TABLE 1

Stars in the Region of IC 4651

Star No.	V_E (mag)	$B-V$ (mag)	$U-B$ (mag)	N
1.....	12.99	+0.54	+0.11	2
2.....	13.52	+0.54	+0.08	3
3.....	12.06	+0.605	+0.12	2
4.....	13.78	+0.63	+0.06	2
5.....	12.92	+0.53	+0.08	2
6*....	15.62	+0.555	+0.10	2
7.....	14.28	+0.655	+0.11	2
8.....	10.78	+1.11	+0.82	2
9.....	11.49	+0.41	+0.15	2
10.....	11.58	+0.56	+0.10	2
11.....	12.56	+0.475	+0.08	2
12.....	10.40	+1.105	+0.90	2
13.....	12.34	+0.565	+0.105	2
14.....	13.15	+0.515	+0.03	2
15.....	13.55	+0.575	+0.03	2
16.....	12.46	+0.55	+0.11	2
17.....	12.68	+0.505	+0.105	2
18.....	11.88	+0.575	+1.13	2
19.....	12.35	+0.62	+0.11	2
20.....	12.56	+0.53	+0.11	2
21.....	12.06	+0.615	+0.12	2
22.....	10.94	+1.14	+0.915	2
23.....	10.68	+1.125	+0.89	2
24.....	12.80	+0.53	+0.07	2
25.....	12.70	+0.525	+0.09	2
26.....	13.07	+0.565	+0.035	2
27.....	10.21	+0.04	+0.75	3
28.....	12.24	+0.575	+0.075	2
29.....	14.05	+0.575	+0.03	2
30*....	14.93	+0.925	+0.63	2
31*....	15.30	+0.70	+0.30	2
32.....	13.12	+0.54	+0.08	2
33.....	13.64	+0.60	+0.08	2
34.....	13.52	+0.58	+0.01	3
35.....	12.58	+0.535	+0.04	2
36.....	14.40	+0.66	+0.09	2
37.....	12.34	+0.525	+0.145	1
38*....	13.60	+0.625	+0.135	2
39.....	12.40	+0.59	+0.11	2
40.....	12.45	+0.32	+0.16	3
41.....	13.17	+0.565	+0.025	2
42*....	14.55	+0.74	+0.41	2
43.....	14.35	+0.74	+0.15	2
44.....	12.63	+0.56	+0.07	2
45.....	14.27	+0.62	+0.045	1
46.....	10.54	+0.285	+0.20	2
47.....	12.61	+0.545	+0.03	2
48*....	12.83	+1.27	...	2
49.....	13.50	+0.52	+0.04	2
50.....	12.46	+0.55	+0.08	2
51.....	14.96	+0.78	+0.245	2
52*....	15.39	+0.81	+0.42	1
53.....	13.50	+0.62	+0.12	2
54.....	12.24	+0.69	+0.14	3
55.....	12.30	+0.585	+0.10	2
56.....	12.12	+0.61	+0.13	3
57*....	13.98	+1.57	...	1
58.....	10.86	+1.23	+1.19	3
59.....	12.88	+0.545	+0.045	2
60.....	10.90	+1.13	+1.04	3
61.....	13.22	+0.56	+0.08	2
62*....	13.48	+1.43	...	1
63.....	12.68	+0.55	+0.09	2
64.....	13.78	+0.58	+0.065	2
65.....	10.88	+1.275	+1.185	2
66.....	12.76	+0.555	+0.05	2
67.....	12.52	+0.55	+0.06	5
68†....	Var	+0.575	+0.05	4
69.....	14.63	+0.77	+0.23	1
69A....	14.96	+0.78	+0.245	2
70.....	12.12	+0.615	+0.09	3
71.....	12.92	+0.59	+0.05	2
72.....	12.89	+0.47	+0.11	2
73.....	13.28	+0.575	+0.075	2
74.....	12.18	+0.59	+0.10	3
75.....	12.13	+0.31	+0.24	3
76.....	10.44	+1.35	+1.34	2
77.....	12.20	+0.60	+0.07	2
78.....	10.46	+1.255	+1.23	1
79.....	13.53	+0.56	+0.035	2
80*....	13.68	+1.26	+1.175	2
81.....	13.18	+0.55	+0.045	2
82.....	13.84	+0.58	+0.055	2
83.....	10.94	+1.14	+0.94	2
84.....	13.12	+0.555	+0.08	2
85.....	13.68	+0.535	+0.04	2
86.....	13.80	+0.63	+0.085	1
87*....	13.85	+1.155	+0.84	1
88*....	14.60	+0.715	+0.34	1
89*....	13.85	+1.57	...	1
90.....	12.10	+0.61	+0.135	3
91.....	10.61	+1.01	+0.69	2
93.....	8.95	+1.68	+2.01	2
94.....	11.64	+0.605	+0.12	3
95.....	12.04	+0.77	+0.275	3
96.....	10.41	+1.33	+1.285	2
97*....	11.68	+1.30	+1.33	1
98.....	10.94	+1.175	+1.025	2
99.....	12.46	+0.53	+0.09	2
100.....	12.72	+0.535	+0.09	2
101.....	12.80	+0.52	+0.10	2
102.....	12.07	+0.58	+0.10	1

* Nonmember.

† In No. 68, V_E varies from 12.97 to 13.28 mag.

TABLE 2

Early-Type Stars near IC 4651

HD	V_E (mag)	$B-V$ (mag)	$U-B$ (mag)	N	Sp	E (mag)	$m-M$ (mag)
157455...........	6.94	−0.06	−0.61	2	B8	+0.15	7.9
157523...........	8.96	−0.02	−0.44	2	B8	+0.15	9.3
157533...........	9.83	+0.005	−0.26	3	B9	+0.13	9.45
157556...........	7.92	−0.035	−0.48	2	B9	+0.14	8.35
157598...........	9.64	−0.01	−0.43	2	B8	+0.16	9.95
157599...........	6.20	−0.02	−0.25	3	B8	+0.10	5.8
157662...........	5.92	+0.105	+0.055	2	B9	+0.12	4.1

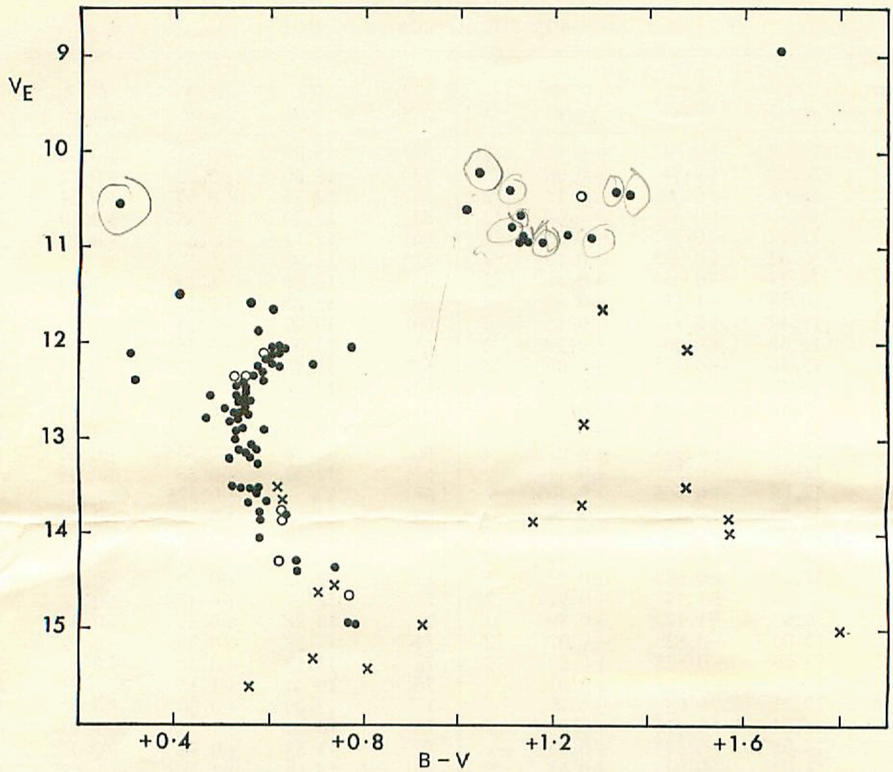

FIG. 2.—Observed (V_E, $B - V$) relation for the stars in Table 1. *Crosses*, probable nonmembers; *open circles*, those objects for which a single *UBV* observation was obtained.

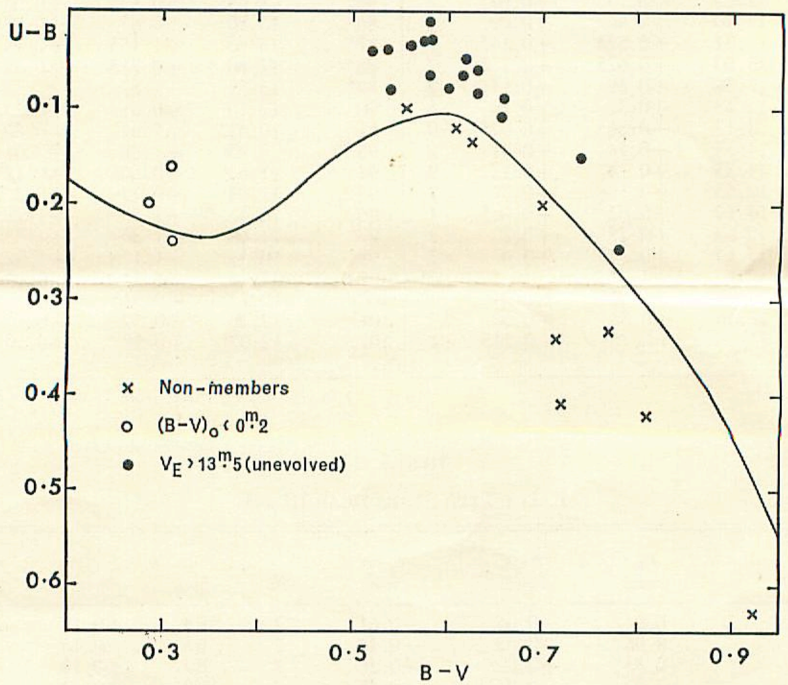

FIG. 3.—Main-sequence stars in IC 4651 (*open* and *filled circles*) and probable nonmembers (*crosses*). Continuous curve represents the relation for Hyades main-sequence stars, modified by $E(B - V) = +0.15$ mag.

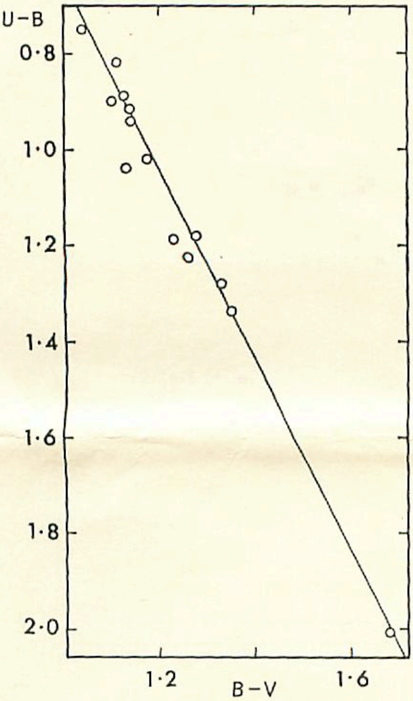

FIG. 4

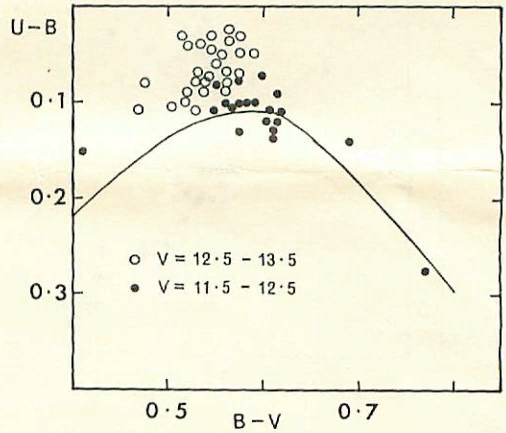

FIG. 5

FIG. 4.—The $(U - B, B - V)$ = relation for cluster giants. The straight line represents the relation for giants in the Hyades group, modified by $E(B - V) = +0.15$ mag.

FIG. 5.—Evolved stars in IC 4651. Continuous curve represents the $(U - B, B - V)$-relation for Hyades main-sequence stars, modified by $E(B - V) = +0.15$ mag.

nosity array is shown in the $(M_V, B - V)$-plane of Figure 6, where the continuous curve represents the age-zero main sequence (Eggen 1965). The members of the very similar, but apparently somewhat younger, cluster NGC 752 (Eggen 1963) for which $(m - M)_0 = 7.8$ $E(B - V) = +0.04$ mag and $\delta(U - B)_{0.45} = +0.06$ mag (Eggen and Sandage 1964) are represented in Figure 6 by crosses. The ultraviolet excess of $\delta(U - B) = +0.06$ mag for both clusters has not been corrected for in Figure 6. This correction, which would require that the values of $B - V$ between +0.4 and +0.6 mag be increased by $\Delta(B - V)$ near +0.05 mag, would remove the apparently systematic displacement of stars in both clusters from the Hyades main sequence in Figure 6.

At least three of the four blue stragglers in IC 4651 seem to be cluster members, judging from the position of two of the three with intrinsic colors bluer than $B - V = +0.2$ mag in Figure 3 and the one with $B - V$ near +0.4 mag in Figure 5.

The red giants in the cluster are discussed in more detail elsewhere in connection with (R, I) observations of these and other cluster giants (Eggen 1971), but the tendency for clusters of this age to show concentrations of giants near $B - V = +1.0$ mag, together with a short segment of what seems to be a horizontal branch, is now well established (cf. Eggen 1968; Cannon 1970).

Although IC 4651 and NGC 752 seem very similar in many respects in Figure 6, they differ strikingly in the position of the gap in the stellar distribution, just above the main sequence, and in the distribution of red giants. Various features of the color-

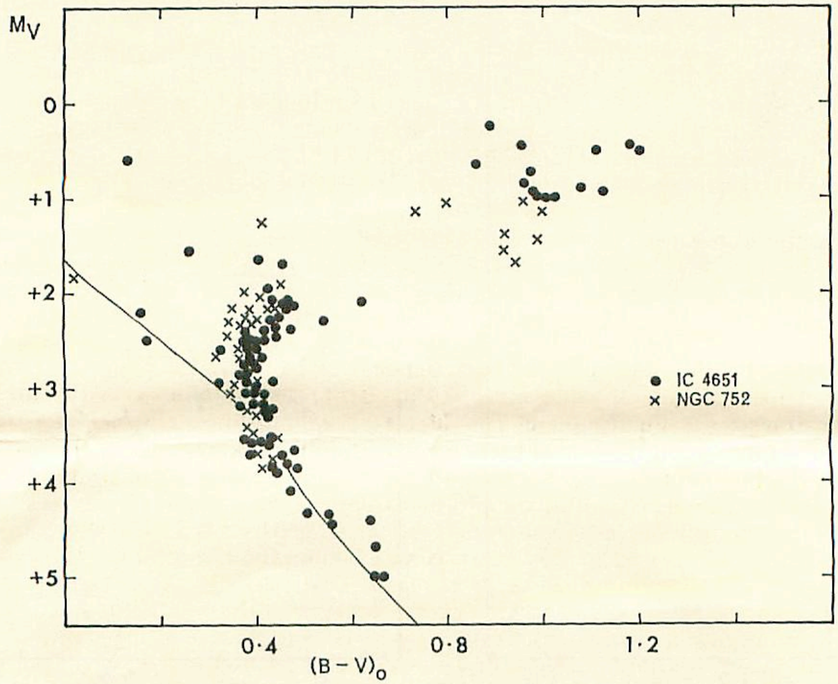

FIG. 6.—The (M_V, $B-V$)-relation for members of IC 4651 (*filled circles*) and NGC 752 (*crosses*). Continuous curves represent the age-zero main sequence.

luminosity arrays of clusters have been suggested from time to time as indicators of age or metal abundance. The most recent suggestions, for intermediate-age and old clusters, are the width of the gap at the base of the evolved main sequence and the luminosity difference between this gap and the maximum luminosity of a stellar model during the thick hydrogen-shell-burning phase of evolution, as indicators of helium and metal abundance (Aizenman, Demarque, and Miller 1969; Demarque and Heasley 1971). Various features of some well-studied clusters are listed in Table 3 (Eggen 1963 [NGC 752]; Eggen and Sandage 1964 [M67 and NGC 752]; Eggen 1969 [NGC 3680]). The color-luminosity arrays of NGC 752 and IC 4651 are compared in Figure 6, and the

TABLE 3

FEATURES* OF COLOR-LUMINOSITY ARRAYS OF SOME OLD AND INTERMEDIATE-AGE CLUSTERS

Parameter	NGC 752	IC 4651	NGC 3680	M67
Gap luminosity................	+2.8	+3.4	+3.1	+3.45
Gap width......................	0.2:	0.25	0.25	0.15
Evolved main sequence above gap	0.8	1.3	0.7:	0.35
Giant clump ($B-V$)............	+1.00	+0.94:	+1.12	+1.05
Giant clump (M_V)............	+0.9	+1.5	+1.4	+1.0
Main-sequence knee ($B-V$)......	+0.33	+0.37	+0.42	+0.50
$\delta(U-B)_{0.45}$....................	+0.06	+0.06	+0.06	+0.04

* In magnitudes.

cluster members above the main-sequence gap of NGC 3680, M67, and IC 4651 are shown in Figure 7.

If the clusters are ordered by the observed color at the knee of the evolved main sequence, as in Table 3, then both the luminosity and color of the concentration of red giants, as noted previously (Eggen 1969), and the luminosity at the center of the main-sequence gap show no regular progression. The wide main-sequence gaps in NGC 3680 and IC 4651 may indicate both high helium and high metal contents, Y near 0.4 and Z near 0.06 (Demarque and Miller 1969). Although it is difficult to determine the precise relation of the length of the evolved main sequence above the gap with the quantity ΔM_{bol}(peak) defined by Demarque and Heasley (1970), the assumption that they measure the same quantity would lead to quite different helium contents for the stars in the two clusters if equality in the observed ultraviolet excess is interpreted as equality of metal content. On the other hand, the significantly redder color of the clump of red giants in NGC 3680 might be taken as indicating a greater metal abundance for NGC 3680 than for the stars of IC 4651 (cf. Sandage and Wallerstein 1960).

Perhaps the simplest explanation of the distribution of both the red giants and the blue stragglers in Figures 6 and 7 is the presence, in all these clusters, of a significant spread of formation times of clusters members, so that a knowledge of the mass as well as of the luminosity of the giants and blue stragglers is needed to read indications of both mean age and chemical composition from the color-luminosity arrays. A strong argument against this explanation may be the presence of well-defined main-sequence gaps that would persist in this situation only if the evolution times in these gaps were extremely short for the whole range of masses that might be present at the gap luminosity. The intermingling of the red giants, other than those in the marked clumps, of the various clusters in Figures 6 and 7 supports the presence of a significant range of formation times within a cluster; but the variation from cluster to cluster of both the color and the luminosity of the red-giant clump, and the width and mean luminosity of the main-sequence gap, would still require abundance variations. If the near equality

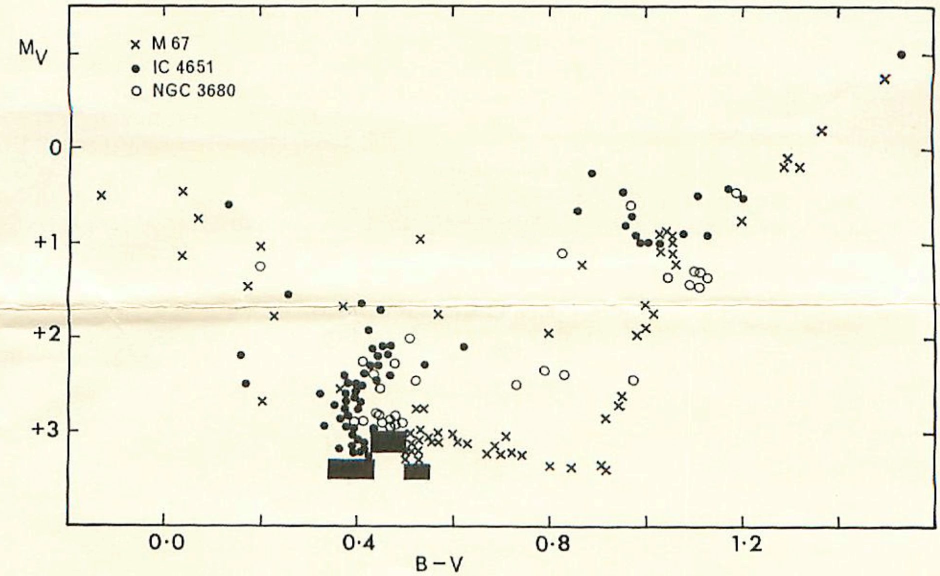

FIG. 7.—The (M_V, $B - V$)-relation for evolved stars in NGC 3680 (*open circles*), M67 (*crosses*), and IC 4651 (*filled circles*). *Bars*, position and width of the main-sequence gap.

of the ultraviolet excess of these clusters means equality of metal abundance, then large variations in the helium/hydrogen ratio are required.

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