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RESULTS OF A PILOT PROGRAM TO DISCOVER NEW SUBDWARFS IN THE SOLAR NEIGHBORHOOD

ALLAN SANDAGE
Mount Wilson and Palomar Observatories
Carnegie Institution of Washington, California Institute of Technology
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ABSTRACT

New three-color photometry is reported for fifty-six stars previously known to be subdwarfs but for which photometric data were meager or lacking. Photometry is also reported for an additional ninety-four stars observed as candidates in a pilot program to discover new subdwarfs. Forty-four of the candidate stars were found to have ultraviolet excess values exceeding $0^m.10$, and of these, twenty-seven have $\delta(U - B) \geq 0^m.16$, which puts them in the class of extreme subdwarfs similar to stars on the main sequences of the halo globular clusters. Radial velocities have been obtained and are reported for many of the new extreme subdwarfs.

The distribution of the $B - V$ colors for subdwarfs with $\delta(U - B) \geq 0^m.16$ shows an abrupt blue cutoff at $B - V = 0^m.38$ if no reddening corrections are applied, or $B - V = 0^m.34$ if the Parenago reddening equation is used. Both values are bluer by $0^m.04$ and $0^m.08$ than the previously reported colors of the main-sequence termination points of the well-studied halo clusters. This tends to support the belief that the true termination colors for the main sequences of halo globular clusters are bluer than previously suspected, due either to interstellar reddening (Arp 1962*b*), or to small errors in previous faint photometry, or to both. If this is confirmed by direct observations in the halo clusters themselves, then ages of these clusters would be closer to 10^{10} years than to 2×10^{10} years.

I. INTRODUCTION

Miss Roman's discovery (1954, 1955) that stars of low metal abundance have an excess of ultraviolet radiation provides a powerful photometric method to find more stars of this type. Following Kuiper (1939), Parenago (1946), and others, we shall call these stars "subdwarfs" if M_V is fainter than about +3.5 and if the ultraviolet excess is greater than $0^m.10$, although the evidence now available (Sandage and Eggen 1959; Melbourne 1960; Eggen and Sandage 1962) suggests that a separate subdwarf sequence may not exist in the H–R diagram when the color or spectral type data are corrected for line blanketing.

Subdwarfs are of particular interest because they are similar, if not identical, to the main-sequence stars of the halo globular clusters in their physical and kinematical properties. They are relics from the time of first star formation, and their study provides clues to the past history of the galactic system. In particular, the distribution of color indices of subdwarfs is expected to show an abrupt blue cutoff which signals the main-sequence termination point. The color index of this cutoff, so important for the age-dating problem, is determined with greater ease using nearby field subdwarfs rather than with stars in the halo globular clusters because (1) there is less interference with interstellar reddening, and (2) the photometric errors for bright field stars are nearly negligible.

Unfortunately, the available sample of known subdwarfs is very small—only about one hundred are known from the work of Adams, Joy, Humason, and Brayton (1935); Kuiper (1939); Popper (1942, 1943); and Münch (1944). A summary list of all subdwarfs known in 1958 as determined from their spectroscopic characteristics has been given by Eggen and Sandage (1959).

II. THE NEW DATA

A pilot photoelectric discovery program was begun recently at the Mount Wilson and Palomar Observatories to increase the total sample. This paper reports observations made between 1959 and 1962 of a list of candidate stars prepared by O. J. Eggen from high proper-motion catalogues of high weight. Three-color photoelectric observations were obtained for stars on the candidate list and for known subdwarfs which either had no previous photometric history or had photometry of low weight. The data were secured with the 20-inch and 60-inch reflectors equipped with a normal refrigerated 1P21 photometer. Transfers were made on each observing night to an average of fifteen standard stars of the U, B, V system chosen from the lists of Johnson and Morgan (1953), and Johnson and Harris (1954). The over-all accuracy of the data is of the order of $\pm 0^m.015$ (m.e.) per star in magnitude and is somewhat better in color.

After the preliminary photometric results were known, radial velocities were determined from thirty-five of the candidate stars which had ultraviolet excess values greater than $0^m.14$. The spectrograms were obtained with the 200-inch coudé spectrograph using the 18-inch Schmidt camera, a combination which gives a linear dispersion of 18Å/mm. These observations were made on nights which had been scheduled for prime-focus work, but for which weather conditions were too poor for photometric programs. Enough partially cloudy weather prevailed during 1959 to 1962 so that most candidate stars with $\delta(U - B) \geq 0^m.16$ brighter than $V = 11.0$ were observed spectrographically. All radial velocities on the program were obtained from the spectrograms by using J. L. Greenstein's adopted wavelength system for the absorption lines of subdwarfs. A description of this system as related to the *General Catalogue of Stellar Radial Velocities* (Wilson 1953) will be given by him when his velocities are discussed.

Table 1 contains the new data for the previously known subdwarfs. The columns have the following meaning: (1) is the identification of the star using the numbers in the Wilson *General Catalogue;* (2) identifies the star by other common designations; (8) is the ultraviolet excess, defined as usual as the difference between the $U - B$ color actually observed and the $U - B$ color of the Hyades two-color relation (taken from Table III of Sandage and Eggen 1959), read at the observed $B - V$ value; (9) is the number of photoelectric observations on separate nights; and (10) lists some cross-identifications of the stars in question. Here the G numbers refer to the Lowell Observatory high proper-motion catalogues by Giclas and his co-workers (1959, 1960).

Table 2 contains stars from the candidate program which were found to have $\delta(U - B) \geq 0^m.10$, and are therefore assigned as "new" subdwarfs. Column (9) lists the heliocentric radial velocity with its internal mean error, and column (10) gives the number of spectrographic plates. When more than one plate was taken, the individual velocities are given in the notes to the table.

Table 3 lists stars with $\delta(U - B)$ less than $0^m.10$. These are evidently not extreme subdwarfs in the globular cluster sense, but their relatively large proper motion does put them in an intermediate velocity class.

The external accuracy of the photometric and spectroscopic data in the three tables was estimated by comparing stars in common with lists of other observers. The three photometric lists available are Roman (1955); Cousins, Eggen, and Stoy (1960); and Kowal (1964). Thirteen stars in common with Roman give the residuals $\Delta V = 0^m.000 \pm 0^m.009$ (A.D.); $\Delta(B - V) = -0^m.005 \pm 0^m.005$; $\Delta(U - B) = +0^m.003 \pm 0^m.006$ in the sense "Sandage minus Roman." Eleven stars in common with Cousins *et al.* give $\Delta V = +0^m.058 \pm 0^m.011$, $\Delta(B - V) = -0^m.005 \pm 0^m.006$; and eleven stars in common with Kowal give $\Delta V = -0^m.008 \pm 0^m.006$, $\Delta(B - V) = -0^m.007 \pm 0^m.008$, and $\Delta(U - B) = +0^m.003 \pm 0^m.005$. The agreement is satisfactory except for the comparison in V with Cousins *et al.*, where there appears to be a zero point difference of $0^m.06$ in the sense that we measure the stars to be brighter than the Cape observers. No explanation has yet been found.

The spectroscopic standard of comparson is the *General Catalogue of Stellar Radial Velocities* (Wilson 1953), where there are thirteen stars in common with the present work. A systematic difference of $\Delta\rho = -0.85 \pm 0.81$ km/sec exists when all thirteen

TABLE 1

NEW PHOTOMETRY OF KNOWN SUBDWARFS
MOST OF WHICH LACKED PREVIOUS PHOTOMETRY

Wilson No. (1)	Other (2)	α(1950) (3)	δ(1950) (4)	V (5)	B−V (6)	U−B (7)	δ(U−B) (8)	n (9)	Remarks (10)
390*	+71°31	$0^h40^m.3$	+71°54′	10.20	0.38	−0.21	+0.22	3	Roman 21
987*	+72°94	1 43 .0	+73 13	9.94	0.41	−0.22	0.23	4	
1800	Wolf 1324	3 13 .1	+37 57	10.67	1.17	+0.98	....	2	
1892	Ross 374	3 24 .0	+23 37	10.83	0.53	−0.11	0.17	4	G 5-36
1904	Ross 34	3 25 .5	+37 14	11.11	1.32	+1.06	....	2	G 38-1; LFT 283
1919	+66°268	3 26 .4	+66 35	9.90	0.65	−0.10	0.29	2	CC 236
3562	Ross 49	5 42 .2	+09 14	11.84	0.56	−0.17	0.26	3	G 99-31
3562N	.....	5 42 .2	+09 14	12.64	0.82	+0.15	0.32	1	
4400	.....	6 43 .7	+58 41	10.32	0.43	−0.18	0.18	4	
5757	CC 486	8 40 .9	+36 26	10.96	0.58	−0.12	0.23	4	
5793	−12°2669	8 44 .4	−13 11	10.26	0.31	−0.15	0.21	1	
5815	Ross 683	8 47 .8	+ 7 49	11.32	0.74	+0.15	0.17	3	G 46-5
5909*	−3°2525	8 56 .6	− 3 49	9.69	0.48	−0.20	0.22	2	CC 501
5951	CC 508	9 02 .1	+39 00	11.60	0.50	−0.24	0.27	3	
6236	Ross 889	9 38 .2	+ 1 15	10.50	0.38	−0.19	+0.21	3	G 48-29
6237	+1°2341	9 38 .2	+ 1 15	10.25	0.42	+0.04	−0.04	2	East. Not sd.
6294	HD 84937	9 46 .2	+13 59	8.34	0.39	−0.21	+0.22	1	Roman 229
6269	+44°1910	9 46 .4	+44 32	10.93	0.42	−0.20	0.21	3	
6704	+29°2091	10 44 .6	+28 41	10.24	0.50	−0.21	0.24	2	CC 589
6728	Ross 106	10 47 .4	+56 43	12.58	0.60	−0.14	0.27	2	CC 590
6734	HD 94028	10 48 .8	+20 33	8.21	0.48	−0.18	0.20	1	Roman 252
6869	Wolf 365	11 8 .5	+ 6 42	11.41	0.72	−0.03	0.32	2	G 10-4; CC 614
6880	+36°2165	11 10 .0	+36 01	9.77	0.43	−0.19	0.19	7	
7017	AC+77°	11 29 .2	+76 55	11.53	0.65	−0.07	0.26	1	AC+77°4245
7087	Ross 451	11 37 .5	+67 36	12.23	1.45	+1.16	....	1	
7117	+26°2251	11 42 .1	+25 50	10.37	0.47	−0.12	0.13	2	
7131	+51°1696	11 44 .0	+51 10	9.92	0.55	−0.15	0.23	2	
7266	−4°3208	12 04 .8	− 5 27	10.06	0.40	−0.20	0.21	3	G 13-9
7296	Ross 453	12 08 .4	+ 0 41	11.13	0.42	−0.21	0.22	2	G 11-44
7567	Wolf 1447	12 31 .9	+15 33	12.02	0.42	−0.23	0.24	2	G 59-24
7913*	Ross 484	13 16 .4	− 2 48	10.86	1.01	+0.67	0.19	5	G 14-45; LFT 991
7923	AC+64°	13 17 .7	+64 26	13.30	0.61	−0.14:	0.29:	2	AC+64°4188
7951	AC+74°	13 21 .1	+74 27	11.66	0.48	−0.24	0.26	1	AC+74°4690
8236	+34°2476	13 57 .0	+34 07	10.04	0.41	−0.22	0.22	5	Roman 323
8246	Ross 838	13 59 .2	+ 9 11	11.59	0.72	+0.09	0.20	2	CC 828
8249*	HD 122563	14 00 .1	+ 9 56	6.17	0.91	+0.38	0.28	1	Roman 324
8296	−13°3834	14 07 .8	−13 41	10.70	0.60	−0.11	0.24	2	CC 835
8691	.....	14 57 .0	−21 48	8.66:	0.56:	−0.14:	0.23:	1	
8758	.....	15 05 .7	+32 37	11.12	0.67	+0.07	0.15	1	CC 912
9069	HD 140283	15 40 .4	−10 46	7.24	0.48	−0.20	0.22	2	Roman 373
9236	+42°2667	16 01 .6	+42 24	9.86	0.46	−0.20	0.21	4	
9401	Ross 530	16 17 .7	+22 46	11.51	0.71	+0.08	0.19	1	CC 982
9483	.....	16 26 .8	+44 48	11.29	0.68	−0.08	0.31	1	CC 993
9840	+17°3154	17 01 .6	+17 16	9.14	0.61	+0.10	0.05	1	Roman 406
10287	+25°3344	17 44 .7	+25 46	6.94	0.20	+0.14	0.00	1	Roman 430
10289	−8°4501	17 44 .7	− 8 46	10.64	0.56	−0.14	0.23	2	G 20-15; CC 1064
11017*	+13°3683	18 31 .0	+13 08	10.57	0.64	−0.08	0.26	2	Ross 148
11060	Ross 711	18 33 .4	+28 40	11.38	0.40	−0.26	0.27	1	
12730	HD 193901	20 20 .6	−21 31	8.61	0.55	−0.13	0.21	1	
12754	.....	20 22 .6	+24 54	10.84	0.41	−0.27	0.27	1	
....	HD 195636*	20 30 .1	− 9 32	9.54	0.65	0.00	0.19	R	
13327	HD 201891	21 09 .7	+17 32	7.41	0.50	−0.21	0.24	1	
....	+17°4708	22 09 .1	+17 51	9.45	0.45	−0.20	0.20	3	
14539	Ross 786	23 07 .0	+ 0 28	9.94	0.70	+0.01	0.25	2	G 28-43
14568	+38°4955	23 11 .3	+39 09	11.07	0.62	−0.13	0.29	1	CC 1407
14704*	+59°2723	23 24 .2	+60 20	10.47	0.44	−0.22	0.22	2	

Notes to Table 1

W 390: Roman (1955) gives 10.27, 0.36, −0.16; Kowal gives 10.20, 0.43, −0.24.
W 987: Two radial velocity plates give −267.7 ± 0.4, −263.8 ± 0.5. JLG gives −269.8.
W 5909: One radial velocity plate gives +32.8 ± 0.5. JLG says variable velocity.
W 7913: One radial velocity plate gives +125.2 ± 0.8.
W 8249: JLG says not subdwarf but K2 III with very weak lines. Probably like a globular cluster giant.
W 11017: One radial velocity plate gives +81.9 ± 1.2. JLG gives +78.2. Lines extra weak.
HD 195636: One radial velocity plate gives −257.4 ± 1.0. JLG gives −258.2. Photometry quoted here by Roman (1955).
W 14704: Three radial velocity plates give −103.6 ±0.7; −98.9 ± 0.7; −107.0 ± 0.9, for a mean of −103.2. JLG from one plate gives −105.5.

TABLE 2

CANDIDATES FOR NEW SUBDWARFS WITH $\delta(U-B) \geq 0^m.10$

Star (1)	α(1950) (2)	δ(1950) (3)	V (4)	B−V (5)	U−B (6)	δ(U−B) (7)	n(p) (8)	ρ ε (9)	n(ρ) (10)	Remarks (11)
								km/sec		
− 9°122*	0h36m.0	− 8°35′	9.27	0.45	−0.16	0.16	2	− 41.9 ± 0.4	1	Roman 18
− 8°128	0 41 .4	− 7 48	9.40	0.59	+0.02	0.10	2	−112.1 ± 0.6	1	
−11°220	1 07 .7	−10 39	9.21	0.57	−0.02	0.12	2	+ 43.8 ± 0.4	1	
− 2°181	1 10 .9	− 2 08	8.95	0.69	+0.13	0.11	2	− 9.9 ± 0.4	1	
−17°219*	1 11 .7	−16 42	10.06	0.72	0.02	0.26	2	+ 81.4	2	
− 7°603	3 25 .9	− 6 42	8.26	0.62	+0.02	0.14	2	+ 63.4 ± 0.3	1	Roman 81
+39°916	4 00 .4	+39 40	10.71	0.56	−0.05	0.14	3	....	...	
− 5°1355	5 37 .5	− 5 04	8.91	0.64	+0.08	0.10	2	....	...	
− 6°1598	6 30 .2	− 6 27	8.62	0.56	−0.08	0.17	2	+ 7.5	JLG	
− 0°1520	6 56 .1	− 0 24	9.05	0.57	−0.02	0.12	2	− 91.6 ± 0.4	1	HD 51754
− 1°1792*	7 37 .3	− 1 24	9.23	0.82	+0.30	0.17	2	+ 49.2 ± 0.4	1	Roman 173
+ 9°2190*	9 26 .6	+ 8 51	11.13	0.38	−0.20	0.22	2	+265.5	2	
+65°737	9 45 .9	+65 33	9.70	0.67	+0.10	0.12	3	− 33.1 ± 0.4	1	
−14°3322	11 23 .6	−15 26	10.45:	0.58	−0.11	0.22	2	+ 11.4 ± 1.5	1	
−21°3420	11 53 .0	−22 06	10.18:	0.52	−0.14	0.19	2	+ 13.1 ± 0.6	1	
−16°3469	12 25 .8	−16 39	9.45	0.94	+0.62	0.10	2	....	...	
+71°646*	13 13 .2	+70 33	10.13	0.75	+0.17	0.17	2	− 97.6	2	
LTT 5137	13 17 .8	− 2 46	11.04	0.58	−0.10	0.21	1	....	...	
Minn Pub*	13 22 .1	+20 43	12.18	0.44	−0.19	0.19	1	....	...	LTT 13899
+77°521	13 44 .1	+77 29	9.45	0.66	+0.08	0.13	2	− 87.2 ± 0.6	1	
− 8°3858	14 52 .5	− 8 53	9.52	0.72	+0.16	0.13	2	− 64.3 ± 0.3	1	
+65°1050	15 21 .3	+65 22	10.14	0.55	−0.04	0.12	2	....	...	
G 15-24	15 28 .3	+ 8 34	11.43:	0.57	−0.11	0.21	2	− 84.6 ± 0.6	1	
G 16-15 B*	15 51 .9	− 4 09	14.24	1.34	+1.01	....	1	....	...	L 985-18
G 16-25*	15 59 .0	+ 5 32	13.33	0.59	−0.12	0.24	3	....	...	Wolf 624
− 0°3119*	16 25 .3	− 0 58	9.64	0.70	+0.15	0.10	2	−167.0	2	G 17-16
− 6°4455	16 30 .5	− 6 39	10.18	0.80	0.22	0.22	2	....	...	
− 3°3968*	16 32 .2	− 4 06	9.60	0.75	0.12	0.22	2	variable	2	G 17-25
+18°3407	17 33 .1	+18 55	10.02	0.83	+0.40	0.10	2	....	...	
− 9°4604	17 45 .1	− 9 35	9.68	0.66	−0.06	0.27	2	−134.2 ± 0.7	1	
+20°3603*	17 52 .8	+20 17	9.71	0.44	−0.19	0.19	2	−243.4 ± 0.6	2	
+68°986	18 16 .4	+68 37	10.13	0.69	+0.11	0.13	3	....	...	
G 21-22	18 36 .7	+00 06	10.72	0.53	−0.11	0.17	2	+ 59.1 ± 0.5	1	L 993-1
+74°792*	18 48 .5	+74 40	7.15	0.74	+0.15	0.17	2	−194.3	JLG	Roman 453
− 4°4617	18 51 .9	− 4 40	9.07	0.58	−0.05	0.16	2	+ 17.8 ± 0.4	1	G 22-6
−15°5243	19 05 .1	−15 19	9.59	0.62	−0.04	0.20	2	....	...	
G 22-19	19 10 .3	+ 6 39	12.64	0.68	−0.01	0.24	2	....	...	L 1139-56
+26°3578	19 30 .4	+26 15	9.37	0.39	−0.21	0.22	3	−130.2	JLG	Roman 471
+10°4091*	19 52 .8	+10 36	8.83	0.58	−0.11	0.22	2	variable?	2	
− 7°5235*	20 13 .9	− 7 36	8.39	0.58	−0.03	0.14	2	−109.0	2	
+ 5°4481*	20 17 .9	+ 5 53	10.10	0.67	−0.05	0.27	2	+101.5	2	G 24-13
−10°5549	20 53 .9	− 9 51	10.27	0.54	−0.11	0.18	2	....	...	
G 18-39*	22 16 .1	+ 8 11	10.38	0.46	−0.16	0.17	3	−231.5	2	Wolf 1032
G 27-45	22 42 .3	− 2 36	11.50	0.67	−0.07	0.28	2	− 15.0 ± 0.7	1	Ross 288

Notes to Table 2

− 9°122: A. Przybylski (1961) gives ρ = −45.7.
−17°219: Two ρ plates give +82.8 ± 0.5; +80.1 ± 0.5.
− 1°1792: W 5107 where ρ is given as +45.3 (b).
+ 9°2190: Two ρ plates give +265.2 ± 0.9; +265.8 ± 0.9. JLG (1954) gives ρ = +265 ± 3 from one plate taken at 38 A/mm.
+71°646: Two ρ plates give −99.0 ± 0.4; −96.2 ± 0.5. JLG says not sd. Could be globular cluster giant.
Minn Pub: This star is number 24, page 73, of Minnesota Publication III, 1944.
G 16-15B: This is one component of the close double LTT 6349; brighter component is reported in Table 3.
G 16-25: This is Wolf 624 = LFT 1240.
− 0°3119: This is G17-16 = LTT 6567. Two plates give −170.6 ± 0.7; −163.5 ± 0.7.
− 3°3968: This is G 17-25. Two ρ plates give −178.4 ± 0.5; −154.1 ± 0.8.
+20°3603: Two ρ plates give −243.4 ± 0.6; −243.4 ± 0.7.
+74°792: This is W 11307 where ρ is given as −181 (c). Not sd. Roman gives G5 III. Yale π = −0.008.
+10°4091: Two ρ plates give −194.5 ± 0.5; −206.7 ± 0.7. Variable?
− 7°5235: Two ρ plates give −108.1 ± 0.6; −109.9 ± 0.7.
+ 5°4481: Two ρ plates give +100.0 ± 0.7; +103.1 ± 1.2 (½ wt.).
G 18-39: Two ρ plates give −229.9 ± 0.4; −233.0 ± 0.5.

TABLE 3

CANDIDATES FOR NEW SUBDWARFS WHICH WERE LATER FOUND TO HAVE δ(U−B) < $0^m.10$

Star	α(1950)	δ(1950)	V	B−V	U−B	δ(U−B)	n(p)	ρ (km/sec)	ε	Remarks
+23°46	$0^h20^m.1$	+23°38′	9.30	1.25	+1.17	....	2	....		
− 6°131	0 43.6	− 5 56	9.20	0.65	0.12	+0.07	2	....		
− 6°145	0 47.8	− 6 28	9.49	0.57	0.01	0.09	2	....		
− 3°146	1 01.9	− 2 39	9.18	0.80	+0.36	0.07	2	− 17.5	± 0.5	G 70-35; LTT 604
−14°363	1 54.3	−14 25	9.74	0.38	−0.07	0.09	2	.. ..		
− 5°353	1 55.1	− 5 28	9.25	0.95	+0.80	0.06	2	....		
− 3°795	4 27.5	− 3 10	8.98	0.63	0.11	0.06	2	....		G 82-22
−21°910	4 31.2	−21 15	9.79	0.67	0.15	0.07	2	....		
+32°843	4 48.0	+32 50	9.25	0.86	0.53	0.03	2	....		
−10°1085	5 02.2	−10 13	9.69	0.80	0.39	0.04	2	....		
+59°886*	5 28.6	+59 07	9.89	0.75	0.33	0.01	1	+ 32.7	± 0.6	
+38°1451	6 15.5	+38 35	10.22	0.73	0.21	0.09	2	+144.0	± 0.8	
− 1°1677	7 19.7	− 1 46	8.72	0.76	+0.34	0.01	2	....		
− 2°2924	9 31.8	− 2 56	8.26	0.48	−0.05	0.07	2	....		
+66°704 W*	11 8.2	+66 17	8.25	0.70	+0.26	0.00	2	....		W 6864
+66°704 E*	11 8.2	+66 17	8.18	1.37	1.61	....	2	....		
− 5°3444	12 8.8	− 5 39	8.20	0.62	0.13	0.03	2	....		W 7298
− 5°3449	12 9.8	− 5 42	10.60	0.60	0.10	+0.03	2	....		
− 2°3487	12 13.6	− 2 46	8.81	0.62	0.19	−0.03	2	....		
− 7°3509*	12 53.0	− 8 27	9.66	0.72	0.20	+0.09	2	− 14.8	± 0.9	
LTT 5046	13 08.4	− 0 28	12.78	0.55	0.11	−0.03	1	....		
+74°526	13 10.0	+74 7	9.35	0.58	+0.02	+0.09	2	....		
+74°528	13 10.3	+74 23	10.48	0.46	−0.05	0.06	1	....		
+30°2428 A	13 34.8	+30 20	9.33	0.64	+0.11	0.07	3	....		ADS 8970
+30°2428 B	13 34.8	+30 20	10.53	0.86	0.52	0.04	2	....		" "
− 2°3811	14 12.7	− 3 13	9.24	0.57	0.03	+0.07	3	+ 28.8	± 0.5	
− 6°3983	14 19.9	− 7 23	9.35	0.47	0.10	−0.09	2	....		
+68°813	14 58.5	+67 55	9.77	0.58	0.04	+0.07	2	....		
Near γ CrB*	15 40.9	+26 26	10.70	1.28	1.32	....	1	....		
Near γ CrB*	15 40.9	+26 26	11.68	0.67	0.16	0.06	1	....		
G 16015 A*	15 51.9	− 4 09	11.50	0.96	0.72	+0.04	3	....		LTT 6349
− 5°4242	16 04.9	− 5 33	9.86	0.58	0 14	−0.03	2	....		
− 3°3951	16 28.3	− 3 58	9.31	0.68	0.17	+0.06	3	....		
+21°2978	16 42.3	+20 50	9.20	0.71	0.27	0.00	2	....		
−23°13889	18 02.7	−23 31	9.07	0.77	0.31	0.06	2	....		
+40°3374	18 25.3	+40 41	9.87	0.86	0.50	0.06	2	....		
− 3°4288 A	18 25.8	− 3 54	8.31	0.76	0.29	0.06	2	....		
− 3°4288 B	18 25.8	− 3 54	8.40	0.63	0.14	+0 03	1	....		
− 6°4817	18 35.3	− 6 52	8.33	0.84	0.53	−0.01	2	....		G 21-20
+14°4170	20 03.5	+14 39	10.42	0.69	0.16	+0.08	2	....		
−15°5634	20 18.7	−15 07	10.22	0.78	0.39	0.01	2	....		
− 3°4864*	20 19.4	− 3 22	10.20	0.83:	0.43	0.07:	2	+ 33.8	± 0.7	
−10°5424	20 29.7	−10 11	10.15	0.76	0.42	0.07	2	....		
+80°662	20 33 3	+80 58	8.68	0.59	+0.06	0.06	2	....		
+71°1053	21 11.1	+71 27	9.74	0.54	−0.02	0.09	2	− 22.1	± 0.5	
+62°1916	21 14.0	+62 37	9.49	0.76	+0.33	0.02	2	....		
−11°5781	22 10.5	−11 26	9.33	0.89	0.60	0.02	1	....		
−11°5829	22 22.9	−11 26	9.67	0.66	0.13	0.08	1	....		
− 9°6001	22 30.7	− 9 19	8.73	0.59	0.03	0.09	1	....		
+33°4737*	23 32.3	+33 46	9.04	0.80	+0.39	+0.04	2	− 28.1		

Notes to Table 3

+59°886: Values discordant; 20″ values on 27/28 Oct 1959 gave V = 10.08, B−V = 0.71, U−B = 0.16. The 60-inch photometry reported in the table are probably correct and are to be preferred until star is remeasured.

+66°704: Identification uncertain. Two equally bright stars are in position; photometry of both are given. The one designated by 66°704 W is probably correct since spectral type in Wilson (W 6864) is G5, which corresponds with the measured color.

− 7°3509: Double. Photometry refers to both components.

Near γ CrB: The star is $0^m.3$ following and 1′ south of γ CrB. It is double and the photometry of both components is reported.

G 16-15: This is LTT 6349 and is a close double. The brighter component is reported in this list, the fainter in Table 2.

− 3°4864: Spectral type possibly G8 IV-V.

+33°4737: Two ρ plates give −28.2 ± 0.5; −28.0 ± 0.4.

stars are considered. Restriction to stars of quality class *a* and *b* in the standard catalogue gives $\Delta\rho = -0.78 \pm 0.92$ km/sec. This correction is satisfactorily small and has not been applied to our final data.

III. DISTRIBUTION OF COLOR INDICES OF SUBDWARFS

The present program was initially undertaken to increase the data available on high-velocity stars so that studies of the early dynamical history of the galactic system would be more complete. The data reported in Tables 1 and 2 have already been used for this

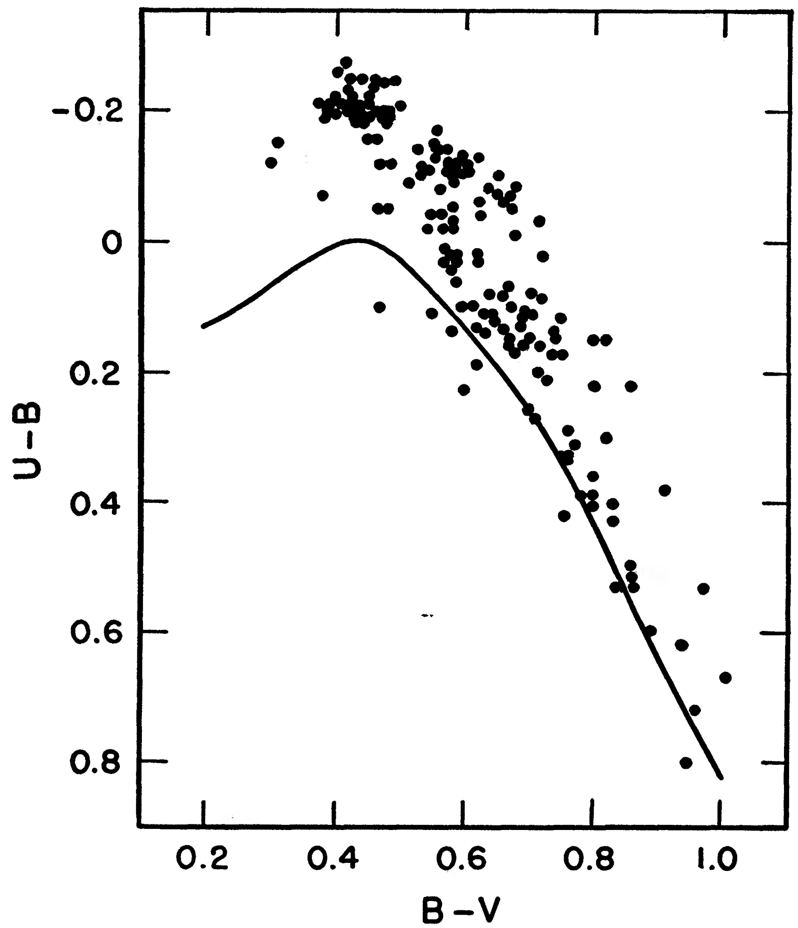

FIG. 1.—The two-color diagram for stars in Tables 1, 2, and 3 of the present paper and in Table V of Eggen and Sandage (1959). The standard Hyades two-color relation is shown as a solid line.

purpose by Eggen, Lynden-Bell, and Sandage (1962). However, a secondary result concerning the distribution of color indices of subdwarfs has emerged and this forms the subject of this section.

Figure 1 shows the two-color diagram for all stars in Tables 1 and 2 together with the previously known subdwarfs as given by Roman (1954, 1955) and summarized in Table V of Eggen and Sandage (1959). There are enough stars in the sample so that the upper envelope of the distribution is well determined, and it is of some significance that this envelope line agrees well with the two-color diagram for those globular clusters where reliable photometry has been carried to the main sequence.

The most striking feature of Figure 1 is the sharp cutoff in the distribution of colors at $B - V = 0.38$. With the exception of two stars, to be discussed later, all subdwarfs are redder than $B - V = 0.37$. The existence of this cutoff has previously been discussed in another context by Dixon (1963) using the data from the southern hemisphere.

The results of Figure 1 are shown in a different form in Figure 2 as a series of histograms. Because the extreme subdwarfs are the only ones of interest for the globular cluster problem, we have restricted Figure 2 to stars in the sample which have $\delta(U - B) \geq 0^m.16$. Figure 2, *a*, is the distribution of $B - V$ values as measured, uncor-

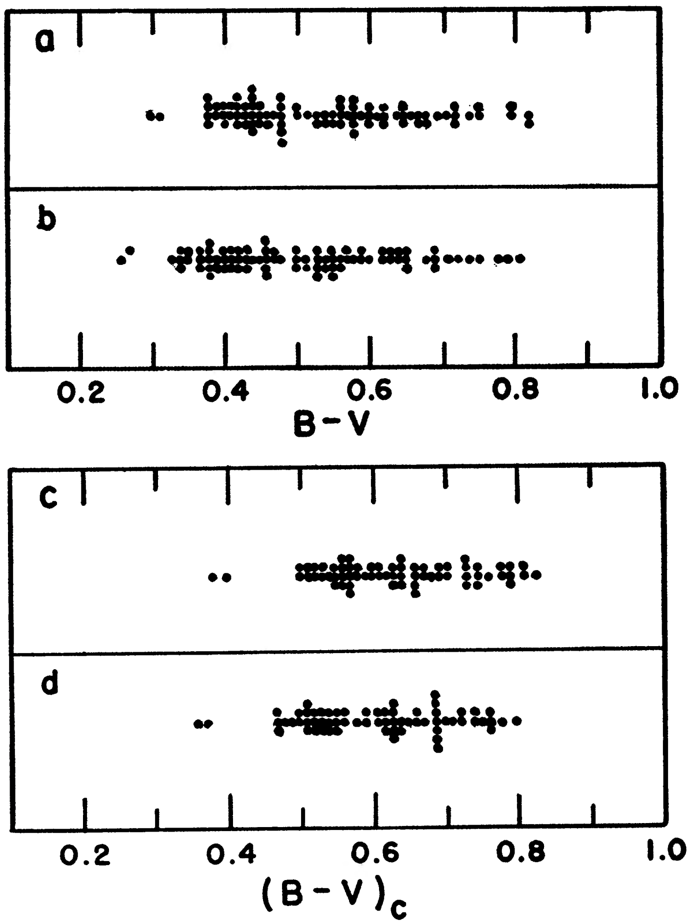

FIG. 2.—*a*, The distribution of $B - V$ colors for stars with $\delta \geq 0^m.16$ contained in the tables quoted in the caption to Fig. 1. The $B - V$ values are uncorrected for reddening or blanketing. *b*, Same as *a* but with the stars corrected for reddening by the equation in the text. *c*, Same as *a* but with the stars corrected for blanketing. *d*, Same as *a* but with the stars corrected for blanketing and reddening.

rected for reddening and blanketing, and here the sharp cutoff at $B - V = 0.38$ is particularly evident. However, this value is probably not the intrinsic color of the cutoff because it is unrealistic to think that all stars in our sample are unreddened, since their distances range up to 300 pc from the sun. Figure 2, *b*, shows the color distribution of the same sample statistically corrected for reddening by Parenago's (1940) equation

$$E(B - V) = 0.057 \csc b \, (1 - e^{-r \sin b / 187}) , \quad (1)$$

where the two numerical constants are those determined recently by Abt and Golson (1962). The distance r for each star was found from its photometric parallax using the subdwarf main sequence adopted by Eggen and Sandage (1962). The cutoff occurs in Figure 2, *b*, at $B - V = 0.34$, but the determination is of relatively low weight because the six bluest stars which, in effect, control the result are among the most distant in the sample. They range from 105 pc to 235 pc, and the reddening corrections are not negligible. Since the distribution of absorbing clouds is extremely patchy, equation (1) can only be of a statistical nature, and for reddening values as low as we encounter at these small distances, the individual results are subject to some uncertainty. All that can safely be said from the present material is that the cutoff is perhaps bluer than $B - V = 0^m.38$ and is probably redder than $B - V = 0.34$.

Both these values are bluer than has been observed for the globular cluster main sequences themselves. The clusters M3 (Johnson and Sandage 1956), M5 (Arp 1962*a*), and M13 (Baum, Hiltner, Johnson, and Sandage 1959) all have observed main-sequence colors which range between $B - V = 0.40$ and $B - V = 0.42$. The difference between these values and those shown in Figures 1 and 2 must be due either to reddening in front of the globular clusters (Arp 1962*b*) or to inaccurate photometry at the $V = 18$ to $V = 20$ level in the globular clusters, or to both. To test these possibilities, extensive new photometry has recently been completed for main-sequence stars in M3, M13, M15, and M92, and independent reddening values have been determined for each cluster. The results, although not yet fully analyzed, appear to support our present conclusion that the true colors of the main-sequence termination points for these halo globular clusters are all bluer than $B - V = 0.42$, and in one case (M15) may be as blue as $B - V = 0.35$. It therefore appears that the field subdwarfs of Figures 1 and 2 have nearly the same, if not identical, colors for the main-sequence termination point as the halo globular clusters.

The relation of this observation to the question of the ages of globular clusters can be found by comparing the colors of Figure 2, *a* and *b*, with the termination colors of M67 and NGC 188. Here it is necessary to correct the subdwarf photometry for the effects of differential line blanketing. This has been done by using Table 4 of Wildey, Burbidge, Sandage, and Burbidge (1962) with the results shown in Figure 2, *c* and *d*. The main-sequence termination color of subdwarfs, corrected to the Hyades system of line strengths, is between $(B - V)_c = 0.49$ and $(B - V)_c = 0.46$. This implies that the main-sequence termination point for these field subdwarfs should be closer to M67 than to NGC 188, and that the ages of the youngest of these stars should be smaller by about a factor of 2 from the value recently reported by Sandage (1962).

This result does not apply directly to the individual halo globular clusters because there may be some spread in their ages which will cause small differences in the termination colors from cluster to cluster. But the fact that the limiting termination color of the field subdwarfs is so blue does suggest that some reddening applies or that more accurate photometry will yield a bluer color for the halo clusters, and that their ages are probably smaller than the old value of 2×10^{10} years.

We now return to the two bluest stars in Figures 1 and 2 which fall outside the general distribution. These are BD + 25°1981 and W5793. Both stars have large ultraviolet excesses and high space motions. They undoubtedly belong to the class of stars we are discussing. It seems probable that these are the field star counterparts of the stars on the extension of the main sequence in M3 brighter than the termination point (see Fig. 1 of Sandage 1953). New photometry shows that these bright main-sequence stars in M3 have an ultraviolet excess of $\delta(U - B) \simeq 0.15$, which virtually proves that they belong to the cluster. The similarity of the $B - V$ colors and the $\delta(U - B)$ values for the M3 stars and for BD + 25°1981 and W5793 are the reasons for assigning these field stars to the extension-of-the-main-sequence group. A more complete discussion with additional examples will be made when the results of a current photometric discovery program for additional subdwarfs contained in the proper-motion catalogues of the Lowell Observatory is completed.

It is a pleasure to thank Dr. O. J. Eggen for many discussions which led to the present program and for his finding list of candidate stars.

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