	15	+.07	4.5	22	+.26	1	1050	+.03	+.05	+.05
2000–3000	2460	+.06	13.5	13	+.11	3.5	27	+.05	4	1500	+.10	−.04	−.03
>3000	3850	+.19	8.5	15	+.13	3	25	+.33	0.5	1890	+.16	+.03	+.04

1. Selection of residuals: Too small a diameter is obtained if the observed distance is too small; clusters affected with this error will be more numerous in the first group, those affected with the opposite error in the last group. This effect might explain the negative residual in the first, and the positive residual in the last group, but not the steady progress in the intermediate figures.

2. Systematic errors in the distance determination. In the more distant clusters as a rule only B and A type stars have been observed, while in the nearer clusters F and G type dwarf stars have often been included. This source could not account for more than a small fraction of the observed discrepancy.

3. Systematic errors in the classification of near and distant clusters. These need hardly be considered; their effect on the diameters is relatively small and for most of the clusters here considered good photographs were available as well as star counts.

4. Systematic errors in the estimates of the apparent diameters. These must indeed be feared as it is difficult to estimate the diameters of large and near clusters on the same basis as small and distant ones. Our discrepancy would require that the latter have been estimated too large, but this appears *à priori* very unlikely. The fainter cluster members as a rule are scattered over a larger area than the brighter ones, and the omission of the former in the distant clusters should rather make their diameter estimates too small. Owing to the considerable range in the linear diameters of open star clusters the correlation between apparent diameter and distance is not very close; that is, even among the clusters of the same apparent diameter we find a considerable range in distance. It is therefore possible to decide from the residuals themselves whether the observed discrepancy depends on the distance or on the apparent diameter. In Table 11 the clusters are ordered according to their apparent diameters, and the group means show decidedly smaller correlation than in the third column of Table 10. Still more convincing proof that our systematic error depends on the distance and not on the diameter is given in columns 6 and 9 of Table 10 which contain the average residuals v' taken separately for two small intervals of apparent diameter; while the mean diameters (column 5 and column 8) vary very little in each column, the run of the residuals with the distance is just as pronounced as in the third column for all clusters taken together. As none of the observational errors discussed offers a plausible explanation of the observed discrepancy there are only two alternatives left; either to admit an actual change in the dimensions of open clusters with increasing distance or to assume the existence of an absorption of light within our stellar system. In favor of the first alternative it might be argued that the dimensions of clusters are possibly influenced by the star density of the space in which they are situated and that this star density on the whole decreases with greater distance from the center of the local system. If we consider, however, the amount in question it is extremely unlikely that any such influence could be powerful enough to nearly double the dimensions of remote clusters.

TABLE 11

DEPENDENCE OF RESIDUALS ON APPARENT DIAMETER

Apparent diameter	First approximation: Average v'	First approximation: Weight	Second approximation, Average v''
>160′	+.01	3	+.13
80–160	−.12	2	.00
40–80	−.05	11.5	+.02
20–40	−.01	32	+.01
10–20	−.01	26	−.03
5–10	+.08	13.5	−.04

The assumption of an absorption of light on the other hand is not only able to give a satisfactory numerical representation of the residuals of Table 10 but receives support also from color-index observations in clusters.

7. Absorption of Light in the Milky Way System

Our method of deriving cluster distances from magnitudes and spectral types was based on formula (1) which expresses the law that the apparent brightness of a star diminishes with the square of the distance from the observer. If interstellar space is not perfectly transparent this law does not hold; the apparent brightness decreases more rapidly, our distance results are too large, and the error increases with the distance of the cluster. The linear diameters computed with these distance results are then also too large, and the error also progresses with distance, just like the residuals in column 3 of Table 10.

Let us suppose for the moment that the absorbing material is uniformly distributed throughout the galactic system. The loss of star light in magnitudes caused by absorption is then

$$\Delta m = kr$$

where r is the stars' true distance and k the absorption constant of photographically effective wavelengths. The relation between apparent and absolute magnitude of a star and its distance is accordingly

$$m\text{-}M = 5 \log r + kr - 5 \tag{3}$$

This equation must be substituted for equation (1) in the case of uniform absorption.

Our observed cluster distances r' (Table 3, column 8), on the other hand, were computed with formula (1) and the relation between the true distance r and our observed value r' is given by

$$\log r' = \log r + \frac{k}{5} r \tag{4}$$

The linear diameter D' (Table 3, column 11) was calculated by formula (2) with the observed distance r', which in logarithmic form is

$$\log D' = -3.536 + \log d + \log r'$$

(d = apparent diameter in minutes of arc)

The true linear diameters D would have been obtained from

$$\log D = -3.536 + \log d + \log r$$

Hence the error in the logarithms of our observed linear diameters are

$$\log D' - \log D = \log r' - \log r = \frac{k}{5} r \tag{5}$$

The residuals v' were obtained by deducting the mean diameter logarithm of the subclass from the individual diameter logarithm of each cluster

$$v' = \log D' - \overline{\log D'} \qquad (6)$$

If we take the mean of equation (5) we have

$$\overline{\log D'} - \overline{\log D} = \frac{k}{5}\bar{r}$$

Since we assume the true diameters D of all clusters of the same subclass to be the same,

$$\overline{\log D} = \log D$$

and

$$\overline{\log D'} = \log D + \frac{k}{5}\bar{r} \qquad (7)$$

or from (6) and (7): $v' = \log D' - \log D - \frac{k}{5}\bar{r}$ (8)

and combining this with equations (5)

$$v' = \frac{k}{5}r - \frac{k}{5}\bar{r}$$

$$v' = a + br \qquad (9)$$

The residual must be a linear function of the true distance r with the two constants $a = \frac{k}{5}\bar{r}$ and $b = \frac{k}{5}$. Equation (6) is strictly true only for the clusters of the same subclass; but since the mean distance $\bar{r}$ is approximately the same for all subclasses, we can also apply it for all clusters taken together.

Our task is now to determine the numerical values of the two constants a and b from the observed residuals v', and to see if the latter are sufficiently well represented by formula (9). Unfortunately the variable r, the true distance, is not known, but only the observed distance r'. a and b have therefore to be determined from the two equations:

$$\left.\begin{aligned} a + br &= v' \\ \log r + br &= \log r' \end{aligned}\right\} \qquad (10)$$

using the data of Table 10 (columns 2–4) by gradual approximation. The first approximation is obtained by considering that for clusters with small distances (first group mean) br is small and a is nearly equal to the mean v' of the first group (−.09). Elimination of $b\,r$ from the two equations (10) leads to

$$\log r = \log r' - v' + a \qquad (11)$$

Entering in this equation our approximate value of a, we obtain approximate values of r for each group mean of Table 10. We then proceed to determine a and b by least squares solution, applying the first equation (10) as equation of condition to the group means of Table 10. With the results for a and b obtained by this first approximation the true mean distances r of the group means are recomputed in two ways. First, from the second equation (10), and secondly from equation (11).

TABLE 12

	First approximation	Second approximation	Third approximation
a	−.133	−.136	−.134
$1000b$	+.141	+.159	+.158

The first corrects the observed spectroscopic distances for absorption; the second corrects them on the basis of uniform linear diameters. The means of both methods are used as the basis for a second approximation. The results for a and b of the successive approximations are found in Table 12; those of the third approximation are finally adopted and furnish for the constant of photographic absorption

$$k = 5b = 0.79 \text{ magnitudes per 1000 parsecs.}$$

In columns 11–12 of Table 10 the resulting true distances of the group means and the corresponding absorption effects A on the observed linear diameters D' are given which were computed from the formula $A = a + br$. The residuals $v' - A$ (col. 13, Table 10) are small and show no systematic arrangement. It may therefore be stated that the apparent increase in the linear diameters of open star clusters is fully removed by the assumption of an absorption of light within our Milky Way system to the amount of 0.79 magnitudes per 1000 parsecs for photographically effective rays.

If the light of the stars in the more distant clusters has been dimmed by the passage through an absorbing material, it seems *à priori* likely that such absorption is selective, and varies with the wave length of the light and thus changes the color of the stars. Since the color of a star depends on its temperature a change of color by absorption can only be detected if its temperature is observable by some other means; *e. g.*, from the spectral types which measure the temperature by means of the ionization and excitation of the atoms in the stellar atmosphere. Spectral type estimates based on comparison of intensities of spectral lines are not affected by a general absorption. For the brighter and nearer stars which are little affected by absorption the relation between color indices and spectral types has been well established, but differs slightly for giant and dwarf stars. From this relation we can find the normal color index corresponding to a given spectral type. The difference between this and the color index actually observed is called the color excess of the star. The existence of large discrepancies between observed color indices and spectral types in open star clusters has been known for some time, but to test our hypothesis of an absorption of light in space it is necessary to show that the average color excesses in various clusters depend on their distance. The spectral types in open clusters determined with the 1-prism slit spectograph and the slitless quartz spectrograph made it possible to compute the average color excess for a number of clusters in which color-indices have been measured by various observers. Leaving out the few nearest clusters which are of little interest for our purpose and using only color indices determined by direct comparison with the North Polar sequence, seven clusters ranging widely in distance were available. Table 13 gives for each of these the observed distance r' (from magnitude and spectral types), the finally adopted distance (Table 16) which is corrected for absorption, the average color excess of the cluster stars, the number of stars used, and the name of the observer of the color indices.

TABLE 13

COLOR-EXCESS OF OPEN CLUSTERS

Cluster		Observed dist. r'	Adopt. corr. dist.	Color excess	Number of stars	Observer of color-ind.	Formula	Obs. —Form
NGC2682	Messier 67	690	740	$+0^{m}.26$	81	Shapley[17]	$+^{m}.24$	$+^{m}.02$
1647		800	610	+0.17	33	Hertzsprung[18]	+.19	−.02
				+0.19	6	Seares[19]	+.19	.00
2099	Messier 37	1450	820	+0.05	25	v. Zeipel and Lindgren[20]	+.26	−.21
1960	Messier 36	1650	980	+0.05	40	Wallenquist[21]	+.31	−.26
6705	Messier 11	2200	1340	+0.65	46	Shapley[22]	+.43	+.22
7654	Messier 52	2400	1360	+0.49	43	Wallenquist[23]	+.43	+.06
663		3500	2170	+0.71	41	Wallenquist[23]	+.69	+.02

In all clusters we find a positive excess, and the latter is largest for the 3 most distant clusters. It must be kept in mind, of course, that color indices are subject to systematic errors of observation and especially that errors in the zero point of the photographic and visual magnitude scales may occur, due to changes in the observing conditions between the exposures on the cluster and on the North Pole. It is, however out of question that errors of the order of $0^{m}.5$–$0^{m}.7$ could result from this source, especially if the North Polar comparisons have been repeated on different days. Wallenquist, aware of the large discrepancy between his color indices of NGC 663 and the spectral types of the same stars, and unable to account for it by observational errors, concludes: "The most probable explanation is, perhaps, the assumption of selective absorbing clouds within (and in the surroundings of) the cluster NGC. 663." That the effect is not due to an error in method is well illustrated by the fact that Wallenquist observed three clusters by the same method and instrument and that only the two more distant ones show a large color excess; the same is true for the two open clusters investigated by Shapley. In a former publication[24] I drew attention to the large excess of Shapley's color observations in the cluster Messier 11 and, averse to the idea of a general selective absorption in our stellar system, took rather a skeptical attitude concerning the correctness of Shapley's results until these were confirmed by Wallenquist's observations of two more distant clusters. We are thus led to the assumption of a general absorption of light in our stellar system by two quite independent sets of observations; by the study of the linear diameters of star clusters as well as by color-index observations in such clusters. That the absorption is not caused merely by an absorbing cloud involved in the cluster itself as Ten Bruggencate[25] and Wallenquist suggest is shown by the increase in the color-indices with the distance and by a similar increase in the apparent linear diameters.

If we speak of a general absorption this does not mean that it is necessarily uniform throughout the stellar system; the absorbing material may have many local irregularities but must be so distributed that *on the average* the absorption in magnitudes is approximately proportional to the distance, as this condition seems to be necessary to explain the residuals of the observed linear diameters in Table 10. It is true that the color-excesses of the 7 clusters in Table 13 do not increase quite smoothly with the distance and might suggest local irregularities. If we interpolate these color excesses E by a linear formula

$$E = c\,r \qquad (12)$$

where r is the adopted corrected distance, we find by least squares solution

$$c = +0^{m}.32 \pm {}^{m}.03 \text{ (per 1000 parsecs)}$$

[17] *Mount Wilson Contr.* No. 117.
[18] *Mount Wilson Contr.* No. 100, *Ap. J.* **42**, 120, 1915.
[20] *Kgl. Svenska Vet. Akad. Handlingar*, **61**, No. 15, 1921.
[21] *Meddel. Upsala* No. 32, 1927.
[22] *Mount Wilson Contr.* No. 126, *Ap. J.* **45**, 164, 1917.
[23] *Meddel. Upsala*, No. 42, 1929.
[24] *L. O. Bull.* **12**, 12, 1925.
[25] Ten Bruggencate, *Sternhaufen*, 1927, p. 146.

The color excesses computed by formula (12) for the seven clusters are found in the 7th column of Table 13 and the residuals between the observed and computed values, in the 8th column, are in all cases of such small amounts that they can be explained by errors of observation. It would therefore hardly be justifiable to draw from the data of Table 13 a definite conclusion that the absorption is not uniform, although it is rather striking that the two clusters with larger negative residuals are situated in the same region of the sky only a few degrees apart.

To show that the absorption does not depend much on the galactic longitude, the photographic absorption coefficient was determined from the residuals of the cluster diameters for four separate intervals of galactic longitude. These intervals were taken somewhat narrower in those parts of the Milky Way where distant clusters with spectroscopically determined distances are more numerous. The method is similar to that described on page 164, except that the final residuals v'', resulting from a second approximation explained later, and the adopted distances in the 11th column of Table 16, both already corrected for absorption, were used to determine corrections Δk to the adopted absorption constant. In each longitude interval the clusters more distant than 500 parsecs (true distance) were combined with all nearer clusters for the determination by least squares solution of the constants Δa and Δb in the equation (derived from (10)):

$$\Delta a + r\Delta b = v'', \text{ where } \Delta b = \frac{\Delta k}{5}$$

The results are given in Table 14:

TABLE 14

DEPENDENCE OF ABSORPTION CONSTANT ON GALACTIC LONGITUDE

Galactic longitude	1000 Δb	κ	*p. e.*
330°– 45°	−.001	0ᵐ79	±ᵐ09
45 –110	−.041	0.59	±.08
110 –195	+.016	0.87	±.17
195 –330	(−.085)	(0.37)	±.16
All clusters	−.024	0.67	±.07

Every one of the four intervals gives evidence of an absorption effect, and the numerical values of the constant k differ little more than should be expected from their probable errors. The small result for k in the last interval (195°–330°) deserves very little confidence as this interval includes only southern clusters for which no spectroscopic data of the fainter cluster stars are available. The first interval covers the region between *Sagittarius* and *Cygnus* where the Milky Way is divided. This division is sometimes attributed to absorption, and it is perhaps significant that the absorption constant derived from cluster diameters in this region is slightly larger than the average. On the whole, however, there is no convincing observational evidence contrary to the assumption that the absorbing material is of a fairly regular distribution.

It is natural to interpose here the question why such an absorption of light should not have been discovered in the discussion of the diameters of globular clusters which are much more distant, and how it is possible that we still find small color-indices in some globular clusters (such as Messier 13) despite of their great distances. There is only one way which seems to lead out of the dilemma: the hypothesis that the absorbing medium, like the open clusters, is very much concentrated toward the galactic plane. We shall see later that two-thirds of all open clusters lie within 100 parsecs of their plane of symmetry, and it is not improbable that the absorbing material has a similar distribution, thinning out very rapidly at greater distances from the galactic plane and forming so to speak a thin sheet (perhaps 200–300 parsecs thick) extending along the galactic plane to distances of at least 2000 and perhaps 4000 or 6000 parsecs. It is evident that the absorption caused by a material of such distribution is practically negligible (less than 0ᵐ1) for objects in high galactic latitudes. Only for objects lying within 8° of the galactic circle could the photographic absorption amount to 0ᵐ5 or more and the color excess to 0ᵐ25 or more. Of the relatively few globular clusters falling within these limits there are four in which variable stars or magnitudes of the brighter stars have been observed[26]. These four (NGC 6266, 6626, 6638, 6712) do indeed show some effect of absorption, that is, the distance determined from magnitudes is greater than that derived from the diameters. A more thorough investigation of the linear diameters of globular clusters is necessary, however, to draw any definite conclusions.

If our hypothesis is correct, some of the open clusters must also lie outside of this thin layer of absorbing material, and their light should be subject to absorption for part of the distance only. To show that this is the case we take the five clusters of Table 3 for which the distance Z' from the plane of symmetry of the clusters exceeds 200 parsecs and form the average of the final residuals $v'' = \log D'' - \log C''$ (last column of Table 3). The result is $v'' = -0.13$. This means that the corrected linear diameters D'' (Table 3, column 12) are too small, and that the same is true for their corrected spectroscopic distances (Table 3, column 8). The absorption correction applied to the latter must have been too large; these clusters seem

[26] *H. C. O. Bull.* No. 869.

to be less affected by absorption than the majority of clusters at the same distance which lie close to the galactic plane.*

We are thus led to the conclusion that some general and selective absorption is taking place in our Milky Way system, but that this absorption is confined to a relatively thin layer extending more or less uniformly along the plane of symmetry of the system. Perhaps this absorbing material is related to interstellar calcium or to the diffuse nebulae which are also strongly concentrated to the galactic plane.

The change in the color of stars with distance exhibited by Table 13 must be due to the fact that the absorption depends on the wave-length of light, being smaller for the longer wave length used in visual observations than for the shorter waves photographically effective. Designating by k_v the absorption constant per 1000 parsecs of visual observations and by k_p that of photographic observations, the change of color c, determined on p. 165, gives us the difference of the two absorption constants:

$$c = k_p - k_v = +0^{m}.32$$

Combining this with the photographic absorption constant determined from the cluster diameters, for which we adopt the final value in the last line of Table 14, we have

$$k_p = +0^{m}.67 \text{ per 1000 parsecs}$$
$$k_v = +0.35$$

The photographic absorption is nearly twice the visual one. This is not very different from the extinction in the Earth's atmosphere where the ratio of the photographic to the visual extinction is about 2.5.

Defining the absorption coefficient κ by the equation

$$I = I_o e^{-\kappa t}$$

where I_o is the intensity of the incident light, I that of transmitted light and t the length of the path in *cm*:

$$\kappa = 0.20 \times 10^{-21} \text{ for } \lambda = 4300 \text{ A}$$
$$= 0.10 \times 10^{-21} \text{ for } \lambda = 5600 \text{ A}$$

8. Determination of Distances and Diameters (Second Approximation)

As the investigations of the preceding section give strong evidence of the existence of a general absorption of light within our stellar system it becomes necessary to recompute the cluster distances from the observed $m-M$ (column 7, Table 3) by the formula

$$5 \log r + k\frac{r}{1000} = m - M + 5 \qquad (13)$$

which takes into account the effect of absorption, and in which the numerical value

$$k = +0^{m}.79 \text{ per 1000 parsecs}$$

found on page 164 was adopted. The results are given as corrected distances in Table 3, column 9. For the 24 clusters with data printed in italics the systematic error found in Table 8 was also corrected for by the addition of $1^{m}.05$ to the observed $m-M$; this corresponds to the average residual v' of Table 8, reduced by the distance effect of Table 10 (interpolated from the 12th column for the average distance of the clusters).

The corrected distances were adopted as final results of the distance determinations from magnitudes and spectral types; they were used to compute the corrected values D'' of the linear diameters in the 12th column of Table 3, which of course are somewhat smaller on the average than the uncorrected results of the preceding column. On this account the calculation of mean linear diameters of the different subgroups of our classification had to be repeated following the same procedure as before except that all clusters were used this time, giving half weight to the 24 clusters with less certain distance determinations. The results are found in Tables 5, 6, 7 under "Second approximation."

The residuals v'' in the last column of Table 3 are the differences between the logarithm of the corrected linear diameter D'' of each individual cluster and the logarithm of the adopted mean linear diameter C'' (last column of Table 5) corresponding to its classification:

$$v'' = \log D'' - \log C''$$

The discussion of the residuals is now repeated in Tables 8, 9, 10 and 11 in second approximation. Table 8 shows that the corrected cluster distances derived from different observational data now form a homogeneous system. In Table 11 a small dependence of the residuals v'' on the apparent diameter is perhaps still noticeable, but in the opposite sense than before. There is now an indication that the apparent diameters of small and faint clusters were slightly underestimated, which does not seem unlikely. Disregarding the first group mean, which is entirely due to one large residual, this effect, if real, is of the order of the errors of observation and in no case amounts to more than 10%. It seemed therefore justifiable to neglect it.

* J. P. Van Rhijn (Derivation of the change of color with distance and apparent magnitude; Diss. Groningen 1915) from a discussion of color-indices and spectral types of the Yerkes Aktinometry also found a change of color with distance. That his value of c ($+0^{m}.15$ per 1000 parsecs) is smaller than ours, fits in well with our hypothesis that the absorbing medium is highly concentrated to the galactic plane. The stars investigated by Van Rhijn are situated in high galactic latitudes 50 to 350 parsecs distant from the galactic plane and must lie partly outside of the absorbing medium, or in the region where it is gradually thinning out.

According to the last column of Table 10 no appreciable correlation exists between the residuals v'' and the distance; but the determination of a correction to the adopted absorption coefficient from the residuals v'' which is mentioned on page 166 yields for this constant a slightly smaller value. It is therefore possible that our final cluster distances are slightly over-corrected for absorption. If the smaller absorption constant ($k = 0^m67$) is correct, our final results for the distances and linear diameters of open star clusters are on the average 4% too small. This small difference, however, lies well within the limits of observational uncertainty and it did not seem necessary to correct it by a further approximation.

From the residuals v'', which have the character of accidental errors of observation, the probable error ϵ is calculated, taking into account the eight empirically determined constants. For a cluster of full weight we thus obtain

$$\epsilon = \pm.067, \text{ corresponding to } 16\%$$

This error results from three sources of observational error:

1. Errors in the spectroscopic distance determinations (ϵ_r).
2. Errors in the estimates of angular diameters (ϵ_d).
3. The effects of errors in the classification (ϵ_c).

The latter affect the mean linear diameter C'' used for forming the residual v''.

The following estimates for these three probable errors:

$$\epsilon_r = \pm.05 \ (\pm 12\%)$$
$$\epsilon_d = \pm.035 \ (\pm 8\%)$$
$$\epsilon_c = \pm.03 \ (\pm 7\%)$$

represent rather minimum values. Their combined effect is

$$\epsilon = \pm\sqrt{\epsilon_r^2 + \epsilon_d^2 + \epsilon_c^2} = \pm.068$$

The estimated errors of observation thus fully explain the amount of the residuals v''.

Our assumption that clusters of the same constitution have the same linear diameter appears justified if we admit the existence of an absorption of light in our stellar system. It is then possible to determine the distance of a cluster from its apparent diameter and its classification with a probable error of about ±12%, *i. e.*, with the same accuracy as our determinations from magnitudes and spectral types.

9. The Dimensions of Open Star Clusters

It is of interest to examine our results on the dimensions of open star clusters more closely. In the first place it must be recalled that our figures for apparent or linear diameters are "estimated diameters" and must be distinguished from "limiting diameters" which give the extreme limits of clusters. The latter can be ascertained only from star counts or by segregating the physical members from the background stars by their common proper-motions. The few objects for which such investigations have been carried out indicate that the estimated diameter generally refers to the more concentrated central part of the cluster. This denser central part is surrounded by a region where only very few scattered cluster stars occur which gradually thin out towards the limit and do not detach themselves sufficiently from the background stars. As a rule the limiting diameter of a cluster is 2–3 times larger than the estimated diameter. The distribution of the 100 clusters of Table 3 according to their linear diameter D'' (column 12 of Table 3) is given in Table 15 and illustrated in Fig. 1.

TABLE 15

Distribution of Clusters According to Linear Diameters

Estimated linear diameter D'' in parsecs	Number of clusters	
0–1	0	
1–2	1	
2–3	18	77
3–4	25	
4–5	21	
5–6	13	
6–7	7	
7–8	4	
8–9	1	
9–10	4	
10–11	1	
11–12	3	
12–13	1	
13–14	0	
14–15	1	
	100	

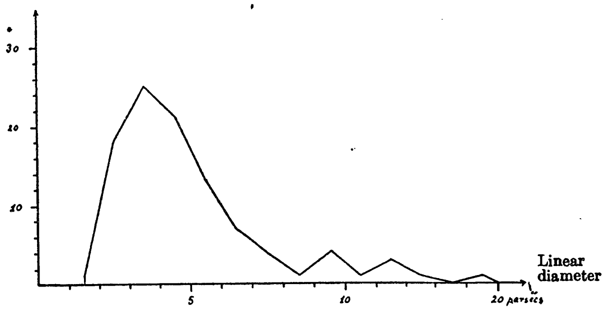

Fig. 1. Distribution of open clusters according to linear diameters.
The ordinate gives the number of clusters with linear diameters falling within the interval plotted as abscissa.

By far the majority of the clusters (77%) have estimated diameters between 2 and 6 parsecs. While the frequency curve of figure 1 drops very sharply on the side of the smallest diameters it runs out gradually in the direction of increasing diameters; a group of abnormally large clusters (our Class IV) is well indicated although having few members.

The relation between the mean linear diameters and our classification of clusters shown in Tables 5, 6, and 7 (second approximation) is of importance for the study of the laws governing the constitution of star clusters. For clusters containing the same number of members we find the diameter to decrease with increasing central concentration. The difference between groups I and II, however, is small, and it is especially group III, with no noticeable central concentration, which stands out by its larger size.

The increase in the cluster diameters with the number of members is quite natural and was anticipated; this increase is more rapid from the poor to the medium rich clusters and rather small between medium rich and rich ones. In Table 7 the average number of stars for a cluster of each subdivision is given as well as the relative volume which is proportional to the third power of the relative diameter. From these two data the relative star density is calculated. It appears from these figures that in a medium rich and in a poor cluster the star density is on the average the same. The larger number of stars is simply accommodated by a larger volume and diameter. But when we pass from a medium rich to a rich cluster we find the increase in stars no longer compensated by a proportional increase in the volume and the star density in very rich clusters is considerably higher than in the poorer ones.

It is further of interest to compare the dimensions of open clusters with those of globular clusters; if we adopt for the latter Shapley's[27] data we have:

	Estimated diameter parsecs	Limiting diameter parsecs	Number of stars
Open clusters Gr I-III	3-7	6-20	10-2000
Open clusters Gr IV	8-12	15-25	10-2000
Globular clusters	40	150	5000-500,000

The globular clusters evidently distinguish themselves not only by the large number of stars they contain but also by their greater linear dimensions. The star density in globular clusters appears to be of similar order as in open clusters.

10. Preliminary Catalogue of Open Star Clusters

The investigations of the preceding chapters have shown that it is possible to determine with a fair degree of accuracy the distance of any cluster for which a good photograph or description is available. It is for this purpose only necessary to classify the cluster according to the system described on page 160 and to estimate its apparent diameter d in minutes of arc. The most probable value C'' of its linear diameter is then taken from the last column of Table 5 and the distance r of the cluster in parsecs is calculated by the formula

$$r = 3438\frac{C''}{d} \qquad (14)$$

For the 100 clusters of Table 3 the results so obtained are found in the 10th column.

To study the general space distribution of open star clusters it is desirable to apply this method as far as possible to all open star clusters known. Unfortunately there is no comprehensive catalogue of this kind at present available. The catalogue of Melotte gives diameter estimates as well as descriptions for 162, most of the brighter and more prominent open clusters, but is very incomplete for the smaller and fainter ones. The *New General Catalogue* of Dreyer and the two subsequent *Index Catalogues* offer the most complete list of clusters, but a careful examination of the (more than 600) objects so described showed that a large number of them refer to scarcely noticeable groupings of a few stars which are probably accidental and of little interest, or to rich Milky Way star fields.

It thus became necessary to compile a new list of open clusters suited for distance determination. The purpose was to select all those star groupings which undoubtedly form physical systems (stars situated at the same distance and probably of common origin) and which at the same time are sufficiently rich in stars for statistical investigation. There are probably numerous physical systems of less than a dozen stars, but these were as a rule not included as they should rather be classed with multiple or double stars. It is hardly possible to describe the constitution of such systems by statistical laws of star distribution (estimated diameter, central concentration, etc.) on which our method for determining distances from apparent diameters is based.

The probability of a clustering forming a physical system was judged on the one hand from the denser congregation of the cluster stars as compared with the surroundings, on the other hand from the regularity or symmetry in the formation of the group, from the definiteness of its outline and an eventual central concentration. It is clear that some arbitrariness can not be avoided in drawing the line of demarcation between open star clusters and related formations such as multiple stars, globular clusters and the smaller star clouds of the Milky Way. The rule followed was to include among open clusters only such star formations as appear to be physical systems and contain not less than a dozen and not more than a few thousand stars.

[27] *Mt. Wilson Contr.* No. 152, 1917.

Every object described as a cluster in the *New General Catalogue*, the two *Index Catalogues*, or mentioned by other observers was thus examined on a copy of the *Franklin Adams Chart* covering the whole sky and on the excellent Milky Way photographs by Barnard. The regions of the *Magellanic Clouds*, however, were excluded, and the examination of the fainter objects was restricted to those lying within 20° of the great circle of the Milky Way. A list of the 334 open clusters thus selected is found in Table 16. The first column gives the designation of the cluster; a plain number refers to the *New General Catalogue*, I. C. to the first or second *Index Catalogues*, Mel to Melotte's Catalogue, An to anonymous clusters not previously listed or newly discovered by the writer. The second and third columns contain the right ascension and declination for 1900 computed mostly from the *New General Catalogue*, the fourth and fifth, the galactic longitude L and latitude B, the sixth to eighth, the rectangular galactic coordinates

$$x = \cos B \cos L$$
$$y = \cos B \sin L$$
$$z = \sin B$$

For the position of the Galactic North Pole $\alpha = 12^h 40^m$, $\delta = +28\overset{\circ}{.}0$ (1900) was used.

TABLE 16

Classification, Diameters and Distances of 334 Open Galactic Star Clusters

(An asterisk in the first column refers to a remark at the end of the table)

N.G.C. I. C.	R. A. 1900	Decl. 1900	Galactic Long.	Galactic Lat.	Galactic coordinates x	y	z	Angul. diam.	Class	Adopted distance parsecs	Wt.	Rectangular coordinates X	Y	Z
103	0h19m8	+60° 47	87°5	− 1°1	+.043	+ .999	−.020	4′	I 2p	2580	......	+ 110	+2580	− 51
129	24.3	+59 40	88.0	− 2.3	+.034	+ .999	−.040	13	IV 2p U	2090	......	+ 70	+2090	− 83
136	25.9	+60 58	88.3	− 1.0	+.030	+ .999	−.017	2.2	II 2p	5320	......	+ 160	+5310	− 90
188	35.1	+84 47	89.9	+22.8	+.002	+ .922	+.387	14	II 1r	1180	......	0	+1090	+456
225	37.6	+61 14	89.7	− 0.7	+.005	+1.000	−.013	14	III 1p	1100	......	+ 10	+1100	− 14
381	1 2.1	+61 3	92.7	− 0.8	−.047	+ .999	−.014	7	III 2p	2210	......	− 100	+2210	− 31
436	9.4	+58 17	93.8	− 3.5	−.067	+ .996	−.061	6	I 3m	1970	2	− 130	+1960	−120
457	12.8	+57 48	94.4	− 3.9	−.076	+ .995	−.068	12	I 3r	1480	2	− 110	+1470	−101
559	22.8	+62 47	94.9	+ 1.2	−.085	+ .996	+.021	6	I 2m	2290	......	− 190	+2280	+ 48
581	26.6	+60 11	95.8	− 1.3	−.100	+ .995	−.023	6.5	II 3m	1960	2	− 200	+1950	− 45
An. 1	29.0	+60 46	96.0	− 0.6	−.104	+ .994	−.011	4.5	I 3p	2290	......	− 240	+2280	− 25
609	30.3	+64 2	95.5	+ 2.6	−.095	+ .995	+.045	3	I 2p :	3430	......	− 330	+3410	+155
*637	36.0	+63 30	96.2	+ 2.2	−.108	+ .993	+.038	3.5	II 3p :	3340	......	− 360	+3320	+127
654	37.2	+61 23	96.8	+ 0.1	−.118	+ .993	+.002	5.5	I 2p	1870	......	− 220	+1860	+ 4
659	37.4	+60 12	97.1	− 1.0	−.123	+ .992	−.018	5	II 2p	2340	......	− 290	+2320	− 42
663	39.2	+60 44	97.2	− 0.4	−.125	+ .992	−.008	14	IV 2m	2170	2	− 270	+2150	− 17
744	51.8	+54 59	100.2	− 5.6	−.177	+ .979	−.098	14	I 2p	740	......	− 130	+ 720	− 73
752	51.8	+37 11	105.4	−22.7	−.246	+ .889	−.385	45	III 1m	390	2	− 100	+ 350	−150
869	2 12.0	+56 41	102.4	− 3.1	−.215	+ .975	−.054	30	IV 3r	1330	2	− 290	+1300	− 72
884	15.4	+56 39	102.9	− 3.0	−.222	+ .974	−.052	30	IV 3r	1330	2	− 300	+1300	− 69
I.C.1805	25.2	+61 0	102.4	+ 1.5	−.215	+ .976	+.026	20	IV 3m N	1810	2	− 390	+1770	+ 47
957	26.4	+57 5	104.1	− 2.0	−.243	+ .969	−.035	9	II 3m U	1680	......	− 410	+1630	− 59
An. 2	30.2	+55 32	105.2	− 3.2	−.262	+ .963	−.056	18	II 3p	680	1.5	− 180	+ 650	− 38
1027	35.0	+61 7	103.5	+ 2.1	−.232	+ .972	−.037	21	IV 3m	1590	2	− 370	+1550	− 59
1039	35.6	+42 21	111.7	−14.8	−.357	+ .899	−.255	30	I 3m	450	2	− 160	+ 400	−115
I.C.1848	43.5	+60 1	104.9	+ 1.6	−.256	+ .966	+.028	22	IV 3mN	1610	......	− 410	+1560	+ 45
1193	59.2	+43 59	114.8	−11.3	−.411	+ .890	−.196	3.2	I 2r	4720	......	−1940	+4200	−925
An. 3	3 3.6	+62 52	105.6	+ 5.3	−.267	+ .959	+.092	17	II 3p	690	......	− 180	+ 660	+ 63
1220	4.4	+52 57	110.8	− 3.2	−.355	+ .933	−.055	2.0	I 2p	5150	......	−1830	+4800	−284
1245	7.8	+46 52	114.5	− 8.0	−.411	+ .901	−.140	7	III 2r	3200	......	−1320	+2880	−448
Perseus	15	+48 15	114.8	− 6.2	−.417	+ .903	−.108	240	IV 3m	170	2	− 71	+ 154	− 18
1342	25.2	+36 59	123.0	−14.3	−.527	+ .813	−.248	15	II 2m	1010	......	− 530	+ 820	−250
Pleiades	41.5	+23 48	134.7	−22.2	−.651	+ .658	−.378	120	II 3r N	150	2	− 98	+ 99	− 57
1444	41.9	+52 21	115.8	− 0.4	−.436	+ .900	−.006	3.5	II 3p	3340	......	−1460	+3010	− 20
1502	58.7	+62 3	111.3	+ 8.5	−.358	+ .922	+.148	8	II 3p	1450	2	− 520	+1340	+215
1513	4 2.6	+49 15	120.3	− 0.6	−.505	+ .863	−.010	9	II 2m U	1680	......	− 850	+1450	− 17
1528	7.8	+50 59	119.7	+ 1.2	−.495	+ .868	+.022	22	II 2m	900	2	− 450	+ 780	+ 20
I.C. 361	10.7	+58 3	115.1	+ 6.6	−.425	+ .900	+.115	6	III 2m	3390	......	−1440	+3050	+390
Taurus	14	+15 23	147.0	−22.4	−.775	+ .503	−.382	400	II 3m	37	2	− 29	+ 19	− 14
1545	13.4	+50 0	121.1	+ 1.2	−.516	+ .857	+.021	15	I 2p	690	......	− 360	+ 590	+ 14
1605	27.8	+45 2	126.3	− 0.5	−.592	+ .806	−.008	4.5	III 2m	4520	......	−2680	+3640	− 36
1647	40.2	+18 53	148.2	−15.4	−.820	+ .507	−.265	35	III 2m	610	2	− 500	+ 310	−162
1662	42.9	+10 45	155.5	−19.7	−.857	+ .390	−.336	14	II 2p	840	1.5	− 720	+ 330	−282
1664	43.9	+43 31	129.4	+ 0.7	−.634	+ .773	+.013	13	II 2m	1160	......	− 740	+ 900	+ 15
1746	57.6	+23 40	146.8	− 9.3	−.826	+ .540	−.161	40	IV 2m	870	2	− 720	+ 470	−140

TABLE 16—(*Continued*)

N.G.C. I.C.	R. A. 1900	Decl. 1900	Galactic Long.	Galactic Lat.	Galactic coordinates x	y	z	Angul. diam.	Class	Adopted distance parsecs	Wt.	Rectangular coordinates X	Y	Z
1778	5h 1m3	+36°55′	136°6	− 0°7	−.726	+ .687	−.013	10′	II 2p	1170	......	− 850	+ 800	− 15
1807	4.9	+16 24	153.9	−12.1	−.878	+ .431	−.209	14	I 2p	720	1.5	− 630	+ 310	−151
*1817	6.3	+16 34	153.9	−11.7	−.879	+ .431	−.202	16	III 2r	1400	......	−1230	+ 600	−283
1857	13.2	+39 14	136.1	+ 2.5	−.720	+ .693	+.044	9	II 2m	1680	......	−1210	+1160	+ 74
1883	18.5	+46 27	130.6	+ 7.4	−.646	+ .752	+.128	3	I 2m	4580	......	−2960	+3440	+586
1893	19.2	+33 18	141.7	+ 0.2	−.784	+ .620	+.003	15	I 3m	920	......	− 720	+ 570	+ 3
1907	21.4	+35 14	140.3	+ 1.6	−.769	+ .638	+.028	5	I 2m	2750	......	−2110	+1750	+ 77
1912	22.0	+35 45	140.0	+ 2.0	−.765	+ .642	+.035	18	II 2r	870	2	− 670	+ 560	+ 30
1960	29.5	+34 4	142.2	+ 2.4	−.790	+ .612	+.042	16	I 3m	980	2	− 770	+ 600	+ 41
*1981	30.2	− 4 30	175.7	−17.5	−.951	+ .071	−.301	25	II 3p	490	2	− 470	+ 30	−147
2099	45.8	+32 31	145.3	+ 4.5	−.820	+ .568	+.078	24	I 1r	820	2	− 670	+ 470	+ 64
2112	48.7	+ 0 22	173.6	−11.1	−.975	+ .110	−.193	9	I 2m	1530	......	−1490	+ 170	−295
2126	55.2	+49 54	130.7	+14.4	−.632	+ .734	+.248	5.5	III 2p	2810	......	−1780	+2060	+697
2129	55.0	+23 18	154.3	+ 1.6	−.901	+ .433	+.027	7	II 3p	1770	......	−1590	+ 770	+ 48
2141	57.5	+10 26	165.8	− 4.3	−.967	+ .245	−.075	8	IV 2r	4860	......	−4700	+1190	−365
An. 4	58.9	+24 0	154.2	+ 2.7	−.899	+ .435	+.047	5.5	II 2p	2130	......	−1910	+ 930	+100
2158	6 1.3	+24 6	154.3	+ 3.2	−.900	+ .432	+.056	4.5	I 2r	3360	......	−3020	+1450	+188
2168	2.7	+24 21	154.3	+ 3.6	−.899	+ .433	+.063	29	III 3r	840	2	− 760	+ 360	+ 53
2169	2.8	+13 58	163.3	− 1.4	−.958	+ .287	−.025	6	II 3p	1950	......	−1870	+ 560	− 49
2186	6.8	+ 5 28	171.2	− 4.7	−.985	+ .152	−.082	4.5	I 3p	2290	......	−2260	+ 350	−188
2192	8.2	+39 53	141.0	+12.0	−.760	+ .616	+.207	5	III 2m	4060	......	−3090	+2500	+840
2194	8.2	+12 50	164.9	− 0.8	−.966	+ .260	−.015	6	I 2r	2520	......	−2430	+ 660	− 38
2204	11.3	−18 37	193.5	−14.7	−.940	− .226	−.254	9	I 2m	1530	......	−1440	− 350	−389
2215	16.0	− 7 15	183.6	− 8.7	−.986	− .063	−.151	8.5	II 2p	1380	......	−1360	− 90	−208
2236	24.3	+ 6 54	172.1	− 0.2	−.990	+ .138	−.004	6	I 2m	2290	......	−2270	+ 320	− 9
*2243	26.0	−31 13	206.9	−16.8	−.854	− .433	−.290	4	I 2m	3440	......	−2940	−1490	−998
2244	27.0	+ 4 56	174.1	− 0.6	−.995	+ .102	−.010	27	IV 3m N	1340	2	−1330	+ 140	− 13
2251	29.3	+ 8 26	171.3	+ 1.6	−.988	+ .151	+.028	7	II 2p	1770	......	−1750	+ 270	+ 50
2254	30.6	+ 7 45	172.1	+ 1.6	−.990	+ .138	+.028	3.8	I 2p	2710	......	−2680	+ 370	+ 76
An. 5	31.2	+ 9 31	170.6	+ 2.5	−.986	+ .164	+.044	9	III 1r	2490	......	−2460	+ 410	+110
2259	33.0	+10 58	169.5	+ 3.6	−.981	+ .182	+.063	3.5	I 3m	3920	......	−3850	+ 710	+247
2264	35.5	+ 9 59	170.6	+ 3.7	−.985	+ .162	+.064	30	II 3p N	450	2	− 440	+ 70	+ 29
2266	37.0	+27 4	155.4	+11.7	−.890	+ .407	+.203	6	I 2r	2520	......	−2240	+1030	+512
2269	38.6	+ 4 40	175.7	+ 1.9	−.997	+ .075	+.033	3	II 2p	3900	......	−3890	+ 290	+129
2281	42.3	+41 10	142.5	+18.4	−.753	+ .578	+.316	15	I 3p	720	1.5	− 540	+ 420	+228
2286	42.6	− 3 4	183.0	− 0.9	−.998	− .052	−.015	9	III 2p	1720	......	−1720	− 90	− 26
2287	42.7	−20 38	198.7	− 9.0	−.936	− .316	−.156	32	I 3r	410	2	− 380	− 130	− 64
2301	46.6	+ 0 35	180.3	+ 1.7	−1.000	− .005	+.030	15	I 3m	920	......	− 920	0	+ 28
2304	49.2	+18 8	164.9	+10.4	−.950	+ .257	+.180	4	I 1m	3440	......	−3270	+ 880	+619
2309	51.2	− 7 4	187.6	− 0.9	−.991	− .131	−.015	3	II 2p	3900	......	−3860	− 510	− 59
2311	52.8	− 4 27	185.4	+ 0.7	−.995	− .095	+.013	4.5	II 2p	2600	......	−2590	− 250	+ 34
2323	58.2	− 8 12	189.4	+ 0.1	−.987	− .163	+.002	16	I 2m	830	1.5	− 820	− 140	+ 2
2324	59.0	+ 1 12	181.2	+ 4.8	−.996	− .020	+.083	8	I 2m	1720	......	−1710	− 30	+143
2335	7 1.8	− 9 56	191.3	+ 0.1	−.981	− .196	+.002	10	II 2p	1170	......	−1150	− 230	+ 2
2343	3.5	−10 30	192.0	+ 0.2	−.978	− .208	+.004	6	II 3p	1950	......	−1910	− 410	+ 8
2345	3.7	−13 1	194.2	− 1.0	−.969	− .246	−.017	11	II 2p U	1060	......	−1030	− 260	− 18
2353	9.8	−10 8	192.4	+ 1.7	−.976	− .215	+.030	20	I 3m U	760	1.5	− 740	− 160	+ 23
2354	10.1	−25 34	206.0	− 5.6	−.894	− .436	−.098	20	III 1m	1020	......	− 910	− 440	−100
2355	11.3	+13 57	171.1	+13.3	−.962	+ .151	+.230	7	I 2m	1960	......	−1890	+ 300	+451
2360	13.2	−15 27	197.5	− 0.1	−.954	− .301	−.002	11	I 2r	1370	......	−1310	− 410	− 3
2362	14.6	−24 46	205.8	− 4.4	−.898	− .434	−.076	7	I 3p	1250	1.5	−1120	− 540	− 95
2367	15.9	−21 45	203.3	− 2.6	−.918	− .395	−.046	4.5	II 3p E	2600	......	−2390	−1030	−120
2368	16.2	−10 12	193.2	+ 3.1	−.972	− .229	+.054	4	II 2p	2920	......	−2840	− 670	+158
2374	19.4	−13 4	196.1	+ 2.3	−.960	− .278	+.041	4.5	II 2p	2600	......	−2500	− 720	+107
2383	20.4	−20 44	202.9	− 1.2	−.921	− .390	−.022	6	I 2p	1720	......	−1580	− 670	− 38
2384	20.7	−20 50	203.1	− 1.2	−.920	− .392	−.021	4.5	II 3p	2600	......	−2390	−1020	− 55
*2395	21.5	+13 47	172.4	+15.4	−.955	+ .128	+.266	14	III 2p :	1100	......	−1050	+ 140	+293
An. 6	21.9	−24 6	206.0	− 2.6	−.898	− .438	−.045	5.5	I 2p	1870	......	−1680	− 820	− 84
An. 7	23.1	−23 50	205.9	− 2.2	−.898	− .437	−.039	5.5	II 3p	2130	......	−1910	− 930	− 83
Mel. 66	23.4	−47 32	227.0	−13.5	−.663	− .711	−.234	11	II 2m	1370	......	− 910	− 970	−321
2401	24.8	−13 46	197.4	+ 3.1	−.953	− .299	+.055	2	I 2p :	5150	......	−4910	−1540	+283
2414	28.7	−15 14	199.1	+ 3.2	−.943	− .327	+.056	8	I 3p	1200	......	−1130	− 390	+ 67

TABLE 16—(*Continued*)

N.G.C. I. C.	R. A. 1900	Decl. 1900	Galactic Long.	Galactic Lat.	Galactic coordinates *x*	*y*	*z*	Angul. diam.	Class	Adopted distance parsecs	Wt.	Rectangular coordinates *X*	*Y*	*Z*
2420	7h32m5	+21°48′	165°8	+21°1	−.904	+ .229	+.360	6′	II 2m	2520	......	−2280	+ 580	+907
2421	31.9	−20 23	204.0	+ 1.3	−.914	− .406	+.022	9	II 2p	1300	......	−1190	− 530	+ 29
2422	32.0	−14 16	198.7	+ 4.4	−.944	− .320	+.077	30	II 3m	480	2	− 450	− 150	+ 37
2423	32.5	−13 38	198.2	+ 4.8	−.946	− .312	+.084	19	I 2m	720	......	− 680	− 220	+ 61
Mel. 71	32.9	−11 50	196.7	+ 5.8	−.953	− .286	+.102	8	II 2m	1890	......	−1800	− 540	+193
Mel. 72	33.7	−10 27	195.6	+ 6.7	−.956	− .267	+.116	5	II 1p	2340	......	−2240	− 620	+272
2432	36.5	−18 51	203.2	+ 3.0	−.918	− .394	+.052	4.5	II 2p	2600	......	−2390	−1020	+135
2437	37.2	−14 35	199.6	+ 5.3	−.938	− .334	+.093	27	II 2r	660	2	− 620	− 220	+ 61
2439	37.0	−31 25	214.0	− 3.4	−.827	− .559	−.059	9	II 3m U	1680	......	−1390	− 940	− 99
2447	40.4	−23 38	207.8	+ 1.3	−.885	− .466	+.023	18	I 3r	850	1.5	− 750	− 400	+ 20
2451	41.8	−37 44	220.0	− 5.8	−.762	− .639	−.102	37	I 3p	285	2	− 220	− 180	− 29
2453	43.6	−27 0	211.0	+ 0.1	−.857	− .516	+.002	4	I 3p	2580	......	−2210	−1330	+ 5
2455	44.6	−21 3	206.1	+ 3.5	−.897	− .439	+.060	5.5	III 2p	2810	......	−2520	−1230	+169
2477	48.7	−38 17	221.2	− 4.9	−.750	− .656	−.086	25	I 2r	600	......	− 450	− 390	− 52
2482	50.7	−24 2	209.4	+ 3.1	−.870	− .490	+.054	11	II 2p	1060	......	− 920	− 520	+ 57
An. 8	50.8	−17 33	203.9	+ 6.6	−.908	− .402	+.114	9	II 1p	1300	......	−1180	− 520	+148
An. 9	51.1	−25 40	210.8	+ 2.3	−.858	− .512	+.040	5	II 3p	2340	......	−2010	−1200	+ 94
2489	52.2	−29 48	214.4	+ 0.2	−.825	− .565	+.004	7	I 2m	1960	......	−1620	−1110	+ 8
*2506	55.2	−10 31	198.4	+11.2	−.931	− .310	+.194	11	I 2r	1370	......	−1280	− 420	+266
2509	56.3	−18 48	205.7	+ 7.0	−.895	− .430	+.122	4.5	I 2m :	3050	......	−2730	−1310	+372
2516	56.7	−60 36	241.2	−15.5	−.464	− .845	−.267	50	I 3r	305	2	− 140	− 260	− 81
2527	8 1.1	−27 53	213.9	+ 2.9	−.829	− .557	+.051	15	II 2p	780	......	− 650	− 430	+ 40
2533	3.0	−29 37	215.6	+ 2.3	−.813	− .581	+.040	4	I 2p	2580	......	−2100	−1500	+103
2539	6.0	−12 32	201.6	+12.4	−.908	− .360	+.214	22	II 1m	740	2	− 670	− 270	+159
*2546	8.7	−37 20	222.6	− 1.1	−.736	− .676	−.020	45	III 2p	420	2	− 310	− 280	− 8
2547	7.7	−48 58	232.1	− 7.9	−.609	− .781	−.138	17	II 3p	690	1.5	− 420	− 540	− 95
2548	8.8	− 5 30	195.8	+16.7	−.922	− .261	+.287	30	I 2r	470	2	− 430	− 120	+135
2567	14.6	−30 20	217.6	+ 3.9	−.791	− .608	+.069	11	II 2m	1370	......	−1080	− 830	+ 95
2571	14.9	−29 26	216.9	+ 4.5	−.797	− .598	+.078	10	I 3p	1030	......	− 820	− 620	+ 80
2588	19.2	−32 39	220.0	+ 3.3	−.764	− .642	+.058	2.5	II 2p :	4680	......	−3580	−3000	+271
2627	33.1	−29 36	219.4	+ 7.6	−.766	− .629	+.132	8	II 2m	1890	......	−1450	−1190	+249
2632	34.3	+20 20	173.3	+34.0	−.824	+ .096	+.559	90	I 2r	150	2	− 123	+ 14	+ 84
2635	34.5	−34 25	223.4	+ 4.8	−.724	− .684	+.084	3	II 2m :	5040	......	−3650	−3450	+423
I.C.2391*	37.4	−52 42	237.8	− 6.4	−.528	− .842	−.111	45	II 3p	210	2	− 110	− 180	− 23
2658	39.4	−32 18	222.4	+ 6.9	−.733	− .669	+.121	9	I 2m	1530	......	−1120	−1020	+185
2659	39.2	−44 36	231.8	− 1.0	−.618	− .786	−.017	11	II 2m	1370	......	− 850	−1080	− 23
I.C.2395	40.0	−47 49	234.4	− 3.0	−.582	− .812	−.052	20	II 3p	500	2	− 290	− 410	− 26
*2669	42.0	−52 36	238.3	− 5.8	−.523	− .846	−.101	14	I 3p	740	......	− 390	− 630	− 75
2670	42.3	−48 25	235.1	− 3.0	−.571	− .819	−.053	11	I 2p	940	......	− 540	− 770	− 50
2671	42.6	−41 31	229.9	+ 1.5	−.644	− .764	+.026	4	II 2p :	2920	......	−1880	−2230	+ 76
An. 10	44.2	−42 7	230.5	+ 1.3	−.635	− .772	+.023	30	II 3p	350	2	− 220	− 270	+ 8
2682	45.8	+12 11	183.6	+33.3	−.834	− .053	+.549	18	II 2r	740	2	− 620	− 39	+406
2818	9 12.0	−36 12	229.9	+ 9.3	−.636	− .755	+.161	9	II 2m	1680	......	−1070	−1270	+271
I.C.2488	24.6	−56 32	245.4	− 4.1	−.415	− .907	−.071	18	IV 2m U	1970	......	− 820	−1790	−140
2910	27.0	−52 28	243.0	− 0.8	−.454	− .890	−.014	6	II 2p	1950	......	− 890	−1740	− 27
2925	30.3	−53 0	243.7	− 0.9	−.443	− .896	−.016	16	II 2p	730	......	− 320	− 650	− 12
2972	36.7	−49 52	242.4	+ 2.2	−.462	− .886	+.038	4.5	I 2m	3050	......	−1410	−2700	+116
3033	45.4	−55 57	247.2	− 1.8	−.387	− .922	−.031	5	II 2p	2340	......	− 910	−2160	− 73
3105	57.2	−54 18	247.6	+ 0.5	−.380	− .925	+.009	2.5	II 2p :	4680	......	−1780	−4330	+ 42
3114	59.5	−59 38	250.9	− 3.6	−.326	− .943	−.064	37	II 3r	440	2	− 140	− 410	− 28
An. 11	10 1.9	−61 7	252.0	− 4.7	−.307	− .948	−.082	4	II 2p	2920	......	− 900	−2770	−239
An. 12	3.2	−59 49	251.4	− 3.5	−.318	− .946	−.062	4	I 2m	3440	......	−1090	−3250	−213
3228	17.8	−51 13	248.6	+ 4.8	−.364	− .927	+.084	20	I 2p	500	2	− 180	− 460	+ 42
An. 13	20.3	−59 35	253.1	− 2.2	−.290	− .956	−.038	4	II 2m :	3770	......	−1080	−3600	−143
3255	22.9	−60 10	253.7	− 2.5	−.280	− .959	−.044	3	I 2p :	3430	......	− 960	−3290	−151
I.C.2581	23.7	−57 8	252.3	+ 0.1	−.304	− .953	+.002	10	II 3p	1170	......	− 360	−1120	+ 2
3293	32.0	−57 43	253.6	+ 0.2	−.283	− .959	+.003	8	II 3r	1990	1.5	− 560	−1910	+ 6
3330	34.6	−53 37	251.9	+ 4.0	−.309	− .949	+.069	8	II 3m	1890	......	− 580	−1790	+130
Mel. 101	38.6	−64 34	257.4	− 5.6	−.217	− .971	−.097	15	II 2m	1010	......	− 220	− 980	− 98
I.C.2602	39.4	−63 52	257.2	− 4.9	−.221	− .972	−.085	65	II 3m	210	2	− 50	− 200	− 18
An. 14	40.1	−59 2	255.1	− 0.5	−.257	− .966	−.009	4	I 3m N	3440	......	− 880	−3320	− 31
An. 15	40.8	−58 50	255.1	− 0.3	−.257	− .967	−.005	3.5	I 3p	2940	......	− 760	−2840	− 15

TABLE 16—(*Continued*)

N.G.C. I.C.	R. A. 1900	Decl. 1900	Galactic Long.	Galactic Lat.	Galactic coordinates x	y	z	Angul. diam.	Class	Adopted distance parsecs	Wt.	Rectangular coordinates X	Y	Z
An. 16	10^h41^m2	−59°11′	255°3	− 0°6	−.254	− .967	−.010	10′	IV 3m NU	3550	......	− 900	−3430	− 36
An. 17	52.2	−58 41	256.4	+ 0.5	−.236	− .972	+.008	5.5	I 3p	1870	......	− 440	−1820	+ 15
3496	55.8	−59 48	257.2	− 0.4	−.221	− .975	−.007	7	III 2m	2900	......	− 640	−2830	− 20
3532	11 2.2	−58 8	257.4	+ 1.5	−.218	− .975	+.026	55	II 2r	350	2	− 80	− 340	+ 9
3572	6.2	−59 42	258.4	+ 0.2	−.201	− .980	+.003	5	II 3p	2340	......	− 470	−2290	+ 7
An. 18	7.2	−60 8	258.6	0.0	−.198	− .982	.000	12	IV 3m	2960	......	− 590	−2910	0
An. 19	10.0	−57 3	258.0	+ 2.8	−.208	− .977	+.050	13	IV 2m	2730	......	− 570	−2670	+136
3603	10.8	−60 43	259.3	− 0.6	−.186	− .983	−.010	2	I 3m :	6880	......	−1280	−6760	− 69
I.C.2714	13.6	−62 10	260.1	− 1.8	−.172	− .984	−.032	11	II 2r	1500	......	− 260	−1480	− 48
Mel. 105	15.2	−62 58	260.5	− 2.5	−.164	− .985	−.044	4	I 3m	3440	......	− 560	−3390	−151
3680	20.9	−42 41	254.9	+17.0	−.249	− .923	+.292	12	I 2p	860	......	− 210	− 790	+251
3766	31.5	−61 3	261.8	− 0.1	−.142	− .990	−.002	12	I 2r	1220	1.5	− 170	−1210	− 2
*3960	45.9	−55 8	262.3	+ 6.1	−.134	− .986	+.106	7	I 2m	1960	......	− 260	−1930	+208
*4052	56.8	−62 38	265.1	− 1.0	−.086	− .996	−.018	10	II 2m E	1510	......	− 130	−1500	− 27
4103	12 1.5	−60 41	265.3	+ 1.0	−.082	− .997	+.017	9	I 3m	1530	......	− 130	−1530	+ 26
4230	11.8	−54 45	265.9	+ 7.0	−.071	− .980	+.122	4.5	II 2p :	2600	......	− 180	−2550	+317
4337	18.5	−57 34	267.1	+ 4.2	−.050	− .996	+.073	4	I 2p	2580	......	− 130	−2570	+188
4349	19.0	−61 20	267.5	+ 0.6	−.044	− .999	+.010	17	II 2r	970	......	− 40	− 970	+ 10
Coma	20	+26 40	195.6	+85.2	−.078	− .022	+.997	300	II 3p	81	2	− 6	− 2	+ 81
4439	22.9	−59 32	267.8	+ 2.4	−.038	− .998	+.042	3.5	II 2p	3340	......	− 130	−3330	+140
4463	24.3	−64 14	268.3	− 2.3	−.030	− .999	−.040	5	I 3p	2060	......	− 60	−2060	− 82
An. 20	33.9	−60 3	269.2	+ 1.9	−.013	− .999	+.034	10	III 2r	2240	......	− 30	−2240	+ 76
4609	36.5	−62 25	269.6	− 0.4	−.007	−1.000	−.007	4.5	II 2p	2600	......	− 20	−2600	− 18
4755	47.7	−59 48	270.9	+ 2.2	+.017	− .999	+.038	12	I 3r	1090	1.5	+ 20	−1090	+ 41
4815	51.8	−64 25	271.3	− 2.4	+.022	− .999	−.043	4	I 3m	3440	......	+ 80	−3440	−148
4852	54.1	−59 4	271.8	+ 2.9	+.032	− .998	+.050	11	II 2m	1370	......	+ 40	−1370	+ 68
5138	13 20.9	−58 29	275.3	+ 3.1	+.093	− .994	+.054	8	II 2p	1460	......	+ 140	−1450	+ 78
5168	24.6	−60 25	275.5	+ 1.1	+.095	− .995	+.019	3.2	I 3m	4300	......	+ 410	−4280	+ 82
An. 21	25.5	−62 17	275.3	− 0.7	+.092	− .996	−.013	5	I 3p	2060	......	+ 190	−2050	− 27
5281	39.7	−62 24	276.8	− 1.2	+.119	− .993	−.021	4	I 3m	3440	......	+ 410	−3420	− 72
5288	41.6	−64 11	276.7	− 3.0	+.116	− .992	−.052	3	II 2p	3900	......	+ 450	−3870	−203
5316	46.9	−61 22	277.9	− 0.4	+.138	− .990	−.007	11	II 2p	950	1.5	+ 130	− 940	− 7
5460	14 1.2	−47 50	283.8	+12.0	+.233	− .950	+.208	35	II 3m	470	2	+ 110	− 450	+ 98
5606	20.5	−59 11	282.5	+ 0.4	+.217	− .986	+.006	2.2	II 2p :	5310	......	+1150	−5240	+ 32
5617	22.3	−60 16	282.4	− 0.7	+.214	− .977	−.013	14	I 2r	1010	1.5	+ 220	− 990	− 13
An. 22	23.7	−60 43	282.3	− 1.2	+.214	− .977	−.021	7	III 2p	2210	......	+ 470	−2160	− 46
5662	28.0	−56 7	284.7	+ 2.8	+.253	− .966	+.049	15	II 3p E	670	2	+ 170	− 650	+ 33
5715	36.1	−57 7	285.3	+ 1.4	+.264	− .964	+.025	9	II 2m	1680	......	+ 440	−1620	+ 42
5749	41.8	−54 6	287.4	+ 3.8	+.297	− .952	+.066	8	II 2p	1460	......	+ 430	−1390	+ 96
5764	46.5	−52 16	288.8	+ 5.1	+.321	− .943	+.088	2.2	I 2p :	4690	......	+1510	−4420	+413
5822	57.9	−53 57	289.5	+ 2.8	+.333	− .942	+.049	40	III 1m	560	2	+ 190	− 530	+ 27
5823	58.3	−55 12	288.9	+ 1.7	+.324	− .946	+.029	10	III 2m	2030	......	+ 660	−1920	+ 59
5925	15 20.2	−54 10	292.1	+ 0.8	+.377	− .926	+.015	20	III 2m	1020	......	+ 380	− 940	+ 15
5999	44.3	−56 10	293.7	− 2.8	+.401	− .915	−.049	6	I 2r	2520	......	+1010	−2310	−123
6005	47.8	−57 8	293.4	− 3.8	+.397	− .916	−.067	3.5	I 2m	3920	......	+1560	−3590	−263
An. 23	52.8	−53 14	296.5	− 1.4	+.446	− .894	−.024	5	III 2p	3090	......	+1380	−2760	− 74
6025	55.2	−60 13	292.1	− 6.8	+.374	− .920	−.119	11	II 3 p	1020	1.5	+ 380	− 940	−121
6031	59.8	−53 47	296.9	− 2.5	+.452	− .891	−.043	2	II 2p :	5850	......	+2650	−5210	−252
6067	16 5.4	−53 57	297.4	− 3.2	+.460	− .886	−.055	16	I 2r	940	......	+ 430	− 830	− 52
6087	10.6	−57 39	295.3	− 6.3	+.425	− .898	−.110	18	II 3m	870	1.5	+ 370	− 780	− 96
6124	18.8	−40 26	308.6	+ 4.8	+.621	− .779	+.084	25	I 3r	620	2	+ 390	− 480	+ 52
6134	20.3	−48 55	302.6	− 1.2	+.539	− .842	−.022	8	II 2r	2060	......	+1110	−1730	− 45
6152	24.9	−52 24	300.6	− 4.2	+.507	− .859	−.072	20	I 2m	690	......	+ 350	− 590	− 50
6167	26.8	−49 23	303.1	− 2.4	+.544	− .836	−.041	14	I 3m	980	......	+ 530	− 820	− 40
6178	28.5	−45 25	306.1	+ 0.1	+.589	− .808	+.002	4	II 3p	2920	......	+1720	−2360	+ 6
6192	33.3	−43 10	308.4	+ 1.0	+.621	− .784	+.017	7	I 3m	1960	......	+1220	−1540	+ 33
6204	39.1	−46 50	306.3	− 2.2	+.591	− .806	−.038	6	II 2m	2520	......	+1490	−2030	− 96
6208	41.5	−53 38	301.3	− 6.8	+.515	− .848	−.119	20	IV 2m U	1770	......	+ 910	−1500	−211
*6216	42.2	−44 33	308.4	− 1.1	+.620	− .784	−.020	3.8	II 2m	3970	......	+2460	−3110	− 79
6231	47.0	−41 38	311.2	0.0	+.658	− .753	.000	16	I 3r	980	1.5	+ 640	− 740	0

TABLE 16—(*Continued*)

N.G.C. I. C.	R. A. 1900	Decl. 1900	Galactic Long.	Galactic Lat.	Galactic coordinates x	y	z	Angul. diam.	Class	Adopted distance parsecs	Wt.	Rectangular coordinates X	Y	Z
An. 24	16h48m8	−40°33′	312°2	+ 0°4	+.672	− .740	+.008	60′	IV 3m N	580	2	+ 390	− 430	+ 5
6242	48.8	−39 20	313.2	+ 1.2	+.684	− .729	+.021	11	I 3m	1280	1.5	+ 880	− 930	+ 27
6249	50.4	−44 37	309.2	− 2.3	+.632	− .774	−.041	7	II 2p	1770	......	+1120	−1370	− 73
6253	51.2	−52 33	303.0	− 7.3	+.541	− .832	−.127	5	I 2m	2750	......	+1490	−2290	−349
6259	53.5	−44 31	309.6	− 2.7	+.637	− .769	−.047	16	IV 2r	2430	......	+1550	−1870	−114
6268	55.2	−39 35	313.7	+ 0.1	+.691	− .722	+.001	7	II 2p	1770	......	+1220	−1280	+ 2
6281	58.0	−37 45	315.6	+ 0.8	+.714	− .700	+.013	9	II 2p	1300	......	+ 930	− 910	+ 17
6318	17 10.8	−39 20	315.7	− 2.2	+.716	− .697	−.038	5	II 2m	3020	......	+2160	−2100	−115
*6322	11.3	−42 50	312.9	− 4.3	+.679	− .730	−.075	9	II 3p	1230	1.5	+ 840	− 900	− 92
I.C.4651	16.9	−49 50	307.6	− 9.0	+.603	− .782	−.157	14	II 2r	1180	......	+ 710	− 920	−185
An. 25	17.8	−38 54	316.9	− 3.1	+.729	− .683	−.054	5	I 2p	2000	......	+1460	−1370	−108
An. 26	21.9	−29 23	325.3	+ 1.5	+.821	− .569	+.027	7.5	II 2p	1560	......	+1280	− 890	+ 42
6383	28.2	−32 30	323.4	− 1.3	+.802	− .596	−.023	5.5	II 3p	2130	......	+1710	−1270	− 49
An. 27	29.6	−33 25	322.7	− 2.0	+.795	− .605	−.036	8	I 2p	1290	......	+1030	− 780	− 46
An. 28	30.2	−32 25	323.7	− 1.6	+.805	− .592	−.028	7.5	II 2p	1560	......	+1260	− 920	− 44
6396	31.5	−34 56	321.7	− 3.2	+.783	− .619	−.056	4	I 2p	2580	......	+2020	−1600	−144
6400	32.7	−36 53	320.2	− 4.4	+.766	− .638	−.078	7.5	I 2p	1370	......	+1050	− 870	−107
6404	33.0	−33 11	323.3	− 2.5	+.802	− .597	−.044	5	II 3m	3020	......	+2420	−1800	−133
6405	33.5	−32 9	324.3	− 2.0	+.811	− .584	−.036	26	II 3m	520	2	+ 420	− 300	− 19
An. 29	34.7	−40 3	317.7	− 6.5	+.734	− .669	−.112	14	II 2p	830	......	+ 610	− 560	− 93
6416	37.8	−32 18	324.6	− 2.9	+.814	− .578	−.051	22	III 2p	730	1.5	+ 590	− 420	− 37
6425	40.5	−31 29	325.6	− 3.0	+.824	− .564	−.052	10	II 1p	1170	......	+ 960	− 660	− 61
I.C.4665	41.4	+ 5 45	358.2	+15.6	+.962	− .030	+.269	50	II 2p	280	2	+ 270	− 10	+ 75
6451	44.3	−30 11	327.2	− 3.0	+.839	− .542	−.052	6	II 2m	2520	......	+2110	−1370	−131
6469	46.9	−22 19	334.2	+ 0.5	+.900	− .435	+.009	15	IV 2m	2370	......	+2130	−1030	+ 21
6475	47.3	−34 47	323.5	− 5.9	+.800	− .592	−.102	50	I 3m	255	2	+ 200	− 150	− 26
An. 30	49.7	−35 18	323.3	− 6.6	+.796	− .594	−.114	15	IV 3m	2370	......	+1890	−1410	−270
6494	51.0	−19 0	337.6	+ 1.4	+.924	− .382	+.024	27	I 2r	660	2	+ 610	− 250	+ 16
An. 31	53.6	−28 10	329.9	− 3.7	+.864	− .500	−.065	4.5	II 2m	3360	......	+2900	−1680	−218
6520	57.1	−27 54	330.5	− 4.3	+.868	− .490	−.074	4.5	II 3m	3360	......	+2920	−1650	−249
6530	58.6	−24 20	333.8	− 2.8	+.896	− .440	−.049	14	II 2m N	1090	2	+ 980	− 480	− 53
6531	58.6	−22 30	335.4	− 1.9	+.909	− .416	−.033	12	I 3p	980	2	+ 890	− 410	− 32
*6546	18 1.2	−23 19	335.0	− 2.8	+.905	− .422	−.049	13	IV 3r	3000	......	+2720	−1270	−147
6568	6.8	−21 37	337.1	− 3.1	+.920	− .389	−.055	15	III 1m	1350	......	+1240	− 530	− 74
6583	9.8	−22 10	337.0	− 4.0	+.918	− .390	−.070	3.8	I 2m	3620	......	+3320	−1410	−253
An. 32	11.9	−13 23	344.9	− 0.2	+.966	− .260	−.004	5.5	I 2p	1870	......	+1810	− 490	− 7
6603	12.6	−18 27	340.6	− 2.8	+.942	− .333	−.049	4.5	I 2r	3360	......	+3160	−1120	−165
6604	12.5	−12 16	346.0	+ 0.2	+.970	− .243	+.004	2.8	I 3p	3680	......	+3570	− 890	+ 15
6611	13.2	−13 49	344.7	− 0.7	+.964	− .264	−.012	8	II 3m N	2050	2	+1980	− 540	− 25
6613	14.1	−17 10	341.8	− 2.5	+.949	− .311	−.043	7	II 3p	1780	1.5	+1690	− 550	− 77
An. 33	18.8	−19 44	340.1	− 4.7	+.937	− .339	−.082	5.5	I 3p	1870	......	+1750	− 630	−153
6631	21.6	−12 6	347.2	− 1.7	+.975	− .222	−.029	4.5	I 2p	2290	......	+2230	− 510	− 66
6633	22.7	+ 6 30	3.8	+ 6.8	+.991	+ .065	+.119	25	I 2p E	380	2	+ 380	+ 20	+ 45
I.C.4725	25.8	−19 19	341.3	− 6.0	+.942	− .320	−.104	35	IV 3r	980	2	+ 920	− 310	−102
6645	26.8	−16 58	343.5	− 5.1	+.955	− .284	−.088	13	I 2r	1230	2	+1170	− 350	−108
6649	27.9	−10 28	349.4	− 2.3	+.982	− .184	−.040	7.5	I 2m	1830	......	+1800	− 340	− 73
6664	31.3	− 8 18	351.7	− 2.0	+.989	− .145	−.035	20	IV 2m	1770	......	+1750	− 260	− 62
I.C.4756	34.0	+ 5 22	4.0	+ 3.8	+.995	+ .070	+.067	50	III 1m	405	2	+ 400	+ 30	+ 27
An. 34	34.4	− 8 34	351.8	− 2.8	+.988	− .143	−.048	10	II 2p	1170	......	+1160	− 170	− 56
An. 35	37.7	− 4 14	356.0	− 1.4	+.997	− .070	−.025	5	II 2m	3020	......	+3010	− 210	− 76
6694	39.8	− 9 30	351.6	− 4.4	+.986	− .146	−.077	9	II 2m	1610	2	+1590	− 240	−124
6704	45.5	− 5 19	355.9	− 3.7	+.995	− .071	−.065	5	I 2p	2060	......	+2050	− 150	−134
6705	45.7	− 6 23	355.0	− 4.3	+.994	− .087	−.074	12.5	II 2r	1340	2	+1330	− 120	− 99
6709	46.7	+10 14	9.8	+ 3.3	+.984	+ .170	+.058	12	II 2p	940	2	+ 920	+ 160	+ 55
6716	48.6	−20 1	343.1	−11.1	+.939	− .285	−.192	8	II 3p	1320	1.5	+1240	− 380	−253
6717	49.1	−22 50	340.5	−12.4	+.921	− .325	−.214	3	II 2p	3900	......	+3590	−1270	−835
6755	19 2.8	+ 4 4	6.3	− 3.1	+.992	+ .109	−.054	15	IV 2m	2370	......	+2350	+ 260	−128
6756	3.7	+ 4 31	6.8	− 3.1	+.992	+ .118	−.054	4	I 2p	2570	......	+2550	+ 300	−139
6802	26.2	+20 4	23.0	− 0.3	+.920	+ .391	−.005	5	III 1m E	4060	......	+3740	+1590	− 20
6811	35.2	+46 20	46.9	+11.2	+.671	+ .716	+.194	13	III 1p	950	2	+ 640	+ 680	+184
6819	37.9	+39 57	41.5	+ 7.6	+.742	+ .657	+.132	6	I 2r	2520	......	+1870	+1660	+332

TABLE 16—(*Concluded*)

N.G.C. I.C.	R. A. 1900	Decl. 1900	Galactic		Galactic coordinates			Angul. diam.	Class	Adopted distance parsecs	Wt.	Rectangular coordinates		
			Long.	Lat.	*x*	*y*	*z*					*X*	*Y*	*Z*
6823	19h38m9	+23° 4′	27°1	− 1°3	+.890	+ .456	−.022	7′	IV 3p	3890	......	+3460	+1770	− 86
6830	46.8	+22 50	27.9	− 3.0	+.883	+ .467	−.052	10	IV 2m	3550	......	+3140	+1660	−185
6834	48.2	+29 9	33.4	+ 0.2	+.835	+ .550	+.003	7	I 2m	1960	......	+1640	+1080	+ 6
Mel. 227	59	−79 36	281.4	−31.0	+.170	− .840	−.516	60	II 2p	240	2	+ 40	− 200	−124
6866	20 0.5	+43 43	47.0	+ 6.0	+.679	+ .727	+.105	10	I 2p	960	2	+ 650	+ 700	+101
6871	2.1	+35 30	40.3	+ 1.2	+.762	+ .647	+.021	25	IV 3p	1340	1.5	+1020	+ 870	+ 28
An. 36	7.0	+40 55	45.3	+ 3.5	+.702	+ .710	+.060	6	III 1r	3740	......	+2630	+2660	+224
*6882	7.5	+26 15	33.3	− 5.0	+.832	+ .548	−.087	8	I 2p	1350	2	+1120	+ 740	−117
6883	7.5	+35 33	41.0	+ 0.3	+.755	+ .656	+.005	15	IV 3p	1810	......	+1370	+1190	+ 9
*6885	7.8	+26 11	33.3	− 5.1	+.832	+ .547	−.089	22	III 2p	630	2	+ 520	+ 340	− 56
I.C.4996	12.8	+37 20	43.0	+ 0.5	+.731	+ .682	+.008	6	I 3p	1840	2	+1340	+1250	+ 15
6910	19.5	+40 27	46.3	+ 1.3	+.690	+ .723	+.022	13	IV 3p	2090	......	+1440	+1510	+ 46
6913	20.3	+38 12	44.6	− 0.2	+.711	+ .702	−.004	7	III 3p	2100	2	+1490	+1470	− 8
6939	29.4	+60 18	63.3	+11.9	+.440	+ .874	+.207	8	II 1r	1800	2	+ 790	+1570	+373
6940	30.4	+27 58	37.8	− 8.1	+.783	+ .606	−.141	26	III 1m	800	2	+ 630	+ 480	−113
7031	21 4.1	+50 26	59.0	+ 1.8	+.515	+ .856	+.031	7	II 3p U	1770	......	+ 910	+1510	+ 55
I.C.1369	8.7	+47 20	57.3	− 0.9	+.540	+ .842	−.016	3	II 2p	3900	......	+2110	+3280	− 62
7044	9.2	+42 5	53.7	− 4.7	+.590	+ .803	−.082	5	I 2r	3020	......	+1780	+2420	−248
7062	19.6	+45 57	57.6	− 3.2	+.535	+ .844	−.056	6	II 2p	1950	......	+1050	+1650	−110
7063	20.4	+36 4	51.0	−10.6	+.618	+ .764	−.183	8	II 2p	1460	......	+ 900	+1120	−267
*7067	20.6	+47 35	58.8	− 2.3	+.518	+ .854	−.040	2.5	II 2p	4680	......	+2420	+4000	−187
7086	27.1	+51 9	62.1	− 0.2	+.468	+ .884	−.003	7.5	I 2m	1840	......	+ 860	+1630	− 6
7092	28.6	+48 0	60.2	− 2.7	+.496	+ .867	−.048	32	II 2p	330	2	+ 160	+ 280	− 16
An. 37	35.9	+57 2	66.9	+ 3.5	+.392	+ .918	+.060	60	IV 3r N	730	1.5	+ 290	+ 670	+ 44
7128	40.6	+53 15	65.0	+ 0.1	+.422	+ .907	+.002	3.2	II 2p	3650	......	+1540	+3310	+ 7
7142	43.5	+65 20	72.9	+ 9.3	+.291	+ .943	+.162	11	II 1m	1370	......	+ 400	+1290	+222
7160	50.9	+62 8	71.5	+ 6.3	+.314	+ .943	+.110	10	I 3p	1030	......	+ 320	+ 970	+113
7209	22 1.2	+46 0	63.4	− 7.7	+.444	+ .886	−.134	20	II 2p	570	2	+ 250	+ 500	− 76
7226	6.9	+54 55	69.1	− 0.8	+.356	+ .934	−.014	2.5	II 2p	4680	......	+1670	+4370	− 66
I.C.1434	6.7	+52 20	67.7	− 3.0	+.379	+ .924	−.052	7	III 2m	2900	......	+1100	+2680	−151
7235	9.0	+56 47	70.4	+ 0.6	+.335	+ .942	+.011	4.5	II 3p	2600	......	+ 870	+2450	+ 29
7243	11.3	+49 23	66.7	− 5.8	+.394	+ .914	−.101	21	III 2p	750	2	+ 300	+ 690	− 76
7245	11.5	+53 50	69.1	− 2.1	+.356	+ .934	−.036	4	II 2p	2920	......	+1040	+2730	−105
7261	16.8	+57 35	71.7	+ 0.7	+.314	+ .949	+.012	7	II 2p	1770	......	+ 560	+1680	+ 21
7296	24.2	+51 47	69.7	− 4.8	+.346	+ .935	−.084	4	II 2p	2920	......	+1010	+2730	−245
7380	43.0	+57 34	74.8	− 0.9	+.262	+ .965	−.015	9	III 2p	1840	2	+ 480	+1770	− 28
7419	50.3	+60 18	76.8	+ 1.1	+.228	+ .973	+.014	2.2	II 2p :	5320	......	+1210	+5180	+ 74
7510	23 7.3	+60 2	78.7	+ 0.1	+.197	+ .980	+.001	3	II 2m U	5040	......	+ 990	+4940	+ 5
7654	19.8	+61 3	80.4	+ 0.5	+.166	+ .986	+.009	13	II 2r	1360	2	+ 230	+1340	+ 12
7686	25.4	+48 34	77.5	−11.6	+.211	+ .956	−.202	13	I 3p	790	......	+ 170	+ 760	−160
7762	45.0	+67 28	84.7	+ 6.0	+.091	+ .990	+.105	11	I 1m U	1250	......	+ 110	+1240	+131
7788	51.7	+60 50	84.1	− 0.6	+.102	+ .995	−.011	11	IV 3p	2470	......	+ 250	+2460	− 27
7789	52.0	+56 10	83.3	− 5.2	+.116	+ .989	−.091	19	III 1r	1140	2	+ 130	+1130	−104
7790	52.0	+60 40	84.1	− 0.8	+.102	+ .990	−.014	4.5	II 2p	2600	......	+ 270	+2570	− 36

NOTES TO THE TABLE

NGC 637.—Position corrected by $\Delta\alpha=+1^m1$, $\Delta\delta=-2'$.

NGC 1817.—The cluster Melotte 29 should undoubtedly be identified with this and not with NGC 1807.

NGC 1981.—Position of NGC corrected.

NGC 2243.—R. A. corrected according to I. C. II Notes and Corrections.

NGC 2314.—This cluster was omitted from the list on account of its high galactic latitude. It may be a loose globular system similar to NGC 5053.

NGC 2395.—Position corrected according to Wolf, *A. N.* **231**, 231, 1927.

NGC 2506.—Position corrected according to I. C. II Notes and Corrections.

NGC 2546.—Position of center corrected according to chart of cluster in *Cordoba Photographs* p. 119.

I. C. 2391.—Position corrected so as to refer to center of cluster.

NGC 2669.—Declination of NGC corrected by +1°.

NGC 3960.—R. A. of NGC corrected by -3^m6, it must be the same cluster as Melotte 108.

NGC 4052.—R. A. of NGC corrected.

NGC 6216.—Melotte 152 should be identified with this and not with NGC 6222.

NGC 6322.—Position corrected.

NGC 6546.—Declination corrected.

NGC 6882, 6885.—In the region around 20 *Vulpeculae* two clusterings seem to be superposed: A loose clustering of 20–30 mostly faint stars, about 8′ in diameter, with center at $20^h 7^m 28^s$ +26° 15′0 (1900) was identified with NGC 6882. The coarse group of a few bright stars clustered around 20 Vulpec, with a diameter of about 22′ was identified with NGC 6885. In each of the two clusters a physical relationship of the stars is indicated by the magnitude spectral class diagram, but the two clusters are evidently at different distances.

NGC 7067.—R. A. corrected according to I. C. II, Notes and Corrections.

The apparent diameter in minutes of arc (9th column) and the classification (10th column) were estimated as described on pages 159 and 160. Column 11 gives the finally adopted distance. For those clusters contained in Table 3 this is the mean of the spectroscopic determination (Table 3, column 9) and of the determination from apparent diameter and classification (Table 3, column 10). The result of each method normally received weight 1 but spectroscopic distances printed in italics were given half weight. The weight of the adopted distance in the 12th column of Table 16 is the sum of the weights of the two determinations. When no weight is entered in this column the adopted distance is based entirely on the diameter method, and the weight is 1. For the five nearest clusters the spectroscopic method is given double weight. In these cases the result of the diameter method is rejected as uncertain, owing to the difficulty of estimating the angular diameters of such large clusters. The probable error of unit weight is about $\pm 12\%$.

Thirty-seven of the clusters in Table 16 were not found in any previous cluster catalogue although some of them have been mentioned by other observers. Table 17 gives a brief description of these objects and of four others contained in the *New General Catalogue* but not correctly described as open clusters.

TABLE 17

NGC 136	Described in N. G. C. as globular cluster. A photograph taken with the Crossley Reflector (40^m, H. D. Curtis) shows it to be a small loose open cluster of 40–50 stars 13–18^m.
An 1	I. Roberts draws attention to a group of four 10–11^m stars in a straight line. These form the center of a well defined cluster of about 40 stars 10–15^m
An 2	Mentioned by Barnard (*Bd. Atl.* pl. 1). Pretty well defined clustering of bright and faint stars, not rich, not quite regular.
NGC 1193	Described in NGC as nebula. Photograph with Crossley Reflector (90^m, Curtis) shows it to be a typical open cluster with slightly over 100 stars 14–19^m
An 3	Mentioned by Barnard (*Bd. Atl.* pl. 2). Very loose open cluster not rich, but regular in outline and structure.
NGC 2141	Described in NGC as nebula. Photograph with Crossley Reflector (30^m) shows a well resolved thin but rich cluster of exclusively faint stars (15–18^m).
An 4	Mentioned by Barnard (*Bd. Atl.* pl. 8). Loose and somewhat irregular group of about 30 stars 12–15^m
An 5	Found on pl. 28 and 29 of *Publ. Lick Obs.* vol. 11, where it looks like a nebulosity. Photograph with Crossley Reflector (30^m) shows this to be a fairly large, thin cluster of even star distribution and regular outline, very rich in extremely faint stars ($>17^m$).
An 6	Found on *Bd. Atl.* pl. 10. Pretty well defined clustering of faint stars, not rich, but regular in structure and outline.

TABLE 17—(*Continued*)

An 7	Mentioned by Barnard (*Bd. Atl.* pl. 10). Well defined dense clustering of 20–30 stars 10–15^m, slightly irregular.
An 8	Found on *F. A. Chart.* Pretty well marked thin cluster of faint stars, regular outline and structure.
An 9	Found on *F. A. Chart.* Pretty well marked small group of about 15 bright and faint stars, slightly irregular.
An 10	A large coarse cluster of a few bright and medium bright stars, observed by Dunlop (490) and Bailey. Both observations have been erroneously identified with the cluster NGC 2671, a small cluster of faint stars near by; it is probably for this reason that the cluster was omitted from the NGC.
An 11	Found on *F. A. Chart.* Pretty well defined small cluster, not rich, but regular in outline.
An 12	Found on *F. A. Chart.* Small cluster of regular outline and structure and marked central concentration. Pretty rich in faint stars.
An 13	Found on *F. A. Chart.* Small, somewhat irregular, but dense clustering of faint stars.
An 14	Observed by Gould (*Cordoba Photogr.* pl. 20) and shown in *H. A.* **26**, pl. 8, fig. 2. On a plate taken with the 37″ reflector of the Chile Station by H. D. Curtis this appears as a typical open cluster of bright and faint stars, medium rich, with strong central concentration, slightly unsymmetrical.
An 15	Noticed on Gould's chart of the *η Carinae* region as well as on *H. A.* **60**, VIII pl. 3. Well defined small cluster with considerable concentration regular structure and outline.
An 16	Cluster including *η Carinae*, with its center somewhat south of this star, noted by many observers. NGC 3372 only refers to the nebula, and does not mention the existence of this cluster.
An 17	Found on *F. A. Chart.* A small cluster of bright and faint stars, much concentrated at center.
An 18	Found on *F. A. Chart.* Not very well defined clustering of bright and faint stars close to NGC 3572 and NGC 3590, but rather better marked than these.
An 19	Found on *F. A. Chart.* Medium rich clustering of faint stars with regular outline, passes gradually into surroundings.
An 20	Found on *F. A. Chart.* Rich cluster of regular outline composed exclusively of very faint stars nearly evenly scattered.
An 21	Found on *F. A. Chart.* Small dense group of a few stars around two stars of 10^m Not well resolved on the chart.
An 22	Found on *F. A. Chart.* Fairly well marked cluster of 12^m stars thinly but uniformly scattered with regular outline.
An 23	Found on *F. A. Chart.* Thin cluster of very faint stars, not very conspicuous but regular in outline and structure.
An 24	Mentioned by Barnard (*Bd. Atl.* pl. 16) as a group of stars about 1° in diameter. I. C. 4628 refers to nebulosity involved in the northern part of the cluster.
An 25	Found on *F. A. Chart.* Pretty well defined small regular cluster of faint stars with noticeable central concentration.

TABLE 17—(*Concluded*)

An 26	Mentioned by Barnard (*Bd. Atl.* pl. 18, 21, 22) as "a small group of considerable stars."
An 27	Found on plate 22 of *Bd. Atl.* as a small somewhat irregular cluster of faint stars.
An 28	Mentioned by Barnard (*Bd. Atl.* pl. 24). Fairly dense group of stars 11–14^m with well defined outline but slightly unsymmetrical.
An 29	Found on *F. A. Chart:* Curious cluster of triangular outline and nearly vacant center around which bright and faint stars are densely crowded.
An 30	Mentioned by Barnard (*Bd. Atl.* pl. 24) as "a scattering cluster of smaller stars."
An 31	Found on pl. 26 of *Bd. Atl.* as a small pretty dense cluster of well defined somewhat triangular outline in the Great *Sagittarius* cloud.
An 32	Found on pl. 34 of *Bd. Atl.* A small, regular cluster of about 50 faint stars.
An 33	Mentioned by Barnard (*Bd. Atl.* pl. 32) as "a small group of a few bright stars."
An 34	Mentioned by Barnard (*Bd. Atl.* pl. 35) as "a small cluster or intensification of the Milky Way."
An 35	Mentioned by Barnard (*Bd. Atl.* pl. 36) as "a very small detached mass of stars."
An 36	Found on *Bd. Atl.* (pl. 44). According to a photograph with the Crossley Reflector (40^m) this is a very rich beautiful cluster of exclusively faint stars (17–19^m) densely but evenly scattered with regular circular outline.
An 37	Found on *Bd. Atl.* (pl. 49): Large loose somewhat irregular cluster of bright and faint stars, triangular figure, involved in nebulosity.
NGC 7226	Given in NGC as nebula in cluster. A photograph with the Crossley Reflector (1^h 45^m, Curtis) shows only a small loose cluster of a few dozen faint stars.

Table 16 should not be considered as a complete catalogue of open clusters, as only those were included which seemed to be suited for a determination of the distance. A number of the fainter or smaller clusters not well shown or unresolved on the photographic charts used had to be omitted for lack of adequate classification or diameter estimate. The writer has a more complete catalogue of star clusters in preparation which will be issued with descriptions for each object when the reobservation of the many doubtful objects has been completed.

For judging the completeness of our list as far as small and faint distant clusters are concerned it is of interest to state that only 34 objects of this class given in the *New General Catalogue* or the *Index Catalogues* with galactic latitudes of less than 20° had to be omitted for insufficient observations, while for about half a dozen globular clusters it seemed doubtful whether they should not be included as open clusters. It is also possible that some of the objects described as nebulae may turn out to be resolved into clusters when photographed with sufficiently large instruments, but the cases of this kind so far discovered are rather rare. It is surprising that despite the valuable help of modern photographic methods very few faint clusters in low galactic latitudes have been added to our knowledge during the last fifty years. In the two *Index Catalogues* containing the discoveries between 1888 and 1907 about 50 small clusters are listed (including the numerous cases marked as doubtful). It is remarkable, however, that these objects do not show the concentration toward the Milky Way so characteristic of open clusters, but that they are actually more numerous in high galactic latitudes. Most likely many of these are accidental groupings of three or four faint stars offering a nebulous appearance in a small telescope while some are perhaps globular clusters.

These various considerations make it probable that nearly all of the open star clusters of the Milky Way are at present known, and our list of Table 16 should be representative of the more prominent formations of this kind except for a deficiency of perhaps 30–50 among the more distant ones. We have thus for the first time a fairly adequate knowledge of the distances for a class of galactic objects and a study of their space distribution should furnish valuable information on the dimensions and structure of our Milky Way system.

11. The Apparent Distribution of Open Star Clusters

TABLE 18

Apparent Distribution of Open Clusters According to Galactic Longitude

Galactic longitude	Number of clusters	Constellations
0°– 20°	5	Aquila.
20 – 40	7	Vulp.-Cygn.
40 – 60	15	Cygnus.
60 – 80	19	Cygn.-Ceph.-Lac.
80 –100	21	Cassiop.
100 –120	19	Camel.-Perseus
120 –140	11	Pers.-Auriga
140 –160	17	Auriga-Taur.-Gem.
160 –180	19	Monoceros.
180 –200	27	Monoc.-Can. Major
200 –220	27	Puppis
220 –240	14	Puppis-Vela.
240 –260	29	Vela-Carina
260 –280	22	Crux-Cent.
280 –300	19	Circin.-Norm.
300 –320	22	Norma-Scorp.
320 –340	22	Scorp.-Sag.-Ophiuch.
340 –360	19	Sagittar.-Scutum.
	334	

TABLE 19

APPARENT DISTRIBUTION OF OPEN CLUSTERS ACCORDING TO GALACTIC LATITUDE

Galactic latitude		Longitude 90°–270° Number clusters	Per1000 sq. degr.	Longitude 270°–90° Number clusters	Per 1000 sq. degr.	Total Number clusters	Per 1000 sq.degr.
−90° to	−30°	0	0	1	0.1	1	0.1
−30	−20	3	0.9	0	0	3	0.9
−20	−15	5	2.9	0	0	5	2.9
−15	−10	8	4.5	4	2.3	12	6.8
−10	− 8	4	5.6	2	2.8	6	8.4
− 8	− 6	3	4.2	8	11.2	11	15.4
− 6	− 4	12	16.8	16	22.4	28	37.7
− 4	− 2	19	26.5	38	52.9	57	79.4
− 2	0	34	47.3	28	38.9	62	86.2
0	+ 2	34	47.3	27	37.6	61	84.8
+ 2	+ 4	27	37.6	10	13.9	37	51.5
+ 4	+ 6	12	16.8	2	2.8	14	19.5
+ 6	+ 8	9	12.6	5	7.0	14	19.6
+ 8	+10	2	2.8	1	1.4	3	4.2
+10	+15	7	4.0	3	1.7	10	5.7
+15	+20	4	2.3	1	0.6	5	2.9
+20	+30	1	0.3	1	0.3	2	0.6
+30	+90	3	0.3	0	0	3	0.3
		187		147		334	

We shall first consider the apparent distribution in the sky of the 334 open clusters of Table 16. The distribution according to galactic longitude shown in Table 18 and Fig. 2 has a number of irregularities.

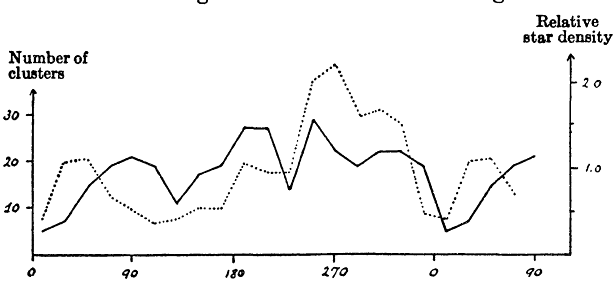

Fig. 2. Distribution of open clusters according to galactic longitude.

The full line gives the number of clusters per interval of 20° in galactic longitude. The dotted line represents the relative star density (mean of galactic latitudes +5°, 0°, −5°) according to Seares. The average star density of this belt is taken as unit and drawn in the same dimension as the average number (18.5) of clusters per 20° interval.

In the first place there is a deep minimum between longitude 0° and 50°, in the constellations *Aquila*, *Vulpecula* and *Cygnus*; *i. e.*, in the region where the dark division of the Milky Way is most pronounced. This seems to lend support to the hypothesis that the division is produced by a cloud of totally absorbing material which prevents us from seeing a part of the clusters in this region. Two less pronounced minima at longitudes 130° (*Perseus-Auriga*) and 230° (*Puppis-Vela*) also fall in somewhat poorer parts of the Milky Way. There is undoubtedly some similarity between the distribution in longitude of the star clusters and the fainter Milky Way stars; this is well exhibited by Fig. 2 in which the average density of stars brighter than 18^m is drawn on the same scale by the dotted line. The data for the star density are taken from Seares[28] and are the means of galactic latitudes −5°, 0, and +5°. Strictly speaking, the two curves are not comparable because the number of star clusters in each longitude interval also depends on the width of the Milky Way structure while the star densities do not. Some of the differences of the two curves must be attributed to this cause, as between longitudes 60° and 210° the open clusters show a larger scattering in galactic latitude than between 240° and 360°. But the excess of clusters over stars in the *Cassiopeia* region (80°–110°) and their deficiency in the *Cygnus* region (20°–60°) are undoubtedly real.

The distribution of clusters in galactic latitude is given in Table 19 and Fig. 3 separately for the two

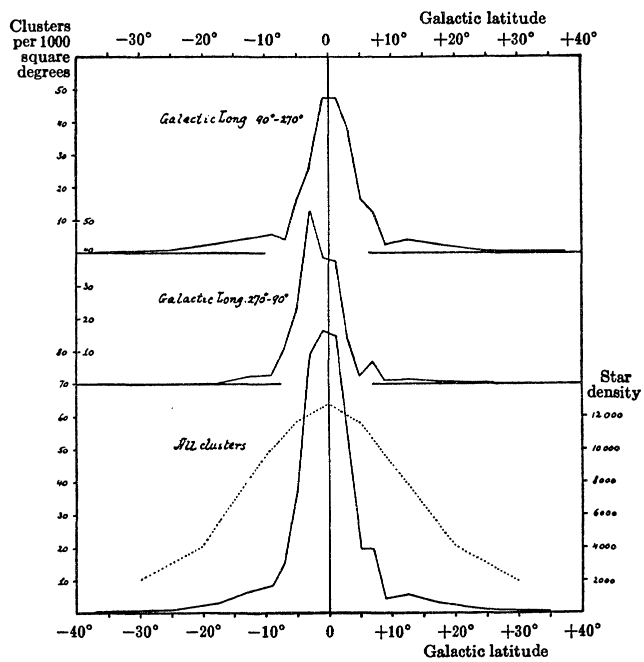

Fig. 3. Distribution of open clusters according to galactic latitude.

Abscissae are galactic latitudes, ordinates give the number of clusters per 1000 square degrees. The first curve applies to clusters falling between galactic longitudes 90° and 270°, the second to clusters between 270° and 90° longitude, the third to all clusters combined. The dotted curve represents the average density per square degree of stars brighter than 18th magnitude as a function of galactic latitude.

hemispheres, as they exhibit some notable differences. In longitudes 90°–270° the open clusters are arranged very nearly symmetrically to the adopted galactic plane and the great majority lie within 7.5° of it covering thus a zone about 15° wide. Between longitudes 270° and 90° the large majority of clusters lie

[28] *Mt. Wilson Contr.* No. 346, Table XVe.

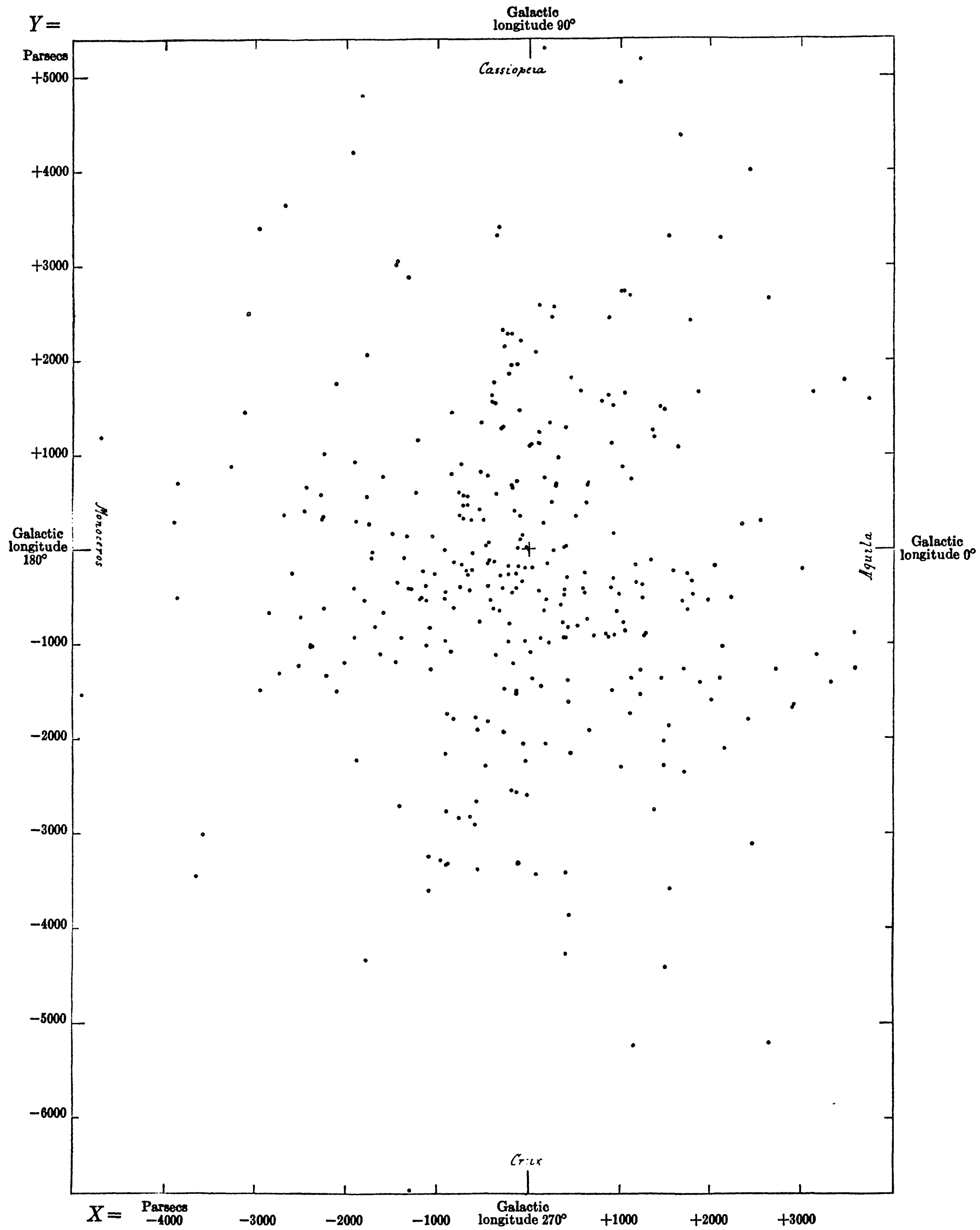

Fig. 4. Space distribution of 334 open clusters.

The figure gives the projection of the clusters on the galactic plane. The few clusters more distant from this plane than 500 parsecs are plotted as open circles. The position of the Sun is marked by the cross at the center; the scale of the *X* and *Y* coordinates (table 16, columns 13–14) is given in parsecs. On this scale the dots represent the correct (limiting) dimensions for the largest clusters, but are about twice too large for the majority of the clusters.

south of the galactic plane and the cluster zone is only about 11° wide. The smaller width of the cluster zone in the second hemisphere has already been mentioned; it is the more surprising since the Milky Way structure is unusually wide in the *Sagittarius-Ophiuchus* region. It is remarkable that practically all open clusters in this part of the sky lie in the southern (*Sagittarius-Scutum*) branch of the Milky Way and extremely few in the *Ophiuchus* branch. The unsymmetrical distribution of the clusters with respect to the galactic plane we shall later show to be due to the fact that the plane of symmetry of the more distant open clusters is somewhat inclined to the galactic plane here adopted.

The distribution of all clusters taken together is still slightly unsymmetrical, which indicates that the observer (Sun) is situated north of the galactic plane as defined by the clusters. The dotted line in Fig. 3 gives the average density per square degree of the stars brighter than 18^m for different galactic latitudes according to Seares[29]. This figure brings out the extremely high galactic concentration of open clusters as compared with the fainter stars; it also shows that, in the Milky Way, stars brighter than 18th magnitude are about 200,000 times more numerous than clusters. Only a very small proportion of the stars are organized in cluster formations.

12. The Space Distribution of Open Star Clusters

In the three last columns of Table 16 the space coordinates in parsecs of each cluster are given in a coordinate system X Y Z so oriented that the Z axis is directed toward the adopted galactic pole (RA 12^h 40^m, Decl. +28°), while the X Y plane coincides with the galactic plane, the $+X$ axis in the direction of galactic longitude 0° (RA 18^h 40^m Decl. 0), the $+Y$ axis in galactic longitude 90°. The space coordinates X Y Z of each cluster are obtained by multiplying x y z of columns 6–8 by the adopted distance r (column 12). In Fig. 4 each cluster is plotted in its projection on the galactic plane; those which are more distant than 500 parsecs from the galactic plane are marked by open circles. Fig. 5 gives a projection of the clusters on the X Z plane which is perpendicular to the galactic plane, the clusters within 1000 parsecs of the center being marked as open circles. A comparison of the two figures shows that the clusters fill a system which has the shape of a flat disk or grindstone. Its thickness is about 1000 parsecs (if we disregard a few isolated objects) while the diameter of the disk in the galactic plane is about 9000 parsecs in the direction of galactic longitude 0° and 180° and about 11,000–12,000 parsecs in the direction of galactic longitude 90° and 270°.

The disk thus appears slightly elliptical, but of course its outline is rather difficult to define on account of the few scattered objects at the circumference. That the plane of symmetry of the cluster system is somewhat inclined to the adopted galactic plane was already noted from the apparent distribution of the clusters. This fact is quite marked in Fig. 5. By least squares solution we find the inclination to be 2°.3 and the pole of the plane of symmetry to fall in galactic longitude 352°. In order to fit the space distribution of the open clusters, the galactic North Pole should be placed at RA 12^h $50^m.4$ Decl. +27°.7 (1900).

Seares[30] has drawn attention to the fact that if the galactic pole is determined from the star distribution its position changes gradually as we include fainter stars. He gives the distance p and the longitude L_O of the determined pole referred to Gould's Pole (1900 : $\alpha = 190°.6$ $\delta = +27°.4$). His data are collected in Table 20.

TABLE 20

Position of the Galactic Pole

		p	L_O
Stars brighter than	9^m	8°.1	275°
	11	6.8	296
	13.5	8.0	319
	16	4.1	357
	18	2.7	350
Open star clusters		1.7	10

[29] *Mt. Wilson Contr.* No. 346, Tables XIV and XVII.

[30] *Mt. Wilson Contr.* No. 347, 26, 1928.

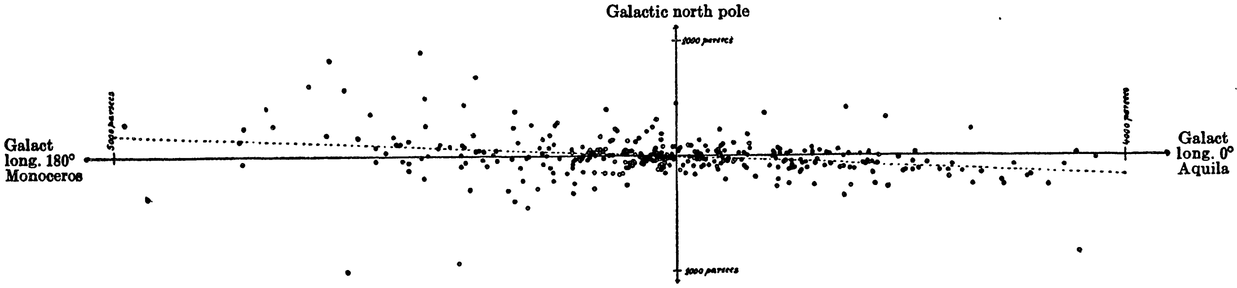

Fig. 5. Space distribution of 334 open clusters.

The figure gives the projection of the clusters on the XZ plane which is perpendicular to the galactic plane and intersects the latter at longitudes 0° and 180°. Clusters within 1000 parsecs of the Sun are plotted as open circles. The dotted line marks the plane of symmetry of the open clusters.

Our result for the open clusters (also referred to Gould's pole) closely follows that for the 18^m stars in the progression of decreasing p and increasing L_O. Seares interprets this change in the position of the galactic pole as being due to a difference between the plane of symmetry of the local system and that of the more remote parts of the Milky Way. The brighter stars belong to the local system and furnish its plane of symmetry; as we proceed to fainter stars the proportion of stars belonging to the local system decreases and we gradually approach the position of the pole of the Milky Way system as a whole. The fact that our result for the open clusters follows in line after the 18^m stars suggests that with our catalogue of open clusters we reach farther out into space than the average distance of 18^m stars. This is quite plausible; a star of spectral type A_o at a distance of 5000 parsecs would be of apparent photographic magnitude 17.8, if we take into account the effect of absorption; while the average luminosity of 18^m stars is probably much less than that corresponding to type A_o.

The clusters plotted in Fig. 4 show a strong central concentration and a gradual thinning out with increasing distance. In fact, the whole figure appears very much like an open cluster. This concentrated central part seems to represent what is generally called the local cluster; but it is evident from our figure that it hardly deserves to be treated as a separate unit. It passes over very gradually into the more irregularly scattered Milky Way regions. It would be difficult to draw any limit for this local system except that it is of considerable dimensions, about 2000–4000 parsecs in diameter.

The center of the cluster system is found by taking the mean of the X Y Z coordinates of all the 334 clusters. This gives:

$$X_c = -117 \quad Y_c = -201 \quad Z_c = -6$$

The center of gravity (giving equal weight) thus lies 6 parsecs south of the adopted galactic plane; if we take into account the fact that the plane of symmetry of the clusters is inclined to the galactic plane we find the Sun situated 10 parsecs north of this plane of symmetry. For the X and Y coordinates this method for determining the center of the cluster system is somewhat unfavorable, because it gives very high weight to clusters at the circumference which are the least complete. The addition of one cluster at the outline will change the coordinates of the center by 15 parsecs. It seems preferable to define the center of the cluster system as the median point, *i. e.* the intersection of two lines drawn parallel to the X and Y axes (in Fig. 4) so that they divide the clusters into two halves of equal number; in this way clusters at the circumference receive no more weight than those near the center. Since the latter are much more numerous, the median point should coincide more nearly with the center of the concentrated central part (local system). It falls at:

Median point: $X_m = -130$ parsecs $Y_m = -305$ parsecs

or at a distance of 350 parsecs in galactic longitude 247°. This is in good agreement with other observers: Charlier[31] finds the center of the B type stars in galactic longitude 244°; Stromberg[32], on the assumption that the preferential motions of the brighter F, G, K, M type stars are rotational in character, finds 257°; Kapteyn[33], from the stream motion, 257° or 77°. Shapley[34] and Seares[35], however, find the longitude of the center to increase with the magnitude of the stars included and the latter gives for stars brighter than 18^m: $L = 305°$ (Galactic latitudes $-5°$ to $+5°$). We would conclude from this that the local system has an eccentric location compared with the stellar system as a whole and that the center of the latter lies near galactic longitude 325°. The distribution of open clusters does not seem to confirm this view, but the question will be discussed later.

Since the space distribution of the clusters is fairly symmetrical around the center, it is possible to study the decrease in the density of clusters with increasing distance by counting the number of clusters in successive circles drawn about the median point. The spread of clusters perpendicular to the plane of symmetry can for this purpose be neglected, as the thickness of the disk-shaped cluster system is approximately uniform. The data are collected in Table 21, in which

TABLE 21

Distribution of Clusters in Galactic Plane

Limits of ring in parsecs	Area of projection in square parsecs	Number of of clusters	Density of clusters per 10^6 square parsecs
0–1000	3.1×10^6	88	28.4
1000–2000	9.4	108	11.5
2000–3000	15.7	77	4.9
3000–4000	22.0	38 (48)	1.7 (2.1)
4000–5000	28.1	16 (36)	0.6 (1.3)
>5000		7	

the first column gives the limits of the rings, the second, their area in square parsecs, the 3d, the number of clusters counted in each ring; this number divided by the area of the ring found in the 4th column is the density of clusters per 10^6 square parsecs in the projection on the galactic plane. In Fig. 6 these densities are plotted as a function of the distance

[31] *Lund Meddel.* II No. 34, 1926.
[32] *Mt. Wilson Contr.* No. 144, *Ap. J.* **47**, 7, 1918.
[33] *Mt. Wilson Contr.* No. 230, *Ap. J.* **55**, 302, 1922.
[34] *Mt. Wilson Contr.* No. 157, *Ap. J.* **49**, 311, 1919.
[35] *Mt. Wilson Contr.* No. 347, *Ap. J.* **67**, 1927.

from the median point, showing the rapid, but continuous thinning out of clusters with increasing distance. At 4500 parsecs from the center the clusters are about 50 times less numerous per unit volume than near the center. Even if we added about 30 clusters in the last two rings as having possibly escaped detection or as being omitted from our list for insufficient description, this result would not be materially changed, as the figures in brackets of Table 21 and the dotted line in Fig. 6 show.

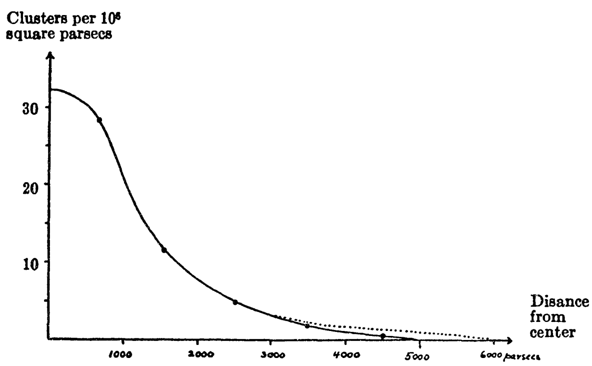

Fig. 6. Distribution of open clusters in the galactic plane.

Abscissae are distances from the median point of the cluster system, measured in the projection on the galactic plane. Ordinates are the numbers of clusters per 10^6 square parsecs of the projection, showing the rapid thinning out of clusters with increasing distance from the center. The full line gives the distribution of the clusters actually observed, the dotted line the probable correction for omitted or undiscovered clusters.

The distribution of clusters perpendicular to the plane of symmetry is shown in Table 22 and Fig. 7. For each cluster the coordinate Z' perpendicular to the plane of symmetry was computed and the numbers of clusters counted for successive intervals of 100 parsecs in Z' are entered in column 3-5 of Table 22 and plotted in Fig. 7 as a function of the distance Z' from the plane.

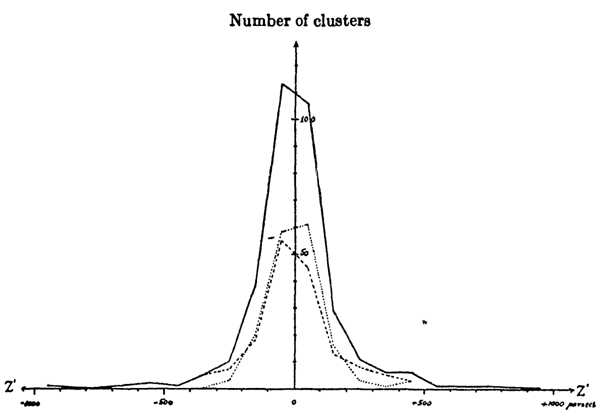

Fig. 7. Space distribution of open clusters perpendicular to their plane of concentration.

Abscissae: Distances Z' from the plane of concentration, measured in parsecs, positive in the direction of the galactic North Pole. Ordinates: Numbers of clusters per interval of 100 parsecs. Dotted line: Hemisphere centered at galactic longitude 0° ($X > -130$). Broken line: Hemisphere centered at galactic longitude 180° ($X < -130$). Full line: All clusters taken together.

TABLE 22

Distribution of Clusters Perpendicular to Plane of Concentration

Z'	Mean Z'	Number of clusters per layer of 100 parsecs thickness $X < -130$	$X > -130$	All
< −800		2	0	2
−800 to −700	−750	0	0	0
−700 −600	−650	0	1	1
−600 −500	−550	2	0	2
−500 −400	−450	1	0	1
−400 −300	−350	5	0	5
−300 −200	−250	7	3	10
−200 −100	−150	18	20	38
−100 0	− 50	55	58	113
0 +100	+ 50	45	61	106
+100 +200	+150	13	16	29
+200 +300	+250	8	3	11
+300 +400	+350	5	1	6
+400 +500	+450	3	3	6
+500 +600	+550	0	1	1
+600 +700	+650	1	0	1
+700 +800	+750	1	0	1
> +800		1	0	1
		167	167	334

The counting was done separately for the hemisphere centered at galactic longitude 180° ($X = -130$ to -5000 parsecs) and for the opposite one ($X = -130$ to $+4000$). The curves show that in the former hemisphere the clusters are slightly more widely scattered, a fact which is well illustrated by Fig. 5 and was already noted in the apparent distribution (page 178). The high concentration of open clusters toward their plane of symmetry is very striking; 68% of them lie within 100 parsecs of this plane. In this respect the open clusters resemble the O and B type stars. The frequency law of clusters for different distances Z' from the plane of symmetry does not follow a normal frequency law (Gaussian error law); it has a considerable positive excess, but is very nearly symmetrical.

While Figs. 6 and 7 describe the general statistical features of the cluster system, there are, of course, many local irregularities. To these must be counted certain groups of clusters which, as a rule, stand out not only by the close proximity in space of the clusters (except for some scattering in distance due to errors of observation) but often also by similarity in structure and spectral types, or by association with a prominent star cloud. In the latter case it is then possible to derive the probable distance of such star cloud from the clusters contained in it. Six of these

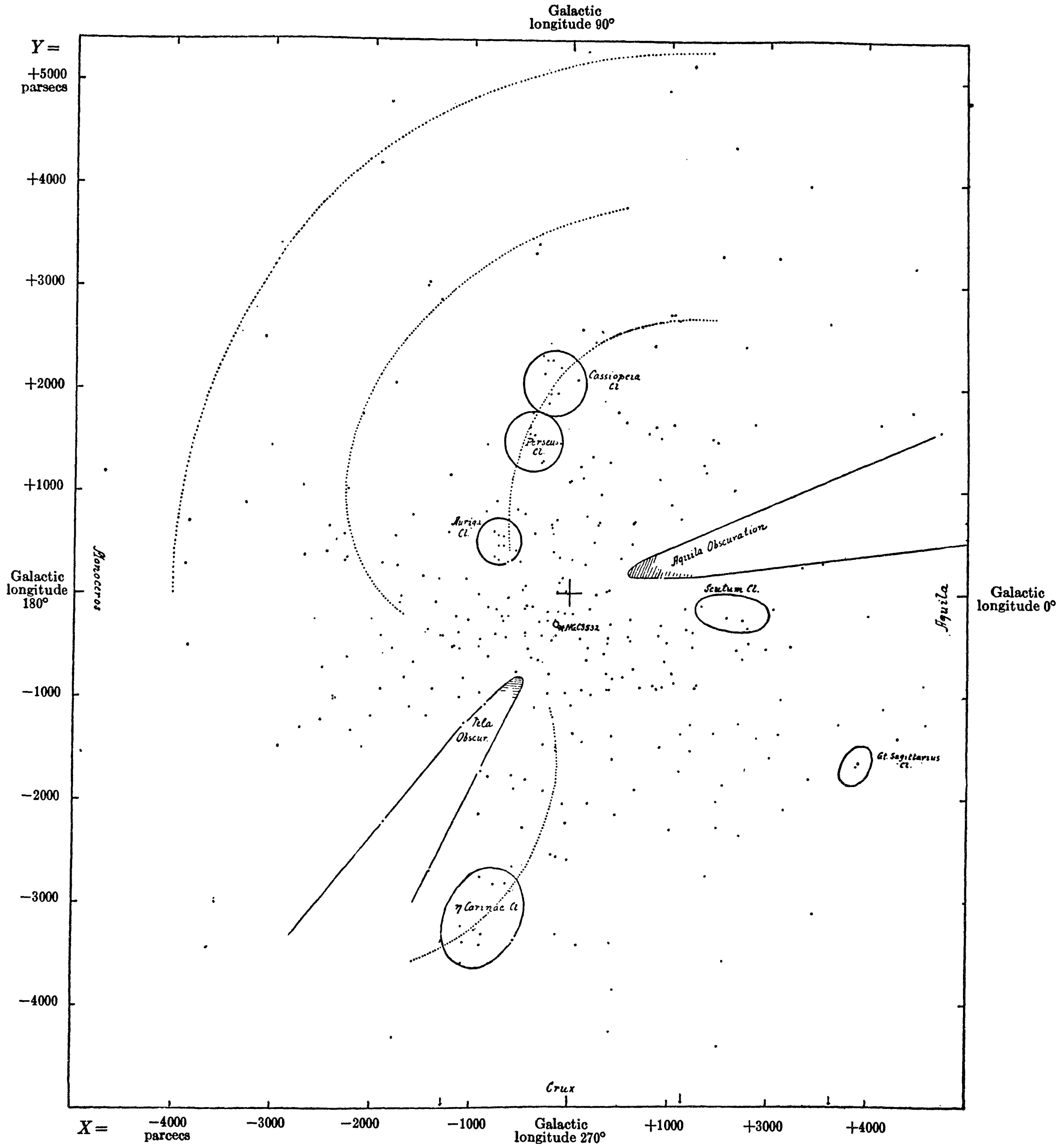

Fig. 8. Special features of the cluster system.

This figure gives a projection of the clusters on the galactic plane like Fig. 4. The position of the Sun is marked by a cross, that of the median point of the system by an open circle, the cluster NGC 3532 by an asterisk. Some traces of spiral structure are indicated by the dotted lines; the large open circles or ovals represent the probable location of cluster groups or star clouds, the shaded areas, dark clouds of absorbing material with their sectors of obscuration.

groups are outlined in Fig. 8 while the clusters composing it are listed in Table 23, together with the mean coordinates and the mean distance of the group and the classification of the magnitude spectral class diagrams (Table 3, column 3) of those clusters which have spectroscopic observations.

Remarkable is the great distance of *η Carinae* with its surrounding star cloud and the nebula, in which two clusters of the fourth group are directly involved. The distance of the *Scutum* cloud derived from the clusters is considerably smaller than that obtained by C. J. Krieger[36] from magnitudes and color indices of faint stars in six areas. The latter result is based on the assumption that there is no absorption of light in interstellar space; if Krieger's result (2800 parsecs)

[36] *L. O. Bull.* **14**, 95, 1929.

TABLE 23

GROUPS OF OPEN CLUSTERS

Group	Clusters	Mean rectangular coordinate in parsecs X	Y	Z	Number of clusters	Mean distance in parsecs	Magnitude spectral class diagram
Cassiopeja	129, 381, 436, 457, 559, 581, An. 1, 654, 659, 663	− 170	+2060	− 41	10	2070	1b (2) 1–2b (2)
Double cluster Perseus	869, 884, IC1805, 957, 1027, IC1848, 1502	− 380	+1490	+ 7	7	1540	1–2o (1) 1b (2) 1–2b (2)
Auriga	1893, 1912, 1960, 2099, 2168	− 720	+ 510	+ 38	5	880	1b (2) 2a (2)
η Carinae cloud	An. 11, An. 12, An. 13, An. 14, 3255, An. 15, An. 16, 3496, An. 18	− 870	−3140	− 94	9	3220	
Large Sagittarius cloud	An. 31, 6520	+2910	−1660	−234	2	3360	
Scutum cloud	6649, 6664, An. 34, 6694, 6704, 6705	+1610	− 210	− 91	6	1630	1–2 b–a (1) 2 b–a (1)

is corrected for absorption (0^m67 per 1000 parsecs) it becomes 1700 parsecs which is in close agreement with ours.

Aside from such groupings, Fig. 4 exhibits some vacancies in the distribution of open clusters. In the outer parts of the figure where clusters are rather thinly scattered, vacancies of considerable size may be due to chance; only those reaching into the denser central part can claim real significance. If in addition they have the shape of a sector, with limits radiating from the Sun, they strongly suggest obscuration by dark matter. Two such cases are marked in Fig. 8: the most striking is that in *Aquila* (galactic longitude 15°) the other in *Vela* (galactic longitude 236°). Both coincide with minima in the apparent distribution of clusters (Fig. 2) and stars and are noticeable as dark spots in the Milky Way. The space distribution of open clusters indicates that the obscuring matter probably lies at a distance of about 500 parsecs in *Aquila* and within 1000 parsecs in *Vela*. There are many other less conspicuous regions of obscuration indicated in Fig. 4.

13. The Structure of the Milky Way System

By the Milky Way system we wish to designate that large system which comprises practically all the stars visible to the naked eye or observable in large telescopes and which is particularly characterized by the dense accumulations of faint stars forming the conspicuous features of the Milky Way. To anybody who closely examines the beautiful Milky Way photographs of Barnard or the Franklin Adams chart it is quite apparent that the open clusters must be related to the star clouds of the Milky Way in which they often appear imbedded like condensations. We have already drawn attention to the similarity in the apparent distribution of stars and clusters except for the greater galactic concentration. Most convincing of all is perhaps the close agreement between the plane of symmetry of open clusters and that of faint stars.

In view of these facts it seems quite justifiable to make the hypothesis that the space distribution of open clusters is similar to that of stars in general and that a study of open star clusters may give us some information concerning the structure of the Milky Way system. As every test seems to indicate that our list of clusters is not much short of completeness we may expect figures 4 and 5 to represent a general outline of the Milky Way system. The features we brought out in the discussion of the open clusters should then for the most part apply also to the Milky Way system, and in fact they are generally in good agreement with the results of the statistical investigations of Seeliger[37], Kapteyn[38] and others who describe the stellar system as a flattened lens shaped system 10,000–15,000 parsecs in diameter and 3000–4000 parsecs in thickness, with the stars concentrated toward the center and thinning out toward the edge. The only difference is that the clusters seem to be more strongly concentrated toward the galactic plane than the stars in general.

The close analogy between these views concerning the structure of our Milky Way system and the main features of many spiral nebulae led to the conclusion that the Milky Way system belongs to this class of objects. Our results concerning the open clusters quite support this conclusion. In some of the nearer spirals especially *M* 51 and *M* 101 we find numerous small nuclei not as well defined as star images which have all the earmarks of open star clusters and in *M* 33 some clusters are even partly resolvable into stars. The size of our Milky Way system suggested by the open clusters (10,000–12,000 parsecs in diameter) is well

[37] *Sitzungsber. d. Münch. Akad. d. Wiss.* 1920, p. 87.
[38] *Mt. Wilson Contr.* No. 230, 1922.

comparable with the dimensions of the *Andromeda* Nebula (13,000 parsecs) and Messier 33 (4600 parsecs) according to Hubble's[39] investigations.

On the other hand it is true that the space arrangement of open clusters as illustrated in Fig. 4 shows hardly any indication of spiral structure. The errors of observation in the cluster distances (p. e. 10–12%) will of course have the tendency to blur any existing spiral structure, and local obscuration by dark matter may at many places have interrupted the spiral arms. Despite of these disturbing influences it seems hardly possible to account for our diagram unless we assume that our Milky Way system is an extremely resolved spiral, even more resolved than Messier 33. Nevertheless there are some traces of spiral structure noticeable which have been drawn in Fig. 8. While they are not sufficiently prominent to prove the spiral structure of the Milky Way system, they may, once we admit the hypothesis of spiral structure, give an indication of its direction. The different fragments of branches especially between galactic longitude 60° and 180° indicate a right-handed spiral as seen from the galactic North Pole. The best marked of these branches is undoubtedly that joining the cluster groups in *Auriga*, *Perseus* and *Cassiopeia*.

It is well known that most spiral nebulae have a pronounced central nucleus, which in the case of the *Andromeda* nebula, for example, produces a nearly star like image with a short exposure. On this account there is probably some significance attached to the fact that one of the richest and most remarkable open clusters: NGC 3532 ($RA = 11^h\ 2^m\!.2$, $Decl = -58°\ 8'$) falls by our distance determination quite close to the median point of the cluster system (center of local system). This cluster which is marked in Fig. 8 by an asterisk contains, according to Raab, more than 100 stars brighter than magnitude 10 (mostly of types B5–A0) and over 300 stars brighter than magnitude 12, and it is imbedded in a region which is also exceptionally rich in stars of magnitude 8–10. It thus seems not impossible that NGC 3532 and the surrounding star field represent the remainder of a central nucleus.

While our results on the space distribution of open clusters support in every way the older views concerning the structure of our Milky Way system and its similarity to a spiral nebula, they disagree entirely with the more recent conclusions by Shapley and Seares that the Sun and its surrounding star concentration (local system) are quite a secondary formation in a much larger galactic system over 100,000 parsecs in diameter, the center of which is situated in the direction of *Sagittarius* (galactic longitude 325°) at a distance of 20,000 to 40,000 parsecs. These conclusions are based mainly on three facts of observation:

1. The distribution of globular clusters (Shapley).
2. The asymmetry in the distribution of faint stars (Seares).
3. The results obtained for galactic rotation.

On the other hand there is no noticeable feature in the distribution of open star clusters which suggests a considerable extension of the Milky Way system in the direction of *Sagittarius*. A careful examination of Barnard's excellent Milky Way photographs of this region, which reach at least to the 17^m, did not reveal any appreciable number of small distant undiscovered star clusters. It is hardly possible that every one of scores or hundreds of such distant clusters should be hidden from our view through absorption by dark matter. But even if we should admit such an assumption, we should still expect the visible parts of the open cluster system to show some arrangement concentric with the distant *Sagittarius* center. We should, for example, expect the limit of the cluster system in the opposite direction (galactic longitude 60°–120°), where there is not so much evidence of dark clouds, to be a segment of a circle of large radius centered in the *Sagittarius* direction; or we should expect the cluster system to widen out in the direction of the center with many distant clusters in galactic longitudes 200°–270° and 0°–70°. None of these expectations is fulfilled, and the hypothesis of a distant galactic center would leave the observed space distribution of open clusters quite unintelligible. But if we examine a little more closely the three facts of observation on which this hypothesis is based we find their evidence not quite convincing.

Taking up the second point first, it is true that the star counts based on the *Durchmusterung* of the selected areas reveal an asymmetry in galactic longitude. If the star density is represented by a simple harmonic of the longitude the maximum of star density gradually shifts from about 260° to 320° as we include fainter stars. Seares interprets this feature as being produced by an eccentric position of the local system compared with the middle of the larger Milky Way system. For the brighter stars, maximum star density falls in the direction of the center of the local system which is in fair agreement with that found for the open clusters. As we proceed to fainter stars we penetrate farther into the region of the Milky Way star clouds and maximum star density will fall in the direction of the center of the Milky Way system. Seares shows that the change in space density with distance in the direction of galactic longitudes 325° and 145° can be represented by the superposition of two concentrations; one very sharp maximum at the center of the local system, and a second more flattened widespread condensation centered around a point 1000 parsecs

[39] *Mt. Wilson Contr.* No. 310, 1926 and No. 376, 1929.

distant from the Sun in galactic longitude 325°, which might be taken as the middle of the Milky Way system. It should be noted that around this point we also find a somewhat loose agglomeration of clusters. Evidently the star distribution in our Milky Way system is characterized by large local irregularities which are smoothed out by the usual statistical methods of determining the density distribution from star counts. While the observed asymmetry in the apparent distribution of faint stars may thus be a consequence of an extensive local congregation of stars, it also seems quite possible that the local system, *i. e.*, the center of concentration of open clusters, actually has a slightly eccentric situation with respect to the outline of the Milky Way system as a whole, and that the latter is more nearly concentric with a point about a thousand parsecs distant from the Sun in galactic longitude 325°. If we take into account the probable obliteration of distant clusters by dark matter which is so evident in the *Aquila* region and which may be effective all along the dark rift in the Milky Way, it even seems likely that the cluster system as plotted in Fig. 4 is incomplete in galactic longitudes 300°–60° and actually extends somewhat farther in this direction. A relatively small number of obscured clusters might change the somewhat uncertain outline of our cluster system so as to bring its center near the suggested point; it is however hardly admissible that such shift could be greater than 1000 parsecs. The writer can find nothing in the data of Seares's investigation which should force us to assume that the galactic center is at a greater distance than this. The hypothesis that the Milky Way system is similar in outline to the open cluster system as illustrated in Fig. 4, extending perhaps 1000 or 2000 parsecs farther in the *Aquila-Sagittarius* region, is then not in contradiction with the apparent distribution of faint stars. Of course this similarity should not be taken too closely and must be confined to the main features; there are unquestionably some parts of the Milky Way where the tendency to form clusterings is more pronounced (*e. g.*, in the *Perseus-Cassiopeia* region) than in others where the proportion of clusters to stars is small (*e. g.*, in the great *Sagittarius* cloud).

The evidence for galactic rotation around a center in the *Sagittarius* region is mainly based on a second harmonic in the observed radial velocities of stars and interstellar calcium. What is observed, of course, is a differential effect and its interpretation necessarily requires certain assumptions about the nature of the rotational motion; furthermore, the observations fur-

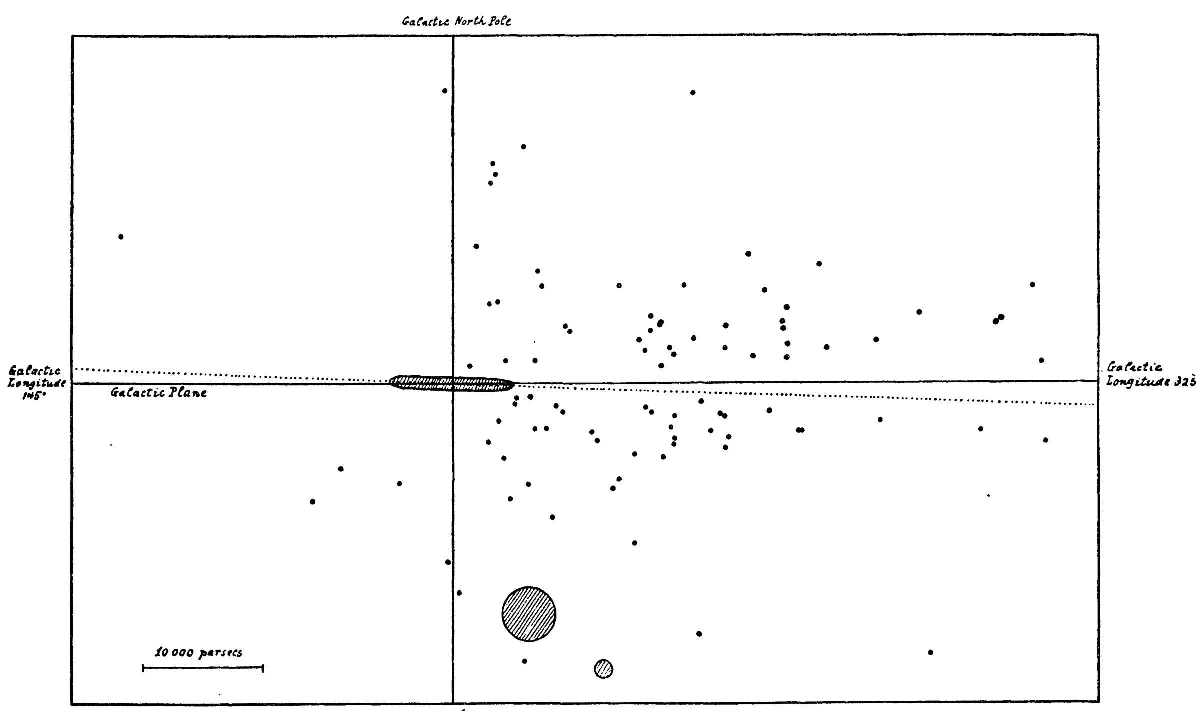

Fig. 9. Space distribution of open clusters, globular clusters, and the Magellanic Clouds.

In this figure the 93 known globular clusters are plotted as full dots in their projection on a plane which passes through the galactic pole and through galactic longitude 325°. On the scale of the chart the dots are about twice as large as the limiting dimensions of the globular clusters. The system of open clusters (Milky Way system) is represented by the elongated shaded area, the two Magellanic Clouds by the shaded circles. The dotted line indicates the plane of symmetry of the open clusters.

nish only the direction of the center of rotation, but not its distance. The question how the observational data concerning galactic rotation can be reconciled with the distribution of open clusters must however be left to a later investigation.

Figure 9 shows the space distribution of globular clusters in the projection on a plane passing through the galactic pole and through galactic longitude 325°. The 93 globular clusters are entered as full dots according to Shapley's most recent data[40]; the dots, on the scale of the chart, are about twice as large as the limiting size of these clusters. The much flattened system of open clusters which according to our hypothesis outlines the Milky Way system and the two Magellanic Clouds are represented according to their dimensions. The nearest spiral nebulae (*Andromeda* Nebula, Messier 33) would be 3–4 times more distant than the diameter of the whole figure.

From the fact that the space distribution of the globular clusters is somewhat symmetrical to the galactic plane, Shapley draws the conclusion that they form an integral part of the Milky Way system and that the center of the latter should therefore be identified with the center of the globular clusters which lies at a distance of at least 20,000 parsecs in the direction of *Sagittarius*, while the dimensions of the galactic system should be of the order of 100,000 parsecs. It must, however, be emphasized, that the distribution of globular clusters in the sky shows practically no relationship to the general star distribution. While the globular cluster system appears nearly spherical in shape there can be no question that the Milky Way system is much flattened. On account of partial obscuration by dark matter there may be some uncertainty about the extent of the star distribution in the galactic plane. No such uncertainty, however, exists in high galactic latitudes. Statistical investigations of stellar distribution show conclusively that in high galactic latitudes the stars do not reach farther than a few thousand parsecs and that the space between the numerous globular clusters in high galactic latitudes is certainly not filled with stars. The majority of globular clusters thus lie outside of the star stratum of our Milky Way system and should in this sense be called extra-galactic systems although this does not exclude the possibility that they have some relation to it. Fig. 9 shows a remarkable resemblance to some of the clusters of extra-galactic objects (spiral nebulae, elliptical and globular nebulae), and it seems worth while to examine the hypothesis that our Milky Way system (approximately as outlined by the open clusters) together with the two Magellanic Clouds and about a hundred globular clusters form a cluster of extra-galactic objects which we may call the "supercluster." Lundmark,[41] who quite independently came to the same conclusion as the writer, suggests also the possible existence of another large system in the *Sagittarius* region partly hidden by obscuring matter which he calls the "Hidden System" and to which the faint variable stars observed by Shapley in the direction of the "galactic center" would belong. It remains, however, to be investigated whether the faintness of these variable stars is not to some extent due to absorption of light rather than to great distance.

The striking feature of the super-cluster is the fact that it contains only one spiral system (the Milky Way system) and two large amorphous systems (the Magellanic Clouds) associated with a hundred or more globular systems of very much smaller but nearly uniform dimensions. Lundmark discusses this point and finds nothing very improbable in such an association in comparison with other clusters of extra-galactic objects.

Summary

1. The distances of 100 open clusters were determined from magnitudes and spectral types of the stars.

2. With these distances and the estimated angular diameters the linear diameters in parsecs were computed.

3. The linear diameters of open clusters vary considerably (2–16 parsecs); they depend on the constitution of the cluster.

4. The linear dimensions of an open cluster increase with the number of stars contained and with decreasing central concentration. There is a distinct but small class of clusters with exceptionally large dimensions.

5. The assumption that clusters of the same constitution have everywhere the same linear diameters leads to the conclusion that within the Milky Way system light is subject to an absorption of $0\overset{m}{.}67$ (photographic) per 1000 parsecs.

6. The discrepancy between color-indices and spectral types observed in open clusters increases with the distance of the cluster and shows that this absorption of light is selective, the photographic absorption coefficient being about twice the visual.

7. The absorption is effective in all galactic longitudes but seems to take place mainly in a thin layer extending along the galactic plane.

8. A method is developed to determine the distance of a cluster from its angular diameter and from a classification of its constitution.

9. A catalogue of 334 open clusters is compiled, which includes 41 objects not previously listed in

[40] *H. C. O. Bull.* No. 869, 1929.

[41] *Publ. A. S. P.* Feb. 1930.

cluster catalogues. This catalogue should be nearly complete for all the more prominent open clusterings of our Milky Way system, except for 30–40 of the smallest or faintest ones.

10. Distances and rectangular space coordinates for the 334 clusters were derived.

11. The plane of symmetry of the open clusters is inclined 2°3 to the adopted galactic plane; its pole lies at RA 12^h 50^m4 Decl: +27°7 (1900). This plane coincides very nearly with the plane of symmetry derived by Seares from the apparent distribution of faint stars.

12. A study of the space distribution of open clusters shows that they form a much flattened disk-like system about 1000 parsecs thick with a diameter of about 10,000 parsecs.

13. This cluster system shows a strong concentration towards a point which is situated at a distance of 350 parsecs in galactic longitude 247° from the Sun. The exceptionally rich open cluster NGC 3532 falls very close to this center.

14. The Sun lies 10 parsecs north of the plane of symmetry of the open clusters.

15. The hypothesis is made that the Milky Way system is in its essential features outlined by the space distribution of open clusters except for a greater galactic concentration of the latter.

16. This hypothesis supports the view that our Milky Way system is a highly resolved spiral nebula, a right-handed spiral as seen from the galactic North pole, of dimensions similar to those of the *Andromeda* nebula.

17. This hypothesis is not in conflict with the apparent distribution of faint stars, but it requires that the globular clusters be treated as extra-galactic objects forming, together with the Milky Way system and the two Magellanic clouds, a super-cluster of extra-galactic objects.

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