

the members of M67. In § II it was found that the only detectable difference between the colors of the members of the two clusters is the fact that the giants in NGC 3680 are brighter in the ultraviolet. The possibility therefore remains that a difference in metal content, undetectable in the main-sequence or near-main-sequence stars, does show itself in the colors of the red giants.

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Figure 5 contains the little-evolved main-sequence stars in both clusters. Here the differential line blanketing with respect to the Hyades stars is the only effect responsible for the displacements from the continuous curve which represents Hyades main-sequence stars. The observations of members of M67 led to  $\Delta(B - V) = 0.03$  as the mean value for this blanketing effect (Eggen and Sandage 1964), and from Figure 5 it appears that within the observational uncertainties the same value holds for the members of NGC 3680.

In summary, aside from a small apparent ultraviolet excess in the red giants of NGC 3680, the color-color relation for the other stars of the two clusters is identical within the observational uncertainty.

#### IV. DISCUSSION

If the result that the moduli and the differential line blanketing (and therefore, presumably, the metal contents) of the two clusters, M67 and NGC 3680, are identical is correct, then the differences between the two color-luminosity arrays in Figure 3 are caused only by age and/or an unknown parameter. The outstanding features of the arrays can then be compared directly and may be of major importance in considerations of stellar models. Some of these features are as follows.

*a) The break in the evolved sequence near the main sequence.*—This break, first noted in NGC 2477 (Eggen and Stoy 1960) and later in NGC 752 (Eggen 1963*b*), M67 (Eggen and Sandage 1964), NGC 188 (Eggen and Sandage 1968), and NGC 2360 (Eggen 1968) presumably exists because of the short time scale of the gravitational contraction that follows the depletion of core hydrogen and precedes the hydrogen burning in the shell. The relation between the luminosity and color of this break in the arrays of the two clusters, indicated by parallel lines in Figure 3, compares with those for NGC 752 and 2360 as in the accompanying tabulation, where  $(B - V)_T$  is the observed value, cor-

Name	$M_V$	$(B - V)_T$	$\Delta(B - V)$
M67.....	+3.3	+0.49	+0.03
NGC 3680.....	3.1	.40	.03
NGC 752.....	2.8	.30	.03-0.04
NGC 2360.....	+1.9	+0.27	+0.03-0.04

rected for reddening only, of the blue boundary of the breakaway from the main sequence. The values of  $\Delta(B - V)$ , the differential line blanketing with respect to the Hyades stars, obtained from the main-sequence objects in each cluster are also listed. For a given chemical composition it is likely that the values of  $M_V$  and  $(B - V)_T$  listed above also order the clusters by age.

*b) The luminosities of the nearly horizontal subgiant sequences.*—The fact that the subgiant sequence of NGC 3680 is a half-magnitude brighter than that of M67 and the difference, noted above, in  $(B - V)_T$  both lead to approximately a factor of 2 in age difference and a 20 per cent difference in maximum mass of the stars in the two clusters (cf. Iben 1967).

*c) The clump of red giants near  $(B - V)_0 = +1.05$  in M67 and  $+1.1$  in NGC 3680.*—The fact that these stars in the presumably younger NGC 3680 are redder than in M67 may be in contradiction to the age and mass difference discussed above. Faulkner (1966) suggests that this clumping in M67 may represent the stars which have not been affected by mass loss during their late evolution, whereas the pseudohorizontal branch stars, brighter than  $V_0 = 11.5$  and bluer than about  $B - V = +0.8$  in Figure 3, may represent those that have lost mass. If this is the case, Faulkner's results would indicate that the metal content of the giants in NGC 3680 is considerably lower than that of

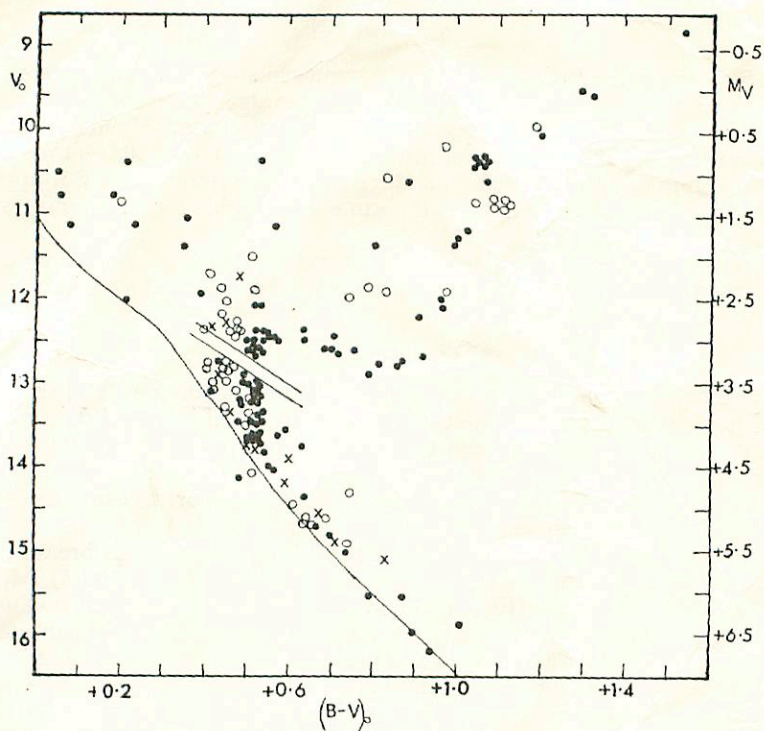


FIG. 3.—Same as Fig. 2, but the members of M67 have been added after correcting for  $E(B - V) = +0.06$  mag. Continuous curve represents the age-zero main sequence corrected for  $\Delta(B - V) = 0.03$  mag, for  $B - V$  greater than  $+0.3$  mag, and  $V_0 - M_V = 9.5$  mag.

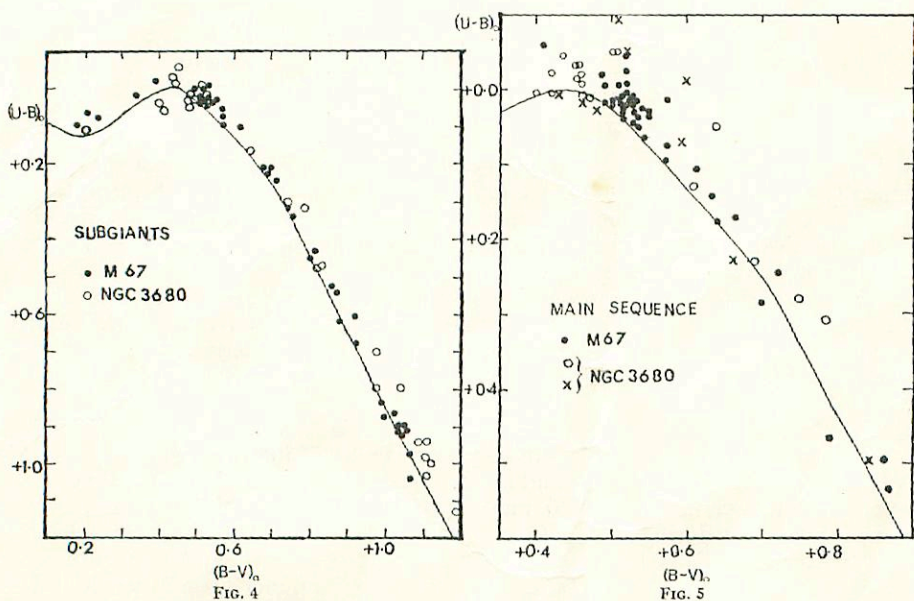


FIG. 4.—The color-color relation for the subgiants in M67 and NGC 3680, corrected only for reddening. Continuous curve represents the Hyades main-sequence stars.

FIG. 5.—Same as Fig. 4 but for the main-sequence or near-main-sequence cluster stars.

## III. LINE BLANKETING

When gravity effects were taken into account for the evolved stars, the observations of the members of M67 indicated a blanketing effect measured by  $\Delta(B - V) = +0.03$  (Eggen and Sandage 1964). The subgiant and giant members of M67 are shown as dots in the  $((U - B)_0, (B - V)_0)$ -plane of Figure 4. The continuous curve represents the main-sequence relation for Hyades stars. The open circles in the figure represent the subgiants and giant members of NGC 3680. For values of  $(B - V)_0$  of about 0.2-0.6

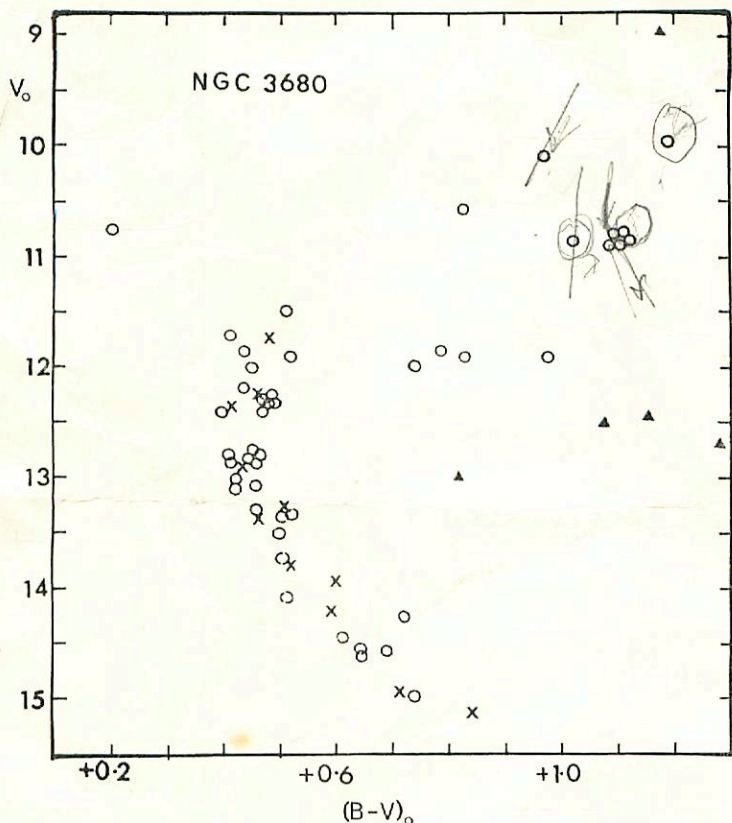


FIG. 2.—The  $(V_0, (B - V)_0)$ -diagram for stars within the boundary marked in Fig. 1. Open circles represent two or more observations, crosses, single observations, and triangles, stars considered to be non-members. Magnitude and colors are corrected for  $E(B - V) = +0.04$  mag.

the color-color relation is gravity-sensitive, and the stars with surface gravities lower than that of main-sequence stars will lie below those indicated by the continuous curve in Figure 4 (Eggen 1963*a*, 1966). On the other hand, the presence of differential line blanketing, with respect to Hyades stars, will place the stars above the relation shown in the figure (cf. Sandage and Eggen 1959). The two effects nearly cancel each other for the M67 stars in Figure 4 (Eggen and Sandage 1964), and the same is apparently true for the members of NGC 3680. The only systematic difference between M67 and NGC 3680 members in Figure 4 is the possibility that the red giants in the latter cluster are displaced from those of the former in the sense that at a given  $B - V$  the values of  $U - B$  are about 0.05 mag smaller in NGC 3680.

TABLE 1  
STARS IN NGC 3680

No.	$V_E$ (mag)	$B-V$ (mag)	$U-B$ (mag)	$n$	No.	$V_E$ (mag)	$B-V$ (mag)	$U-B$ (mag)	$n$
1.....	11.98	+0.475	0.00	2	40*	12.55	+1.12	+1.00	2
2.....	14.75	0.685	+0.20	2	41.....	11.01	1.15	+0.97	2
3.....	11.60	0.55	+0.02	3	42.....	13.04	0.47	+0.04	1
4.....	12.95	0.50	+0.04	3	43.....	12.50	0.45	-0.05	1
5.....	12.86	0.49	0.00	3	44.....	10.06	1.23	+1.16	3
6.....	12.48	0.52	+0.08	4	45.....	12.04	0.56	+0.05	4
7*	13.50	1.60	.....	2	46.....	13.49	0.50	+0.05	1
8*	12.80	1.32	+1.3:	2	46A.....	13.50	0.495	+0.03	5
9.....	14.20	0.55	+0.055	3	47†	13.75	0.86	+0.39	1
10.....	12.91	0.445	+0.025	2	48.....	11.83	0.45	+0.09	2
11.....	10.96	1.085	+0.82	3	49*	13.08	0.855	+0.355	2
12.....	15.06	0.75	+0.26	1	50.....	11.97	0.83	+0.35	3
13.....	10.90	1.15	+1.06	2	51.....	14.70	0.68	+0.08	3
14.....	12.40	0.48	+0.01	3	52.....	15.10	0.775	+0.34	2
15.....	12.54	0.51	+0.045	2	53.....	10.91	1.14	+0.01	2
16.....	13.35	0.545	-0.015	2	54*	8.96	1.18	+1.21	3
17.....	12.05	1.015	+0.81	2	55.....	12.02	0.87	+0.50	2
18.....	12.10	0.78	+0.33	3	56.....	10.87	0.24	+0.14	3
19.....	12.49	0.515	+0.06	3	57.....	12.56	0.44	+0.075	2
20.....	10.20	1.01	+0.725	2	58.....	12.96	0.495	0.00	2
21.....	14.57	0.65	+0.16	3	59*	12.56	1.19	+1.13	2
21A.....	14.69	0.73	+0.26	3	60.....	14.36	0.63	+0.10	1
22.....	13.47	0.55	-0.02	3	61.....	14.46	0.79	+0.31	2
23.....	14.06	0.64	+0.02	1	A*	9.75	0.495	+0.01	2
24.....	13.92	0.56	-0.02	1	B*	11.64	1.28	+1.30	1
25.....	13.89	0.55	-0.06	1	C*	12.41	0.90	+0.57	1
25A.....	13.84	0.48	-0.01	1	D*	13.09	0.59	+0.005	2
26.....	11.04	1.13	+0.97	3	E.....	11.81	0.565	+0.09	2
27.....	10.97	1.165	+1.03	2	F*	12.86	0.62	-0.05	1
28.....	15.24	0.88	+0.53	1	G*	13.30	0.58	+0.08	1
29.....	12.14	0.49	-0.03	2	H*	14.32	0.77	+0.23	2
30.....	13.63	0.54	-0.02	2	I*	13.87	0.71	+0.16	2
31.....	13.22	0.46	+0.04	3	J*	12.58	0.79	+0.42	2
32.....	12.95	0.49	+0.02	3	K*	12.74	0.44	+0.04	2
33.....	11.88	0.52	+0.06	1	L*	15.16	0.61	+0.02	2
34.....	10.69	0.87	+0.50	3	M*	13.81	0.01	+0.15	1
35.....	13.17	0.50	+0.01	4	N.....	12.88	0.50	+0.07	1
36.....	13.44	0.56	+0.03	3	O*	12.43	1.24	+1.27	1
37.....	13.13	0.46	+0.01	4	P.....	12.72	0.49	+0.03	1
38.....	12.47	0.53	+0.05	4	Q.....	13.24	0.53	+0.02	1
39.....	12.41	+0.52	+0.07	2	R.....	12.49	+0.47	+0.06	1

\* Probable field star.  
† Close double.

TABLE 2  
EARLY-TYPE STARS NEAR NGC 3680

Name	$V_E$ (mag)	$B-V$ (mag)	$U-B$ (mag)	$n$	$E$ (mag)	$M_V$	$R$ (pc)	$b$	$l$	Sp.
HR 4423.....	5.18	-0.03	-0.105	2	+0.02	+1	67	+17°5	287°	B9
HD 110119....	7.21	-0.05	-0.195	2	+0.04	+0.5	220	+18.5	287	B8
NGC 3680.....					(+0.04)	.....	795	+17	287	.....
HR 4402.....	6.12	-0.175	-0.79	2	+0.06	-5	1550	+17.5	286	B0 III

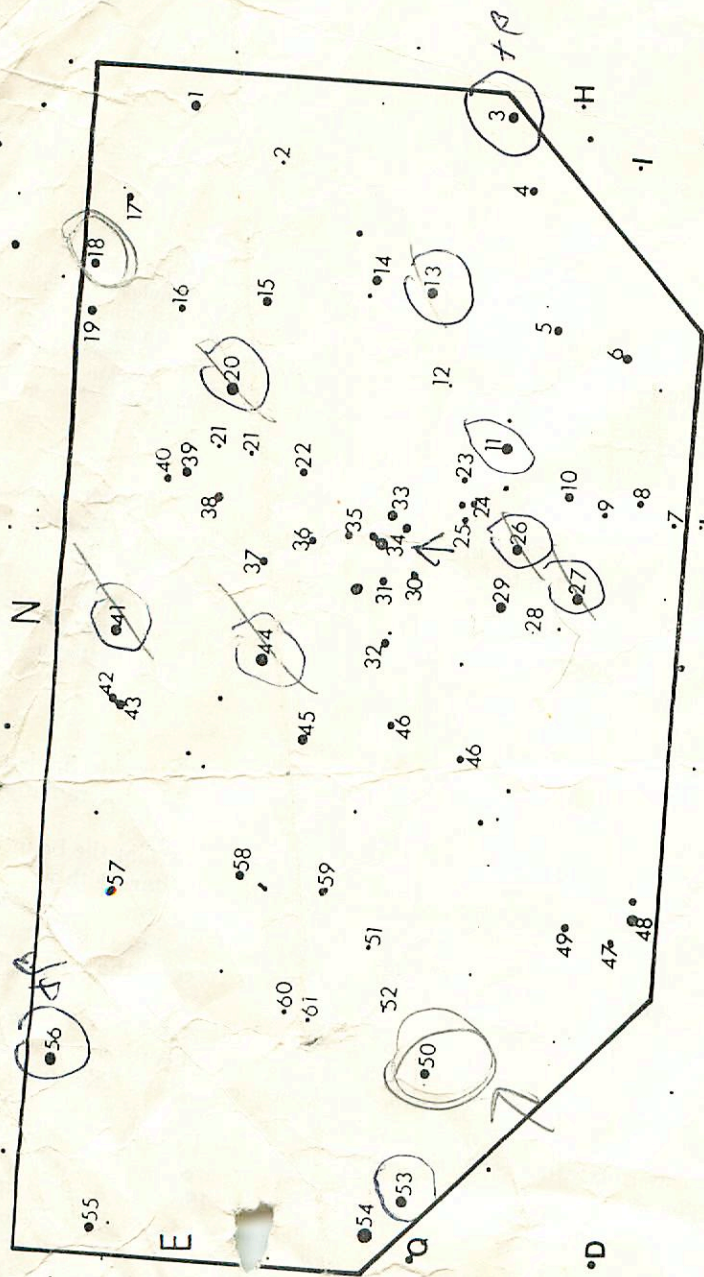


FIG. 1.—The cluster NGC 3680. Taken from a 10-min exposure with 03aO plate at the Newtonian focus of the 74-inch reflector.

1900  
 11 20 59  
 -42 -71  
 ✓ (28) 2+R  
 (52) 2+R  
 ✓ (34) 2+  
 13  
 11 1 ✓

## THE OLD GALACTIC CLUSTER NGC 3680

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Received July 1, 1968

## ABSTRACT

Photoelectric ( $UBV$ ) observations have been obtained for seventy-nine stars in and near the galactic cluster NGC 3680. The cluster ( $a$ ) has, within the observational uncertainty, a modulus identical with that of M67 (9.5 mag), ( $b$ ) is probably only slightly younger than M67, ( $c$ ) has stars with the same (or possibly somewhat lower) metal abundance as the members of M67, and ( $d$ ) shows a pronounced gap in the distribution of evolved stars near the main sequence at  $M_V = +3.1$ . Early-type stars near the cluster give  $E(B - V) = +0.04$ . Although several features of the color-luminosity array indicate that NGC 3680 is slightly younger than M67, the clump of red giants, characteristic of old clusters, is redder in NGC 3680.

## I. INTRODUCTION

Photoelectric ( $UBV$ ) survey observations have been made of stars in several clusters south of  $-45^\circ$  (Hogg and Hunt 1965) in a search for old galactic clusters. One such cluster is NGC 3680, which appears to be very similar to M67, although not as rich in stars. One hundred and fifty observations, with the 40-inch reflector at Siding Spring Mountain, have been made of sixty-one stars lying within the cluster boundaries drawn in Figure 1. These observations are listed in Table 1 together with an additional twenty-six observations of eighteen stars lying outside these boundaries. The cluster has a galactic latitude of  $+17^\circ$ .

## II. REDDENING AND DISTANCE

Three early-type stars near the cluster are listed in Table 2. The reddening is small in this direction and the value of  $E(B - V) = +0.04$  is obtained by interpolation for the distance of NGC 3680 derived below.

The  $(V_0'(B - V)_0)$ -relation is shown in Figure 2 for the stars within the boundaries indicated in Figure 1 and corrected only for  $E(B - V) = +0.04$ . Stars with more than one observation are shown as open circles, and those with only one observation as crosses. Five stars, indicated by asterisks in Table 1, are probably not cluster members and are represented in Figure 2 by filled triangles. Two or three of the outlying stars may also be cluster members.

Three features of Figure 2 are reminiscent of the old galactic cluster M67 (Eggen and Sandage 1964); the tight clump of red giants, the horizontal subgiant sequence, and the obvious gap in the sequence of slightly evolved main-sequence stars. The stars in M67 for which more than one observation was available are shown in the  $(V_0'(B - V)_0)$ -plane of Figure 3 as dots after correction only for  $E(B - V) = +0.06$  (Eggen and Sandage 1964). The members of NGC 3680 from Figure 2 are also shown in Figure 3 with the same symbols. The age-zero main sequence (Fagen 1965) with a blanketing of  $\Delta(B - V) = 0.03$  applied to stars with  $B - V$  redder than 0.3 and with  $V_0 - M_V = 9.5$  is shown as a continuous curve in Figure 3. Although the observations in each cluster have only been corrected for reddening, the little-evolved main-sequence stars occupy the same position of the  $(V_0'(B - V)_0)$ -plane within the observational uncertainty. That is, both clusters have a modulus near 9.5 mag.