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NGC 2818, AN OPEN CLUSTER CONTAINING A PLANETARY NEBULA

by

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Submitted December, 1971

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ABSTRACT

Three color UBV photometry of the cluster NGC 2818 shows it to lie at a distance of 3.2 kpc. The cluster has a color excess E_{B-V}=0.22 and an ultraviolet excess of 0.09. The evolutionary turnoff from the main sequence occurs in mid A. The faint main sequence in the cluster shows a distinct bend or discontinuity. Preliminary velocity measurements indicate that the high excitation planetary nebula NGC 2818 is probably associated with the cluster.

INTRODUCTION

NGC 2818 is a southern open cluster with equatorial coordinates $\alpha=9^h15^m\!.0$, $-36^o30'$(1975) and galactic coordinates l=262.0, b=+8.8. It was chosen for study because it lies well above the galactic plane at an appreciable distance and because a planetary nebula (also designated NGC 2818) is possible associated with the cluster. In appearance, the cluster/planetary combination resembles NGC 2437/2438. In that case the planetary radial velocity differs from the cluster and seems to preclude membership. NGC 2818 presents a better case for physical association since preliminary radial velocities show similar motions. This paper is concerned primarily with the galactic cluster; a more detailed study of the planetary and the certainty of its association with the cluster is in progress.

PHOTOMETRY IN THE CLUSTER

A photoelectric UBV sequence extending to V=17.0 was established during ten nights in 1959 using the Mount Stromlo 50-inch and 74-inch telescopes. Transfers were carried out on four nights at the 50-inch telescope using stars in M67 and IC4665 as UBV standards. Table I summarizes the photoelectric transfer. Table II contains the photoelectric sequence including smoothed photographic data for the stars. Plate I is a B photograph of the cluster and identifies the photoelectric standards. Transfer uncertainty is estimated to be ±0.02 in V and B-V and ±0.04 in U-B, although the internal accuracy indicated in the four transfers is somewhat better.

Photographic plates for photometry of stars in the cluster were obtained at the Mount Stromlo 74-inch Newtonian focus during 1959 and 1960. All plates were taken with a 45-inch stop. The V plate filter combination was 103a-D + Chance OY4, B was 103a-0 + Schott GG14, and U was 103a-0 + Schott UG2. Four V, three B, and two U plates were of excellent quality and were used in the final study. The region about the cluster was divided into three radial zones as indicated in Plate II where all stars are identified. Plate II is a V plate and shows the planetary nebula only weakly. Each photographic plate was photometered in a single session at the Steward Observatory semi-automated Cuffey Iris Photometer. The data were reduced to final magnitudes and colors by previously described procedures (Tifft,and Snell, 1971). Color equations relating the photographic and

TABLE I. PHOTOELECTRIC TRANSFERS

STANDARD	STAR A			STAR B		
	V	B-V	U-B	V	B-V	U-B
IC 4665	10.568	.062	-.052	11.301	.720	.194
IC 4665	10.572	.060	-.072	11.314	.715	.167
M 67	10.543	.045	.000	11.319	.702	.215
IC 4665/M 67	10.555	.057	-.044	11.323	.685	.174
Adopted	10.561	.058	-.043	11.316	.710	.177

TABLE II. STANDARD STARS

IDENTIFICATION		PHOTOELECTRIC			PHOTOGRAPHIC		
		V	(B-V)	(U-B)	V	(B-V)	(U-B)
A	3-120	10.56	.06	- .05	10.56	.06	- .05
B	1- 1	11.32	.71	.18	11.31	.75	.22
C	3- 1	11.45	.44	- .06	11.46	.40	- .11
D	1- 4	12.08	1.16	.76	12.06	1.18	.70
E	3- 31	12.20	.60	- .01	12.34	.43	.07
F	1-161	12.72	1.52	1.71	12.73	1.54	1.65
G	1- 61	12.88	.80	.32	12.86	.81	.26
H	1- 15	13.39	.45	discord	13.31	.53	- .09
I	2-100	13.85	.57	.16	13.86	.52	.18
J	1- 73	13.91	.44	.16	13.91	.43	.17
K	2- 68	14.09	.34	.21	14.08	.36	.22
L	2- 87	14.13	.54	.15	14.18	.45	.18
M	1- 20	15.18	.81	.36	15.27	.73	.38:
N	1-148	15.40	.36	.12	15.39	.35	.15
O	1-131	15.64	.50	.04	15.62	.52	- .07
P	1-109	15.72	.72	- .01	15.81	.61	.06:
Q	1-157	15.95	.74	.23	15.95	.75	.14:
R	1-162	16.16	.97	1.01	16.17	1.06	
S	1-151	16.49	.79	.19	16.49	.79	.18:
T	1-123	16.86	.73	.00	16.85	.62	.11:
U	1-153	17.07	.70	.04	16.89	.95	

PLATE I

A B photograph of NGC 2818. Photoelectric standard stars are identified. Star A is CoD-36°5518, star B is CoD-36°5514, and star C is CoD-36°5504.

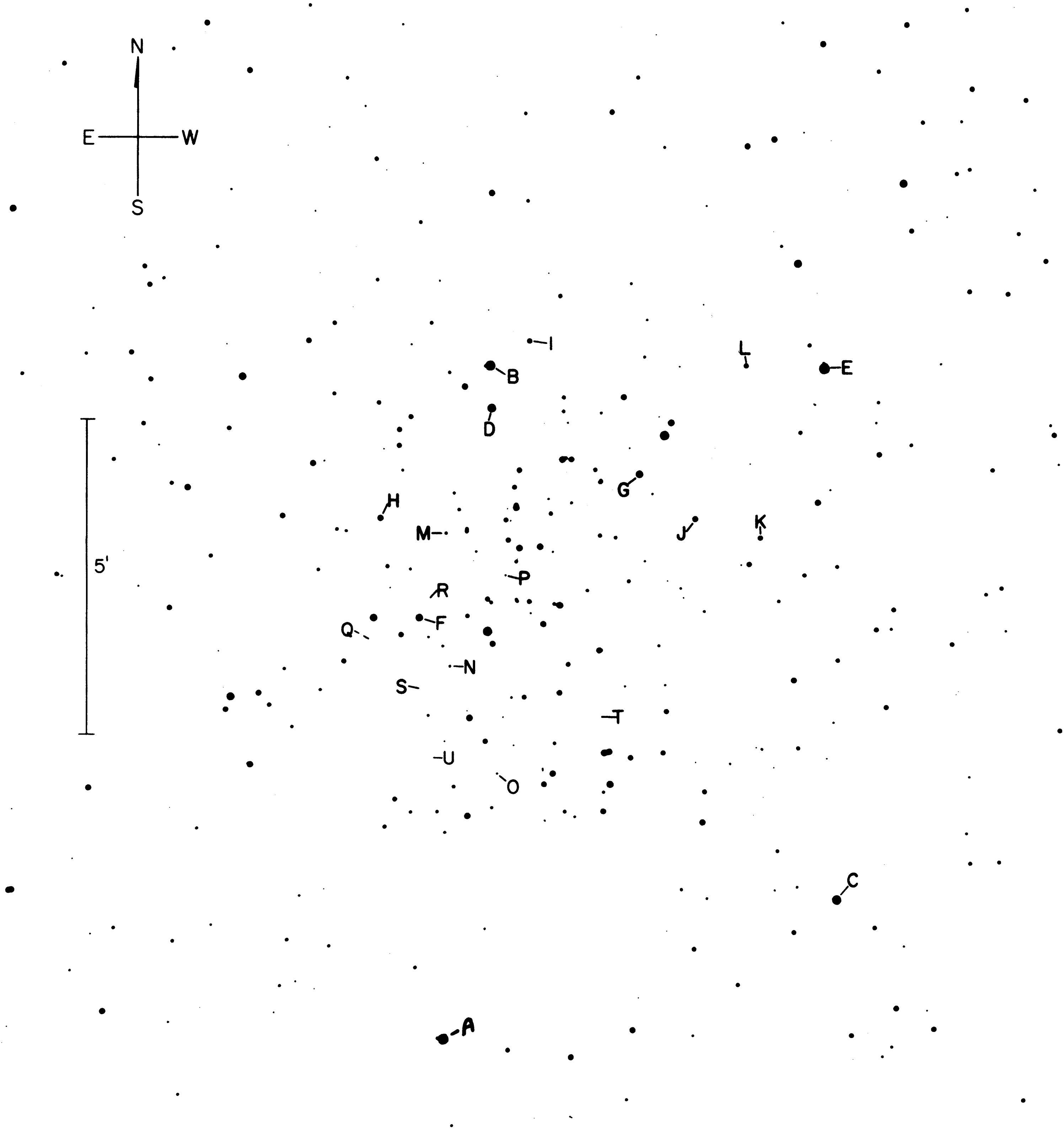


PLATE I

PLATE II

A V photograph of NGC 2818. Stars measured photographically in the three radial zones studied are identified.

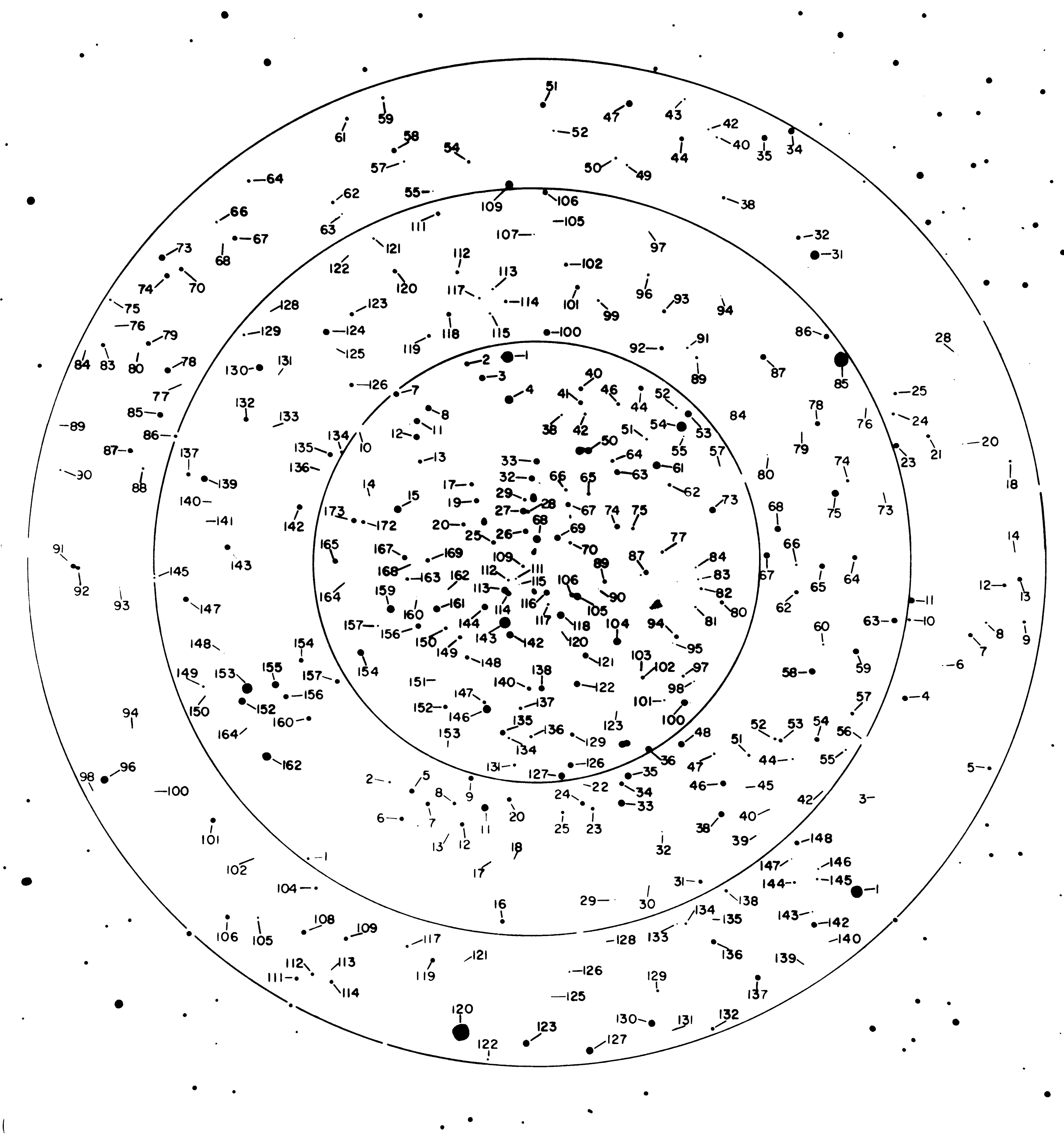


PLATE II

photoelectric photometry were required as follows:

$$V = V_{pg} + 0.112(B_{pg} - V_{pg}), \tag{1}$$

$$B = B_{pg} - 0.066(B_{pg} - V_{pg}), \tag{2}$$

$$B - V = 0.822(B_{pg} - V_{pg}), \tag{3}$$

$$U = U_{pg}, \tag{4}$$

$$U - B = (U_{pg} - B_{pg}) + 0.066(B_{pg} - V_{pg}). \tag{5}$$

A discussion of the derivation of these equations will be given in a subsequent paper concerned with the open cluster NGC 4349.

Figure 1 illustrates the final fit between the photographic and photoelectric photometry. Internal random uncertainty is about ±0.02 in B and V and ±0.03 in U. V photometry was carried to about magnitude 16.5 and B was obtained for all stars measured in V. U photometry was carried to U=16.3. Table III contains the tabulation of the final photographic photometry on all stars.

SPECTROSCOPIC DATA

A brief spectroscopic analysis of the planetary nebula has been given by Johnson (1960) based upon a single low dispersion spectrogram. Since the cluster can be reached from the northern hemisphere, spectra were obtained of both the planetary and several stars to determine spectral types and approximate velocities for both the cluster and nebula. The Steward Observatory 90-inch Cassegrain Image Tube Spectrograph was used at low dispersion, 230A/mm. The planetary and two stars, 1-104 and 1-118, were observed under good conditions. Two additional stars, 1-15 and 1-154, were observed under poor conditions so their data are less reliable. Table IV contains the spectroscopic data. The planetary and the two best observed cluster stars agree in velocity and indicate a good probability of membership of the planetary in the cluster. The spectral types of the two well observed cluster stars, which are among the brightest but are not the bluest in the cluster, indicate that the cluster main sequence evolutionary turnoff occurs in mid A.

FIGURE 1

Comparison of photoelectric and photographic magnitudes for the standard sequence stars.

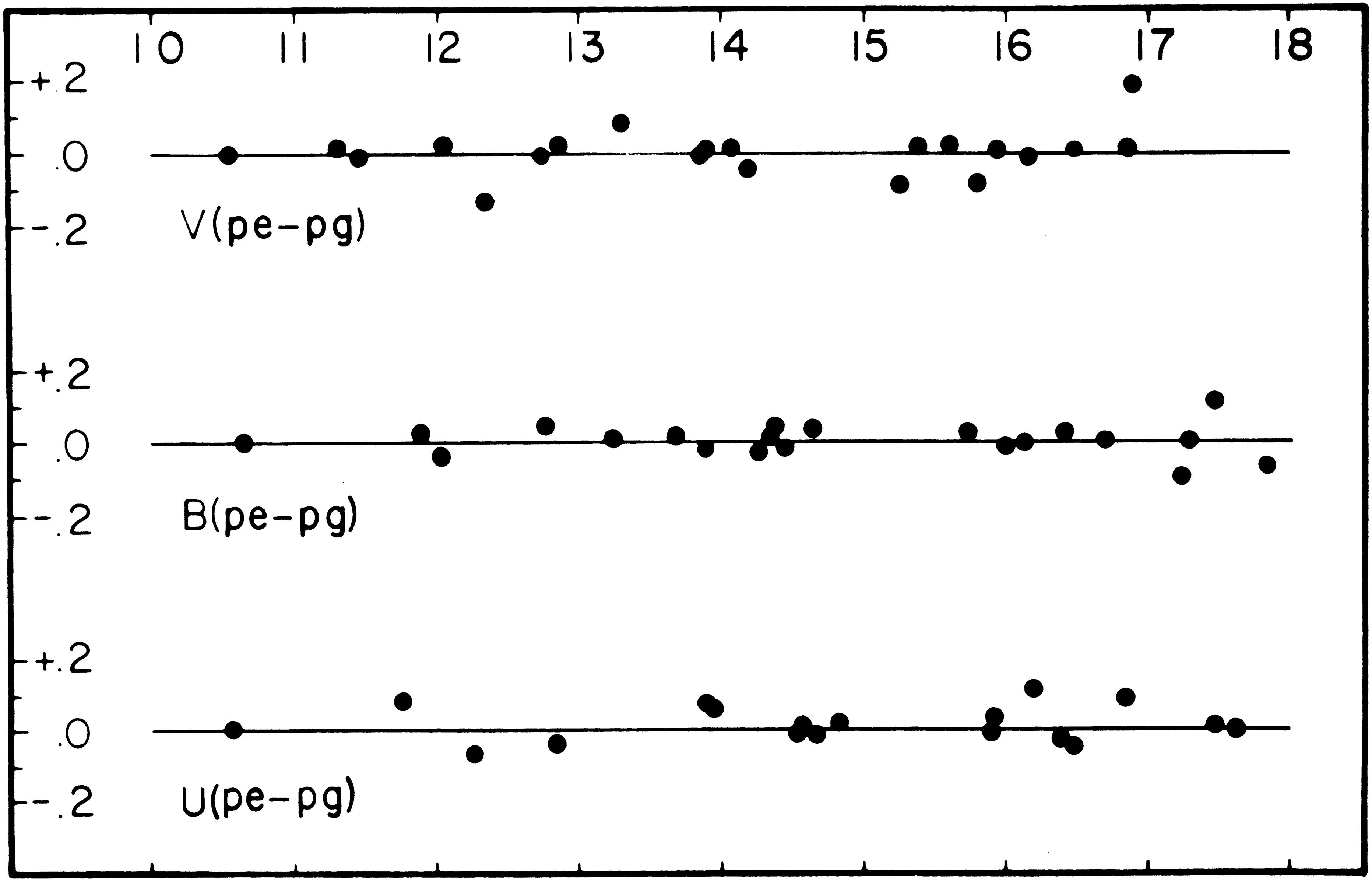


FIGURE 1

TABLE III. PHOTOGRAPHIC PHOTOMETRY

REGION 1

STAR NO.	V	B-V	U-B
1	11.31	.75	.22
2	15.11	.30	.17
3	13.40	1.18	.79
4	12.06	1.18	.70
7	14.57	.32	.08
8	14.24	.44	.02
10	16.45	.64	
11	14.15	.39	.21
12	14.19	.41	.17
13	15.39	.39	.01
14	16.58	.58	
15	13.31	.53	-.09
17	15.48	.37	.05
19	15.13	.33	.15
20	15.27	.73	
25	15.49	.37	.14
26	14.38	.99	.70
27	14.46	.35	.18
28	16.15	.32	
29	15.64	.86	
32	14.53	.30	.17
33	14.17	.49	.19
38	16.17	.62	
40	15.10	.49	.09
41	15.32	.29	.16
42	15.98	.58	
44	13.72	1.04	.58
46	15.76	.39	.14
50	14.18	.22	.08
51	16.01	.61	
52	16.00	.64	
53	13.29	.90	.49
54	11.77	.81	.19
55	16.30	.81	
57	16.40	.76	
61	12.86	.81	.26
62	15.84	.41	
63	13.81	1.03	.50
64	15.13	1.00	
65	15.87	.39	
66	15.92	.51	
67	15.01	.35	.16
68	13.46	.44	.20
69	13.68	1.01	.54
70	15.98	.48	

STAR NO.	V	B-V	U-B
73	13.91	.43	.17
74	15.03	.31	.16
75	15.40	.94	
77	15.91	.54	
80	15.51	.32	.14
81	16.40	.57	
82	16.03	.52	
83	15.85	.97	
84	16.31	.62	
85	16.51	.77	
87	15.19	.60	.19
89	15.52	.40	.20
90	16.56	.58	
94	15.43	.27	.19
95	16.42	.73	
97	15.80	.80	
98	16.48	.61	
100	14.28	.26	.27
101	16.47	.50	
102	15.82	.43	
103	16.31	.64	
104	13.71	.34	.18
105	13.69	.47	.26
106	15.59	.36	.15
109	15.81	.61	
111	16.49	.62	
112	16.09	.68	
113	14.13	.35	.23
114	15.07	.30	.21
115	16.49	.65	
116	14.58	.39	.09
117	16.05	.72	
118	13.72	.36	.13
120	16.64	.54	
121	14.68	.24	.11
122	14.18	.42	.30
123	16.85	.62	
126	13.55	1.17	.86
127	13.79	.45	.15
129	15.29	.35	.16
131	15.62	.52	-.07
134	16.09	.57	
135	13.86	1.05	.58
136	15.90	.57	
137	15.87	.39	

TABLE III. PHOTOGRAPHIC PHOTOMETRY (CONTINUED)

STAR NO.	V	B-V	U-B
138	14.44	.46	.18
140	15.61	.38	.14
142	13.50	.74	.09
143	11.59	.67	-.03
144	14.35	.29	.27
146	12.91	.62	-.08
147	15.92	.48	
148	15.39	.35	.15
149	15.42	.44	.14
150	15.57	.55	.10
151	16.49	.79	
152	15.26	.32	.12
153	16.89	.95	
154	13.95	.35	.18
156	13.89	1.04	.49
157	15.95	.75	
159	12.59	1.15	.67
160	16.32	.59	
161	12.73	1.54	1.65
162	16.17	1.06	
163	15.80	.40	
164	16.48	.58	
165	14.77	.42	.15
167	14.66	.62	-.00
168	16.41	.63	
169	15.39	.35	.15
172	15.21	.67	.23
173	14.87	.30	.08

REGION 2

STAR NO.	V	B-V	U-B
1	15.80	.39	
2	15.93	.38	
5	13.94	.98	.57
6	14.37	.88	.51
7	14.97	.27	.24
8	14.99	.67	.16
9	14.67	.34	.22
11	13.10	.65	.04
12	15.15	.27	.20
13	16.05	1.05	
16	15.24	.34	.22
17	16.51	.68	
18	16.01	.85	
20	15.10	.28	.20
22	16.42	.61	
23	15.54	.33	.21
24	14.99	.34	.14
25	15.76	.32	
29	16.26	.62	
30	16.58	.71	
31	15.19	.30	.23
32	16.32	.71	
33	13.68	.46	-.06
34	15.27	.31	.15
35	13.10	1.07	.76
36	13.94	.58	-.10
38	13.60	1.04	.59
39	16.34	.72	
40	16.13	1.06	
42	16.47	.82	
44	16.05	.70	
45	16.41	.84	
46	14.44	.37	.25
47	16.11	.55	
48	14.24	.32	.21
51	15.85	.57	
52	16.07	.50	
53	15.60	.40	.17
54	14.83	.44	.09
55	15.97	.80	
56	16.55	.79	
57	15.76	.35	
58	13.73	.63	.05
59	14.52	.25	.30
60	16.21	.61	
62	15.08	.55	.10
63	14.08	.59	.05
64	14.96	.29	.19
65	14.66	.25	.20
66	16.18	.53	
67	14.09	.32	.23
68	14.08	.36	.22
73	16.48	1.19	
74	15.85	.39	
75	13.47	.45	.24
76	16.51	.62	
78	14.90	.20	.27
79	16.52	1.00	
80	16.09	.82	

TABLE III. PHOTOGRAPHIC PHOTOMETRY (CONTINUED)

STAR NO.	V	B-V	U-B
84	16.23	1.21	
85	10.98	.10	-.10
86	14.76	.16	.25
87	14.18	.45	.18
89	15.82	.38	
91	16.13	.50	
92	15.43	.28	.24
93	15.58	.33	.16
94	15.96	.92	
96	15.30	.99	
97	16.45	.81	
99	16.09	.50	
100	13.86	.52	.18
101	14.46	1.09	
102	15.70	.37	.15
105	16.47	.81	
106	14.57	.62	.06
107	16.15	.72	
109	12.92	.68	.03
111	14.74	.78	.50
112	15.57	.30	.25
113	16.00	.58	
114	15.81	.39	
115	16.02	.62	
117	16.07	.48	
118	14.77	.55	.07
119	15.60	.37	.16
120	14.97	.53	.10
121	15.91	.42	
122	16.44	.60	
123	14.41	.98	.66
124	13.68	.56	-.05
125	16.45	.77	
126	14.87	.58	-.05
128	16.28	1.05	
129	15.72	.59	
130	12.58	1.38	1.16
131	16.40	.73	
132	14.16	.85	.22
133	16.53	.94	
134	15.72	.47	
135	13.57	1.42	
136	16.21	.55	
137	14.25	1.10	.75
139	12.92	1.05	.54

STAR NO.	V	B-V	U-B
140	15.89	1.26	
141	16.44	.55	
142	13.81	1.01	.57
143	14.36	.35	.25
145	15.27	1.02	
147	13.42	1.25	1.07
148	16.19	.65	
149	15.93	.45	
150	16.44	.85	
152	13.43	.65	-.02
153	12.04	.44	-.08
154	15.06	.37	.25
155	13.40	.62	-.06
156	14.34	.81	.59
157	15.09	.30	.21
160	14.93	.30	.25
162	12.90	.30	.17
164	16.89	.75	

REGION 3

STAR NO.	V	B-V	U-B
1	11.46	.40	-.11
3	16.50	.91	
4	14.17	.56	.18
5	15.54	.24	.23
6	16.48	.46	
7	14.49	.94	
8	16.06	.53	
9	15.57	.52	.21
10	15.45	.89	
11	14.20	.39	.25
12	14.94	.79	
13	14.51	.62	.24
14	16.46	.87	
18	14.64	1.59	
20	16.38	.58	
21	15.09	.58	.17
23	13.87	.81	.46
24	15.71	.56	
25	15.27	.81	
28	15.87	1.10	
31	12.34	.43	.07
32	15.15	.23	.41
34	13.11	1.07	
35	13.29	1.05	.72

TABLE III. PHOTOGRAPHIC PHOTOMETRY (CONTINUED)

STAR NO.	V	B-V	U-B	STAR NO.	V	B-V	U-B
38	15.61	.34	.24	67	14.73	.52	.08
40	15.97	.76		68	16.46	1.18	
42	16.32	.42		70	14.88	.56	.14
43	15.86	.72		73	13.70	.55	-.03
44	15.12	.26	.23	74	13.64	1.26	1.20
47	13.41	.81	.48	75	15.12	1.04	
49	16.06	.53		76	16.41	.79	
50	15.91	.55		77	16.30	.78	
51	14.56	.32	.24	78	13.73	.59	-.05
52	16.07	.56		79	13.65	1.43	
54	15.80	.36		80	16.28	.59	
55	15.97	.71		83	14.54	.67	.20
57	15.81	.70		84	16.41	.67	
58	14.24	.66	.18	85	13.96	.61	-.03
59	15.46	.53	.10	86	15.34	.47	.09
61	15.49	.30	.27	87	14.34	.49	.14
62	15.54	.30	.24				
63	16.08	.48					
64	15.37	.63					
66	15.85	.52					

TABLE IV. SPECTROSCOPIC DATA

OBJECT	CLASSIFICATION	VELOCITY (km/sec)
Star No. 1- 15	F6III:	- 22:
1-104	A5III	+ 5
1-118	A5III	+ 3
1-154	F0V:	+159:
Planetary		
N Component		- 9
S Component		+ 12

COLOR-MAGNITUDE ANALYSIS

Figure 2 presents the color-magnitude diagram for the inner zone of the cluster. The diagram contains the zero age main sequence adjusted for color excess, line blanketing, and absorption for a true distance modulus $(m-M)_T=12.54$. A dashed line indicates the cluster main sequence, subgiant and giant regions.

The stars in the color-magnitude diagram have been distinguished by separate symbols according to their probable stage of evolutionary history or probability of being field stars. Very few field stars brighter than V=15.7 appear in the small inner region of the cluster. Those that are present are almost exclusively seen between B-V=+0.4 and +1.0. These probable "field" stars and all fainter stars without U-B available are indicated by X symbols. The faintest "field" stars with U-B data appear to be normal F to K dwarfs and show reddening, if any, less than the cluster. Most of the field stars within about 1 kpc will fit an unreddened main sequence.

A tight concentration of stars appears between V=14.8 and 15.7 and B-V between 0.20 and 0.42 as shown with small dots in the figure. These stars form the upper end of the NGC 2818 main sequence which has a blue edge at $(B-V)_o=0.15 \pm 0.04$ corresponding to A5 main sequence stars. The zero age main sequence has been fit to the points after allowance for evolutionary deviation, reddening, and line blanketing and implies an apparent modulus of 13.24 and a true modulus of 12.54 with an estimated uncertainty of ±0.2. The distance of the cluster is, therefore, 3.2 kpc and it lies 0.5 kpc above the galactic plane.

Directly above the main sequence concentration, at V=14.8, there is a break in the star frequency. This gap in the evolutionary pattern between the main sequence and subgiants is similar to the gap in NGC 752 (Eggen, 1963) and older well studied clusters. Directly above the gap in the color magnitude diagram a distinct concentration of A subgiants is present, indicated in the figures by small open circles and falling in the zone $13.4<V<14.8$, $0.15<(B-V)<0.50$.

Redward of (B-V)=1.0 and brighter than V=14, a distinct concentration of red giants appears, sloping upward to the very red star 1-153 at $(B-V)_o=1.4$, $M_V=-0.5$. Two stars lying above the giant branch are shown with star symbols. These stars are possibly in the Helium burning phase of giant star evolution. They bear the proper relationship to the giant stars, are redder than most

FIGURE 2

The color-magnitude diagram for the central region of NGC 2818. The majority of the stars are cluster members. Small dots denote main sequence stars; large dots indicate red giants. Small open circles indicate subgiants and large open circles indicate field stars of large UV excess which appear to be F subgiants. Star symbols indicate two stars which may be in the Helium burning phase of giant evolution. The characteristic features of the cluster are indicated by dashed lines and the zero age main sequence fit by a solid line. The faint main sequence in the cluster shows a distinct break near V=16.2.

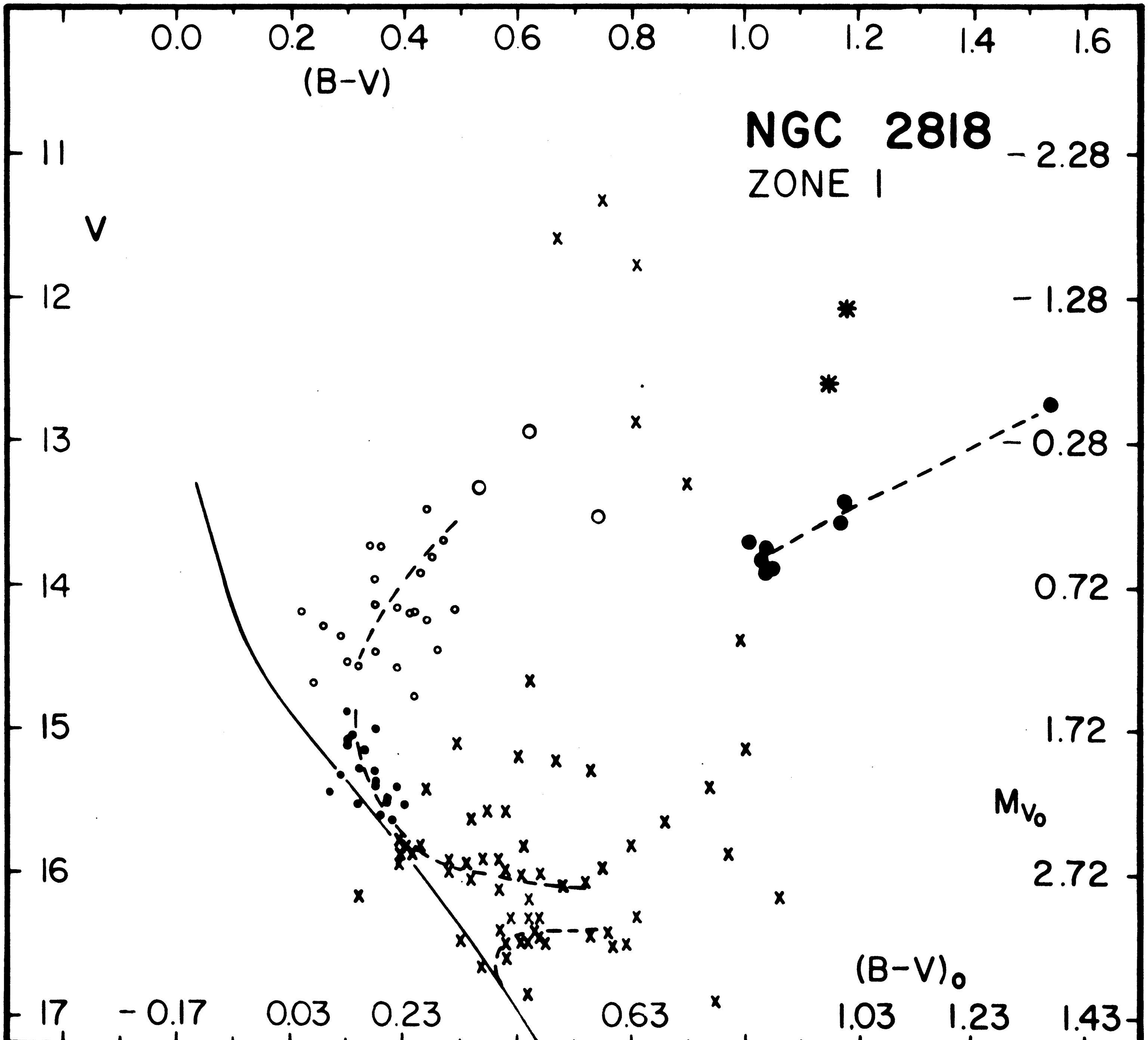

NGC 2818
ZONE I
(B−V)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
V
11
12
13
14
15
16
17
−2.28
−1.28
−0.28
0.72
1.72
2.72
M_Vo
(B−V)o
−0.17
0.03
0.23
0.63
1.03
1.23
1.43

FIGURE 2

field stars, and fall in the inner part of the cluster where field star contamination is minimal. These stars also show an ultraviolet excess similar to the red giant stars.

The color magnitude diagram for NGC 2818 is consistent with the post main sequence evolutionary tracks for stars of 2-3 solar masses as given by Iben (1967). The cluster is somewhat younger than NGC 752 which resembles NGC 2818 in its color-magnitude character (Eggen, 1963). An age slightly less than 10^9 years is indicated by the A5 turnoff point. In Figure 3 the NGC 2818 color magnitude pattern for $V<15.8$ is superimposed upon the composite c-m diagram of galactic clusters given by Sandage and Eggen (1969). NGC 2818 shows good agreement with the other clusters.

The color-color diagram for the inner zone of NGC 2818 is shown in Figure 4. Symbols are the same as in Figure 2; the main sequence line is shown both unreddened and for $E_{B-V}=0.22$. The color excess has been fixed from a variety of considerations. The brighter field stars, mostly appearing with X symbols in the diagrams, for all zones around the cluster, indicate little reddening out to nearly 1 kpc. Two bright field stars, 2-85 and 3-120 appear photometrically to be late B stars with modulii about 10.2 if main sequence luminosities are assumed. They show a color excess of 0.12 ±.02 and suggest that significant absorption is encountered slightly beyond 1 kpc. The next feature for which a fairly certain reddening can be obtained is a field star component discussed later which has $E_{B-V}=0.22$ at a distance of 4 kpc and apparently lies beyond the cluster. The cluster itself does not permit determination of a certain value of E_{B-V} because of the interplay between reddening and ultraviolet excess effects, however, there is good reason to assume that the value $E_{B-V}=0.22$ found for the background also applies to the cluster. When the value of $E_{B-V}=0.22$ is assumed the cluster shows a similar UV excess for the main sequence and giant stars, whereas if the main sequence is fit with zero UV excess at about $E_{B-V}=0.12$ the giants show a large UV excess, about 0.2. On almost any model the cluster lies at a distance beyond 3 kpc and 500 pc above the plane. It is unlikely that appreciable absorption will be present between 3 and 4 kpc that far above the plane. A value of cluster reddening near 0.2 is also consistent with the observed colors and spectral types of the two best observed stars in Table IV. For all subsequent discussion we will, therefore, assume that a reddening of 0.22 occurs in B-V due to absorption between 1-2 kpc, and that this excess applies to all the more distant stars in the field. Using

FIGURE 3

The color magnitude diagram of NGC 2818 (dashed lines) shown with respect to well studied clusters according to Sandage and Eggen (1969).

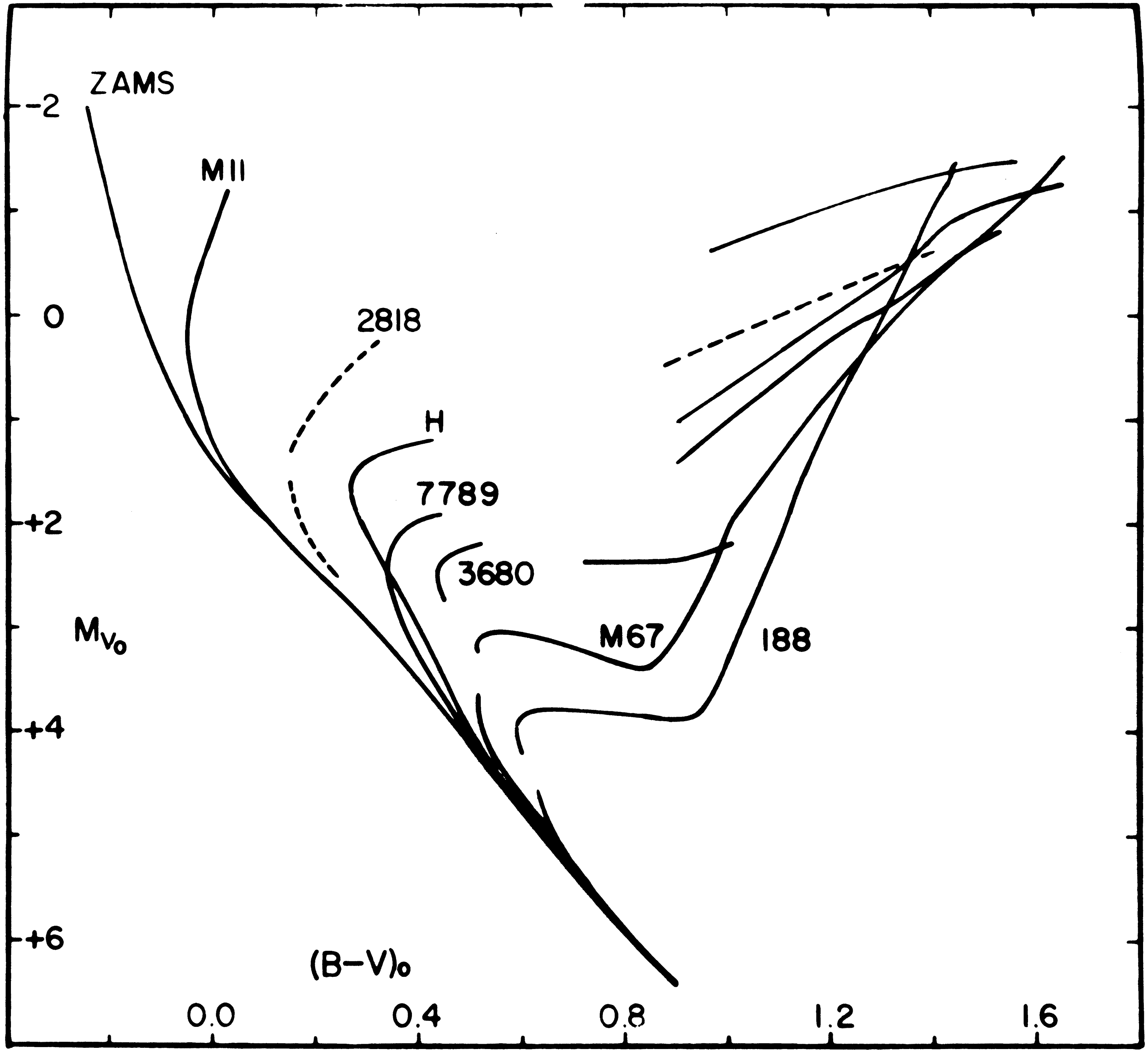


FIGURE 3

FIGURE 4

The color-color diagram for the central region of NGC 2818. Symbols are the same as in Figure 2. Both the unreddened main sequence (dashed lines) and reddened main sequence (solid lines) for $E_{B-V}=0.22$ are shown. The cluster stars show a distinct ultraviolet excess.

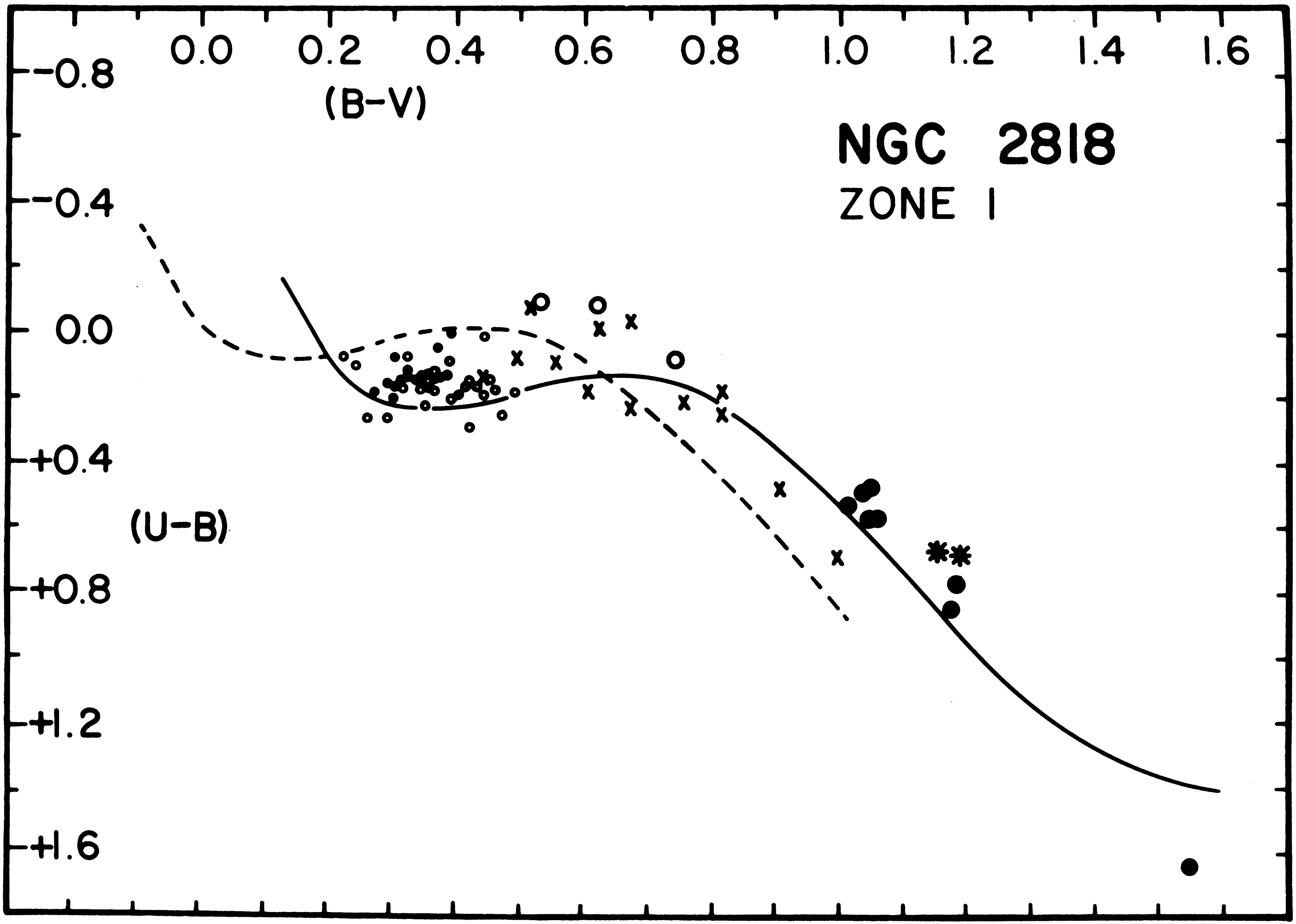


FIGURE 4

$A_V/E_{B-V}=3.0$, the absorption correction for the cluster and background field is 0.66 with an estimated uncertainty of ±0.1.

Both the main sequence and giant stars in NGC 2818 as shown in Figure 4, indicate an ultraviolet excess of 0.09. Blanketing corrections of 0.05 in B-V and 0.04 in V were assumed along with the excess and absorption just discussed to perform the zero age main sequence fit to the cluster.

The giant and main sequence stars show a well defined UV excess, however, the subgiant stars show difference. The bluer subgiants agree with the main sequence, however, the redder stars show a distinct UV deficiency with respect to the cluster main sequence. This effect has been noted previously in NGC 752 (Eggen, 1963) and is apparently a direct manifestation of the changing electron pressure in passing from the main sequence to the subgiants. The two possible Helium burning stars in the red giant region suggest a slightly larger UV excess than the normal giants.

An interesting group of stars is shown with large open circles in the color-magnitude and color-color diagrams. They lie at $12.8<V<14.0$, $0.5<(B-V)<0.75$, directly along the extension of the subgiant sequence in the color-magnitude diagram. They show an extreme ultraviolet excess compared to either the bluer subgiants or most of the fainter field stars of similar B-V colors. The bluest of the three stars of this type in the inner zone is 1-15 which was included in the spectroscopic study summarized in Table IV. The star was classified as F6III consistent with cluster membership as is its velocity. However, from the distribution of stars of the 1-15 type radially about the cluster a field star identification is most likely. The presence of significant numbers of such stars in a cluster is not consistent with the very rapid evolution expected across the Hertzsprung gap.

In Figures 5 and 6 the color-magnitude and color-color diagrams of the stars in the ring immediately outside the cluster core are shown. This zone has twice the area of the inner zone. As expected from the area increase field stars are more common and most of the brighter "field" (X symbol) stars of intermediate color are well represented by an unreddened main sequence. The characteristic features of the cluster are reproduced in the color-magnitude diagram as dashed lines.

Comparison of the color-color diagrams for the inner and intermediate radius zone of the cluster show a distinct transition from cluster to field. In the blue main sequence (small dot symbols) a distinct splitting occurs with most stars in the intermediate zone falling on the main sequence

FIGURE 5

The color-magnitude diagram for the intermediate radius zone surrounding NGC 2818. Symbols are as in Figure 2. Only a few stars in this zone are cluster members. The characteristic features of the cluster are indicated with dashed lines. The ZAMS fit to a background field is shown with a solid line.

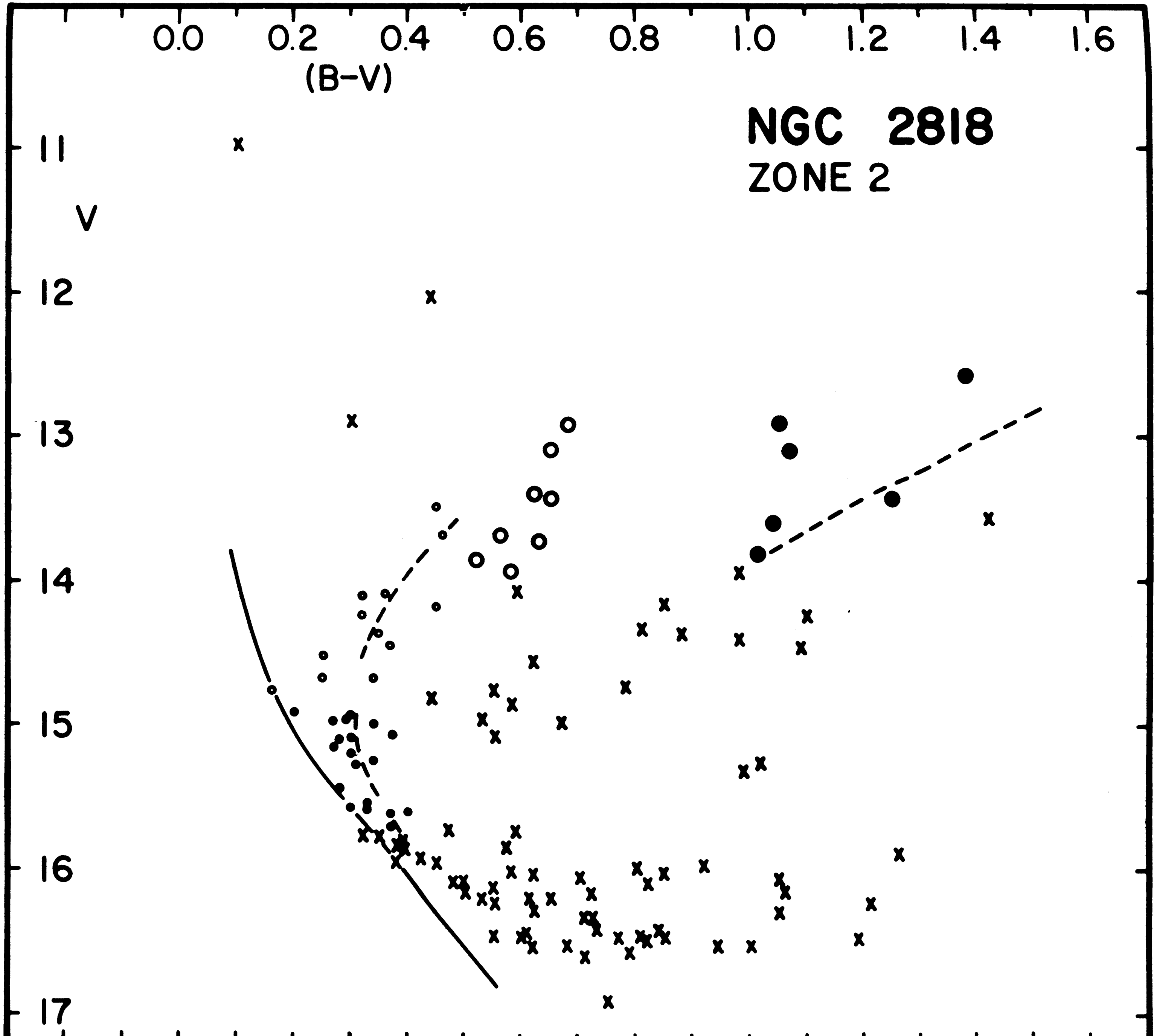


FIGURE 5

FIGURE 6

The color-color diagram for the intermediate radius zone surrounding NGC 2818. Symbols and lines are as in Figure 2. The majority of the stars fit closely the reddened main sequence at $E_{B-V}=0.22$ and show no ultraviolet excess. A few main sequence stars show the characteristic ultraviolet excess of the cluster.

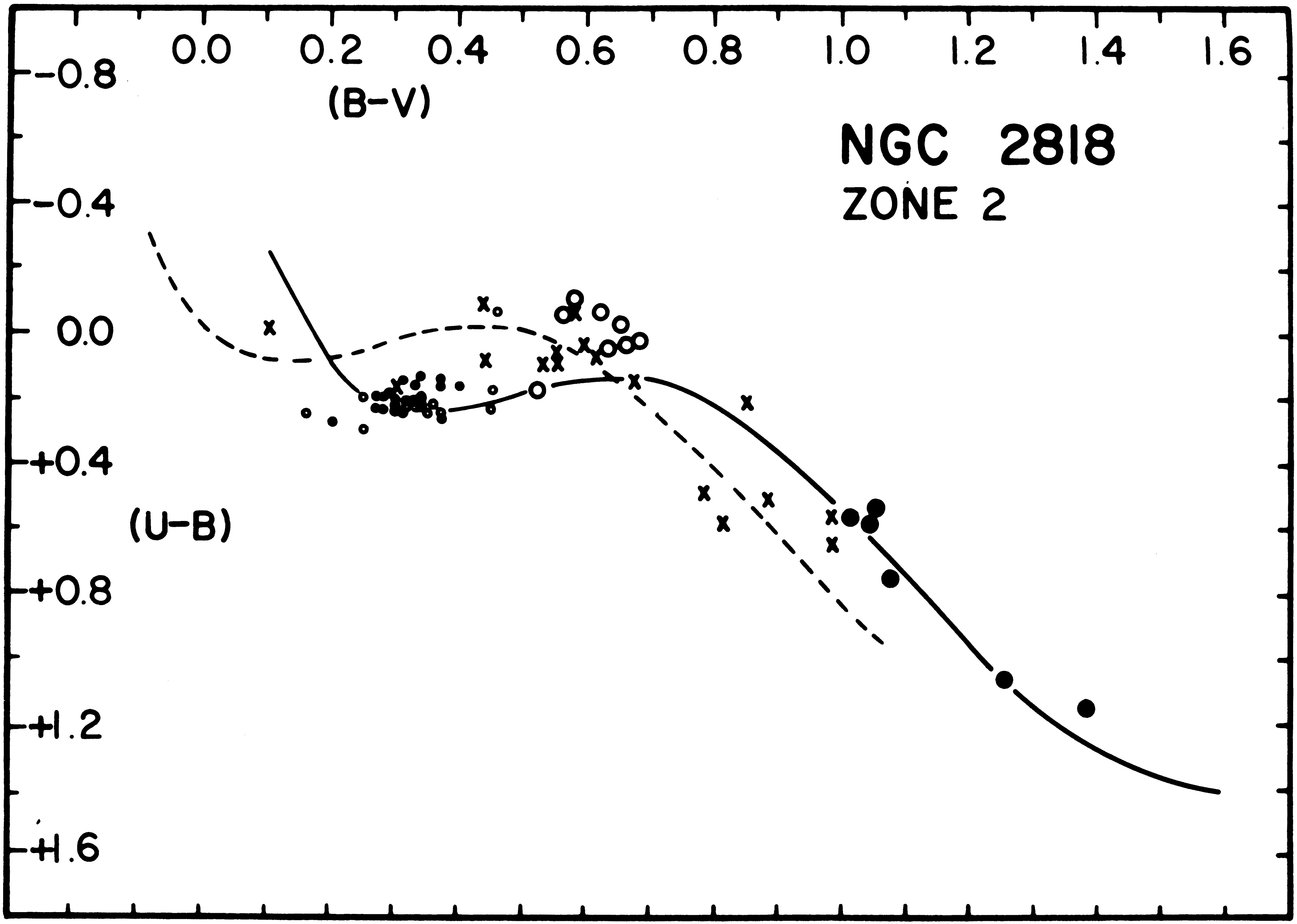


FIGURE 6

for E_{B-V}=0.22 and zero ultraviolet excess. Six stars of the main sequence variety show an ultraviolet excess and fall precisely in the part of the color-color diagram populated by the cluster stars in the inner zone. The cluster is, therefore, weakly present in the intermediate zone in a number ratio of about 6:15 compared with the inner zone, or 3:15 for equal areas. Specific identification of the six stars shows that five of them lie in the inner half of the middle zone. They suggest the cluster extends slightly north and southwest from the inner zone and cuts off distinctly on the east. The net effect of the six stars is to shift the cluster center west, closer to the planetary nebula, which enhances the likelihood of the planetary's membership in the cluster.

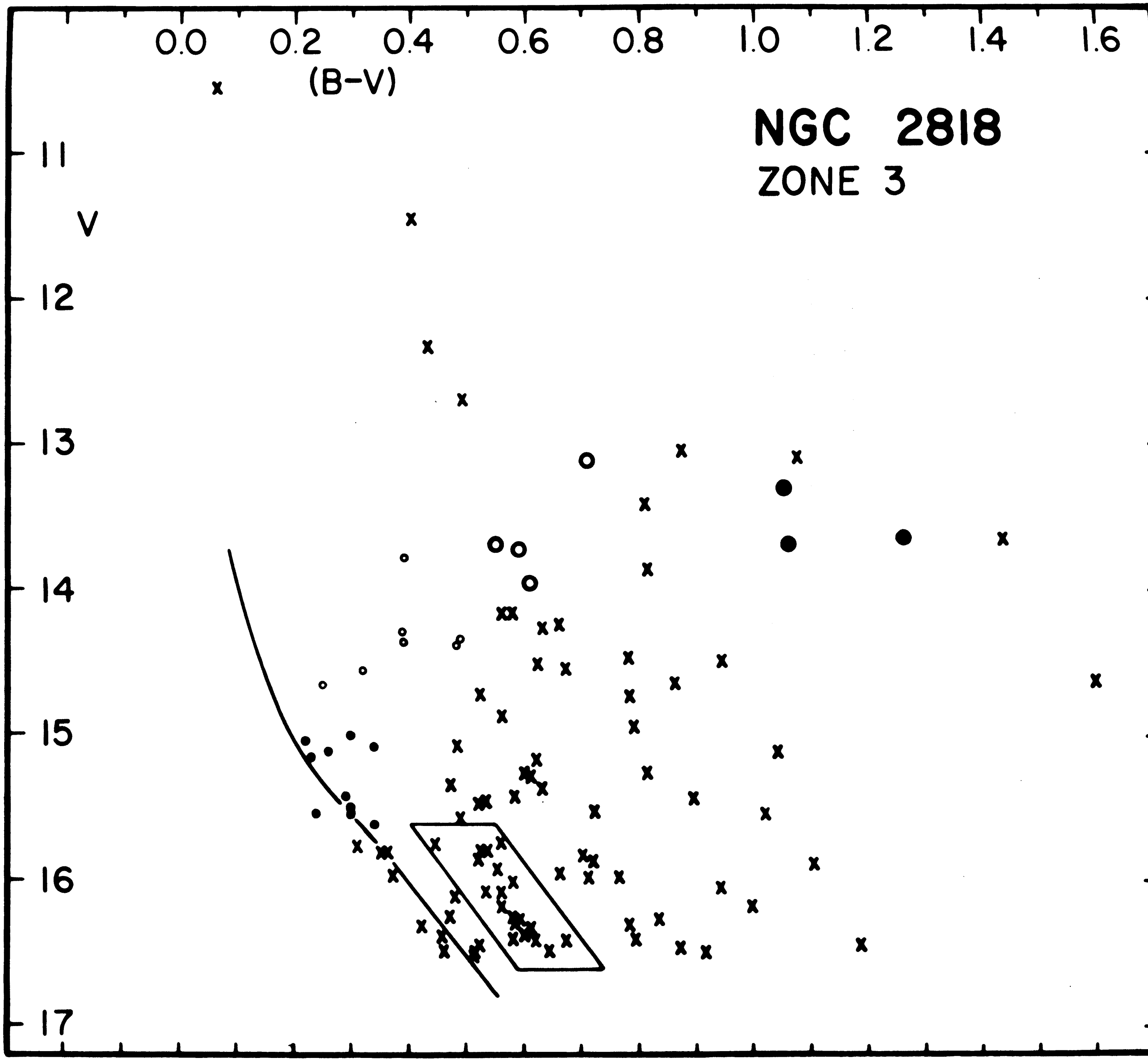
Along with the sharp decrease in the cluster main sequence stars in the middle zone one expects and finds a sharp decrease in the number of subgiant and giant stars. The giant star candidates show little uniformity in luminosity and no evidence for ultraviolet excess and, thus, appear to contain no certain cluster members. The non-cluster dwarf and giant component combined is a very well represented by a stellar population of zero ultraviolet excess at a color excess of 0.22; the only exceptions are the intermediate color stars of large UV excess.

The frequency of the large UV excess stars increases essentially in proportion to the zone areas in going from the inner to the intermediate radius zone, hence, most or all must be associated with the field and not the cluster. The stars are relatively bright and similar in the brightness so that their cutoff near B-V=0.7 is not an effect of limiting magnitude. If they were subdwarfs there would be no reason to expect the sharp cutoff at B-V=0.7. Examination of the UV excess in detail as a function of B-V suggests that the UV excess with respect to the reddened main sequence decreases with increasing B-V. From both the narrow color range of occurrence and the dependence of ultraviolet excess on B-V the stars may form a homogeneous group of subgiants. They closely resemble in color the subgiants found in NGC 752. A few candidates for large UV excess stars appear directly below the large UV excess "subgiant" group; there is, however, no concentration of fainter unevolved "main sequence" stars with which to associate the "subgiants". NGC 752 also shows an apparent absence of unevolved main sequence stars below the subgiants (Eggen, 1963).

Figures 7 and 8 present the color-magnitude and color-color diagrams for the outer zone surrounding NGC 2818. There is no evidence for cluster stars at all in this zone which has an area of 2.3 times the innermost region.

FIGURE 7

The color-magnitude diagram for the outer radius zone surrounding NGC 2818. Symbols are as in Figure 2. No cluster members are seen in this zone. The ZAMS is shown fit to a characteristic feature of the diagram which appears as a distinct cloud of stars lying beyond the cluster at 4.0 kpc. A region of the color magnitude diagram below V=15.6 is outlined for use in statistical separation of the faint cluster main sequence from field stars.



NGC 2818
ZONE 3
(B–V)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
V
11
12
13
14
15
16
17

FIGURE 8

The color-color diagram for the outer radius zone surrounding NGC 2818. Symbols and lines are as in Figure 2. No cluster members are present in this zone.

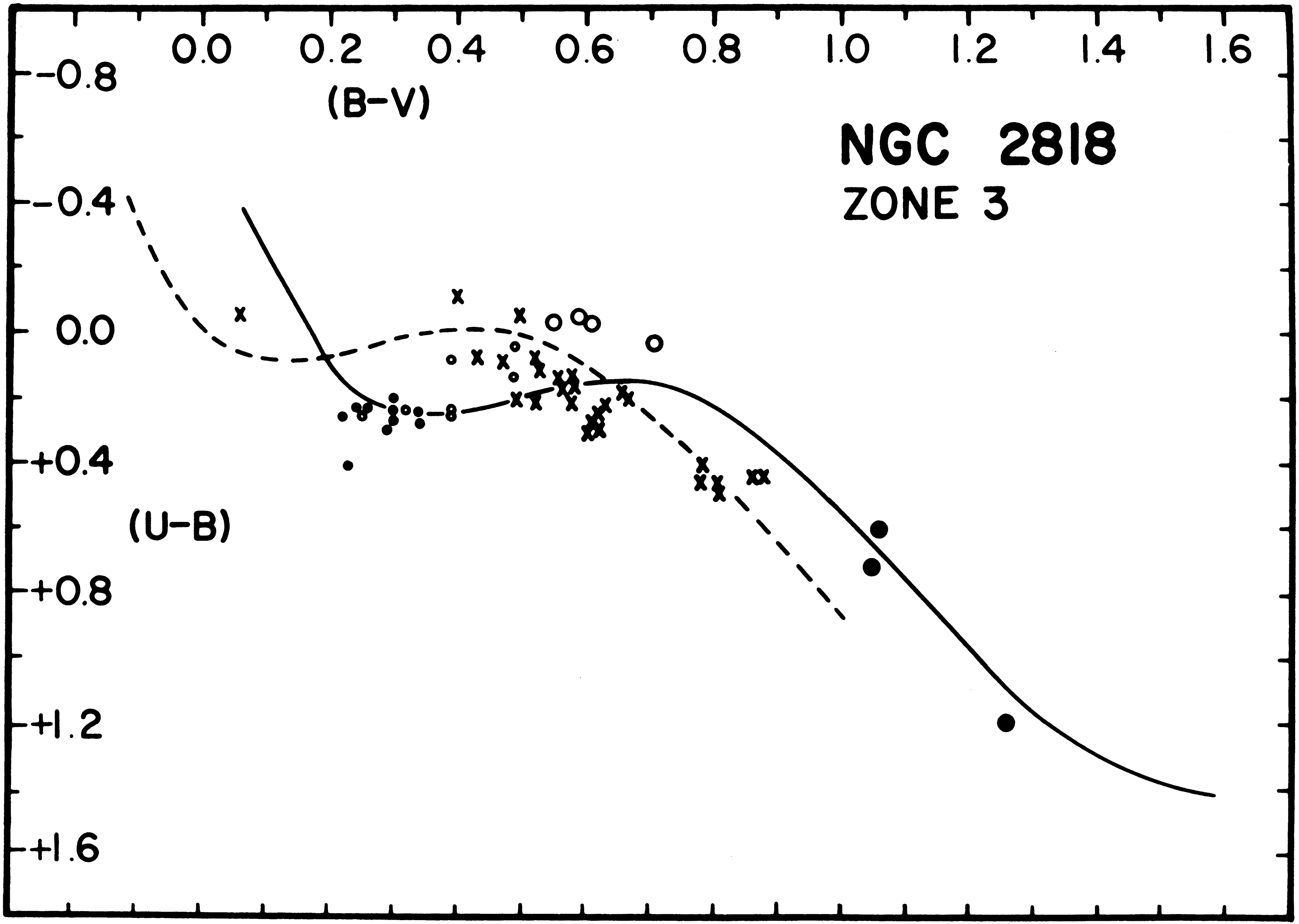


FIGURE 8

All the bluer faint main sequence type stars are associated with a uniform field component which appears as a distinct feature in the color-magnitude diagram. The zero age main sequence has been fitted to this faint field star component in Figure 7 and is also shown in Figure 5, assuming $E_{B-V}=0.22$ and zero ultraviolet excess. The resulting modulus corrected for absorption is 13.02 which implies a distance of 4.0 kpc. The cloud of stars is 600 pc above the galactic plane but shows no ultraviolet excess. The bluest stars in this component have $(B-V)_o=0.0$, hence, the cloud includes stars as early as A0.

As a final point of discussion we consider the faint main sequence stars in the cluster and field components. In Figure 2 for the inner region the main sequence appears to terminate quite abruptly at V=15.9 although the photometry is essentially complete to V=16.5. A similar termination is seen in NGC 752 (Eggen, 1963). Unlike NGC 752, however, commensurate with the termination in NGC 2818 a redder group of stars appears and continues downward to the limit of the photometry. A similar "displaced" configuration of stars appears in the intermediate and outer zones so the field obviously contributes to population in this part of the color-magnitude diagram. In Figure 7 for the outer region a small zone is indicated between V=15.6 and V=16.6 enclosing the "displaced" configuration of stars. The relative numbers of stars in the three zones falling in the indicated part of the c-m diagram are from inner to outer, 21:19:19 and reduced to equal area 21:10:8. On the basis of the main sequence study the outer zone contains no cluster stars, therefore, subtracting 8 as a field star contribution, the number of cluster members in the faint "displaced" region is 13:2:0 which compares very well with the main sequence star ratio previously found of 15:3:0. It, therefore, follows that 2/3 of the inner zone stars in the "displaced" region are cluster members. The displacement in the NGC 2818 main sequence may extend further to the red. There is still some enhancement of star densities in a zone extending 0.2 further to the red. Figured as in the primary zone the equal area number ratio is 7:3:0. Still further to the red the effect disappears and a ratio of 2:3:0 is found. The field star contribution to the "displaced" main sequence might be associated with the large UV excess "subgiant" concentration.

The bend or break in the NGC 2818 main sequence at V=15.9 is almost certainly real; between $(B-V)_o=0.25$ and some unknown redward limit, the main sequence deviates distinctly from the standard ZAMS. In Figure 2 the faint main sequence has been drawn to reflect a break. Examination of the color-magnitude diagram for the Pleiades (Johnson and Mitchell, 1958) indicates that the B-V=0.2 to 0.5 portion of the color magnitude diagram includes a kink or bend in the main sequence and may have gaps in the star frequency. The break in NGC 752 is possibly a manifestation of the same thing.

PLANETARY NEBULA

Table V contains a list of identified lines in the planetary nebula; the spectrum is reproduced in Plate III. NGC 2818 is a very high excitation object as previously indicated by Johnson (1960). Location of this object in a cluster with a well defined distance and reddening provides an important calibration point for this type of planetary nebula. Vorontsov-Velyaminov (1934) gives an estimated distance of 3.6 kpc to the nebulae in good agreement with the cluster photometric distance of 3.2 kpc. The conclusive association of the cluster and nebula is of considerable import in studies of stellar evolution. The central star in the NGC 2818 planetary is faint but is visible at $V \simeq 17.5$.

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Johnson, H. L. and Mitchell, R. I. 1958, Ap.J. 128, 31.

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Sandage, A. and Eggen, O. J. 1969, Ap.J. 158, 685.

Tifft, W. G. and Snell, C. M. 1971, M. N. 151, 365.

Vorontsov-Velyaminov, B. A. 1934, Zsf. Ap. 8, 195.

TABLE V. LINE IDENTIFICATION FOR NGC 2818 PLANETARY NEBULA

WAVELENGTH	ELEMENT
3345.9	[NeV]
3425.8	[NeV]
3726.16/3728.91	[OII]
3835.386	H9
3868.74	[NeIII]
3889.051	H8
3967.51/3970.074	[NeIII], Hε
4068.62/4076.22	[SII]
4101.737	Hδ
4340.468	Hγ
4363.21	[OIII]
4541.59	HeII
4685.682	HeII
4716 Blend	[NeIV], [AIV]
4740.3	[AIV]
4861.332	Hβ
4958.91	[OIII]
5006.84	[OIII]

WAVELENGTH	ELEMENT
5198.5/5200.7	[NI]
5411.524	HeII
5754.8	[NII]
5875?	HeI
6300.23/6310.2	[OI], [SIII]
6548.1	[NII]
6569.099/6562.817	HeII, Hα
6583.6	[NII]
6717.0	[SII]
6731.3	[SII]

NIGHT SKY LINES

3897.938	NaI
4046.557	HgI
5460.742	HgI
5577.350	[OI]

PLATE III

A low dispersion untrailed slit spectrogram of the NGC 2818 planetary nebula. The stronger lines are identified. The spectrograph slit was oriented north-south across the center of the nebula. The southern component is brighter.

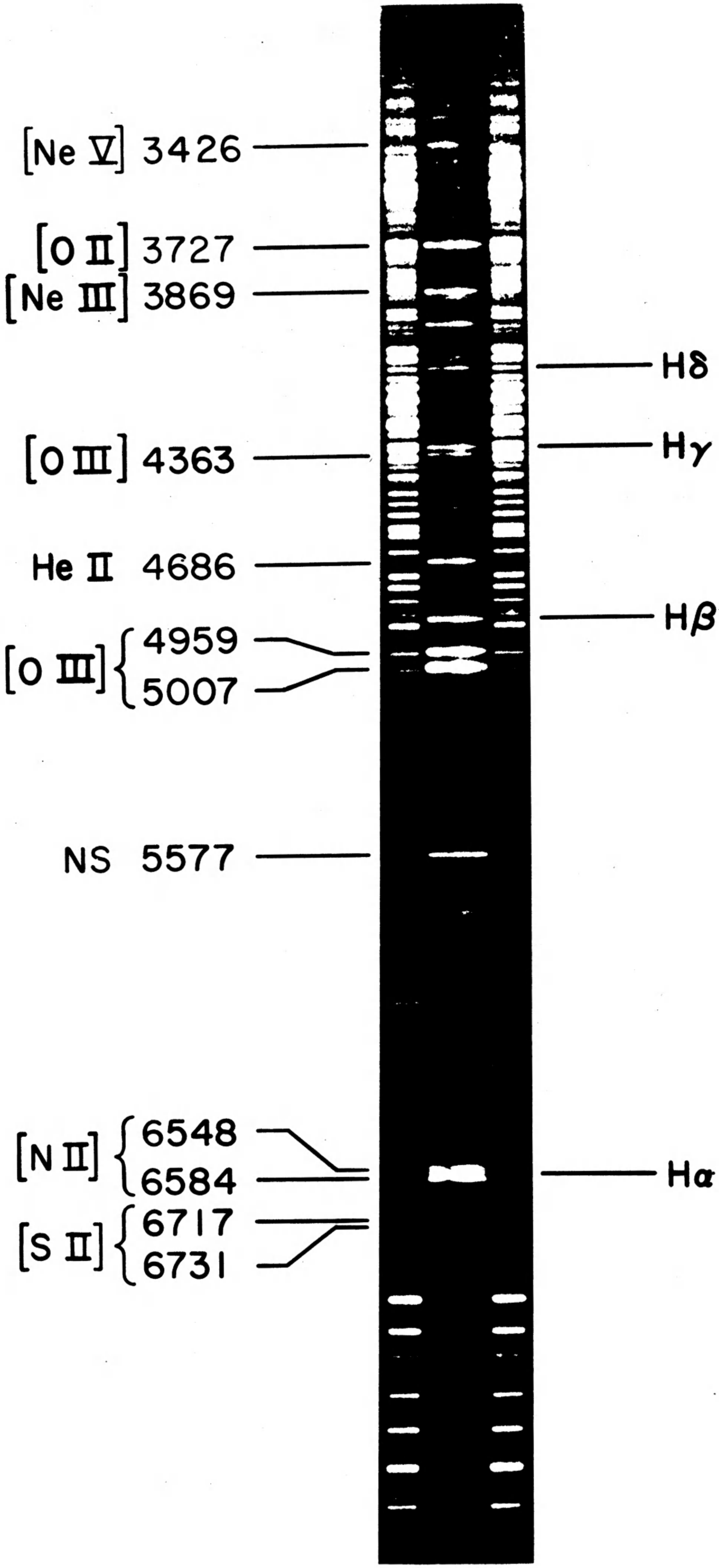
[Ne V] 3426
[O II] 3727
[Ne III] 3869
[O III] 4363
He II 4686
[O III] 4959
5007
NS 5577
[N II] 6548
6584
[S II] 6717
6731
Hδ
Hγ
Hβ
Hα

PLATE 3