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UBV Photometry of Star Clusters in the Magellanic Clouds*

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Integrated *UBV* observations are reported for 39 clusters in the Large Magellanic Cloud, 13 clusters in the Small Magellanic Cloud, and 7 galactic star clusters. Comparison of open clusters in the Galaxy with clusters in the Clouds yields a mean reddening $\langle E_{B-V}\rangle = 0.20\pm0.05$ for young clusters with ages smaller than 3×10^7 yr. Older clusters with ages between 3×10^7 and 1×10^9 yr are found to have a mean reddening $\langle E_{B-V}\rangle = 0.06\pm0.01$. The globular clusters in the Magellanic Clouds do not follow the relation between intrinsic color $(B-V)_0$ and metallicity index Q which had previously been found for galactic globular clusters. This is probably due to systematic differences between the color–magnitude diagrams of Cloud globulars and globular clusters in the Galaxy. Attention is drawn to the existence of very red stars near the tips of the giant branches of many globular clusters in the Magellanic Clouds. Such objects, which may be mild carbon stars, are also observed in the Sculptor system but do not seem to occur in galactic globular clusters. The fact that the W Virginis star in NGC 121 falls on the period–luminosity relation observed in dwarf spheroidal systems serves to emphasize the similarity between Population II in the Clouds and in some dwarf spheroidal galaxies. In addition to these differences between the old stellar populations in the Galaxy and the Magellanic Clouds, differences also exist between the young stars in these systems. Furthermore the dust-to-gas ratio in the SMC is found to be at least 10 times smaller than it is near the sun. It is suggested that the observed differences between the Galaxy and the Magellanic Clouds are due to *small* differences in helium and (or) heavy element abundance.

I. INTRODUCTION

THIS paper reports the results of a program of *UBV* photometry of the integrated light of 52 star clusters in the Magellanic Clouds. Gascoigne (1966) has previously reported $B-V$ colors for 15 clusters in the Clouds. Additional data on the $P-V$ system, which may be converted to $B-V$, are given by Gascoigne and Kron (1952) and by Kron and Mayall (1960). No integrated $U-B$ colors have been published so far for any of the clusters in the Magellanic Clouds. Some multicolor work on a few Cloud clusters is reported by Kron (1961) and by McClure and Van den Bergh (1968). The spectral energy distributions of some clusters in the Magellanic Clouds have been measured by Aller and Faulkner (1964).

II. OBSERVATIONS

The observations reported in this paper were obtained with the 91-cm (36-in.) Cassegrain $f/13.5$ telescope of the Cerro Tololo Inter-American Observatory during 11 consecutive photometric nights between 18 January and 29 January 1968. The standard filters of the *UBV* system were used in front of a 1P21 photomultiplier (CTIO No. 57) which was refrigerated with dry ice. All observations were made using an integrating time of 10 sec. The amplified output of the photomultiplier was traced on a Brown recorder. Stars were observed through a 15″ or 30″ diaphragm; the smaller diaphragm being used only at times of excellent seeing. Star clusters were usually observed through a 60″ diaphragm. A single cluster observation consisted of 15 deflections taken in the order: *BVU* (cluster), *UVB* (north of cluster), *BVU* (cluster), *UVB* (south of cluster), *BVU* (cluster). Red leak observations were also obtained for all objects with $B-V>1.0$.

III. TRANSFORMATION EQUATIONS

Atmospheric absorption corrections were derived from observations of pairs of red and blue stars (see Table I) located close to the celestial equator (Haug, Dachs, Pesch, and Pfleiderer 1967). The transformation

Table I. Observations of equatorial standards.

HD	No.	V_T[a]	V	$(B-V)_T$	$(B-V)$	$(U-B)_T$	$(U-B)$	n
41288	Z3A	8.80	8.82	0.07	0.06	−0.37	−0.38	7
41460	Z3K	7.02	7.04	1.60	1.60	1.98	1.98	7
78282	Z4A	7.16	7.17	0.03	0.02	0.04	0.07	9
79011	Z4K	6.78	6.80	1.32	1.33	1.32	1.34	9
104484	Z5A	7.79	7.78	0.30	0.30	−0.01	0.00	10
104055	Z5K	6.17	6.20	1.26	1.24	1.40	1.43	10

[a] Tololo observations are marked by a subscript T.

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TABLE II. Observations of E region standards.

HR	Q No.	V_T	V	$(B-V)_T$	$(B-V)$	$(U-B)_T$	$(U-B)$	n
1216	E2–40	5.93	5.93	1.24	1.24	1.33	1.36	3
1291	E2–43	6.59	6.58	0.39	0.38	−0.01	0.00	3
1302	E2–64	4.94	4.92	0.35	0.34	0.08	0.07	3
1316	E2–29	6.70	6.70	1.50	1.48	1.83	1.80	3
1326	E2–65	3.86	3.85	1.11	1.10	1.00	1.02	3
1364	E2–45	5.34	5.33	1.09	1.08	0.95	0.96	3
2348	E3–45	5.74	5.76	−0.05	−0.06	−0.15	−0.18	4
2546	E3–36	6.52	6.54	1.52	1.51	1.85	1.81	4
2548	E3–47	5.13	5.14	0.45	0.45	−0.02	−0.04	4
2575	E3–48	6.52	6.51	0.41	0.42	0.16	0.11	4
2579	E3–49	6.47	6.46	−0.10	−0.12	−0.37	−0.39	4
2626	E3–52	6.23	6.21	0.01	0.00	−0.07	−0.06	4
3654	E4–92	4.98	4.99	0.21	0.22	−0.54	−0.59	3
3658	E4–93	5.79	5.78	−0.22	−0.22	−0.82	−0.84	3
3661	E4–40	5.56	5.56	−0.11	−0.12	−0.48	−0.47	3
3670	E4–94	5.92	5.91	−0.04	−0.05	−0.11	−0.10	3
3672	E4–78	5.86	5.84	−0.12	−0.14	−0.49	−0.50	3
3674	E4–79	5.24	5.24	−0.14	−0.16	−0.55	−0.57	3
3680	E4–41	6.26	6.24	−0.06	−0.08	−0.25	−0.27	3
3688	E4–95	6.06	6.03	0.28	0.29	−0.08	−0.19:	3
3692	E4–42	5.10	5.11	1.67	1.66	1.88	1.9::	3
3730	E4–44	5.74	5.74	0.91	0.92	0.62	0.64	3
3842	E4–47	5.49	5.49	0.99	1.00	0.67	0.68	3
4519	E5–51	5.28	5.28	−0.13	−0.13	−0.53	−0.56	4
4546	E5–76	4.45	4.46	1.29	1.30	1.45	1.46	4
4570	E5–37	6.26	6.26	0.39	0.42	0.02	0.04	4
4600	E5–40	5.13	5.14	0.40	0.42	−0.05	−0.04	4
4620	E5–78	5.32	5.33	−0.02	0.00	−0.04	−0.04	3
4624	E5–42	5.73	5.74	0.24	0.25	0.14	0.16	3
4636	E5–27	6.62	6.62	1.08	1.08	0.82	0.8::	3
4652	E5–55	5.30	5.30	1.42	1.43	1.58	1.58	3
5457	E6–41	6.06	6.06	0.51	0.52	0.03	0.04	2
5494	E6–43	5.71	5.74	0.11	0.07	0.05	0.08	2
5509	E6–44	6.29	6.30	1.06	1.08	0.84	0.90	2

equations between the UBV system and the instrumental colors of stars outside the atmosphere were computed from observations of the bright E region standards which are listed in Table II. These objects were chosen as primary standards because they are the most accurately observed stars in the southern hemisphere. The adopted values of V and $B-V$ for stars in the E regions were taken from Cousins (1963); the $U-B$ colors from Cousins (1967). Unfortunately the E regions are deficient in stars with very large negative $U-B$ values. The observations of the E region standards were therefore supplemented by observations (see Table III) of very blue stars in the cluster NGC 2362 (Johnson and Morgan 1953). The following color

TABLE III. Observations of the τ CMa cluster = NGC 2362.

No.	V_T	V	$(B-V)_T$	$(B-V)$	$(U-B)_T$	$(U-B)$	n
20	8.77	8.78	−0.16	−0.15	−0.87	−0.87	7
23	4.38	4.39	−0.16	−0.14	−0.98	−0.99	9
24	11.04:	11.02	0.02:	−0.05	−0.42:	−0.42	2
27	10.15	10.17	−0.08	−0.07	−0.65	−0.58	4
30	8.19	8.21	−0.18	−0.17	−0.91	−0.91	8
31	9.31	9.32	−0.13	−0.12	−0.77	−0.76	7
37	12.50	12.56	0.38	0.36	0.09		3
46	6.79	6.80	−0.17	−0.17	−0.73	−0.73	7

equations were obtained:

$$V=y+0.010(b-y)+\text{const}, \quad (1)$$

$$B-V=0.953(b-y)+0.939, \quad (2)$$

$$U-B=1.007(u-b)-0.816, \quad (3)$$

for $U-B>0.00$ and

$$U-B=0.942(u-b)-0.764, \quad (4)$$

for $U-B<0.00$. In these equations u, b, and y are respectively the instrumental ultraviolet, blue, and yellow magnitudes.

It might be assumed that Johnson's $U-B$ observations in NGC 2362, which were made at sec $Z>1.75$, are affected by a systematic error of 0.035 mag. If Johnson's $U-B$ is too red by this amount all the observations can be represented by a single linear tranformation equation.

The present observations are compared with standard magnitudes and colors in Tables I–IV. Table I compares the Tololo observations of pairs of equatorial standards observed at sec $Z<2.0$ with those of Haug *et al.* (1967). Table II gives a comparison with Cousins' (1963, 1967) observations of E region standards. Table III shows a comparison with observations in NGC 2362 by Johnson and Morgan (1953). Finally Table IV gives a comparison with Wesselink's (1962) observations of standard stars in the Magellanic Clouds. These observations by Wesselink are in good agreement with observations of the same stars by Arp (1958a), Eggen and Sandage (1960), Eggen (1961), Gascoigne (1962), and Westerlund (1961). The data in Tables I, II, III,

TABLE IV. Observations of standard stars in the Magellanic Clouds.

HD	Arp	V_T	V	$(B-V)_T$	$(B-V)$	$(U-B)_T$	$(U-B)$	n
34349	LMC A	7.04	7.03	0.44	0.44	0.00	0.00	8
34543	LMC B	8.38	8.36	−0.04	−0.06	−0.27	−0.28	10
	LMC C	9.39	9.36	1.36	1.36	1.48	1.42	11
35446	LMC D	9.45	9.44	0.34	0.35	−0.02	−0.02	11
[a]	LMC F	12.09		0.58		0.03		5
3719	SMC A	6.86	6.84	0.13	0.11	0.09	0.12	5
7187[b]	SMC B	7.15	7.13	0.10	0.08	0.05	0.06	9
3689	SMC C	7.44	7.40	0.48	0.49	−0.04	−0.07	5
6172	SMC D	7.68	7.67	1.34	1.33	1.47	1.47	9
3395	SMC F	7.86	7.81	−0.93	−0.92	−0.58	−0.58	3

[a] This is also star A of Arp and Thackeray (1967).
[b] Binary, both components in diaphragm.

TABLE V. Standard deviations of the differences between Tololo and standard star observations.

V	$(B-V)$	$(U-B)$
±0.018	±0.014	±0.024

and IV are plotted in Fig. 1. The standard deviations of the differences between the Tololo observations and values for 56 standard stars are listed in Table V. Table VI lists the systematic differences between the present observations and standard values. No systematic differences are present in the colors. Marginally significant differences exist in some of the V magnitudes. Our magnitudes appear to be too faint by 0.02 mag in the Magellanic Clouds and too bright by 0.02 mag in NGC 2362.

IV. CLUSTER OBSERVATIONS

The observations of the integrated colors of 13 clusters in the SMC are given in Table VII. The first column of the table gives the cluster number in the catalogue of Lindsay (1958). The second column gives the number in the catalogue of Kron (1956) and the NGC number. In the body of the table the upper line gives V_{60}, the integrated magnitude through a 60″ diaphragm, $B-V$ and $U-B$. The lower line gives the average deviation for each of the observations. The size of the individual average deviations depends on the apparent brightness of the cluster and on the amount of crowding in the cluster field. The sixth column of the table lists the reddening-free parameter:

$$Q=U-B-0.72(B-V)=(U-B)_0-0.72(B-V)_0. \quad (5)$$

The seventh column of the table gives the number of nights on which each cluster was observed. In the eighth

TABLE VI. Systematic differences (Tololo minus standards).

Sequence	Table	No. Stars	ΔV	$\Delta(B-V)$	$\Delta(U-B)$
Equatorial	I	6	−0.015 ±0.006	−0.002 ±0.005	−0.013 ±0.009
E regions	II	34	+0.001 ±0.002	+0.002 ±0.003	+0.002 ±0.004
NGC 2362	III	7	−0.020 ±0.011	−0.006 ±0.005	−0.012 ±0.013
LMC+SMC	IV	9	+0.023 ±0.010	+0.007 ±0.005	+0.007 ±0.009

column a G indicates a globular cluster and an O an open cluster. The last column gives references to color-magnitude diagrams for cluster stars. An asterisk following the L number of a cluster refers to a remark at the end of the table. Table VIII lists the observations of 39 clusters in the Large Magellanic Cloud. Observations of seven galactic star clusters are given in Table IX.

The positions of the LMC clusters observed during the present program are shown in Plate IV. SMC clusters are identified on a chart published by Kron (1956).

V. DISCUSSION

Figure 2 shows a plot of color versus integrated magnitudes for star clusters constructed from the observations which are listed in Tables VII and VIII. The figure shows that the brightest clusters in the Magellanic Clouds form two distinct subgroups; young populous clusters with $B-V<0^{m}.5$ and old red clusters with $B-V>0^{m}.5$. Similar results had previously been obtained by Gascoigne and Kron (1952) and by Gascoigne (1965).

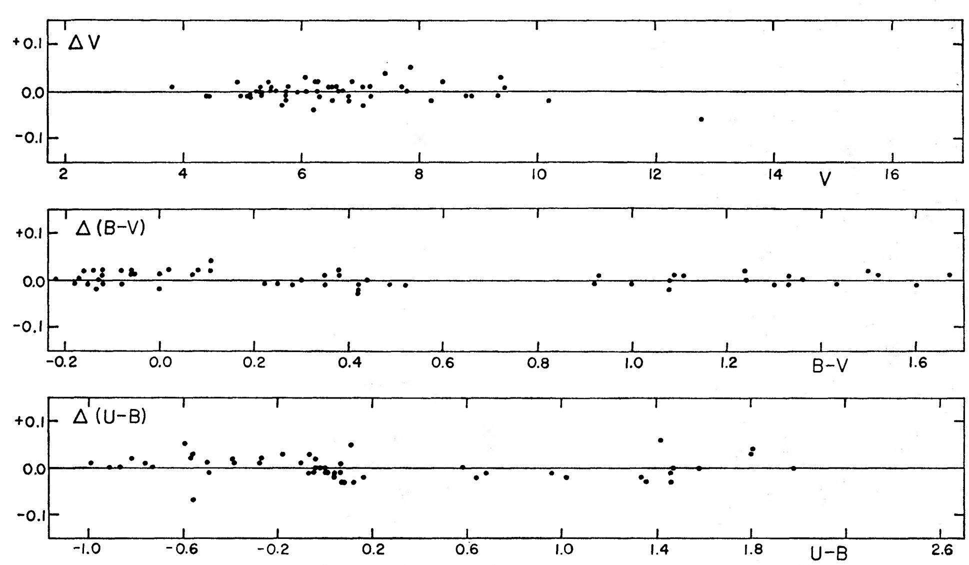

FIG. 1. Comparison between Tololo observations and standard stars in the E regions, in NGC 2362, in equatorial pairs and in the Magellanic Clouds. Differences are plotted in the sense Tololo minus standard.

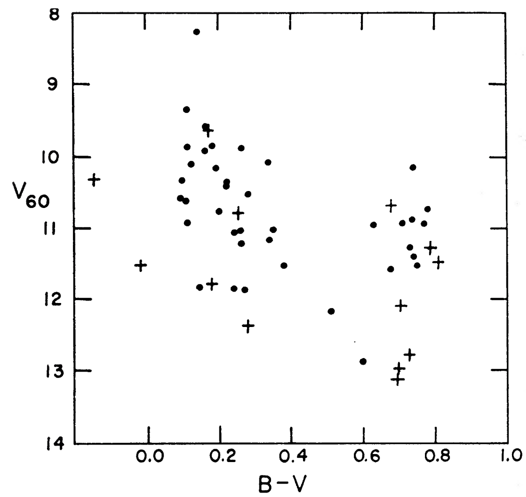

FIG. 2. Plot of color versus integrated magnitude for star clusters in the Magellanic Clouds. The figure shows that the Clouds contain both young blue clusters and old red clusters. Bright clusters of intermediate age are seen to be quite rare. LMC clusters are shown as dots, SMC clusters as crosses.

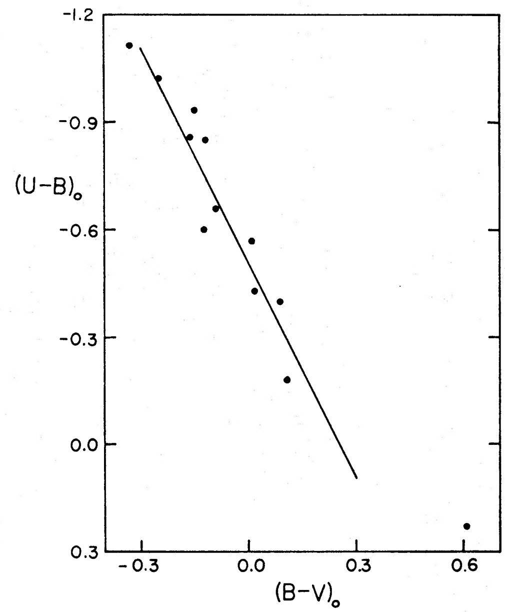

FIG. 3. Intrinsic colors of the brightest galactic open clusters according to Gray (1965). Also shown is the adopted intrinsic color relation for young clusters.

TABLE VII. Clusters in the Small Magellanic Cloud.

Name	Other designations	V_{60}	$B-V$	$U-B$	Q	n	Type	References
L 8	K 3	12.08 0.03	0.71 0.01	0.15 0.02	−0.36	5	G	Gascoigne (1966)
L 10	K 2 NGC 121	11.27 0.00	0.79 0.02	0.14 0.01	−0.43	5	G	Tifft (1963) Gascoigne (1966)
L 15*	K 10 NGC 152	13.12 0.03	0.70 0.01	0.18 0.04	−0.32	4	G	
L 30	K 23 NGC 256	12.37 0.04	0.28 0.03	−0.14 0.01	−0.34	4	O	
L 54*	K 35 NGC 330	9.63 0.03	0.17 0.02	−0.43 0.02	−0.55	7	O	Arp (1959b)
L 56		11.52 0.03	−0.02 0.04	−0.54 0.01	−0.53	3	O	
L 59*	K 36 NGC 339	12.99 0.06	0.70 0.01	0.10 0.02	−0.40	4	G	Gascoigne (1966)
L 60*	K 39 NGC 346	10.31 0.05	−0.15 0.02	−0.85 0.02	−0.74	4	O	
L 67*	K 46 NGC 361	(12.46) 0.06	(0.80) 0.03	(0.24) 0.04	(−0.34)	5	G	Arp (1958c)
L 72	K 49	10.79 0.03	0.25 0.04	−0.38 0.03	−0.56	4	O	Westerlund (1964b)
L 83	K 59 NGC 416	11.46 0.02	0.81 0.04	0.21 0.02	−0.37	4	G	
L 85	K 58 NGC 419	10.66 0.03	0.68 0.02	0.23 0.03	−0.26	4	G	Arp (1958b)
L 96	K 69 NGC 458	11.77 0.02	0.18 0.03	−0.15 0.03	−0.29	4	O	Arp (1959a)

REMARKS
L 15: Low surface brightness.
L 54: $V=9.97$ through 42″ diaphragm.
L 59: Low surface brightness.
L 60: Embedded in bright emission nebulosity. This nebula is N 66 in Henize (1956).
L 67: Star superimposed. This is Arp (1958c) II: 52 for which $V=13.93$, $B-V=1.06$. Assuming $E_{B-V}=0.05$ yields $(B-V)_0=1.01$ which is the intrinsic color of a K0III or K3V star (Johnson and Morgan 1953). The corresponding $(U-B)_0$ values are 0.86 and 0.89 for K0III and K3V respectively. Adopting $(U-B)_0=0.88$ and $E_{U-B}=0.04$ then yields $U-B=0.92$. With this value the true cluster magnitude and colors become $V_{60}=12.78$, $B-V=0.73$ and $U-B=0.11$ from which $Q=-0.42$. These corrected values are used in the discussion.

TABLE VIII. Clusters in the Large Magellanic Cloud.

NGC	V_{60}	$B-V$	$U-B$	Q	n	Type	References
1466	11.59	0.68	0.13	−0.36	4	G	Gascoigne (1966)
	0.03	0.02	0.03				
1644	12.89	0.60	0.19	−0.25	4	G	
	0.02	0.03	0.02				
1711	10.11	0.12	−0.37	−0.45	4	O	
	0.03	0.01	0.02				
1755	9.93	0.16	−0.22	−0.33	3	O	
	0.03	0.01	0.02				
1774	10.76	0.20	−0.27	−0.41	3	O	
	0.03	0.02	0.02				
1783*	10.97	0.63	0.20	−0.26	5	G	Gascoigne (1962)
	0.02	0.02	0.03				Sandage and Eggen (1960)
1786*	(10.16)	(0.67)	(0.06)	(−0.43)	4	G	Hodge (1960a)
	0.04	0.00	0.02				
1805	10.63	0.11	−0.55	−0.63	3	O	
	0.03	0.02	0.01				
1806	11.27	0.73	0.26	−0.27	4	G	Hodge (1960a)
	0.04	0.02	0.02				
1818	9.85	0.18	−0.46	−0.60	5	O	Woolley (1960)
	0.02	0.02	0.00				
1831	11.18	0.34	0.13	−0.11	5	O	
	0.02	0.02	0.02				
1835*	10.16	0.74	0.11	−0.42	5	G	Hodge (1960a)
	0.05	0.04	0.03				
1846	11.40	0.74	0.31	−0.22	5	G	Hodge (1960b)
	0.02	0.03	0.05				
1850*	9.36	0.11	−0.34	−0.42	5	O	
	0.06	0.03	0.07				
1854	10.42	0.22	−0.18	−0.34	3	O	
	0.05	0.01	0.03				
1856	10.07	0.34	0.06	−0.18	5	O	
	0.02	0.01	0.01				
1866*	9.89	0.26	−0.06	−0.25	6	O	Arp and Thackeray (1967)
	0.01	0.02	0.01				
1872*	11.04	0.35	0.06	−0.19	3	O	
	0.04	0.02	0.01				
1898*	11.52	0.75	−0.03	−0.57	4	G:	
	0.06	0.02	0.03				
1903	11.86	0.14	−0.25	−0.35	3	O	
	0.04	0.05	0.01				
1943*	11.88	0.27	−0.17	−0.36	3	O	
	0.01	0.03	0.03				
1951	10.58	0.09	−0.19	−0.25	3	O	
	0.04	0.03	0.01				
1978	10.74	0.78	0.23	−0.34	5	G	Hodge (1960c)
	0.04	0.04	0.07				
1986*	11.07	0.24	−0.20	−0.37	3	O	
	0.02	0.04	0.04				
1987	12.18	0.51	0.18	−0.18	3	G?	
	0.01	0.01	0.02				
2004	9.86	0.11	−0.68	−0.76	3	O	Westerlund (1961)
	0.02	0.01	0.01				Woolley (1960)
2019*	10.95	0.77	0.16	−0.39	3	G	
	0.01	0.01	0.02				
2041	10.36	0.22	−0.17	−0.33	3	O	
	0.01	0.02	0.01				
2058	11.85	0.24	−0.12	−0.29	3	O	
	0.04	0.01	0.01				
2065	11.24	0.26	−0.10	−0.29	3	O	
	0.01	0.02	0.01				

TABLE VIII (*continued*)

NGC	V_{60}	$B-V$	$U-B$	Q	n	Type	References
2070*	8.27	0.14	−0.69	−0.79	3	O	Westerlund (1964a)
	0.02	0.01	0.01				
2100	9.60	0.16	−0.56	−0.67	5	O	Westerlund (1961)
	0.04	0.02	0.02				
2107	11.51	0.38	0.13	−0.15	3	O	
	0.02	0.03	0.03				
2134	11.05	0.26	−0.02	−0.21	3	O	
	0.04	0.02	0.03				
2136	10.54	0.28	−0.13	−0.34	3	O	
	0.02	0.02	0.02				
2157	10.16	0.19	−0.16	−0.30	3	O	
	0.02	0.02	0.01				
2164	10.34	0.10	−0.24	−0.32	3	O	
	0.01	0.01	0.01				
2210	10.94	0.71	0.11	−0.41	4	G	Hodge (1960a)
	0.03	0.03	0.01				
2214	10.93	0.11	−0.27	−0.35	4	O	
	0.01	0.02	0.01				

REMARKS
NGC 1783: $V=11.72$ through a 42″ diaphragm.
NGC 1786: Bright star superposed. Star (plus part of cluster) were measured through a 15″ diaphragm on two nights. These measurements gave $V=10.95$, $B-V=0.61$ and $U-B=0.00$. With these values the corrected cluster magnitude and colors become $V_{60}<10.88$, $B-V=0.74$, $U-B=0.10$ and $Q=-0.43$. These corrected values are used in the discussion.
NGC 1835: High surface brightness similar to that of typical galactic globular clusters.
NGC 1850: In emission nebula Henize N 103.
NGC 1866: $V=10.26$ through 42″ diaphragm.
NGC 1872: The emission nebula Henize N 113 surrounds this cluster.
NGC 1898: $U-B$ color may have been affected by bright background.
NGC 1943: Associated with emission nebula Henize N 130.
NGC 1986: $V=11.85$ through 30″ diaphragm.
NGC 2019: Very compact.
NGC 2070: This is the 30 Doradus cluster which is located in a "hole" in the emission nebula Henize N 157A. The central star of this cluster was observed on two nights through a 15″ diaphragm yielding $V=9.42$, $B-V=0.14$ and $U-B=-0.75$. Westerlund and Smith (1964) give $V=9.47$ for this star.

A. Young Blue Clusters

The instrinsic colors of galactic open clusters have been studied by Gray (1965) and by Schmidt-Kaler (1967). From the 11 brightest blue clusters [$M_V<-5.5$, $(B-V)_0<0.30$] in Gray's list (see Fig. 3) it is found that

$$(U-B)_0=2.00(B-V)_0-0.51. \quad (6)$$

It will be assumed that this equation also holds for the young clusters in the Magellanic Clouds. This assumption seems reasonable because the intrinsic colors of early-type stars, which contribute most of the light in

TABLE IX. Observations of clusters in the Galaxy.

NGC	V	$B-V$	$U-B$	Q	φ	n	Type
1261	9.61	0.70	0.11	−0.39	60″	4	G
	0.02	0.02	0.01				
1851*	8.02	0.79	0.07	−0.50	60	4	G
	0.02	0.01	0.01				
1976*	4.58	0.04	−0.85	−0.88	30	2	O
	0.00	0.01	0.00				
3603*	8.95	0.99	−0.07	−0.78	30	6	O
	0.03	0.02	0.02				
5634	10.38	0.67	0.09	−0.40	60	4	G
	0.02	0.01	0.01				
5694*	11.04	0.71	0.07	−0.44	30	4	G
	0.01	0.01	0.01				
5824*	9.47	0.76	0.13	−0.41	60	4	G
	0.01	0.01	0.01				

REMARKS
NGC 1851: Colors peculiar.
NGC 1976: Orion Trapezium plus nebulosity.
NGC 3603: Sher (1965) finds $V=9.19$, $B-V=+0.86$ and $U-B=-0.16$ from observations on two nights through a 20″ diaphragm.
NGC 5694: In hyperbolic orbit (von Hoerner 1955). $V=10.63$ through 60″ diaphragm.
NGC 5824: $V=9.80$ through 30″ diaphragm.

TABLE X. Adopted intrinsic colors and reddening values for individual young clusters.

Cluster	$(B-V)_0$	E_{B-V}	Cluster	$(B-V)_0$	E_{B-V}
L 30	0.13	0.15	N 1903	0.13	0.01
L 54	−0.03	0.20	N 1943	0.12:	0.15
L 56	−0.01	−0.01	N 1951	0.20	−0.11
L 60	−0.18:	−0.03:	N 1986	0.11	0.13
L 72	−0.04	0.29	N 2004	−0.19	0.30
L 96	0.17	0.01	N 2041	0.14	0.08
N 1711	0.05	0.07	N 2058	0.17	0.07
N 1755	0.14	0.02	N 2065	0.17	0.09
N 1774	0.08	0.12	N 2070	−0.22:	0.36:
N 1805	−0.09	0.20	N 2100	−0.12	0.28
N 1818	−0.07	0.25	N 2107	0.28	0.10
N 1831	0.31	(0.03)	N 2134	0.24	0.02
N 1850	0.07:	0.04:	N 2136	0.13	0.15
N 1854	0.13	0.09	N 2157	0.17	0.02
N 1856	0.26	0.08	N 2164	0.15	−0.05
N 1866	0.20	0.06	N 2214	0.13	−0.02
N 1872	0.25:	0.10:			

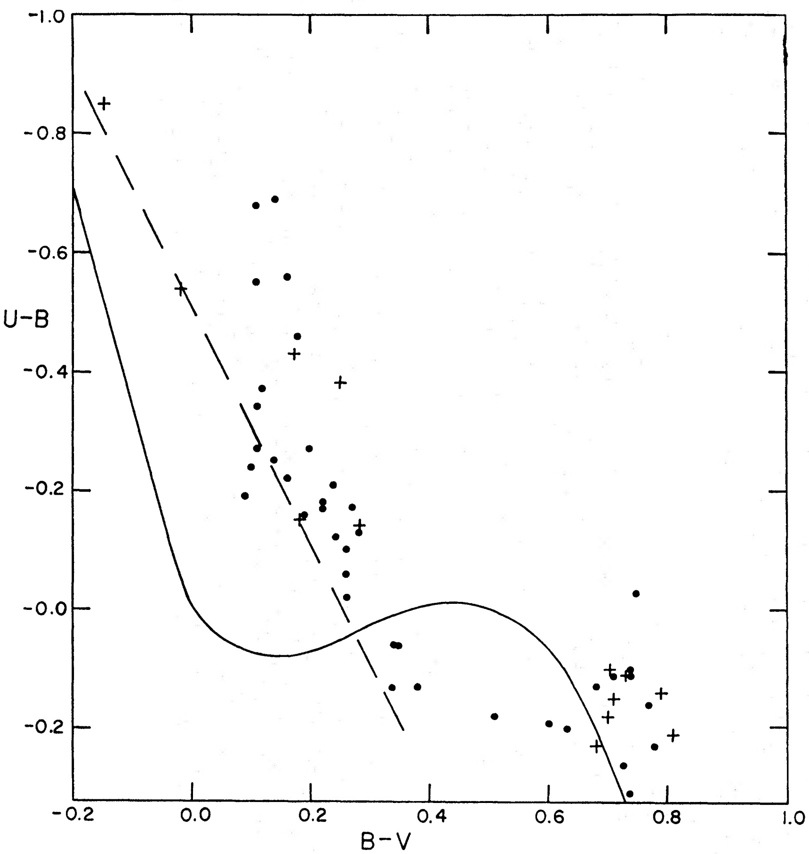

FIG. 4. Color–color plot for clusters in the LMC (dots) and SMC (crosses). The figure shows that most young clusters in the Magellanic Clouds are slightly reddened. The zero-age main sequence is plotted as a smooth curve; the adopted intrinsic color–color relation for bright young galactic star clusters is shown as a dashed line.

young clusters, are not much affected by small changes in metal abundance. Equation (6) is plotted in Fig. 4, which shows a color–color diagram for the star clusters in the Magellanic Clouds. The figure shows that most of the young clusters in the Clouds suffer a small amount of interstellar reddening. The reddening of individual clusters has been calculated by eliminating $(U-B)_0$ between (5) and (6) yielding

$$(B-V)_0=0.78Q+0.40. \qquad (7)$$

Individual intrinsic colors and reddening values computed from Eq. (7) are listed in Table X. It should be emphasized that individual reddening values are quite uncertain. Mean reddening values for the clusters in each Cloud are listed in Table XI. The frequency with which individual reddening values occur is shown in Fig. 5.

Figure 6 shows a plot of the observed reddening values as a function of intrinsic color for the young clusters in the Magellanic Clouds. This figure shows that the youngest clusters, which have the bluest intrinsic colors, are the most heavily reddened. This effect is to be expected if the youngest star clusters are still loosely associated with the interstellar clouds from which they were formed. The mean reddening values for clusters of different ages (Sandage 1963), as determined from $(B-V)_0$, are given in Table XII. The data in the table suggest that a mean reddening value $E_{B-V} \simeq 0.06\pm0.01$ is probably appropriate for old and intermediate-age objects in the Clouds. (The quoted mean error does not include the uncertainty of the galactic

TABLE XI. Mean reddening of young clusters.

	$\langle E_{B-V}\rangle$	No. clusters
Large Cloud	0.10±0.02	27
Small Cloud	0.10±0.05	6

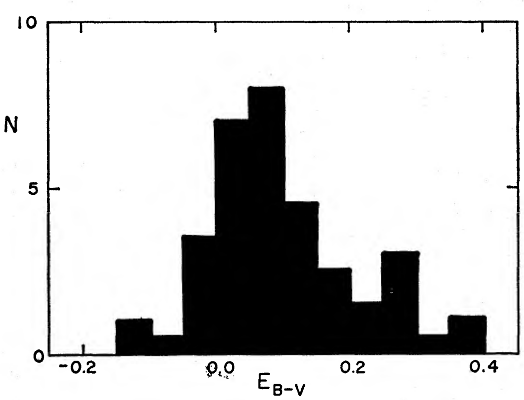

FIG. 5. Histogram of the frequency distribution of the observed reddening values for open clusters in the Magellanic Clouds.

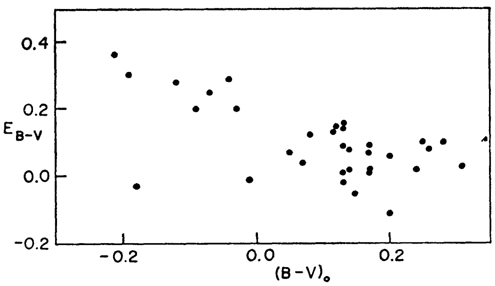

FIG. 6. Reddening of young clusters as a function of intrinsic color. The figure shows that the youngest clusters have the largest mean reddening. This effect is probably due to the fact that young clusters are still loosely associated with the interstellar gas clouds from which they were formed.

calibration of the intrinsic colors of clusters.) Arp (1960) also finds $E_{B-V}=0.06$ for the Cepheids in the SMC.

The 30 Doradus cluster (NGC 2070), which is located in the Tarantula nebula, is the brightest object in the Magellanic Clouds. Adopting $V=8.27$ (Table VIII), $(m-M)_0=18.4$ (van den Bergh 1968; to be published 1970) and $A_V=1.0$ (Table X) yields an absolute magnitude $M_V=-11.1$. This is one magnitude brighter than the most luminous star cluster known in the Galaxy (Buscombe 1963).

As expected, the intrinsic integrated colors of clusters correlate with the magnitudes of stars near the main sequence turnoff point. In the very young cluster NGC 2070, for which $(B-V)_0=-0.22$, the brightest star has $V=9.4$. This value may be compared to $V=16.1$ for the brightest main sequence stars in the intermediate-age cluster NGC 1866 (Arp and Thackeray 1967), which has an integrated color $(B-V)_0=0.20$.

B. Old Red Clusters

In van den Bergh (1967) it was found that the bluest galactic globular cluster has a color index $B-V=0.59$. All clusters in the Magellanic Clouds which are redder than this value have been tentatively classified as globular clusters. The only borderline case in the present sample is the Large Cloud cluster NGC 1987, which has an integrated color $B-V=0.51$.

Figure 7 shows a plot of the observed $B-V$ values of globular clusters in the Clouds as a function of the reddening-free parameter Q. Over the rather limited range of Q values which has so far been observed there is little evidence for a correlation between Q and $B-V$.

In the Galaxy the clusters that have the highest metallicity index Q also have the reddest intrinsic colors. No such correlation between color and metallicity index appears to exist in the Magellanic Clouds. This difference is probably due to systematic differences between the color–magnitude diagrams of globular clusters in the Clouds and in the Galaxy.

TABLE XII. Dependence of cluster reddening on age.

Age (yr)	$\langle E_{B-V}\rangle$	Number of clusters
$T<3\times10^7$	0.20 ± 0.05	9
$3\times10^7<T<1\times10^9$	0.06 ± 0.01	24

Available information on the color–magnitude diagrams of well-observed clusters in the Magellanic Clouds is summarized in Table XIII. The second column of the table gives the $B-V$ color of the reddest star at the tip of the cluster giant branch. In the third column an R indicates that most of the horizontal branch stars are located on the red side of the RR Lyrae gap; a B indicates that most of the horizontal branch stars are situated to the blue of this gap.

The exact position of the termination point of a cluster red giant branch cannot be determined accurately because the upper end of the cluster luminosity function is sparsely populated. Furthermore a very red field star may occasionally be regarded as a cluster member. In spite of these uncertainties it is clear from the data presented in Table XIII that most of the globular clusters in the Magellanic Clouds contain exceedingly red stars (Gascoigne 1963) near the tips of their red giant branches. The reality of these very red colors, which have been reported in four independent investigations, cannot be doubted. No galactic globular clusters are known to contain stars with intrinsic colors $(B-V)_0\geqslant 2.0$. Eight of the twelve clusters observed in the Magellanic Clouds appear to contain such very red stars.

VI. DIFFERENCES BETWEEN THE GALAXY AND THE MAGELLANIC CLOUDS

A. Stars of Population II

According to Van Agt (1967) the period–luminosity relation for W Virginis stars in dwarf spheroidal galaxies differs from that which is observed in galactic

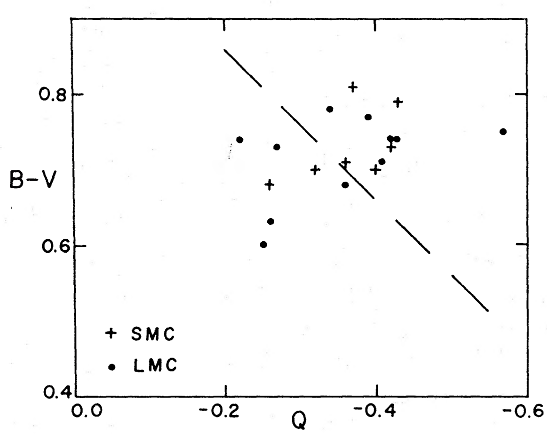

FIG. 7. Metallicity index versus color for globular clusters in the Magellanic Clouds. The figure shows that the clusters in the Clouds do not follow the $(B-V)_0$ vs Q relation (dashed line) obeyed by galactic globulars.

globular clusters. Observations by Tifft (1963) show that the 1.43-day W Virginis star in the SMC cluster NGC 121 lies on the period–luminosity relation of dwarf spheroidal galaxies. For this variable $\langle B\rangle = 18.4$ compared to $\langle B\rangle = 19.7$ for the cluster-type variables in NGC 121. The observed difference $\Delta\langle B\rangle = 1^m.3$ at $P = 1.43$ days is similar to the value $\Delta\langle B\rangle = 1^m.4$, which Van Agt obtains in dwarf spheroidal galaxies and differs from the value $\Delta\langle B\rangle \simeq 0^m.5$ which is found in galactic globular clusters.

In the previous section it was shown that many globular clusters in the Magellanic Clouds contain stars with $B-V \geqslant 2.0$. Such very red stars are not known to occur in galactic globular clusters. Two stars with $B-V > 2.0$ are, however, observed in the Sculptor dwarf galaxy (Hodge 1965). In the Galaxy carbon stars are the only giants with $B-V \gg 2.0$. This suggests that the stars with $B-V > 2.0$ in the Magellanic Clouds may be mild carbon stars.

It is tentatively concluded from these observations that the oldest stellar population in the Magellanic Clouds differs from Population II in the Galaxy and resembles that in some dwarf spheroidal galaxies.

B. Variable Stars

Arp and Kraft (1961) have shown that the Cepheids in the Galaxy and those in the Magellanic Clouds obey different period–luminosity relations. In the SMC the short-period Cepheids have much larger amplitudes than do their galactic counterparts. This difference in pulsation amplitudes is reflected in the differences between the period–frequency distributions of Cepheids in the Galaxy and in the SMC. The LMC Cepheids appear to be intermediate between those in the Galaxy and those in the Small Cloud. Small composition differences are probably required to account for the differences in the observed period versus pulsation amplitude relations.

C. Interstellar Matter

Gaposchkin and Gaposchkin (1966) report observations of 1144 Cepheids in the Small Cloud. From their data the *maximum* absorption in the blue anywhere in the SMC is $A_B = 1^m.0$ from which $E_{B-V} \leqslant 0^m.25$ for all SMC stars. From observations of globular clusters at intermediate and high galactic latitudes van den Bergh and Hindman (1969) find that

$$E_{B-V} = 2.1 \times 10^{-22} N_H, \quad (8)$$

in which N_H is the total number of neutral hydrogen atoms in a line-of-sight column of one cm^2 cross section. If the same relation held in the SMC the limit $E_{B-V} \leqslant 0.25$ would imply that $N_H \leqslant 1.2 \times 10^{+21}$. The actual value of N_H may be deduced from the integrated brightness B_{int} of 21-cm emission. B_{int} is related to N_H by the relation

$$N_H \geqslant 6.2 \times 10^{35} B_{int}, \quad (9)$$

in which the equality sign holds for small optical depth. In the densest part of the SMC, Hindman (1967) finds $B_{int} = 1.8 \times 10^{-14}$ W m^{-2} sr^{-1} so that $N_H > 11 \times 10^{21}$ cm^{-2}. This value is an order of magnitude higher than the value of N_H that was previously derived from optical absorption data. It is concluded that the dust-to-gas ratio is at least 10 times smaller in the SMC than it is in the Galaxy. This result is in agreement with Shapley's (1951) conclusion that the SMC is essentially transparent. Apparently Wesselink's (1961) results indicating large absorption in the SMC are incorrect. This view is supported by recent observations by Basinski, Bok, and Bok (1967).

The observed differences between the Small Magellanic Cloud and the Galaxy occur among both old and young stellar populations. In some respects the LMC appears to be intermediate between the Galaxy and the SMC. Observations by Aller and Faulkner (1962), by Faulkner and Aller (1965), and by Przybylski (1968), show that the present composition of the Magellanic Clouds does not differ greatly from that of the Galaxy. It is therefore concluded that the observed differences between the Galaxy and the Magellanic Clouds are probably due to *small* differences in helium and (or) heavy element abundance.

TABLE XIII. Old clusters with well-observed color-magnitude diagrams.

Cluster	$(B-V)_{max}$	Horizontal branch	References
SMC:			
NGC 121	1.9	R	Tifft (1963)
			Gascoigne (1966)
NGC 339	2.2	R	Gascoigne (1966)
NGC 361	2.1	...	Arp (1958c)
NGC 419	2.7	...	Arp (1958b)
L 1	2.4	R	Gascoigne (1966)
L 8=K3	2.2	R	Gascoigne (1966)
LMC:			
NGC 1466	1.6	B	Gascoigne (1966)
NGC 1783	2.4	R?	Gascoigne (1962)
			Sandage and Eggen (1960)
NGC 1841	1.7	B	Gascoigne (1966)
NGC 1846	2.6	...	Hodge (1960b)
NGC 1978	2.1	...	Hodge (1960c)
NGC 2257	1.8	B	Gascoigne (1966)

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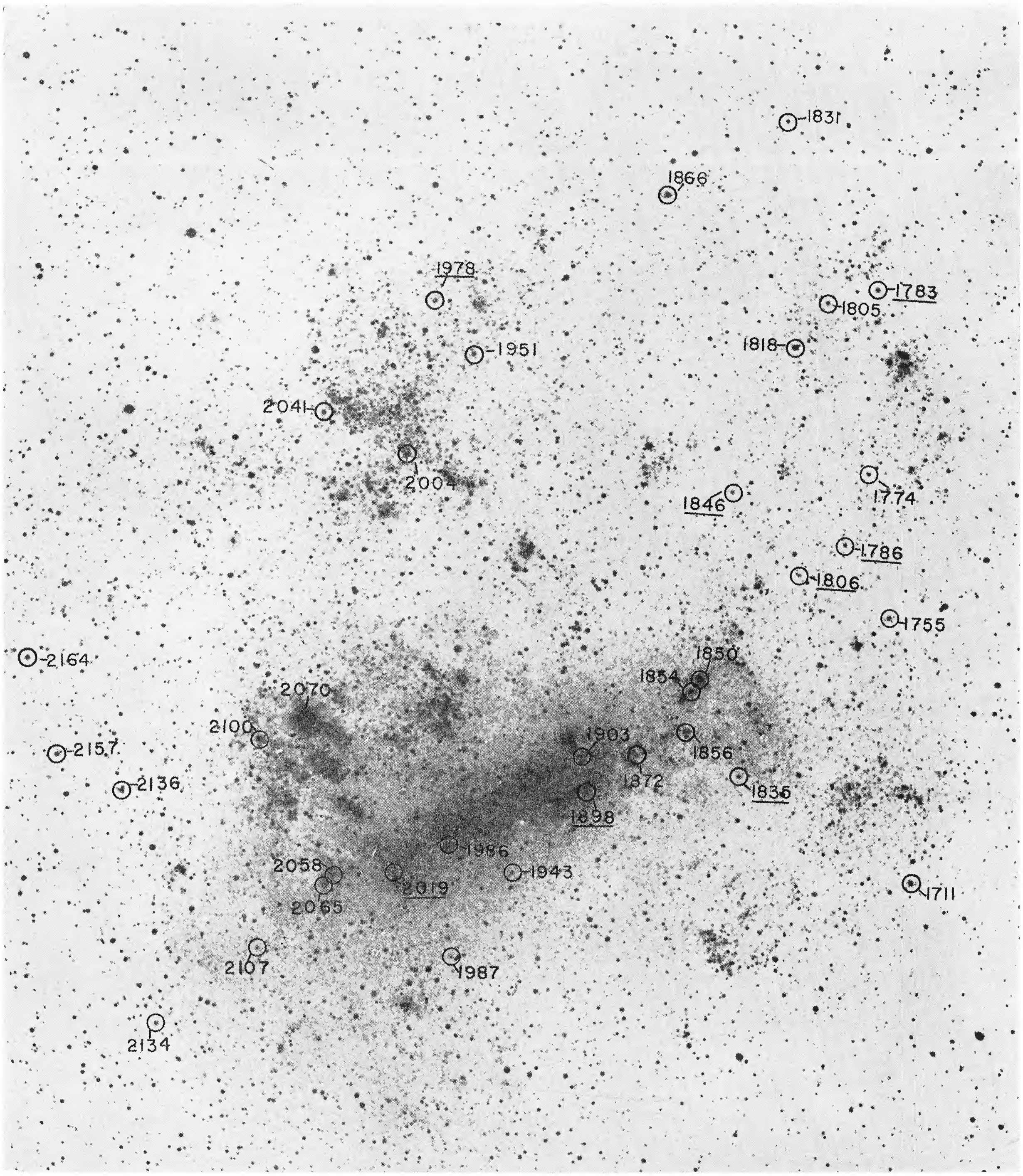

PLATE IV. (No. 1, van den Bergh and Hagen) Identification chart for LMC clusters. The NGC numbers of globular clusters are underlined. The clusters NGC 1466, NGC 1644, NGC 2210, and NGC 2214 lie beyond the edges of the chart. Photograph obtained by D. Sher with the 20-cm $f/1$ Schmidt camera of the Mt. Stromlo Observatory.