1956ApJ...124...81J

THE GALACTIC CLUSTER M11*

H. L. Johnson, A. R. Sandage, and H. D. Wahlquist
Lowell Observatory; Mount Wilson and Palomar Observatories
Carnegie Institution of Washington, California Institute of Technology
Received March 2, 1956

ABSTRACT

The results of three-color photographic-photoelectric photometry on about 400 stars in the galactic cluster M11 are given The cluster reddening is found to be $E_{(B-V)} = 0.42$ mag; the apparent distance modulus, 12 3 mag; and the true distance, 1660 parsecs The ratio of the two color excesses, $E_{(U-B)}/E_{(B-V)}$, has been found to be 0 72 The color-magnitude diagram for M11 appears to be consistent with present-day ideas on stellar evolution The age of M11 is intermediate between the Pleiades and Praesepe.

I. INTRODUCTION

Three-color photometric observations, made by the process of photographic interpolation between photoelectrically measured standards, are here reported for about 400 stars in and near the galactic cluster M11. This cluster is very rich in stars and contains many more yellow giant stars than do most galactic clusters; in these respects, it is similar to the galactic cluster, M67 (Johnson and Sandage 1955) The cluster M11 appears in the sky in the direction of the Scutum cloud. It is probably closer to the sun than is the Scutum cloud and is therefore seen in projection against the very rich background.

II. THE OBSERVATIONS

The photoelectric observations were made with the McDonald 82-inch telescope in the manner described for Praesepe (Johnson 1952), and the probable errors listed there for the cluster stars also apply to M11. The tie-in with the *U*, *B*, *V* system depends upon special observations on five different nights. The photoelectrically obtained values for the cluster standard sequence stars are listed in Table 1.

The photographic observations were made with the 100-inch telescope on Mount Wilson in the manner described for M67 (Johnson and Sandage 1955). The plate and filter combinations were the same as those previously described. Four plates in each of the three wave-length bands were measured to yield *U*, *B*, and *V* magnitudes. Table 2 gives the results for 399 selected stars in M11. To check the photographic system, magnitudes for the standards of Table 1 were read back through the calibration-curves. The adopted values for these stars are also listed in Table 2. Intercomparison of Tables 1 and 2 shows the lack of magnitude and color equations in the final data. The photographic data are therefore on the *U*, *B*, *V* system. The probable error of a single measurement for a *U*, *B*, or *V* magnitude is ± 0.031 mag. The probable error of the tabulated means in Table 2 is ± 0.015 mag.

With the exception of the yellow giants, the stars in the field of M11 were chosen at random for measurement. Every yellow giant was measured which was within the correction-free field of 10 minutes of arc radius from the center of M11. This biased procedure of selection gives approximately two times more yellow giants in the color-magnitude diagram than would be the case if the stars had been chosen strictly at random. This statistical bias was introduced to define better the yellow giant sequence. The luminosity function is not under discussion here.

* Contributions from the McDonald Observatory, No 264.

All stars in Table 2 are labeled by their Küstner numbers (1923), by their Wallenquist numbers (1936), or by supplementary letters. The photoelectric standards and the faint supplementary stars are identified in Figure 1.

III. THE COLOR-MAGNITUDE DIAGRAM

The observed color-magnitude diagram, V versus $B - V$, for M11 is shown in Figure 2. All the stars listed in Table 2 are plotted. A well-populated cluster main sequence is evident, as well as many yellow giant stars. The color-magnitude diagram for this cluster is of the usual galactic-cluster type, similar to the Praesepe cluster or the Hyades, rather than of the globular-cluster type. The diagram is markedly different from that for M67, even though the two clusters are quite similar in physical appearance.

TABLE 1

PHOTOELECTRIC STANDARDS IN M11

Star	V	$B-V$	$U-B$	N	Star	V	$B-V$	$U-B$	N
Küstner nos.:					*Küstner nos.*:				
20	14 06	+0 82	+0 44	1	615	9 34	+0 50	+0 20	Std.
38	12 64	+0 41	+0 17	1	616	11 71	+0 45	+0 25	2
47	15 11	+0 50	+0 29	1	620	9 21	+1 25	+1 10	1
56	11 58	+1 49	+1 39	1	668	14 38	+0 55	+0 33	1
66	13 43	+1 33	+1 02	1	669	14 58	+0 59	+0 41	1
68	11 59	+1 69	+1 90	1	671	14 18	+0 76	+0 43	1
71	14 04	+0 46	+0 32	1	672	14 75	+0 45	+0 41	1
72	14 36	+1 65	.	1	*Wallenquist nos*:				
82	13 43	+1 40	+1 36	1					
91	11 93	+0 33	+0 18	2	81	15 18	+0 44	+0 35	1
94	13 11	+0 28	+0 08	1	265	14 96	+1 59	+1 81	1
132	11 64	+0 38	+0 23	3	*Supplementary stars:*				
149	14 58	+0 52	+0 32	1					
224	11 81	+1 40	+1 15	2	A	15 81	+0 83	+0 24	2
287	14 25	+0 42	+0 32	1	B	15 21	+1 60	+1 70	1
317	12 36	+0 42	+0 25	2	C	15 06	+0 64	+0 43	2
427	11 72	+1 52	+1 43	2	D	15 90	+2 00		1
530	10 81	+0 61	+0 12	1	E	15 76	+1 59	+1 79	1
562	11 92	+0 34	+0 16	2	F	16 01	+1 65	+1 84	1
584	12 87	+0 40	+0 19	2	H	15 45	+0 75	+0 33	1
593	11 97	+0 34	+0 04	2	J	14 75	+2 43	+1 96	2
601	12 04	+0 42	+0 12	1	K	14 54	+0 58	+0 41	1

The color-magnitude diagram appears to be nearly free from field stars brighter than $V = 13$. At about this magnitude numerous stars which are off the M11 sequences begin to appear. Most of these are quite red and are undoubtedly the brightest stars of the background Scutum cloud. The solid slanting line in Figure 2 gives the approximate plate limit of the present data and shows that we have reached only a few magnitudes into the membership of the Scutum cloud.

In order to make more convenient a detailed analysis of the properties of M11, a mean main sequence has been derived from the values for all observed quantities for all the stars in given magnitude intervals. These intervals were $\frac{1}{2}$ mag. for $V < 14$ and $\frac{1}{4}$ mag. for $V > 14$. The yellow giants and all other stars that obviously are not cluster main-sequence stars were omitted from this computation. The results are listed in Table 3.

1956ApJ...124...81J

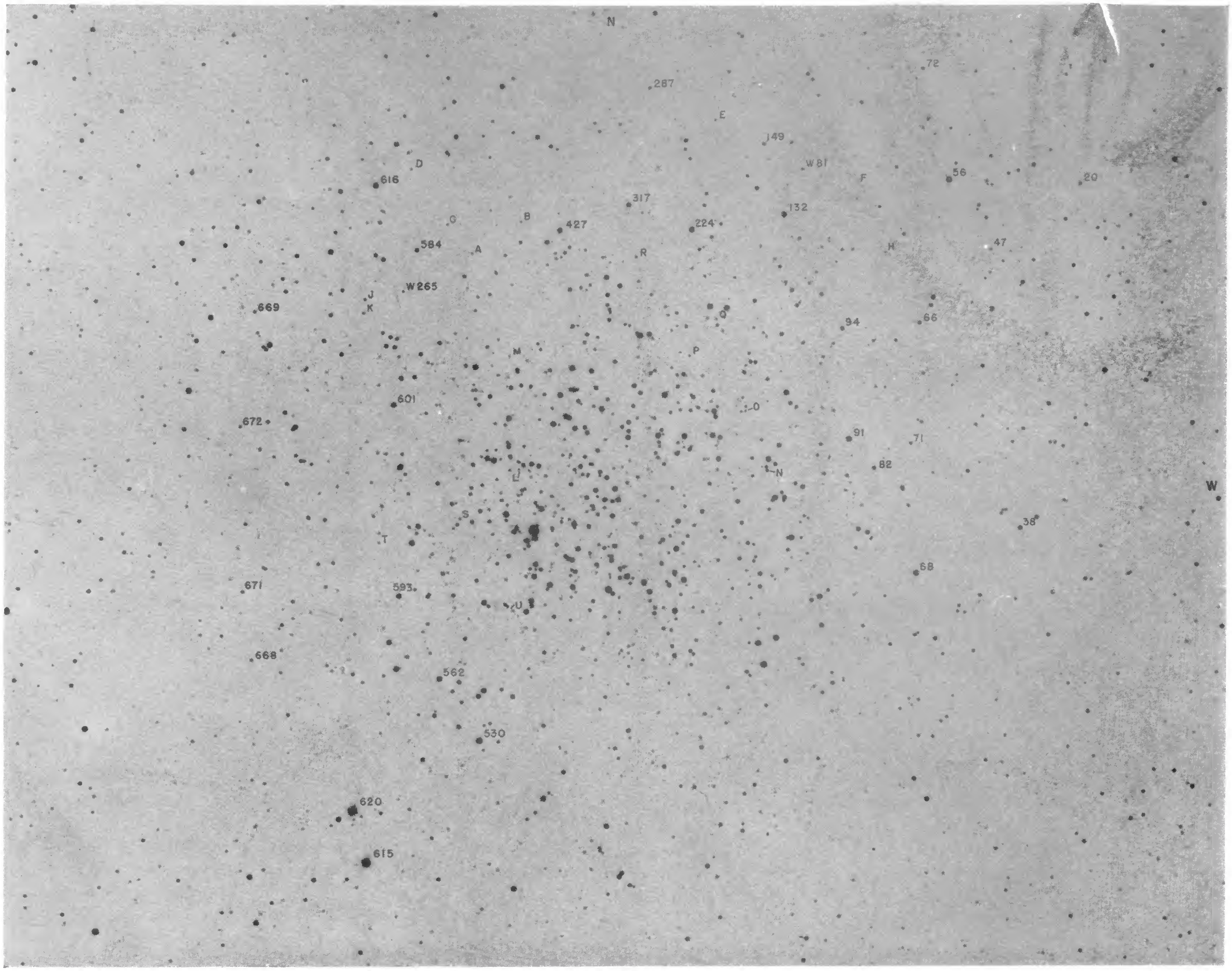

FIG. 1.—Identification chart for the photoelectric standards of Table 1 and for the supplementary stars of Tables 1 and 2. Unprefixed numbers are due to Küstner. Numbers prefixed by *W* are due to Wallenquist.

TABLE 2. COLORS AND MAGNITUDES OF 399 STARS IN M 11.

Star Küstner Nos	V	B-V	U-B
20	14.10	+ 78	+ 48
35	12.71	38	.11
38	12.70	38	.20
46	12 39	27	.15
47	14 96	53	.33
56	11.58	1.44	1.40
60	12.35	.30	.10
61	12.35	.36	.12
66	13.47	1.35	1.07
67	12 59	37	.18
68	11 63	1 71	1 89
71	14.00	47	.32
82	13.39	1.49	1 33
87	12.72	.34	16
91	11 95	.36	.18
92	14.09	.44	39
94	13 07	29	.11
98	14.83	.54	28
99	13.23	.36	.19
101	14.33	.45	39
102	12.48	.39	.16
103	14.56	.51	34
106	13.97	.39	.38
108	14.05	.38	.29
116	12 85	.27	.11
120	13.50	.33	.27
123	11.41	.41	.15
124	13.43	36	.25
127	14.75	52	.42
128	11.83	.31	11
129	12.53	2.06	-
130	14.37	.76	.51
132	11.69	.39	.26
133	12.72	.27	.02
134	11.33	.38	.09
136	11.59	1.60	1.35
138	13.11	.31	.16
139	14.10	39	+ 31
141	11.75	.38	-.06
143	11.04	1.98	+2.26
144	13.84	.39	32
145	12.55	.43	.21
148	11.38	1 60	1.74
151	14.38	.60	.36
152	13 88	.43	.36
153	14.80	.58	30
154	13.89	.30	31
156	14.59	.46	.32
157	13.47	.36	.21
158	14.11	.54	.35
159	14.50	56	.38
160	14.78	55	.37
161	13.23	.37	.22
162	13 47	.36	.21
163	12.88	.34	.18
164	14.25	.56	.33
166	14 73	.52	.32
168	13.41	1.50	1.48
169	13 31	32	.13
170	12.58	.33	.08
173	14.76	.70	28
174	14.17	.48	.26
179	11.80	1.19	84
180	13 87	.44	.41
183	12.54	.38	.21
185	12 32	.39	.10
188	14 81	.57	.43
190	12.67	.36	.11
191	11.72	.42	.02
193	11.77	38	.09
194	13.69	.35	.32
195	13.62	.37	.32
197	11.74	.35	.09
199	14 49	.49	.34
200	14.68	.65	.20
202	13.89	.46	.39
205	14.82	.66	.26
207	12.66	.39	14
208	14.66	.49	.33
211	14.73	63	.31
213	14.00	.49	.32
215	14.03	.51	.43
216	14.03	.43	.38
217	13.08	.39	.19
218	14.63	.59	.37

Star Küstner Nos	V	B-V	U-B
219	14.51	+.68	+.37
222	13 76	.30	10
223	12.71	42	14
224	11.79	1.40	1.13
227	11.34	.52	.15
228	14 20	.63	.48
233	11.37	.39	15
234	13.06	38	.01
235	14.16	.49	41
238	11.90	42	.19
239	11.55	1.72	1.94
240	13.60	.61	.38
241	12.62	.61	.26
243	11.46	.49	.26
247	14.32	.49	31
250	13.36	.39	.32
251	14.32	.53	.48
252	14.74	.59	31
254	11.98	.38	.12
255	14.22	43	41
256	14.50	.49	.42
258	13.57	.38	.33
260	13.40	.38	.25
262	13.81	.36	31
263	11.39	1.25	.77
272	11.59	.49	.06
275	13.81	.46	32
276	13.22	86	.56
280	11.76	.55	.38
282	14.89	.52	.42
283	12.20	.33	.07
284	14.49	.44	.30
286	11 24	1 51	1.71
287	14.24	.47	38
288	14.26	.53	.44
289	14.36	.49	.34
290	12 83	.40	.10
292	13.14	.38	.20
296	14.76	.53	.37
297	13.45	.41	21
298	14.91	.52	32
301	15.00	.59	.50
302	12.59	.35	12
303	13 19	.38	+ 26
305	12.88	.32	- 03
306	14.72	.57	+.35
308	10.82	54	.02
309	12.55	.38	10
311	14 38	.51	.39
313	11.91	1.48	1.29
314	13.71	51	.37
317	12.38	.39	30
320	14.70	.59	.39
321	14 56	.55	35
322	13 21	.36	+.20
323	12.66	.40	-.29
326	11.65	1.51	+1 36
327	12.29	.36	.15
328	12.11	.39	15
329	11.86	1.40	1.33
332	12.01	.45	19
333	12.97	.39	.24
334	12.05	1.44	+1.19
335	12.62	.41	-.03
336	10.30	.37	-.59
339	11.82	1.55	1.54
340	13.74	.50	.36
345	14.21	.57	.39
346	12.39	.38	.07
348	13 79	.41	.41
349	13.50	.40	+ 28
350	12 79	.25	- 21
355	11.81	.46	+.10
356	12.18	.31	.18
357	14 61	.60	.36
358	11.50	.52	.24
362	14.40	54	.33
364	12.64	.44	.25
365	12.86	.38	.19
366	12.25	.39	.07
369	13.66	.39	.27
370	14.65	.60	.41
373	14 42	.61	.38
378	12.11	.39	.19
380	12 45	45	.29

Star Küstner Nos.	V	B-V	U-B
382	14.36	+.46	+.44
384	12 67	.35	.06
388	13.67	.39	.33
389	13.07	.37	.24
391	13.84	.52	.46
392	13.98	.56	.41
393	12.32	.44	.07
394	11.77	.38	.09
395	14 58	.50	.42
397	12.83	.40	08
398	12.46	39	10
403	13.62	41	.32
404	11.81	.45	.09
406	15.12	.63	.48
408	14.53	.67	.34
409	14.18	.45	37
413	12.87	.38	.25
414	11.26	.46	.16
415	13.83	.50	.35
416	14.21	.50	38
420	12.97	41	.32
421	14.24	.51	37
422	14.60	53	.36
423	13.91	41	.39
425	11.38	.40	00
426	13 09	34	.25
427	11.71	1.46	1 44
433	14.93	54	52
434	11.59	.45	.13
436	11.19	.41	14
438	13.04	.49	+ 16
440	11.37	.38	-.29
443	13.26	.38	+ 22
445	12.67	.32	-.02
446	14.02	.39	+.30
448	11.12	1.09	.49
451	13.98	.49	.36
453	14.21	.51	.37
454	14 95	.53	.30
455	12.12	.40	13
456	11.44	1.50	1 36
457	14.71	.58	.36
459	14 06	.45	+ 38
461	11.39	.42	-.01
463	12.79	.33	+.31
464	11.33	.48	.04
465	12.37	.33	+.12
467	12.13	39	-.04
468	13.52	.42	+.34
470	14.56	.45	.39
471	13.46	.42	.27
472	12.62	1.52	1 18
473	11.55	1 80	1 93
474	14.79	.76	.25
475	14.19	.38	.36
479	14.26	49	.29
480	12.45	.38	.10
482	13.03	.41	.24
483	14.85	.45	.34
486	13.49	.43	.22
488	14 19	.45	33
489	12 81	.37	.17
491	11.94	.40	.11
495	12.87	43	.20
496	12.50	.31	.12
501	13.69	32	.37
504	14.37	.53	41
506	11.08	.48	.24
507	14 14	.47	.33
510	13.66	.42	.33
512	12.09	.31	10
513	14.92	53	.54
514	14.68	.63	.31
515	14.81	.44	43
516	11.13	1.79	1.40
521	13.60	.42	.36
522	12.74	.44	.19
524	14.00	.51	.45
525	11.25	1.73	1 49
526	11.88	.51	.22
527	14.92	.36	.60
528	11 81	.43	.19
529	14.01	.40	37
530	10 84	.64	07
531	13.84	.41	29

Star Küstner Nos.	V	B-V	U-B
532	14.49	+.70	+.42
533	12.16	39	.22
534	12.88	.32	.04
537	13.46	.42	.27
538	14.24	.46	.39
539	11.37	1.74	1.93
540	14.50	.58	.36
543	14.55	.67	.33
545	13.56	.47	.54
548	13.30	.79	.50
549	12.80	.37	.19
550	12.83	.44	.24
556	12.52	.39	.32
560	13.29	.49	.22
562	11.88	.38	.17
566	12.88	.35	.19
568	14.57	.50	.42
569	14.58	.53	.33
575	14.55	.58	.43
576	13.91	.46	.41
577	14.66	.59	.46
579	13.11	.46	.33
580	11.98	.44	24
581	14.31	.51	.48
582	14.42	.53	.31
584	12.86	.39	.20
585	13.13	.39	.19
586	11.85	1.46	1.33
588	13.63	.69	33
589	14.17	.41	.35
590	13.93	.49	.37
592	13.97	.67	.44
593	11.97	.38	.02
595	12.23	.47	.26
597	11.88	1.59	1.50
598	14.47	.57	.48
599	13 53	.50	.31
600	13.23	.43	.29
601	12.03	39	14
602	11.75	1.51	1 42
603	12.51	.34	.21
604	13.22	.43	.24
607	14.76	.61	46
608	12.79	.89	.43
609	14.50	.55	.45
610	12.73	.36	.13
612	14.74	.63	.33
615	9.32	.52	.19
616	11.60	.46	.29
617	14.42	.97	.43
618	14 59	.51	.44
620	9.18	1.22	1.11
624	11.95	1.00	.51
625	13.00	.38	.22
627	12.48	.32	.13
630	11 92	.44	.31
631	14.53	.84	.33
632	13.91	.51	.43
635	14.28	.47	35
639	14.36	.49	.41
658	11.90	1.45	1.41
667	12.65	.16	.37
668	14.42	.51	.38
669	14.64	.48	.50
671	14.15	.79	.41
672	14.54	.49	.36
675	12.14	.44	.21
682	11.51	1.62	1.87
684	12.44	.49	.25
Wallenquist Nos.			
68	15.02	.56	.33
81	15.10	.54	.29
89	14.17	1.53	-
90	13.56	1.78	-
99	14.92	.67	.18
100	15.17	.58	.14
102	15.14	.59	.45
103	15.13	.65	.33
105	14.85	.59	.54
109	13.59	1 96	-

Star Wallenquist Nos.	V	B-V	U-B
111	15.11	+ 54	+.35
119	15.06	.70	.14
126	15.06	.51	.41
129	14.70	1.51	-
137	14.78	.79	.29
141	14.58	.79	.44
144	15.16	.78	.06
145	15.07	1.03	.11
150	14.08	1.36	.86
155	15.20	.58	.55
157	14.88	.55	.29
160	14.77	.51	.53
166	13.59	1 63	1.19
171	14.78	.63	.37
174	15.05	.67	.30
177	14.84	1.01	.29
184	14.93	.54	.44
191	15.03	1.01	.22
194	14.77	.52	.50
197	14.21	.50	.38
198	14.97	.59	.28
199	15.07	.68	.38
203	15.25	.66	.31
205	15.17	.68	.36
206	15.13	.63	.39
209	15.03	.86	.10
210	14.95	.76	.18
212	15.11	.67	.21
213	14.68	.67	.18
214	15.23	.60	.21
216	14.92	.58	.35
217	14.40	1.56	-
225	14.78	.55	.33
226	15.13	.69	.29
228	14.69	1.51	-
231	14.94	59	.44
235	14 85	.91	.15
237	14.97	.66	.31
240	15.26	.59	.47
243	14.96	.66	.20
245	13.84	1.38	.74
249	14.94	.59	.36
250	15.03	.62	.27
251	15 10	.68	.56
252	15.25	81	.42
265	14 93	1 61	-
268	13.88	1.86	-
270	15.18	.59	.33
272	15.24	.68	.41
283	14.37	1.73	-
349	11.62	1.47	1.32

SUPPLEMENTARY STARS

A	15 82	+ 84	-
C	15.15	.59	+ 41
H	15.50	68	.18
K	14.57	.54	.52
L	14.91	56	.28
M	15.61	.72	-
N	13.86	1.93	-
O	15.37	.66	.21
P	15.41	.51	+.27
Q	15.45	77	-.04
R	14.95	.65	+.32
S	14 83	.54	.61
T	15.67	.63	.28
U	15.03	+.61	+.44

1956ApJ...124...81J

Since very narrow main sequences have been found in other galactic clusters, such as Praesepe (Johnson 1952), the Pleiades (Johnson and Morgan 1951, 1953), NGC 2362 (Johnson 1950; Johnson and Morgan 1953), and the Coma Berenices star cluster (Weaver 1952; Johnson and Knuckles 1955), it seems safe to assume that these mean values actually represent the true positions of the individual main-sequence cluster stars in the color-magnitude diagram. Haffner and Heckmann (1937, 1940) have shown, however, that some 20 per cent of the Praesepe stars probably are doubles. If we assume that this proportion holds in M11, we can estimate that the values in Table 3 may be about 0.1 mag. too bright to represent main-sequence single stars.

We shall not plot here the mean color-magnitude diagram, V versus $B - V$, from Table 3, but we shall, instead, plot the other color-magnitude diagram that this table permits—V versus $U - B$. This diagram is shown in Figure 3, and its interpretation leads us into the next section.

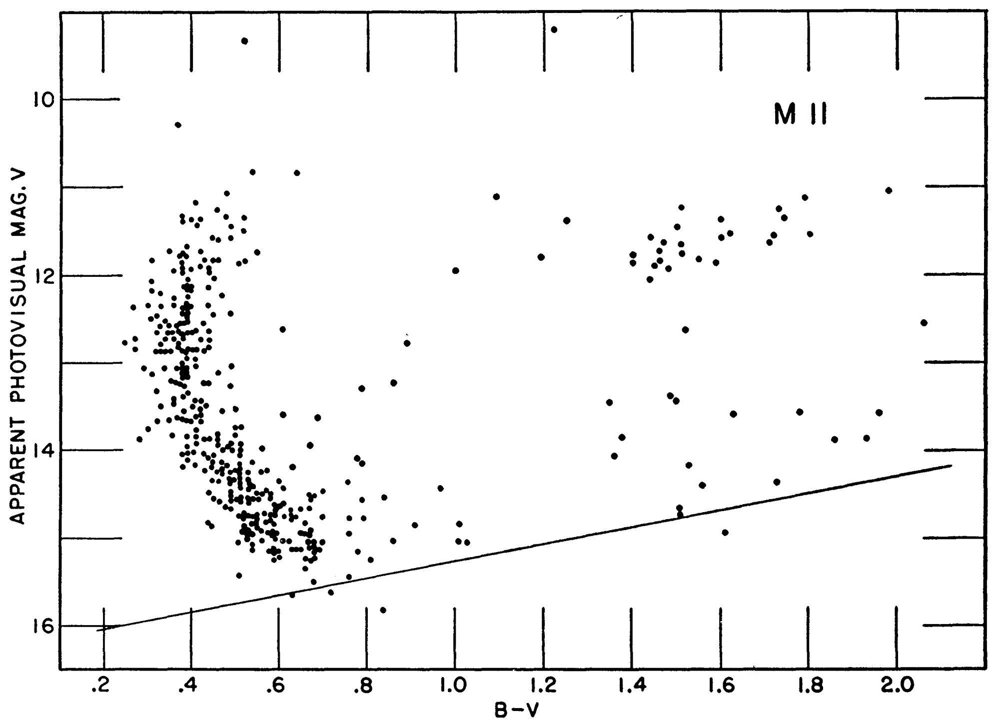

FIG 2 —The color-magnitude diagram for M11 from Table 2

TABLE 3

THE MEAN MAIN SEQUENCE FOR M11

V	$B-V$	$U-B$	No. of Stars	V	$B-V$	$U-B$	No. of Stars
11 32	+0 44	+0 12	11 } ½-mag intervals	14 12	+0 46	+0 36	26 } ¼-mag. intervals
11 80	+ 42	+ 15	24	14 36	+ 51	+ 38	22
12 29	+ 38	+ 15	29	14 61	+ 56	+ 37	33
12 73	+ 37	+ 15	38	14 86	+ 57	+ 36	35
13 24	+ 39	+ 22	30	15 13	+0 64	+0 35	25
13 76	+0 42	+0 35	35				

IV. THE REDDENING OF THE CLUSTER

Figure 3 should be compared with Figure 6 of Johnson and Morgan (1953). The similarity of the two figures in the region of the hydrogen dip (A stars) is evident. Johnson and Morgan's Table 14 shows that $U - B$ goes through a maximum, at about A5 V, of $+0.09$ mag. On the assumption that this value of $+0.09$ mag. also corresponds to the *unreddened* color of the M11 stars at the $U - B$ maximum in Figure 3, we compute the reddening in $U - B$ to be $E_{(U-B)} = +0.29$ mag.

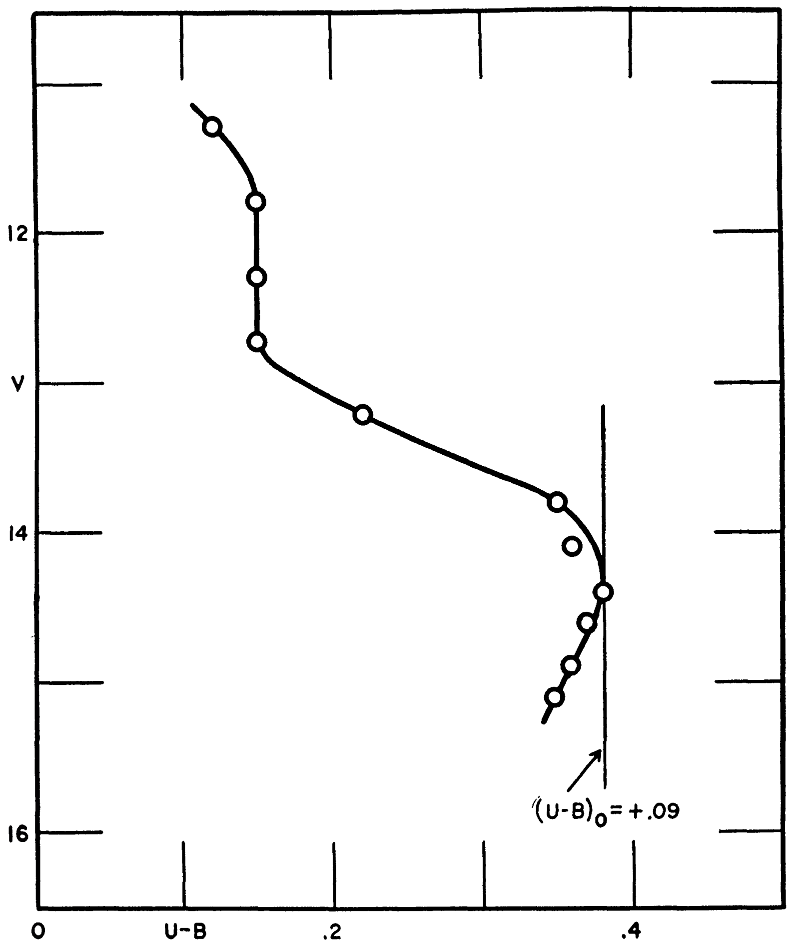

FIG 3 —The color-magnitude diagram in the arguments V and $U - B$. The data are from Table 3

The two-color index diagram, $U - B$ versus $B - V$, plotted from Table 3, is shown in Figure 4. The smooth line, drawn by hand, proceeds through the points in the same order as does the one in Figure 3. As in Figure 3, the line $(U - B)_0 = +0.09$ is tangent at the maximum in $U - B$.

We now make use of the fact that, by definition (Johnson and Morgan 1953, p. 322), $(U - B)_0 = 0$ at A0 V. This means that the $(U - B)_0 = 0$ line intersects the cluster-curve at the same point as does the $(B - V)_0 = 0$ line and that, further, $E_{(B-V)}$ equals the observed $B - V$ at this point. We find that $E_{(B-V)} = +0.405$ mag. The ratio of these two color excesses, $E_{(U-B)}/E_{(B-V)} = 0.72$, confirms exactly the value found by Johnson and Morgan (1953). A second way of estimating the reddening of M11 is by the "Q" method developed by Johnson and Morgan (1953) for individual main-sequence stars. This method cannot be applied to the brighter M11 stars because, as Figures 3 and 4 demonstrate, these stars exhibit, in their colors, effects of their higher luminosity. However, if the Q method is applied to the two bluest points on the *normal* main-sequence line of Figure 4 (not those on the hooked portion), we find $E_{(B-V)} = +0.42$ mag.

Armin Deutsch has estimated spectral types for several M11 stars, and he has permitted us to use them in our discussion. Table 4 lists these types, the intrinsic colors

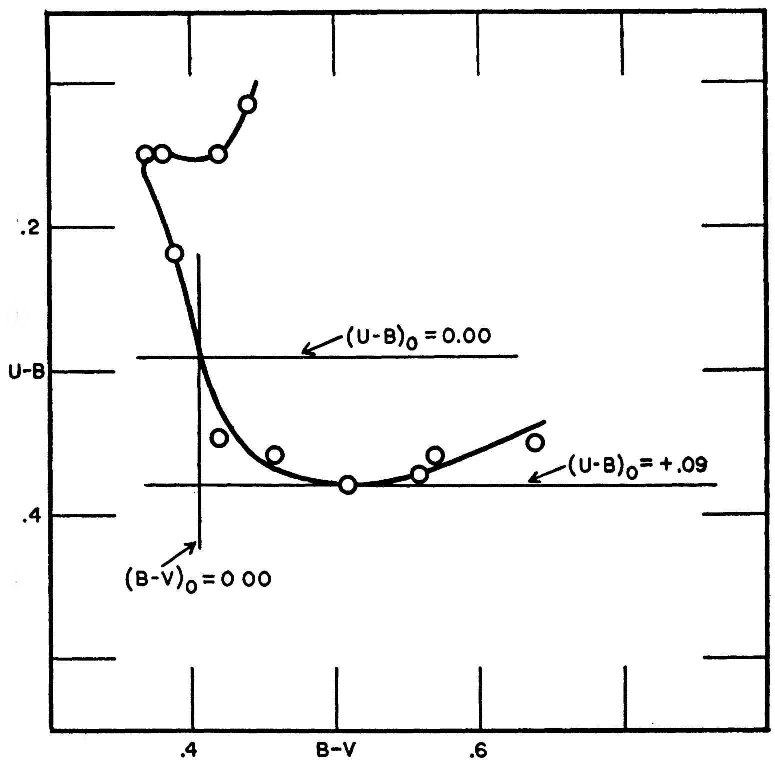

FIG. 4.—The two-color index diagram for the B- and A-type stars in M11. The data are from Table 3

TABLE 4

THE CLUSTER REDDENING FROM SPECTRAL TYPES

Star*	Sp.	$(B-V)_0$	$B-V$	$E_{(B-V)}$
141	B9 V	−0 05	+0 38	+0 43
193	B9 V	− .05	+ 38	+ 43
308	B8 V	− 09	+ 54	+ 63
336	B3p	− 20	+ 37	Nonmember
358	A0 V	00	+ 52	+ 52
434	A0 III:	00	+ 45	+ 45
436	B9 V	− 05	+ 41	+ 46
455	A5 V:	+ 15	+ 40	+ 25
461	A0 V	00	+ 42	+ 42
506	B9 V	−0 05	+0 48	+0 53
Mean		.	.	+0 46±0 02(p.e)

* Küstner numbers.

taken from Johnson and Morgan, the observed $B - V$ from Table 2, and the color excesses. We now have three values of $E_{(B-V)}$: +0.405, +0.42, +0.46. Since the scatter of the individual excesses of Table 4 is large, we give the spectroscopic determination lower weight and adopt $E_{(B-V)} = +0.42$ and $E_{(U-B)} = +0.30$.

V. THE DISTANCE OF THE CLUSTER

The distance modulus for M11 is obtained by fitting the cluster main sequence to the "age zero" main sequence computed by Johnson and Hiltner (1956) after shifting Figure 2 by $E_{(B-V)} = 0.42$ along the color axis. The procedure is illustrated by Figure 5. The apparent modulus is 12.3 ± 0.2 (p.e.) mag. The true modulus, after correction for interstellar absorption [$A_v = 3.0E_{(B-V)}$] is 11.1 mag., corresponding to a distance of 1660 parsecs.

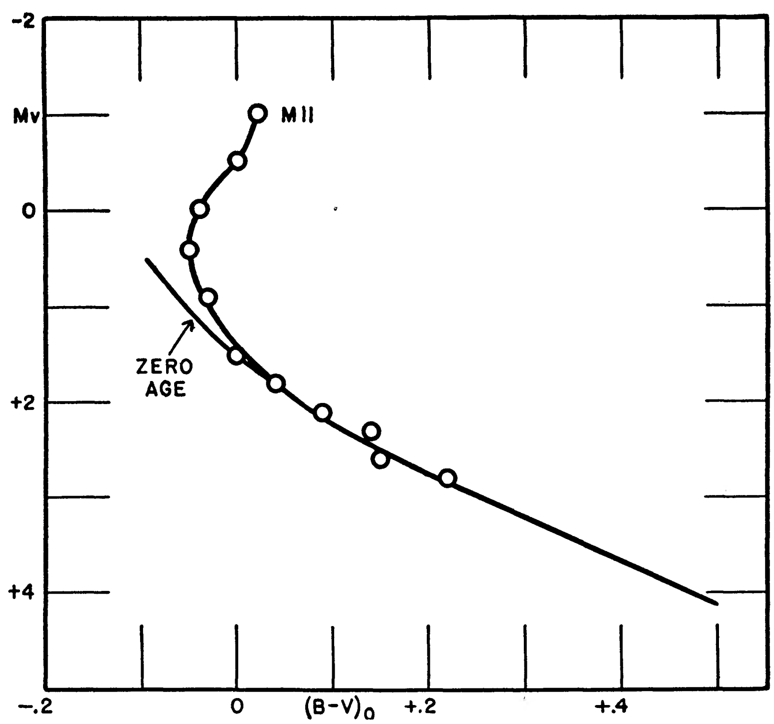

FIG. 5.—The fit of the M11 main sequence to the sequence of zero age computed by Johnson and Hiltner (1956).

The use of this age-zero main sequence, which leads to a significantly smaller distance for M11 than would a fit directly to nearby stars of large parallax but unknown age, seems justified observationally by the work of Johnson and Hiltner (1956), Johnson and Knuckles (1955), and Blaauw, Hiltner, and Johnson (1956). The point here is this: the nearby stars of large parallax probably are a mixture of stars of various and unknown ages and evolutionary motion away from the main sequence toward the higher luminosities. The positions of the brighter M11 stars illustrate the effect of this evolutionary motion for a number of stars, all of about the same age but with slightly different masses. On the other hand, it seems likely that the faintest M11 main-sequence stars are very little evolved and should not be compared directly with the evolved nearby stars without making some correction for the probable evolution. The age-zero main sequence is supposed to make this correction. In view of the errors possible in the foregoing procedure and in the determination of the cluster reddening and absorption, we estimate that the probable error of our derived modulus may be about ± 0.2 mag. We should point out that, in obtaining the distance modulus from a fit on the main sequence, it is assumed that if there are chemical-composition differences between M11 and the stars used in determining the age-zero main sequence, they have little or no effect upon the initial position of the main sequence. It should further be mentioned that our apparent modulus of 12.3 is only as good as the zero point of absolute magnitude for the age-zero main sequence. If this be changed, our modulus will change.

VI. THE EVOLUTIONARY SIGNIFICANCE OF M11

The upward bend of the observed main sequence in M11 shown in Figure 5 is consistent with current ideas of evolution. The departure shown in this figure is in very good agreement with the theoretical diagrams of R. J. Tayler (1954, Fig. 3) and of Sandage (1954, Fig. 4). The main-sequence termination point in M11 occurs near $M_v = -1.0$ and falls between that of the Pleiades and that of Praesepe, suggesting that the age of M11 is intermediate between these two clusters.

The yellow giants in M11 are almost unique among galactic clusters, since they average 1 mag. brighter than the usual giants of luminosity class III at $M_v = 0.0$. However, this situation is entirely expected in populous clusters younger than the Hyades and Praesepe (i.e., with main-sequence terminations brighter than $M_v = 0$), since most current evolutionary theories predict that the entire giant and supergiant region of the M_{bol}, log T_e plane, with the exception of the wedge-shaped Hertzsprung gap, will contain stars if clusters of *all* ages from 10^6 to 5×10^9 years can be found and plotted in a composite diagram. The absolute magnitude of $M_v = -1$ for the M11 giants is therefore not surprising.

One might ask why younger clusters, such as the Pleiades and NGC 2362, do not contain yellow or red intermediate giants at $M_v \approx -3$ to $M_v \approx -4$. The number of giants in a cluster at any given time is determined by the number of main-sequence stars which are immediate candidates for evolution. A convenient index for comparison of clusters is the ratio of the number of giants to the number of main-sequence stars within, say, 2 mag. of the termination point. This ratio in M11 is about 15/100 (obtained by counting in Fig. 1 and dividing the number of giants by the statistical bias of 2). For the Pleiades, Hertzsprung (1928) lists only 4 stars on the main sequence within 2 mag. of the termination point. If the M11 giant to main-sequence ratio applies, we would predict that the Pleiades should contain 0.6 giant. This agrees with the fact that no giants are known in the Pleiades. If the same ratio of 15/100 applies to the Hyades, we expect about 6 Hyades giants. Four are known. The extreme sparseness of 2362 likewise explains the absence of giants in this cluster. Hence the absolute mganitude and the number of giants in M11 do not appear to be anomalous by comparison with other known aggregates.

M11 is not the only cluster known to contain intermediate giants. NGC 2287 studied by A. N. Cox (1954) has 5 intermediate giants at $M_v = -2$. The positions of the main and giant sequences in M11 and NGC 2287 fit well into the scheme of systematics shown in the composite diagram in the previous paper on M67 (Johnson and Sandage 1955, Fig. 6).

VII. SUMMARY

Three-color photometric observations on many stars in M11 permit the determination of a color-magnitude diagram. These observations, together with Deutsch's spectral types for a few stars, give the reddening and distance to the cluster. M11 is a populous galactic cluster with a well-defined main sequence, which terminates at the bright end between that of the Pleiades and that of Praesepe. Its age is intermediate between these two clusters. M11 has many yellow giants, including several of later type than K0. These yellow giants are brighter than those of the Hyades and Praesepe. This is expected

from current evolutionary hypotheses, since the main sequence in M11 terminates at about $M_v = -1.0$. The large number of giants in M11 is not anomalous when the abnormally large population of the cluster itself is considered. M11 is therefore another observational example of the scheme of evolution which has been discussed by many authors over the last fifteen years (Schönberg and Chandrasekhar 1942; Harrison 1944; Ledoux 1949; Sandage and Schwarzschild 1952; Roy 1954; Sandage 1954; Tayler 1954; Johnson and Sandage 1955; etc.).

REFERENCES

Blaauw, A , Hiltner, W A , and Johnson, H L 1956, in preparation.
Cox, A N. 1954, *Ap J* , **119**, 188
Haffner, H., and Heckmann, O. 1937, *Göttingen Veröff* , No 55.
——— 1940, *ibid* , Nos 66 and 67.
Harrison, M. H 1947, *Ap. J* , **105**, 322
Hertzsprung, E 1928, *M N.*, **89**, 660.
Johnson, H. L. 1950, *Ap J* , **112**, 240
——— 1952, *ibid* , **116**, 640.
Johnson, H L , and Hiltner, W. A 1956, *Ap J* , **123**, 267
Johnson, H. L , and Knuckles, C F 1955, *Ap J* , **122**, 209.
Johnson, H L., and Morgan, W W 1951, *Ap. J.*, **114**, 522.
——— 1953, *ibid* , **117**, 313.
Johnson, H L , and Sandage, A R 1955, *Ap J* , **121**, 616.
Küstner, F 1923, *Veröff Sternwarte Bonn*, No 18
Ledoux, P 1949, *Mém Inst d'Ap Liége*, No 309.
Roy, A E. 1952, *M.N* , **112**, 484
Sandage, A R 1954, *Mém Soc R. Sci Liége*, **14**, 254 (*Communications du Colloque d'Astrophysique de Liége*, **1953**)
Sandage, A R , and Schwarzschild, M 1952, *Ap J* , **116**, 463.
Schönberg, M , and Chandrasekhar, S 1942, *Ap J* , **96**, 161.
Tayler, R J 1954, *Ap J.*, **120**, 332.
Wallenquist, A. 1936, *Meddel Uppsala*, No 65.
Weaver, H F 1952, *Ap. J* , **116**, 612.