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NEW SUBDWARFS. II. RADIAL VELOCITIES, PHOTOMETRY, AND PRELIMINARY SPACE MOTIONS FOR 112 STARS WITH LARGE PROPER MOTION

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ABSTRACT

Radial velocities have been measured for 112 stars of large proper motion selected from an unpublished photometric catalog which contains 300 new subdwarf candidates The accuracy of the radial velocities is generally better than ± 2 km sec^{-1}. Nine possible velocity variables have been found, four of which are almost certain cases. Two particularly interesting variables (G9−16, G26−9) probably have blue subluminous companions which are brighter than white dwarfs but considerably fainter than main-sequence stars.

Space motions for all stars are shown in a Bottlinger diagram. The asymmetrical-drift velocity and the dispersions in U and W increase systematically with decreasing metal abundance for the entire range of ultraviolet excess values from $\delta = 0.00$ to $\delta = 0.31$ mag The results are interpreted in terms of a chemical gradient perpendicular to the galactic plane.

Many globular-clusterlike subgiants are present in the material. Candidates are listed to aid future spectroscopic studies.

The existence of subdwarfs possessing high angular momentum which lead the Sun in its galactic rotational velocity seems to be established. There may be a systematic variation of metal abundance with increasingly *positive* V velocity, but more subdwarfs of this type are needed to establish the correlation. Candidates can be found in proper-motion catalogs from among stars whose proper-motion angles are directed *away* from the high-velocity antapex.

A procedure is given to correct observed ultraviolet excess values for stars with the same metal abundance but of different colors for the effect of the guillotine.

I. INTRODUCTION

Clues to the early chemical and dynamical history of the Galaxy are undoubtedly contained in the kinematics of high-velocity stars. Although knowledge of such stars has increased rapidly in recent years, the observational data on field subdwarfs are still meager enough that many of the questions raised by Roman (1965), Eggen, Lynden-Bell, and Sandage (1962; these authors are hereinafter called ELS), and others cannot yet be answered. For example, we would like to know: (1) Is the correlation between metal abundance and space motion (or equivalently the eccentricity of the plane orbit) truly unique, or are there low-velocity stars with very weak metal lines? (2) Are there appreciable numbers of subdwarfs with high angular momentum (that is, stars of low metal abundance which move in direct galactic orbits with large $+V$ velocity) which should exist on the ELS collapse picture? (3) For these high-h stars, a few of which are known to exist, does metal weakening become more pronounced toward the energy boundary ($E = 0$) on the $+V$ side of the Bottlinger diagram, as it does for low-h stars with increasing negative V? These and other questions can be answered only if the sample of subdwarfs is increased and if the discovery procedures are changed to overcome certain types of observational bias.

Fewer than 250 subdwarfs are known for which all necessary photometry, radial-velocity, and proper-motion data exist. The early data on subdwarfs were obtained in the classical work of Luyten and Dartayet (1942, 1945), Luyten, Jose, and Foster (1944, 1945), Luyten and Jose (1948), Luyten, Carpenter, and Deutsch (1952), Kuiper (1939, 1940*a*, *b*, 1942, 1943), Roman (1954, 1955*a*, *b*), and others, prompted by the discovery of the first subdwarfs (then called intermediate white dwarfs) by Adams and Joy (1922) and Adams *et al.* (1935). The material available to 1959 has been summarized elsewhere (Eggen and Sandage 1959; Sandage and Eggen 1959). Most data available to late 1962 are included in Eggen's (1964*a*) high-velocity catalog.

Since 1959, many new subdwarfs have been found, either by accident in the course of other work (cf. the Cape Observatory's lists of fundamental data for southern stars, the last of which [Evans 1966] gives references to previous lists [Sandage and Luyten 1967, 1969]) or by design [cf. Przybylski 1961; Deeming 1962; Sandage 1964*a;* Eggen 1968*a*, *b*, *c*). These surveys show that very many subdwarfs fainter than $V = 8$ remain to be discovered and that the sample can be increased almost at will.

Encouraged by the result of a pilot study (Sandage 1964*a*, hereinafter called Paper I) to find new subdwarfs, Sandage and Kowal in 1961 began a systematic photoelectric survey of proper-motion stars in the first 100 fields of the *Lowell Proper Motion Survey* (Giclas, Burnham, and Thomas 1961–1967). Between 1961 and 1964 nearly 2000 stars were observed (principally by Kowal) in *UBV* colors with either the Mount Wilson 60-inch or the Palomar 20-inch reflector. The criteria for selection were $\mu \geq 0\overset{''}{.}27$ year^{-1}, with *m* brighter than Lowell catalog magnitude 14 (later reduced to 13) and Lowell color class 2 or bluer. A photometric catalog is in preparation, and a discussion of the results will be given later.

To date, nearly 300 new subdwarf candidates have been found in this survey as judged by ultraviolet-excess values larger than $\delta(U - B) = 0.15$. As the photometry became available, all stars with $0.30 < B - V \lesssim 1.0$, brighter than $V \simeq 11.5$, and with $\delta(U - B) \geq 0.15$ were placed on a coudé radial-velocity program which was carried out on a standby basis at the 200-inch reflector on partially cloudy nights originally scheduled for other problems. The possibility of rapidly changing (usually in 15–20 minutes) the 200-inch mirror system from the prime focus to the coudé mode made the standby program possible.

To date, radial velocities of 112 subdwarf candidates have been observed with the 100- or 200-inch coudé 8-, 16-, or 18-inch cameras, which give a linear dispersion of either 18 or 39 Å mm^{-1}. The purposes of the present paper are (*a*) to discuss the radial velocities, (*b*) to list stars of special interest for further spectrographic work, such as field examples of globular-cluster subgiants and giants, (*c*) to list possible radial-velocity variables requiring further study, and (*d*) to show the Bottlinger diagram for the present stars, segregated according to ultraviolet excess, in order to illustrate possible solutions to some of the questions raised earlier. A more complete discussion of item (*d*) will be made by ELS (1970) using the entire available subdwarf data.

II. THE DATA

a) *Radial Velocities*

Of the 112 stars observed for radial velocity, ninety were obtained with the 200-inch and twenty-two with the 100-inch. Most were observed only once, but two or more plates were obtained for twenty stars. The exposure times ranged between 1 and 3 hours, depending on the seeing and the cloud cover. All but four of the stars were observed with a linear dispersion of 18 Å mm^{-1}. The 8-inch aplanatic-sphere camera (Bowen 1952) at the 200-inch, which gives a dispersion of 39 Å mm^{-1} in the third-order blue, was used for stars G9−36, G44−30, G15−23, and G25−24, as noted in Table 1.

The plates were measured principally by Mary Whiteoak and Sylvia Burd, who used about thirty-five stellar lines in each spectrum relative to the iron-arc comparison. As in Paper I, standard wavelengths for the stellar lines were adopted from the system established by Greenstein (private communication), which will be discussed by him in a forthcoming paper on his search for radial-velocity variations in known subdwarfs.

TABLE 1

RADIAL VELOCITIES AND PHOTOMETRY FOR 112 STARS WITH LARGE PROPER MOTION

ε (m.e.)	lo.	Name	LTT	α(1950)	δ(1950)	V	B−V	U−B	N	δ	μ_α	μ_δ	ρ ±
(14)	1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0.4	1*	−9° 122	337	00 36.0	− 8 35	9.27	0.45	−0.16	2	0.16	+″033	−″560	− 41.9
0.6	2*	−8° 128	402	00 41.4	− 7 48	9.40	0.59	0.02	2	0.10	−.101	−.180	−112.1
0.5	3*	G70−35	604	01 01.9	− 2 39	9.18	0.80	0.36	2	0.07	−.191	−.116	− 17.1
0.4	4*	−11°220	655	01 07.7	−10 39	9.21	0.57	−0.02	2	0.11	+.267	−.031	+ 43.8
0.4	5*	−2°181	674	01 10.9	− 2 08	8.95	0.69	0.13	2	0.11	−.196	−.086	− 9.9
0.3	6*	−17°219	681	01 11.7	−16 42	10.06	0.72	0.02	2	0.27	+.178	−.117	+ 81.4(2)
0.3	7*	+72°94	10615	01 43.0	+73 13	10.20	0.38	−0.21	3	0.23	−.214	+.164	−265.7(2)
0.6	8	G71−40	1007	01 50.6	− 1 34	7.43	0.64	0.06	2	0.12	−.184	−.352	− 20.1
0.6	9	+68°138	10667	01 54.7	+68 47	9.31	0.53	−0.03	1	0.08	+.355	−.029	+ 2.7
0.6	10	G72−60	10720	02 05.6	+31 09	10.28	0.56	−0.10	2	0.18	+.220	−.027	+127.6
1.9	11	G4−6	10750	02 11.0	+11 43	10.60	0.56	−0.10	2	0.18	+.263	−.032	− 57.0
0.6	12	G75−31	17399	02 35.7	+ 2 14	10.53	0.46	−0.16	2	0.16	+.310:	.000:	+ 57.6
0.9	13	G76−21	10880	02 38.5	+ 9 33	10.18	0.44	−0.25	2	0.25	+.348	+.016	− 68.3
1.3	14	G4−37	10900	02 41.9	+ 8 16	11.43	0.47	−0.22	1	0.22	−.076	−.206	−106.1
0.5	15	G4−44	10934	02 49.3	+11 10	8.38	0.54	−0.07	2	0.14	+.045	−.439	+ 6.1
0.7	16	G5−17	11029	03 07.2	+15 11	9.07	0.83	0.50	2	0.00	−.074	−.290	− 23.1
0.7	17	G37−34	11092	03 16.5	+33 25	9.68	0.85	0.47	1	0.07	+.430	−.571	−106.0
0.3	18*	G77−54	1639	03 25.9	− 6 42	8.26	0.62	0.02	3	0.13	+.360	−.190	+ 63.4
0.8	19	G8−16	11473	04 11.6	+22 14	9.26	0.41	−0.20	2	0.20	+.441	−.285	+339.6
0.6	20	G8−51	11486	04 38.3	+20 48	8.01	1.08	0.93	2	0.05	−.233	−.254	0.0(2)
0.8	21	G84−29	11566	04 58.6	+ 4 02	9.81	0.36	−0.20	2	0.23	+.166	−.136	+176.6
0.6	22	G96−20	11578	05 01.9	+40 11	9.66	0.42	−0.16	2	0.17	+.309	−.059	+109.7
0.5	23	G84−37	11595	05 07.3	+ 5 29	9.72	0.52	−0.13	2	0.17	+.250	−.073	− 15.6
0.6	24	G98−3	11645	05 22.2	+32 22	9.76	0.60	−0.02	2	0.15	+.145	−.193	− 24.3
0.6	25*	+59°886	11665	05 28.6	+59 07	9.89	0.75	0.33	1	0.01	+.038	−.270	+ 32.7
0.4	26	G102−20	−	05 37.3	+12 09	10.22	0.65	−0.02	2	0.21	+.304:	−.059:	+ 25.0
0.7	27	G102−47	11781	06 03.3	+ 7 19	10.31	0.64	−0.05	2	0.23	+.174:	−.268:	+ 93.9
0.6	28	G98−58	11819	06 12.6	+37 45	8.92	0.59	−0.12	2	0.24	+.059	−.369	+247.9
0.8	29*	G101−33	11827	06 15.5	+38 35	10.22	0.74	0.23	3	0.09	+.124:	−.306:	+144.0
JG	30*	−6°1598	2579	06 30.2	− 6 27	8.62	0.56	−0.08	2	0.16	+.259	+.016	+ 7.5
0.4	31*	G108−43	2698	06 56.1	− 0 24	9.05	0.57	−0.02	2	0.11	+.352	−.602	− 91.6
0.6	32	G87−20	11966	06 59.7	+38 13	9.45	0.64	0.03	2	0.15	−.019	−.262	− 37.2
	33+	G89−14	−	07 19.8	+ 8 55	10.40	0.47	−0.19	2	0.19	+.186	−.326	− 40.2V?(2)
0.8	34	G88−27	17969	07 24.1	+19 12	10.74	0.44	−0.19	3	0.19	−.054:	−.275:	+ 44.1
1.0	35	G90−3	17974	07 26.6	+32 58	10.43	0.48	−0.18	2	0.19	.000:	−.270:	+ 31.6
0.4	36	G88−31	12031	07 27.6	+19 04	8.51	0.51	−0.12	2	0.16	+.031	−.449	+ 92.0
2.2	37	G88−32	12032	07 27.7	+24 12	10.82	0.36	−0.22	2	0.24	+.104	−.247	− 34.6
0.5	38	G88−40	12040	07 31.7	+17 01	8.95	0.51	−0.11	3	0.15	+.008	−.305	− 40.2
0.4	39*	G112−36	2909	07 37.3	− 1 24	9.23	0.82	0.30	2	0.17	+.180	−.250	+ 49.2
0.8	40	G112−43	−	07 41.2	+ 0 03	10.27	0.44	−0.17	1	0.17	−.124:	−.306:	− 83.2
0.4	41	G90−25	12084	07 50.3	+30 45	8.30	0.62	−0.15	2	0.30	+.711	−1.830	−234.4
0.7	42	+80°245	12128	08 03.0	+80 01	10.07	0.50	−0.17	1	0.20	+.150	−.354	+ 1.2
	43+	G9−16	12273	08 41.6	+24 59	9.32	0.31	−0.16	4	0.22	−.102	−.354	+ 49.3V(3)
2.0	44Δ	G9−36	12338	08 55.0	+24 40	11.95	0.57	−0.14	2	0.23	+.260	−.225	− 46.9
0.5	45*	G114−26	3319	08 56.6	− 3 49	9.69	0.48	−0.20	2	0.22	+.300	−.587	+ 32.8V?
0.9	46*	G41−44	12503	09 26.6	+ 8 51	11.15	0.38	−0.20	3	0.22	+.218	−.297	+265.3
0.4	47*	+65°737	12603	09 45.9	+65 33	9.70	0.67	0.10	3	0.11	−.415	−.240	− 33.1
1.4	48	+55°1362	−	10 01.4	+54 35	8.98	0.70	0.02	3	0.23	+.130	−.034	− 40.0
0.6	49	G43−33	12737	10 09.6	+17 33	7.90	0.54	−0.06	2	0.12	−.162	−.203	+ 60.3
2.2	50Δ	G44−30	12848	10 37.7	+11 27	11.30	0.64	0.01	3	0.17	−.030:	−.332:	+112.6
0.5	51	G58−23	18140	10 47.2	+20 46	9.96	0.60	−0.03	2	0.16	−.256	−.094	− 2.9(2)
1.5	52*	−14°3322	4228	11 23.6	−15 26	10.45:	0.58	−0.11	2	0.21	−.114:	+.256:	+ 11.4
0.6	53*	−21°3420	4438	11 53.0	−22 06	10.18:	0.52	−0.14	2	0.18	−.175	−.206	+ 13.9
0.5	54	G13−1	4459	11 56.5	− 4 30	9.00	0.58	−0.05	2	0.16	+.107	−.190	− 23.0
0.8	55	G11−36	13343	12 01.5	+ 3 38	9.25	0.60	−0.05	1	0.18	+.060	−.590	+ 5.9(2)
0.9	56	G59−18	13479	12 21.0	+17 11	10.18	0.72	0.10	2	0.19	−.280:	−.096:	+ 26.7
0.8	57	G59−27	13567	12 34.2	+27 45	10.91	0.40	−0.24	2	0.24	−.194:	−.216:	−123.1
0.7	58	G60−26	13597	12 37.8	+12 55	9.81	0.65	−0.01	2	0.20	−.002	−.323	+115.6
0.9	59*	−7°3509	4942	12 53.0	− 8 27	9.66	0.72	0.20	2	0.09	−.100:	−.173:	− 14.8
0.6	60	G14−32	5030	13 05.8	− 7 03	8.35	0.94	0.56	2	0.16	−.212	+.082	+ 73.8

TABLE 1 (continued)

ε (m.e.)	o.	Name	LTT	α(1950)	δ(1950)	V	B-V	U-B	N	δ	μ_α	μ_δ	ρ ±
(14)	1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0.5	61	HD114762	13819	13 09.9	+17 47	7.32	+.54	-.08	R	0.14	-.579	-.004	+ 46.0
0.4	62*	+71°646	-	13 13.2	+70 33	10.13	0.75	0.17	2	0.17	-.145	-.060	- 97.6(2)
0.8	63*	G14-45	5117	13 16.4	- 2 48	10.86	1.01	0.67	5	0.20	-.645	-.110	+125.2
0.7	64	G63-44	13967	13 35.6	+19 24	8.84	0.68	0.06	2	0.17	+.133	-.322	- 46.2
2.5	65	G64-12	13980	13 37.5	+ 0 13	11.49	0.38	-0.23	4	0.25	-.242:	-.108:	+438.6(3)
0.9	66	G63-46	13981	13 37.5	+12 51	9.39	0.58	-0.08	2	0.19	+.126	-.295	- 22.4
0.6	67*	+77°521	-	13 44.1	+77 29	9.45	0.66	0.08	2	0.12	-.160	-.048	- 87.2
0.5	68*	-2°3811	5592	14 12.7	- 3 13	9.24	0.57	0.03	3	0.07	+.100	-.112	+ 28.8
3.3	69	G66-22	14360	14 40.8	+ 6 02	10.47	0.71	0.10	4	0.17	-.885	.000	-145.4
1.4	70	G66-30	14388	14 47.6	+ 1 03	11.07	0.40	-0.17	3	0.17	-.290:	-.135:	-110.6
0.3	71*Δ	G151-10	5932	14 52.5	- 8 53	9.52	0.72	0.16	2	0.13	-.229	-.319	- 64.3
1.3	72Δ	G15-23	14602	15 27.1	+ 6 19	10.96	0.71	0.04	2	0.23	-.240:	-.434:	- 79.4
0.6	73*	G15-24	14607	15 28.2	+ 8 34	11.43:	0.57	-0.11	2	0.20	-.394:	-.093:	- 84.6
0.7	74	G16-13	14697	15 48.6	+ 8 34	10.01	0.59	-0.05	2	0.17	-.242:	-.226:	- 51.1
0.6	75*	G17-16	6567	16 25.2	- 0 58	9.63	0.71	0.14	4	0.13	-.350:	-.120:	-167.2(2)
	76*+	G17-25	6621	16 32.0	- 4 06	9.63	0.75	0.10	3	0.24	-.135	-.699	-166V(2)
0.7	77	G17-30	6649	16 35.7	- 2 20	8.48	0.62	0.00	2	0.15	-.171	-.283	- 38.6
0.6	78	+25°3252	15157	17 20.3	+24 56	6.87	0.51	-0.06	4	0.10	+.051	-.183	+ 31.7
0.9	79	G19-27	6968	17 28.8	- 2 30	8.14	0.67	0.05	2	0.16	-.294	-.102	+ 2.1
0.7	80	G20-8	15239	17 37.3	+ 2 27	9.97	0.43	-0.26	3	0.26	-.370	+.080	-395.9(2)
0.7	81*	-9°4604	7089	17 45.1	- 9 35	9.68	0.66	-0.06	2	0.26	-.148	-.199	-134.2
0.6	82*	G183-11	15298	17 52.8	+20 17	9.71	0.44	-0.19	2	0.19	-.264:	-.377:	-243.4(2)
1.2	83*	G141-19	15475	18 31.0	+13 08	10.57	0.64	-0.08	2	0.26	-.048	-.274	+ 81.9
0.6	84	+34°3239	15478	18 32.7	+34 23	7.56	0.50	-0.13	2	0.16	+.210	+.201	- 37.0
0.5	85*	G21-22	15497	18 36.6	+ 0 04	10.72	0.53	-0.11	2	0.17	-.180	-.465	+ 59.1
0.4	86*	G22-6	7498	18 51.9	- 4 40	9.08	0.59	-0.06	3	0.18	-.150	-.425	+ 17.8
0.6	87	31 Aql	-	19 22.6	+11 50	5.15	0.79	0.40	R	0.01	+.725	+.640	-100.6
0.7	88	G23-1	15686	19 25.9	+13 54	8.99	0.79	0.26	1	0.15	+.232	+.031	+ 3.6
0.7	89	+16°3924	-	19 36.0	+16 35	8.48	1.85	-	-	-	+.014	-.029	-386.9
0.5	90*	G143-17	15821	19 52.8	+10 36	8.83	0.58	-0.11	2	0.22	-.031	+.272	-200.6(2)
0.7	91	G24-3	15880	20 03.3	+ 3 54	10.44	0.48	-0.18	1	0.20	-.164:	-.226:	-207.4
0.5	92*	-7°5235	8021	20 13.9	- 7 36	8.39	0.58	-0.03	2	0.14	+.319	-.138	-109.8(2)
0.7	93*	G24-13	15949	20 17.9	+ 5 53	10.12	0.61	-0.05	4	0.19	.000:	-.335:	+101.5(2)
0.7	94*	-3°4864	8065	20 19.4	- 3 22	10.20	0.83:	0.43	2	0.06	-.049	-.242	+ 33.8
1.0	95*	-9°5491	-	20 30.1	- 9 32	9.54	0.65	0.00	R	0.21	-.081	-.110	-257.4
0.5	96*	+71°1053	16217	21 11.1	+71 27	9.74	0.54	-0.02	2	0.08	+.210	+.248	- 22.1
2.9	97Δ	G25-24	8434	21 14.1	- 1 31	11.63	0.50	-0.20	2	0.23	+.262:	-.240:	+ 36.0
0.6	98	G25-29	16268	21 24.2	+ 5 14	8.50	0.57	-0.06	2	0.15	+.158	-.238	- 82.2
1.0	99+	G26-9	16295	21 29.6	- 0 00	9.90	0.97	0.49	2	0.28	+.460:	.000:	-150.4
0.8	00	G126-19	16327	21 37.3	+23 02	9.50	0.77	0.21	1	0.16	.000:	+.260:	-106.7
0.4	01	G18-28	16463	22 03.2	+12 08	9.55	0.64	0.03	2	0.15	+.152:	-.360:	-199.7
0.4	02*	G18-39	16531	22 16.1	+ 8 12	10.38	0.46	-0.16	3	0.16	+.267:	-.165:	-231.4(2)
0.4	03	G27-44	16681	22 41.3	+ 3 37	7.44	0.49	-0.10	2	0.12	+.157	+.343	- 28.8
0.7	04*	G27-45	9173	22 42.3	- 2 36	11.50	0.66	-0.06	4	0.26	+.680	-.303	- 15.0
0.3	05	G28-17	16712	22 48.2	+ 1 36	9.34	0.68	0.09	2	0.13	+.088	-.383	- 5.2
0.3	06	G67-49	16811	23 08.3	+18 38	8.56	0.59	0.05	2	0.07	-.213	-.179	- 24.9
0.7	07	G29-23	16851	23 17.1	+ 3 06	10.20	0.43	-0.21	2	0.21	+.334:	-.135:	-246.4
1.4	08	G29-33	16892	23 23.7	+ 8 37	10.54	1.41	1.18	1	-	+.580:	+.246:	- 44.8
0.7	09*	+59°2723	16896	23 24.2	+60 20	10.47	0.44	-0.22	2	0.22	+.466	+.048	-103.2(3)
0.5	10*	G190-34	16933	23 32.3	+33 46	9.04	0.80	0.39	2	0.04	+.372	+.188	- 28.1(2)
0.5	11	G68-30	-	23 33.2	+20 18	9.08	0.56	-0.04	2	0.12	-.159	-.107	- 43.9
0.9	12	SA115-147	9662	23 39.4	- 0 16	8.79	0.73	0.27	1	0.03	+.226	-.043	- 18.1

* Radial velocity is tabulated in Paper I (Ap.J. 139,442).

\+ Suspected radial velocity variable (see Table 2)

Δ Spectra obtained with the 8 inch aplanatic sphere camera at the 200-inch.

The present radial velocities are listed in columns (13) and (14) of Table 1. Included in this table are velocities previously listed in Paper I which were obtained in an early phase of the present program. Such stars (forty-one in number) are indicated by an asterisk in column (1) and are included here both for convenience and to make the discussion of space motions (§ V) more complete.

The decision on nomenclature in Table 1 was difficult. Use of the Lowell numbers, which were adopted here because of the existence of convenient charts, in no way indicates preference (as to the basic data) for the Lowell catalog or the earlier all-sky LTT catalogs of Luyten (1957, 1961). Column (3) lists the LTT numbers, both for completeness and as a reference to Luyten's fundamental compilations and prior proper-motion determinations for many stars.

Listed in Table 1 are the heliocentric velocities together with the internal mean errors, defined as the average residual velocity of each line divided by the square root of the number of lines. The mean errors are generally less than 1 km sec^{-1}. Those cases which have larger mean errors are (1) the four stars observed with the 8-inch camera, (2) stars where the lines are extremely weak and few in number, and (3) a few cases where the plates, curved under pressure, broke in the plate holder and where the plate segments were individually measured.

The external errors of the velocities can be estimated in three ways: (1) Two or more plates are available for twenty stars. There is evidence for velocity variations for four of these (§ III). For the remaining sixteen stars, the standard deviation from the *mean* is $\sigma = 1.69$ km sec^{-1}; i.e., the variance of the distribution of differences of one plate from its mate is $2\sigma = 3.38$ km sec^{-1}. (2) Fifteen stars in Table 1, together with two additional radial-velocity standards taken specially, are common to the *General Catalogue of Stellar Radial Velocities* (Wilson 1953; hereinafter *General Catalogue*). Three stars show large differences between our results and those of the *General Catalogue* and may be variable (§ III). The fourteen remaining stars (Wilson quality class from *a* to *d*) show $\langle \rho_W - \rho_S \rangle = +1.1 \pm 2.9$ (A.D.). The six stars of qualities *a* and *b* show $\langle \rho_W - \rho_S \rangle = +1.5 \pm 2.1$ (A.D.). (3) Six stars in common with lower-dispersion velocities due to Roman (1955*b*), but which are not also common with the *General Catalogue*, give $\langle \rho_R - \rho_S \rangle = -4.8 \pm 3.6$ (A.D.). We conclude from comparison (2) that the present velocities show no significant systematic deviation from the Wilson system and, from comparison (1), that the velocities in Table 1 are generally correct to ± 2 km sec^{-1}. No systematic corrections have been applied to the data.

b) *Photometry*

The photometric data are listed in columns (6)–(10) of Table 1 and are taken either from Paper I, as amended with new observations, or from the unpublished photometric catalog mentioned in § I. Most of the stars were observed more than once, as shown in column (9). Comparison of the individual values shows that the average differences between two measurements of a star are $\Delta V \simeq 0.026$, $\Delta(B - V) = 0.013$, and $\Delta(U - B) = 0.018$ mag, or half these values for deviations from the mean.

An external test of the photometric accuracy is possible from twelve stars in common with Roman's (1955*a*) high-velocity catalog. The differences in the sense Roman *minus* present are $\Delta V = -0.004 \pm 0.024$ (A.D.), $\Delta(B - V) = -0.002 \pm 0.013$ (A.D.), and $\Delta(U - B) = +0.013 \pm 0.025$ (A.D.) ,which are satisfactorily small.

Evidence for possible light variability exists in our present material for only one star (running number 99 = G26−9), which is also a radial-velocity variable (§ III).

Column (10) gives the ultraviolet excess relative to the Hyades fiducial $(U - B, B - V)$-line, read at the observed $B - V$ value, following the definition given elsewhere (Sandage and Eggen 1959, Fig. 4).

c) Proper Motions

Columns (11) and (12) of Table 1 give the adopted proper motions in seconds of arc per year taken from the following sources. If a star appears in Eggen's (1964*a*) *Catalogue of High Velocity Stars* (thirty-eight cases), his weighted mean value is adopted. These have been reduced by Eggen, where possible, to the N30 system (Morgan 1952). The principal proper-motion sources for other stars are the GC, Yale Zone, Greenwich, Toulouse, McCormick parallax-series lists, and in a few cases the Smithsonian tabulation. Where possible, the motions were reduced to the N30 system, either directly for the GC values using the mean differences N30 *minus* GC derived by Morgan (1952) or, in the case of the Yale Zone catalogs, by first correcting to the GC system by tables in the Yale Zone catalogs themselves and then to the N30. Eggen derived new proper motions on the N30 system for a few remaining stars by using a number of special catalogs as described elsewhere (Eggen 1962). I am indebted to Eggen for these data and for advice concerning proper motions in general.

Somewhat less accurate proper motions are available for a number of the fainter stars in Table 1. For these, the mean of the measured proper motions by Luyten in the two LTT catalogs (1957, 1961) and the blink motions by Giclas *et al.* (1961–1967) were generally used. These are indicated by a colon in Table 1.

The accuracy of the proper motions will usually be better than $\pm 0\overset{''}{.}010$ for the brighter stars listed in the fundamental position catalogs, but probably not better than $\sim \pm 0\overset{''}{.}04$ for stars indicated by colons (see Giclas *et al.* 1961–1967 and Luyten 1967 for a comparison of the independent values determined at Minnesota and Lowell).

III. POSSIBLE RADIAL-VELOCITY VARIABLES

Table 2 lists the data for nine possible velocity variables. Those stars where the evidence comes from the present program are given at the top, while stars where our value differs appreciably from other published values are listed on the bottom. Most of the stars in Table 2 show differences greater than $3(2\sigma) = 10.1$ km sec^{-1} as discussed in § II.

The ultraviolet excess in column (4) usually differs from that in Table 1 because it is the "normalized" value at $B - V = 0.60$, corrected to account for the variation of δ with $B - V$ for stars of the *same* metal abundance. The precepts and a correction table for this normalization are given in the Appendix.

Evidence for velocity variation is particularly strong for stars 43 (G9−16), 76 (G17−25), 36 (G88−31), and 99 (G26−9). The stars G9−16 and G26−9 are especially interesting because both show abnormal colors, which independently suggests the presence of blue companions. Because each of the primary stars is undoubtedly a dwarf, as determined either by Jones (1966) or from the trigonometric parallax, both of the secondary components must be rather rare types of subluminous blue stars so as to affect the integrated $B - V$ and $U - B$ values. The companions cannot, however, be normal white dwarfs (whose M_V values are all fainter than $\sim +10$), because they would then be too faint to cause appreciable photometric contamination. Companions similar to, but somewhat fainter than, BD+28°4211 ($M_V \simeq +4$, $B - V = -0.34$, $U - B = -1.26$; Greenstein 1952; Eggen 1959) would fit the necessary conditions.

But there is some evidence from our photometry and from photometry by Eggen that G26−9 varies in light by $\Delta M_V \simeq 0.15$ mag, which, if true, would in itself rule out an ordinary white-dwarf companion. The star BD+28°4211 does not vary in light, so a star of this type would also be excluded. U Gem stars, stars like MacRae +43° (Walker 1954), or even stars like the X-ray source Sco X-1 are remote possibilities for the companion. In view of their unusual characteristics, G9−16 and G26−9 should obviously be followed further.

The space motions for all stars in Table 2 are high (see Table 3 and § IV). More radial-velocity observations of many of these stars would be of great interest, because only a few Population II spectroscopic binaries are known.

IV. PHOTOMETRIC PARALLAXES AND PRELIMINARY SPACE MOTIONS

Only five stars in Table 1 have trigonometric parallaxes greater than 0".040, and distances must be determined in some other way if space motions are to be found. The usual methods for finding photometric parallaxes appear to give results accurate to better than ±0.4 mag in M_V if the following procedure is adopted for weak-line dwarfs.

TABLE 2

SUSPECTED RADIAL-VELOCITY VARIABLES

No.	Name	$B-V$	$\delta(0.6)$	Date	$\rho \pm \epsilon$	Other
				From Internal Evidence		
33	G89–14	0.47	0.22	1962 Feb 5/6	− 48.4 0.8	
				1962 Apr 16/17	− 32.2 1.3	
43*	G9–16	.31	.31	1962 Feb 6/7	+ 61.2 0.6	
				1962 Apr 12/13	+ 41.6 1.4	
				1962 Apr 12/13	+ 41.7 1.3	
76	G17–25	.75	.28	1961 Feb 17/18	−178.4 0.5	
				1962 June 1/2	−153.8 0.7	
90	G143–17	0.58	0.22	1960 June 21/22	−206.7 0.7	
				1960 Oct 23/24	−194.5 0.5	
				From External Evidence		
1	9°122	0.45	0.19	1961 Aug 16/17	− 41.9±0.4	− 50.3±2.3(R)
36	G88–31	51	.17	1961 Oct 7/8	+ 92.0±0.4	+ 79.9±0.8(R)
45†	G114–26	.48	.25	1961 Feb 17/18	+ 32.8±0.5	+ 25c(W)
83‡	G141–19	.64	.27	1961 Aug 22/23	+ 81.9±1.2	+112d(W)
99§	G26–9	0.97	0.47!	1962 Nov 1/2	−150.4±1.0	− 78c(W)

* Four plates by Roman give $\rho = +47.6 \pm 4\ 4$; one plate by Greenstein gives $\rho = +55.5$. Blue $B - V$ suggests blue companion.

† Greenstein says variable velocity which is more conclusive than the data here.

‡ Greenstein gives $\rho = +78.2$; may therefore not be variable, because 112d depends on only one McDonald plate.

§ The abnormal $\delta(0.6)$ suggests blue companion fainter than $M_V \simeq +7$ but brighter than $M_V \simeq +9$. Photometry by Eggen and by Kowal suggests optical variability by $\Delta V \simeq 0.15$ mag. White-dwarf companion 134" distant (EG 145 [Eggen and Greenstein 1965]).

Blanketing corrections (Schwarzschild, Searle, and Howard 1955; Sandage and Eggen 1959; Code 1959; Melbourne 1960) are applied to observed $B - V$ colors, freed if necessary from reddening. The corrections are taken from Table 4 of Wildey *et al.* (1962) by using the observed ultraviolet excess. The star is then fitted to the Hyades age-zero main sequence to obtain M_V and then $m - M$.

The method has been tested against available trigonometric-parallax stars over the relevant range of δ by Eggen and Sandage (1962) and was found to give consistent results within $+0.15 \pm 0.11 \geq \langle \Delta M_V \rangle \geq -0.36 \pm 0.09$ mag if the Wildey *et al.* (1962) corrections are adopted. The accuracy for the extreme subdwarfs with $\delta \geq 0.16$ mag was found to be $\langle \Delta M_V \rangle = 0.03 \pm 0.05$ mag, which appears to be quite satisfactory.

It should be stressed that the above method need be considered in the present context only as an operational procedure. Whether the method permits a conclusion as to a difference between a particular subdwarf *age-zero* main sequence and the Hyades sequence

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Table 3

Space Motions On Various Distance Assumptions

No. (1)	Name (2)	M_V (3)	B-V (4)	D pc (5)	δ(.6) (6)	U km/sec (7)	V km/sec (8)	W km/sec (9)	Type (10)	ΔU/dr km/sec pc (11)	ΔV/dr km/sec pc (12)	ΔW/dr km/sec pc (13)	π_t 0".001 (14)	Other Cat or M_V (15)
1	-9°122	4.59 3.5	0.45	84 138	0.19	-107 -173	-196 -315	-32 -79	ms sg*	-1.215	-2.200	- .864		ER(J5.4)
2	-8°128	5.19	0.59	68	0.10	- 75	- 62	+87	ms	- .839	- .421	- .271		E (J4.8)
3	G70-35	6.10	0.80	41	0.08	- 47	- 2	+ 4	ms	-1.017	+ .094	- .274		J (6.9)
4	-11°220	5.02	0.57	68	0.12	+ 74	- 48	-38	ms	+ .954	- .843	+ .049		J (4.8)
5	-2°181	5.81	0.69	42	0.11	- 43	+ 7	- 2	ms	- .954	+ .230	- .252		J (5.7)
6	-17°219	6.50 3.9 1.5	0.72	51 171 500	0.31	+ 34 + 78 +201	- 40 -152 -460	-81 -85 -94	ms* J M13sg	+ .373	- .937	- .029		E (J3.9)
7	+72°94	4.10	0.38	161	0.29	-316	-111	+35	ms	- .985	+ .611	+ .536	O M (11)	E (J3.2)
8	G71-40	5.57	0.64	23	0.12	- 43	- 20	- 4	ms	-1.474	- .704	- .933	31 C(14)	
9	+68°138	4.78	0.53	79	0.09	+103	- 83	+23	ms	+1.272	-1.071	+ .290	2 G(10)	
10	G72-60	5.32 2.9	0.56	95 288	0.18	+157 +296	- 1 -143	-42 - 4	ms sg	+ .721	- .737	+ .198		
11	G4-6	5.22 3.0	0.56	116 322	0.18	+ 59 +227	-124 -311	+75 +136	ms sg	+ .814	- .909	+ .294		
12	G75-31	4.58	0.46	151	0.19	+177	-138	+ 44	ms	+ .938	- .965	+ .588		
13	G76-21	4.92 3.2	0.44	109 240	0.29	+ 69 +210	-127 -263	+126 +220	ms sg	+1.067	-1.035	+ .718		
14	G4-37	4.92 3.2	0.47	193 427	0.26	-189 -330	-111 -220	- 61 -226	ms sg*	- .603	- .468	- .705		E (J4.8)
15	G4-44	5.02	0.54	46	0.14	- 22	- 76	- 57	ms	- .589	-1.692	-1.157	-13D(15)	
16	G5-17	6.10 4.4	0.83	39 86	0.00	- 41 - 69	- 34 - 69	- 28 - 77	ms* J	- .587	- .749	-1.049		ER(J4.4)
17	G37-34	6.47	0.85	43	0.07	- 46	-175	- 8	ms	+1.018	-3.068	-1.012	22M(11)	J (J6.7)
18	G77-54	5.48	0.62	35	0.13	+ 54	- 72	- 25	ms	+ .330	-1.797	+ .619	22Y(11)	RJ(5.9)
19	G8-16	4.51	0.41	88	0.24	+361	-169	- 67	ms	+ .515	-2.366	+ .572	-3(6)	ER(J4.9)
20	G8-51	6.68	1.08	18	0.06	- 8	- 5	- 28	ms	- .450	- .261	-1.547	79(10)	J (7.2)
21	G84-29	4.00	0.36	141	0.29	+138	-179	- 24	ms	- .140	- .959	+ .304		
22	G96-20	4.40 3.35	0.42	110 178	0.20	+137 +156	- 92 -165	+108 +175	ms sg	+ .277	-1.078	+ .991		
23	G84-37	5.02 3.2	0.52	85 169	0.18	- 12 - 11	- 77 -158	+ 71 +137	ms sg	+ .021	- .956	+ .779		
24	G98-3	5.40 3.7	0.60	73 158	0.15	- 16 - 7	- 85 -182	+ 4 + 8	ms 47Tsg	+ .106	-1.137	+ .051		
25	+59°886	5.68	0.75	70	0.01	+ 74	- 55	- 26	ms	+ .652	-1.003	- .486		E (J5.8)
26	G102-20	5.91 2.35 1.5	0.65	71 364 550	0.21	+ 20 + 5 - 5	- 76 -369 -554	+ 72 +387 +587	ms M13sg M15sg*	- .051	- .997	+1.075		
27	G102-47	5.85 2.5	0.64	76 354	0.23	+ 46 -101	-141 -534	- 2 + 27	ms M13sg	- .532	-1.412	+ .109		
28	G98-58	5.78 2.4	0.58	41 195	0.24	+253 +288	- 49 -306	+ 20 - 63	ms M15sg	+ .228	-1.670	- .541		
29	G101-33	6.00	0.74	69	0.10	+152	- 94	+ 18	ms	+ .161	-1.551	- .121		J (6.0)
30	-6°1598	5.22 3.0 2.3	0.56	47 129 178	0.16	- 2 - 17 - 26	- 26 - 66 - 89	+ 51 +144 +200	ms sg sg	- .178	- .474	+1.120		J (4.7)
31	G108-43	5.19	0.57	58	0.11	-184	-107	+ 8	ms	-1.857	-2.727	+ .167		E (J5.5)
32	G87-20	5.71	0.64	55	0.15	- 25	- 62	- 39	ms	+ .189	-1.125	- .496		
33	G89-14	4.90 3.3	0.47	122 251	0.22	-140 -251	-170 -371	+ 5 + 18	ms sg	- .864	-1.550	+ .102		
34	G88-27	4.62 3.4	0.44	161 283	0.22	+ 14 - 5	-191 -324	-106 -195	ms sg	- .159	-1.095	- .732		
35	G90-3	4.90 3.2	0.48	124 270	0.22	+ 33 + 37	-154 -332	- 37 - 94	ms sg	+ .029	-1.217	- .392		

Table 3 (continued)

No. (1)	Name (2)	M_V (3)	B-V (4)	D pc (5)	δ(.6) (6)	U km/sec (7)	V km/sec (8)	W km/sec (9)	Type (10)	ΔU/dr km/sec pc (11)	ΔV/dr km/sec pc (12)	ΔW/dr km/sec pc (13)	π ± 0".001 (14)	Other Cat or M_V (15)
36	G88-31	5.00 3.3	0.51	49 107	0.17	+ 59 + 31	-126 -240	- 7 - 48	ms sg	- .483	-1.958	- .693	7M(10)	ER(J5.5)
37	G88-32	3.92	0.36	231	0.31	-108	-275	- 8	ms	- .330	-1.225	+ .012		
38	G88-40	4.92 3.5	0.51	62 120	0.16	- 58 - 78	- 66 -141	- 45 - 76	ms sg	- .354	-1.296	- .533		
39	G112-36	6.60 1.7J	0.82	34 316	0.19	+ 5 -264	- 67 -375	+ 15 + 69	ms* sg	- .953	-1.088	+ .190	+37C(13) -4Y(12)	ER(J1.7)
40	G112-43	4.50 3.5	0.44	139 220	0.20	-125 -161	- 78 -153	-180 -275	ms sg	- .445	- .931	-1.175		
41	G90-25	6.00	0.62	28	0.30	-260	-218	- 88	ms	-1.872	-9.101	+ .496	42(6)	ER(J6.2)
42	+80°245	5.02 3.2	0.50	99 229	0.22	+ 68 +157	-138 -322	+ 92 +214	ms sg	+ .684	-1.409	+ .930		
43	G9-16	3.51 4.7J	0.31	141 82	0.29	+ 38 + 38	-235 -142	- 82 - 35	ms J	+ .003	-1.561	- .781		ER(J4.7) Var vel.
44	G9-36	5.58 3.0	0.57	182 603	0.23	-218 -644	-181 -633	+ 97 +389	ms sg*	-1.011	-1.072	+ .693		
45	G114-26	5.00 3.3	0.48	84 182	0.25	-181 -415	-191 -387	- 10 - 39	ms sg*	-2.382	-1.999	- .292		E (J6.2) Var vel.
46	G41-44	4.10	0.38	249	0.27	-189	-426	+205	ms	-1.339	-1.107	+ .165		E (J5.5)
47	+65°737	5.72	0.67	61	0.11	+ 85	- 89	- 73	ms	+1.718	-1.236	- .826		E (J6.0)
48	+55°1362	6.25 0.3	0.70	34 525	0.24	- 41 -279	- 11 - 42	- 16 +184	ms M15sg	- .484	- .062	+ .408		
49	G43-33	5.02	0.54	37	0.12	+ 39	- 60	+ 23	ms	+ .274	-1.001	- .660		
50	G44-30	5.79	0.64	124	0.17	- 30	-222	+ 25	ms	- .549	-1.376	- .544		
51	G58-23	5.46 2.7	0.60	78 275	0.16	+ 66 +237	- 56 -203	- 50 -172	ms sg	+ .863	- .738	- .616		
52	-14°3322	5.58 2.7	0.58	91 347	0.21	+ 96 +367	+ 37 +162	+ 65 +226	ms sg*	+1.060	+ .493	+ .631		
53	21°3420	5.11 3.0	0.52	100 263	0.20	+ 27 + 77	- 95 -234	- 82 -231	ms sg	+ .303	- .848	- .910		
54	G13-1	5.32 2.8	0.58	53 170	0.16	- 44 -146	- 9 - 56	- 39 - 82	ms sg	- .873	- .408	- .371		
55	G11-36	5.60 2.7	0.60	52 200	0.18	- 84 -322	-109 -409	- 51 -209	ms sg	-1.610	-2.035	-1.077	10(5)	ER
56	G59-18	6.20 3.0 1.5	0.72	61 263 525	0.20	+ 56 +241 +481	- 69 -278 -551	+ 12 - 33 - 92	ms 47Tsg M13sg	+ .915	-1.038	- .224		
57	G59-27	4.45	0.40	189	0.29	+ 41	-252	-132	ms	+ .253	-1.351	- .046		
58	G60-26	5.91 1.8	0.65	59 400	0.20	- 57 -323	-101 -527	+ 89 - 41	ms sg*	- .784	-1.256	- .383		
59	-7°3509	5.85	0.72	57	0.09	+ 7	- 40	- 39	ms	+ .035	- .819	- .472		
60	G14-32	7.50 0.5 -1.0	0.94	15 372 741	0.22	- 12 +342 +710	- 36 -145 -257	+ 65 +167 +272	ms* 47Tsg sg*	+ .994	- .302	+ .285	11(7)	
61	HD114762	5.02	0.54	29	0.14	+ 56	- 50	+ 54	ms	+2.219	-1.599	+ .219		R
62	+71°646	1.0 0.2J	0.75	670 968	(0.18g)	+247 +337	-432 -604	+101 +224	sg sg*	+ .380	- .561	+ .305		E(J0.2) G3IIIp
63	G14-45	7.50 9.0T	1.01	47 24	0.31	+ 57 + 6	-146 - 95	+110 +109	ms* sd	+2.211	-2.173	+ .062	43(8)	
64	G63-44	6.00 2.0	0.68	36 229	0.18	- 40 -308	- 29 -188	- 57 -122	ms M13sg	-1.391	- .821	- .334		
65	G64-12	4.29	0.38	265	0.31	- 16	-402	+376	ms	+ .632	-1.084	- .019		
66	G63-46	5.48 2.5	0.58	59 232	0.19	- 67 -283	- 41 -168	- 49 -130	ms M13sg	-1.247	- .729	- .468		R
67	+77°521	5.67 4.3J	0.66	56 107	0.12	- 8 + 16	- 90 -119	- 37 - 20	ms sg	+ .450	- .561	+ .329		
68	-2°3811	4.93	0.57	72	0.07	- 57	- 12	- 7	ms	- .568	- .082	- .418		J(4.4)
69	G66-22	6.20	0.71	72	0.18	+271	-200	+ 6	ms	+2.618	-2.772	+1.747	-20(8)	R
70	G66-30	4.10	0.40	241	0.21	+193	-329	- 9	ms	+ .515	-1.389	+ .318		

Table 3 (continued)

No. (1)	Name (2)	M_V (3)	B-V (4)	D pc (5)	δ(.6) (6)	U km/sec (7)	V km/sec (8)	W km/sec (9)	Type (10)	ΔU/dr km/sec pc (11)	ΔV/dr km/sec pc (12)	ΔW/dr km/sec pc (13)	π_t 0".001 (14)	Other Cat or M_V (15)
71	G151-10	6.00	0.72	50	0.14	+ 49	− 80	− 62	ms	+ .070	−1.822	− .370		E(J6.4)
72	G15-23	6.40	0.71	83	0.25	+ 3	−199	− 70	ms	− .597	−2.268	− .142		
73	G15-24	5.47	0.57	151	0.20	+152	−250	+ 74	ms	+ .644	−1.563	+ .906		E(J5.2)
74	G16-13	5.48 2.8	0.59	78 275	0.17	+ 23 − 8	−131 −432	− 9 + 56	ms sg	− .156	−1.525	+ .332		
75	G17-16	6.01	0.71	52	0.14	+150	−110	− 38	ms	+ .213	−1.473	+ .926		
76	G17-25	8.00 6.60	0.75	22 40	0.28	+117 + 94	− 93 −147	−102 −124	sd ms	−1.230	−2.915	−1.169	46C(7)	E(J6.5)
77	G17-30	5.58 3.7	0.62	37 88	0.15	+ 18 − 2	− 64 −142	− 20 − 22	ms 47Tsg	− .398	−1.514	− .041	24Y(10)	
78	+25°3252	4.81 3.2T	0.51	25 53	0.11	− 37 − 56	+ 12 + 4	+ 5 − 7	ms sg	− .718	− .317	− .437	17A(7)	
79	G19-27	5.92 4.7T 2.2	0.67	27 48 151	0.16	− 6 − 8 − 23	− 30 − 54 −171	+ 26 + 45 +142	ms T sg	− .142	−1.132	+ .934	24Y(7)	
80	G20-8	4.82	0.43	103	0.31	+362	−239	+ 54	ms	+ .232	− .661	+1.651		ER(J5.1)
81	−0°4604	6.20 2.5 1.0	0.66	48 274 550	0.27	+111 + 39 − 48	− 92 −346 −656	− 16 + 14 + 51	ms* M13sg M15sg	− .318	−1.123	+ .132		E(J3.2)
82	G183-11	4.63	0.44	100	0.22	+ 18	−324	− 44	ms	−1.401	−1.612	+ .440		E(J5.0)
83	G141-19	6.07 3.8J 1.5	0.64	77 226 630	0.27	−127 −262 −629	− 14 −147 −506	− 14 − 68 −213	ms* 47Tsg M15sg*	− .905	− .887	− .359	−5Y(12)	E(J3.8)
84	+34°3239	4.92 3.2	0.50	33 72	0.17	+ 50 + 91	− 8 + 20	− 30 − 52	ms sg*	+1.030	+ .729	− .552	−5A(8)	J(4.8)
85	G21-22	5.11	0.53	129	0.18	−210	−226	− 30	ms	−1.242	−1.993	− .257		E(J4.1)
86	G22-6	5.50 4.0J 2.8	0.59	51 100 174	0.18	− 67 −117 −193	− 85 −177 −314	− 16 − 30 − 51	ms sg M13sg*	−1.019	−1.854	− .290	16(7)	E(J4.0)
87	31Aql	4.0T	0.79	17	0.01	+122	− 25	− 23	sg	+3.202	+2.879	−1.570	59(5)	E R (J3.9)
88	G23-1	6.30 1.3	0.79	35 347	0.16	+ 16 +177	+ 17 +144	− 31 −310	ms 47Tsg	+ .517	+ .408	− .892		
89	+16°3924	−3.0	1.85	2000	−	+100	−422	−234	M15g	− .065	− .055	− .124		E KIIp
90	G143-17	5.60 4.5J	0.58	43 71	0.22	+158 +179	−119 − 97	+ 64 + 86	ms sg*	+ .718	+ .762	+ .766		E(J4.5)
91	G24-3	4.92	0.48	122	0.23	+ 23	−253	+ 69	ms	− .960	− .898	+ .142		
92	−7°5235	5.30	0.58	41	0.14	+105	− 71	− 20	ms	+ .559	− .292	−1.521		
93	G24-13	5.73 4.7J 2.4	0.61	73 115 347	0.19	−128 −164 −366	− 5 − 49 −297	− 87 −119 −301	ms J* M92sg	− .871	−1.069	− .784		E(J4.7)
94	−3°4864	6.27	0.83	61	0.06	− 63	− 35	− 31	ms	− .646	− .921	− .318		E(J6.7)
95	−9°5491	6.00 3.7J 1.7	0.65	50 143 363	0.21	+165 +126 + 35	−159 −204 −311	+121 +131 +154	ms J* M15sg	− .416	− .483	+ .104		E(J3.7)
96	+71°1053	4.82	0.54	95	0.08	+133	− 65	− 3	ms	+1.467	− .467	+ .028	14G(12)	E(J4.3)
97	G25-24	5.24 3.0	0.50	183 525	0.25	+ 42 +155	−138 −439	−275 −752	ms M15sg	+ .333	− .880	−1.395		
98	G25-29	5.23 3.7	0.57	44 91	0.15	+ 35 + 32	− 95 −133	− 6 − 57	ms 47Tsg	− .053	− .797	−1.091		
99	G26-9	7.5 5.6	0.97	30 73	0.47!	+120 +188	−104 −109	+ 42 − 21	ms sg**	+1.600	− .119	−1.476	16Y(10) 24A(8)	E Var vel.
100	G126-19	6.40 3.7 1.5	0.77	42 216 398	0.17	+ 57 +191 +331	− 74 + 15 +113	+ 73 +213 +360	ms 188sg 47Tsg*	+ .771	+ .524	+ .806		
101	G18-28	5.68 +3.0	0.64	58 209	0.16	+ 30 − 25	−223 −392	+ 28 −188	ms sg	− .365	−1.118	−1.429		
102	G18-39	4.63	0.46	137	0.19	+143	−273	− 10	ms	+ .620	− .743	−1.128		E(J4.3)
103	G27-44	4.70 3.7	0.49	35 55	0.13	+ 54 + 83	+ 14 + 33	+ 37 + 47	ms 47Tsg	+1.414	+ .948	+ .476	9Y(10)	
104	G27-45	6.10	0.66	116	0.27	+265	−230	−238	ms	+2.258	−1.913	−2.155		E(J7.7)
105	G28-17	5.89	0.68	48	0.13	− 24	− 72	− 47	ms	− .532	−1.435	−1.059	15Y(9)	J(6.5)
106	G67-49	5.00	0.59	51	0.07	− 67	− 25	+ 5	ms	−1.297	− .108	− .206		
107	G29-23	4.58	0.43	128	0.26	+154	−279	+ 83	ms	+1.065	−1.010	− .870		
108	G29-33	10.5	1.41	10	−	+ 30	− 32	+ 31	ms	+2.968	− .247	− .212		
109	+59°2723	4.78	0.44	132	0.26	+224	−206	− 64	ms	+1.996	− .839	− .493		E(J5.2)
110	G190-34	6.02	0.80	40	0.04	+ 70	− 40	+ 22	ms	+1.919	− .400	+ .242		
111	G68-30	5.02	0.56	64	0.12	− 63	− 31	+ 18	ms	− .894	+ .035	− .148		
112	SA115-147	5.68	0.73	42	0.03	+ 35	− 34	0	ms	+ .839	− .584	− .376		
113	γPav	4.45T	0.49	9	0.18	+ 14	+ 44	+ 6	ms	− .677	+3.454	−1.469	111(6)	

in the (M_{bol}, log T_e)-plane is not germane to the present problem. The answer to this question requires an examination of the validity of the adopted blanketing corrections and the extent of evolution of the subdwarfs from their *age-zero* configuration (e.g., Strom and Strom 1967; Cayrel 1968). What is germane here is that the procedure, as applied with the *adopted*[1] blanketing corrections, gives M_V for subdwarfs which agree with the external trigonometric evidence (Eggen and Sandage 1962, Figs. 2, 4, 5, 6) to within the stated accuracy over the excess range of $-0.05 \leq \delta(0.6) \leq +0.32$.

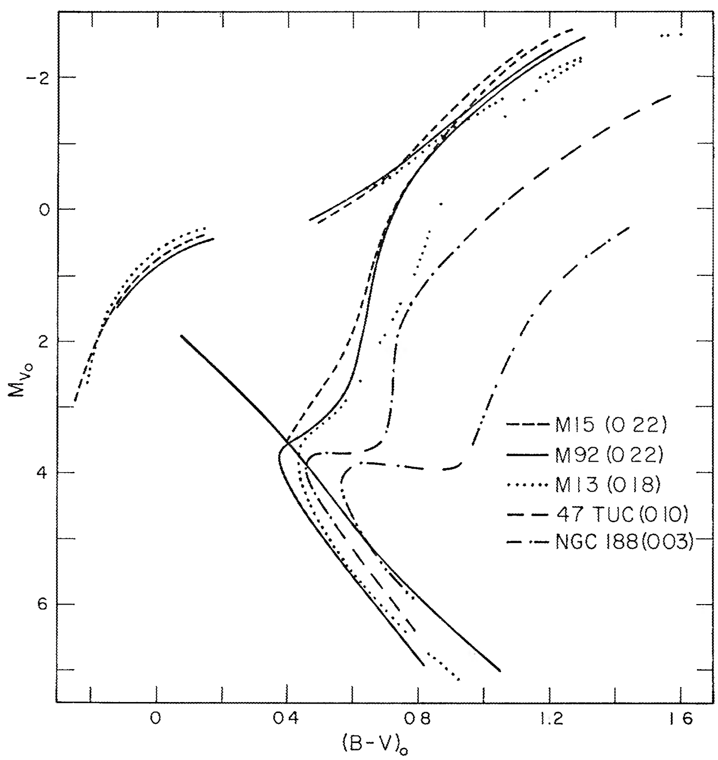

FIG. 1.—Composite C-M diagram for four globular clusters and the old galactic cluster NGC 188, listed in order of increasing metal abundance. The mean observed ultraviolet excess of dwarfs at $(B - V)_0 = 0.45$ is given in parentheses for each cluster Absolute luminosities were found by the method of photometric parallaxes with blanketing corrections. The abscissa and the ordinate are color and luminosity, corrected for reddening but not for blanketing The Hyades age-zero main sequence is shown as a solid line. The diagram is used to obtain M_V for the subgiant choice for stars in Table 3.

But even if the method were perfect, photometric parallaxes for Population II and old disk stars remain uncertain, because, in the absence of additional information, one cannot decide from colors alone whether a star is a subgiant or a dwarf. The problem is illustrated in Figure 1, in which schematic color-magnitude diagrams for four globular clusters and the old galactic cluster NGC 188 are compared. The data for M13 are from Arp and Johnson (1955) and Baum *et al.* (1959), supplemented by new observations near the main-sequence turnoff; 47 Tuc from Eggen (1961), Tifft (1963), and Wildey (1961); NGC 188 from Sandage (1962); and M15 and M92 from an unpublished investigation summarized elsewhere (Sandage 1964*b*, 1968).

Figure 1 was constructed by determining photometric moduli for each cluster by the

[1] The present argument is unaffected if these particular blanketing corrections are in error, because it is the π(phot) determined with *these* corrections which have been shown to be satisfactory as judged by comparison with π(trig).

procedure just described and applying the resulting $m - M$ values to the reddening-free normal $[V_0, (B - V)_0]$-points for each cluster to get M_V values. The clusters were then plotted together in Figure 1 by using $(B - V)_0$ colors as the abscissa (no blanketing corrections), with no freedom to adjust the diagrams into coincidence at any point. The near coincidence of the horizontal-branch positions of M13, M15, and M92 (also M3, not shown) has not been forced. The value of $M_V \simeq +0.4$ for the cluster-variable gaps in these clusters is in near agreement with the statistical-parallax luminosities of the field RR Lyrae stars (van Herk 1965; Woolley *et al.* 1965), and this provides a further and apparently satisfactory test of the present method of photometric parallaxes to about ± 0.3 mag. This accuracy, although not yet sufficient for the reverse problem of attempting a primary recalibration of M_V for RR Lyrae stars, is accurate enough for present purposes.

Several features of Figure 1 require comment. The illustrated clusters have a large range of metal abundance. This is known from previous work (see, e.g., Morgan 1959; Deutsch quoted by Kinman 1959*a*) and is shown here by the observed ultraviolet excesses for main-sequence stars at $(B - V)_0 = 0.45$ given at the right of the cluster name. The shapes of the giant and subgiant branches depend on this metal abundance, as does the position of the main sequences.

Figure 1 shows that two choices for M_V are possible for stars with $(B - V)_0 > 0.4$ whose values of $(B - V)_0$ and δ are known. A large number of subgiants is expected in a sample of weak-line stars that is complete to a given apparent magnitude, and the number can be estimated as follows. If the luminosity function for Population II field stars with $\delta \geq 0.16$ is similar to that for M3 (Sandage 1957, Table 9), the ratio of subgiants in the range $2 \leq M_V \leq 4$ to dwarfs in the range $4 \leq M_V \leq 6$ is ~ 0.4 for *equal volumes of space*. However, in catalogs complete to a given apparent magnitude, the volume surveyed is larger for subgiants ($\langle M_V \rangle = 3$) than for dwarfs ($\langle M_V \rangle = 5$) by a factor of about 15. However, a compensating factor is that, in lists chosen to a given proper-motion limit, the subgiants, which are more distant at a given V, will be discriminated against relative to the dwarfs, because of smaller proper motions for the same space velocities. The factor is quite difficult to estimate because the selection criteria for stars in Table 1 are heterogeneous, but it may be of the order of 3. All of these factors multiply to give $N(\text{sg})/D(d) \simeq (15)(0.4)/3 \simeq 2$ in order of magnitude for stars in Table 1 with $\delta \leq 0.16$. The estimate is quite uncertain and is used here only to show that appreciable subgiant contamination must occur in both Table 1 and in Eggen's (1964*a*) high-velocity catalog. That many subgiants do occur in the present material is shown by Jones's (1966, Figs. 4 and 13) spectroscopic M_V estimates for some of the stars in Table 1 and from similar material from Greenstein's plates of known subdwarfs.

Space motions were calculated for all stars in Table 1 by using distances either found from the procedure outlined earlier for dwarfs or determined from the appropriate sequence in Figure 1 for the choice as a subgiant. The results are listed in Table 3. Columns (1) and (2) are the designations from Table 1; column (3) lists the assumed M_V; column (4), the observed $B - V$; column (5), the distance in parsecs obtained from the modulus $V - M_V$ (no correction for absorption or reddening has been applied, although a few stars undoubtedly suffer some reddening); column (6) is the excess normalized to $B - V = 0.6$ by the method in the Appendix; columns (7)–(9) are the UVW velocity vectors with U directed toward $l^{II} = 180°$, $b^{II} = 0°$, with V toward $l^{II} = 90°$, $b^{II} = 0°$, and with W toward $b^{II} = +90°$; column (10), the assumed type, with ms for main sequence, sg for subgiant, J for the absolute magnitude obtained by Jones (1966), and occasionally more explicit statements as to the type of subgiant such as those in M13, M15, or 47 Tuc from Figure 1; columns (11)–(13) list the gradient in U, V, and W, with distance expressed as km sec^{-1} pc^{-1}; column (14), the trigonometric parallax in 0".001, with the observatory and probable error indicated where only one determination is available and the mean where more than one value exists; and column (15) lists the presence of the star in the catalogs of either Roman (1955*a*) or Eggen (1964*a*), or the M_V assigned by Jones (1966). The present data for stars in common with Eggen are those used by Eggen as they were available in 1963.

Some of the alternative space motions for various M_V values are clearly impossible, because (1) the star would be escaping from the Galaxy ($E > 0$), (2) either Jones (1966) or the trigonometric parallax does not permit the assumed M_V, or (3) the values of δ and M_V are inconsistent with Figure 1 in the sense that, for example, high-δ stars cannot lie along the NGC 188 sequence. These impossible alternative solutions are indicated by an asterisk in column (10).

V. CORRELATION OF SPACE MOTIONS WITH UV EXCESS

It has been known for some time that stars of the various subsystems of the Galaxy have different kinematic properties which gradually change with changing metal abundance. Young disk stars with metal abundances similar to the Hyades (Fe/H within a factor of ~0.5–2 of the Hyades value) move in nearly circular orbits close to the galactic plane. The U, V, and W vectors are confined to small values, usually of the order $|U|$, $|V|$, $|W| < 30$ km sec^{-1}.

Old disk stars in the age range defined by NGC 762 and NGC 7789 ($\sim 2 \times 10^9$ years) to M67 and NGC 188 (~ 5–10×10^9 years) have intermediate U and V velocities of the order of $U \simeq \pm 60$ km sec^{-1}, $-100 < V < -20$ km sec^{-1}, small W motions, and δ-values ranging from ~0.00 to 0.10. The best local examples of such stars have been isolated by Eggen as possible members of several moving groups, summarized as follows:

Group	⟨δ⟩	U	V	W	Reference
Wolf 630.	0.03	−23	−33	−18	Eggen 1965*a*
ζ Her.	.03	+54	−45	−26	Eggen 1958
γ Leo.	.04	−75	− 4	− 8	Eggen 1959
61 Cyg.	.06	+91	−53	Small	Eggen 1964*a*
η Cep	.07	+40	−97	Small	Eggen 1964*a*
σ Pup.	0.10	+70	−80	Small	Eggen 1964*b*

The C-M diagrams for each of these groups are generally similar to M67. The space motion for M67 is also similar to the groups with values close to $U = +40$, $V = -40$, and $W = -20$ (Murray 1966). Even among this sample, which spans only a small range of δ, the total space motion and the δ-values appear to be loosely correlated. Galaxy M67 itself may have a δ near 0.03 (Eggen and Sandage 1969, but see Spinrad and Taylor 1967), indicating slight metal weakening.

The intermediate Population II objects, such as the globular clusters of late spectral type with Morgan (1959) classes V–VIII (whose metal abundances appear to be only a factor $\lesssim 10$ lower than the Hyades), have only moderate $|Z|$ distances (Kinman 1959*a*, Fig. 6) and a relatively small asymmetrical mean drift velocity of $V \simeq -80$ km sec^{-1} (Kinman 1959*b*). These properties are shared by the Bailey type *ab* RR Lyrae stars of shortest period ($0^d.50 \gtrsim P \gtrsim 0^d.20$) (Kinman 1959*b*) or with $\Delta S < 5$ (Preston 1959, Tables 7 and 8; Oort 1965, § 4.2). Objects in this population appear to form an extension of the old disk groups, continuing the trend of increasing $\langle |U| \rangle$, $\langle V \rangle$, and $\langle |W| \rangle$ with increasing $\langle \delta \rangle$ beyond the σ Pup group.

The extreme Population II objects in the halo, such as RR Lyrae variables with $\Delta S > 5$, weak-line globular clusters of Morgan classes I–III or Deutsch class C, and subdwarfs with the lowest metal abundance, show the largest drift velocities ($V \simeq -200$ km sec^{-1}), the largest dispersion in U and W, and the largest mean distance from the plane (Fricke 1950; Kinman 1959*a*, *b;* Preston 1959; Roman 1965, Fig. 4). Greenstein (1955, 1965) was among the first to point out that the velocity dispersion among the subdwarfs themselves increases with increasing line weakening, as estimated directly from spectrograms.

These progressive changes in the kinematic properties of the different subsystems of the Galaxy have been known in a general way since the early work of Stromberg (1924, 1925), Oort (1926), and Lindblad (1927), and later from the studies by Parenago (1946, 1948, 1950), Kukarkin (1954), and others. But the correlation of these properties with metal abundance is a more recent result, now apparently well established by the work of Fricke, Roman, Greenstein, Morgan, Kinman, Preston, Eggen, Lynden-Bell, Sandage, and others in the references cited.

The ease with which line weakening can be determined from the ultraviolet excess for subdwarfs gives a rapid and powerful method of testing how the asymmetrical-drift velocities and the dispersions in U and W change with δ for the subdwarfs alone. We

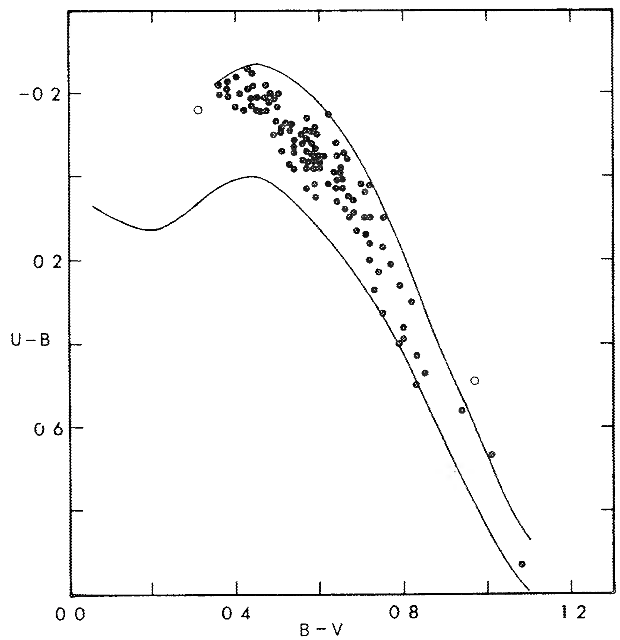

FIG. 2.—Two-color diagram for all stars in Table 1. The Hyades fiducial line forms the lower boundary, while the line showing the maximum abundance effect forms the upper. *Open Circles*, G9−16 and G26−9, which are radial-velocity variables whose colors may be affected by the companions.

would like to know if the changes are gradual or discrete and if the correlations hold for all values of $\delta(0.6)$. Figure 2 is the two-color diagram for all stars in Table 1 and shows the range of ultraviolet excess among the stars in the present program. The Hyades fiducial line forms the lower boundary, while the upper envelope is taken to be the limit for stars which have the maximum metal underabundance (see Appendix). The two radial-velocity variables G9−16 and G26−9 are shown as open circles.

The stars in Table 3 were divided into four excess groups, and the space motions were examined. Figure 3 is the Bottlinger diagram showing lines of equal apogalactica (*closed ovals*) and perigalactica (*near hyperbolae*) as calculated from the model galaxy of Lynden-Bell by using equations (2), (10), (14), (15), and (30) of ELS (1962). The parts of the diagram with low values of U and V agree well with the calculations of Contopoulos and Strömgren (1965). Figure 3 is similar to a diagram published by Schwarzschild (1952).

The stars in Table 3 are plotted as vertical crosses for $0.00 \leq \delta(0.6) \leq 0.09$, open circles for $0.10 \leq \delta(0.6) \leq 0.15$, half-closed circles for $0.16 \leq \delta(0.6) \leq 0.20$, and closed circles for $\delta(0.6) \geq 0.21$.

The space motions are from Table 3 as corrected to the local standard of rest for the Sun's peculiar motion by $U' = U - 10$ and $V' = V + 15$. In a trial plotting of Figure 3 that used all stars in Table 3 with the main-sequence choice of M_V, it was very clear that a progressive change of $\langle V \rangle$ and $\langle |U| \rangle$ with δ was present, but a few stars with large δ existed which had small values of U and V; this clearly violated the general trend. These are listed as suspected subgiants in Table 5 of the next section, an assignment which, if correct, will remove the discrepancy, because the space motions will then be larger. These stars are not plotted in Figure 3, because many of them are in fact subgiants from external evidence as discussed in § VI.

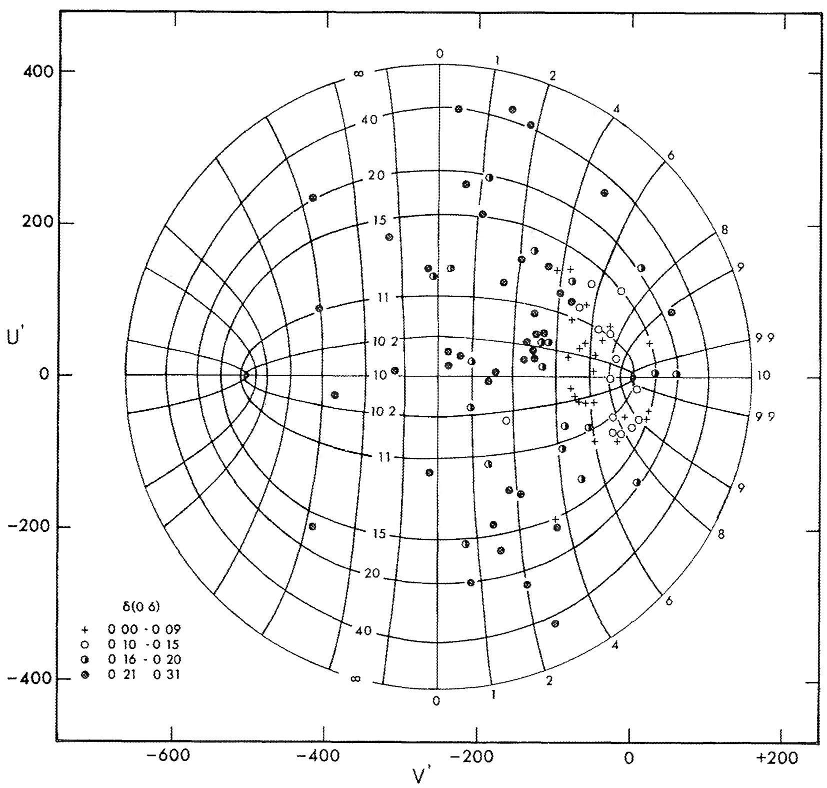

FIG. 3.—Bottlinger diagram for stars in Table 3, excluding those listed in Table 5. Coding separates stars into four ultraviolet-excess groups. Lines of constant apogalactica (*ovals*) and perigalactica (*near hyperbolae*) are marked in kiloparsecs. Velocities are relative to the local standard of rest, obtained from the U and V vectors (relative to the Sun) by $U' = U - 10$, $V' = V + 15$.

The visual impression of Figure 3 that $|V|$ and $\langle |U| \rangle$ gradually increase with increasing δ is confirmed by the calculated mean velocities and their ranges as listed in Table 4. All stars in Table 3 are included in the first part of this Table as if they were dwarfs (with the exception of the two certain globular-clusterlike giants, No. 62 [G3 IIIp] and No. 89 [K3 IIIp]). The second half of Table 4 shows the correlations with the subgiant candidates removed. In either case, the trend of the kinematical properties with increasing δ is clear and is in the sense expected from earlier work (ELS 1962, Figs. 4 and 5).

The increase of $|W|$ with δ is particularly striking and shows that a chemical gradient exists in the galactic halo such that stars with the largest $\langle |Z| \rangle$ have the lowest metal abundance. This gradient appears to be a natural consequence of the collapse of the halo toward the plane, with metal enrichment taking place as the collapse proceeds (ELS 1962), although other explanations may be possible (Schwarzschild [1964] in the discussion at the Herstmonceux conference on evolution).

Although a general gradient appears to exist, it is not true that stars with the lowest metal abundance exist *only* at large distances from the plane, for two reasons: (1) The orbits of stars formed high in the halo pass through the plane, and some will be observed at any given time in the solar neighborhood (but, of course, with high $|W|$ velocities). Many stars of this type exist in Table 3. (2) There are, however, extreme subdwarfs close to the plane which have *low* $|W|$ velocities. These either (*a*) have always been near the plane, formed from that part of the original halo material which was itself close to the plane in the earliest phases of the collapse, or (*b*) might possibly have low W velocities at particular times but higher W values at other times, due to the "exchange" of the $(U^2 + V^2)^{1/2}$ and the W velocities that appears possible in certain types of three-dimensional box orbits (Ollongren 1962, cf. his Figs. 24 and 31, which show different $|Z|_{max}$ values for different orbit numbers), although the effect is small for the particular cases computed by Ollongren.

TABLE 4

MEAN VELOCITIES AND THEIR DISPERSION AS FUNCTIONS OF $\delta(0.6)$ FOR STARS IN TABLE 3*

$\delta(0.6)$	$\langle\delta(0.6)\rangle$	n	$\langle U\rangle$	$\langle\|U\|\rangle$	$\langle V\rangle$	$\langle V-\langle V\rangle\rangle$	$\langle W\rangle$	$\langle\|W\|\rangle$†
	Including Subgiant Candidates							
0.00–0.09 . . .	0.054	14	+15	62	− 45	28	−9	17
0.10–0.15	0.127	23	+14	61	− 62	27	−9	31
0.16–0.20.	0.180	33	+ 6	85	−105	74	−2	49
0.21–0.31 . .	0.236	42	+53	145	−192	78	+4	93
	Excluding Subdwarf Candidates							
0.00–0.09 . . .	0.054	14	+15	62	− 45	28	−9	17
0.10–0.15 . .	0.127	23	+14	61	− 62	27	−9	31
0.16–0.20 . . .	0.184	19	+11	117	−149	82	+4	51
0.21–0.31.	0.254	37	+48	158	−204	79	−2	93

* The spread of the distributions is indicated by the average deviations $\langle|U|\rangle$, $\langle V - \langle V\rangle\rangle$, and $\langle|W|\rangle$. These are smaller than the formal dispersions by a factor of $(2/\pi)^{1/2} = 1.25$ if the distributions are Gaussian.

† A W velocity of 50 km sec^{-1} for a star now in the plane will take the star to a height of 800 pc at the top of its orbit $W = 100$ km sec^{-1} takes a star to 2200 pc.

The chemical gradient then only means that, whereas stars of both high and low metal abundance exist in the plane, the metal abundance is expected to decrease as we sample to progressively larger Z distances. We would expect to find only the extreme metal-deficient stars at Z, say, 5–10 kpc. Tests as to whether this is true can be made by sampling the metal abundance of subdwarfs fainter than $V \simeq 18$ in the galactic poles. The prediction is that every subdwarf fainter than this magnitude should have $\delta(0.6) > 0.21$. That a general trend of this type may be present is suggested by Eggen's data (1965*b*) for subdwarfs in the distance range $0 < Z < 2$ kpc, but data to fainter magnitudes are needed.

VI. POSSIBLE SUBGIANTS IN TABLE 3

Many stars in Table 3 have large $\delta(0.6)$ values but low U, V, and W velocities, which violates the correlations of Table 4. For convenience in future spectroscopic investigations, all stars with $\delta(0.6) \geq 0.16$ whose "eccentricity of the plane orbit" (as defined in ELS 1962) is $e \leq 0.4$ are listed separately in Table 5. Columns (6) and (7) are the U and V velocities (referred to the local standard of rest) calculated on the assumption that the stars are dwarfs. The velocities if the star is a subgiant can be found from Table 3 either directly or by using the velocity gradients listed in columns (11)–(13). Columns

Table 5

Candidates For Subgiants

Stars with δ(0.6) ≥ 0.16 But With e ≤ 0.40 If
Assigned Main Sequence or Trigonometric Luminosities

	No.	Name	α(1950)	B-V	δ(0.6)	U′	V′	W	R_2	R_1	e	M_V	π_t
							km sec^{-1}		kpc	kpc			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	6*	-17^o219	01 11.7	0.72	0.31	+24	-25	-81	8	10.2	0.12	sg(J)	-
	23	G84-37	05 7.3	0.52	0.18	-22	-62	+71	5.8	10.2	0.27	-	-
	26	G102-20	05 37.3	0.65	0.21	+10	-61	+72	5.8	10	0.27	-	-
	30*	-6^o1598	06 30.2	0.56	0.16	-12	-11	+51	9	10.2	0.06	ms(J)	-
	38	G88-40	07 31.7	0.51	0.16	-68	-51	-45	6	11	0.30	-	-
-4(12)	39*	G112-36	07 37.3	0.82	0.19	- 5	-52	+15	6	10	0.25	sg(J)	37(13), -
	48	$+55^o1362$	10 01.4	0.70	0.24	-51	+ 4	-16	8.8	13	0.19	-	-
	51	G58-23	10 47.2	0.60	0.16	+56	-41	-50	6.2	10.8	0.27	-	-
	53	-21^o3420	11 53.0	0.52	0.20	+17	-80	-82	4.5	10.1	0.38	-	-
	54	G13-1	11 56.5	0.58	0.16	-54	+ 6	-39	9	13	0.18	-	-
	56	G59-18	12 21.0	0.72	0.20	+46	-54	+12	6	10.5	0.27	-	-
	60*	G14-32	13 05.8	0.94	0.22	-22	-21	+65	8	10	0.11	sg(T)	11(7)
	63*	G14-45	13 16.4	1.01	0.31	- 4	-80	+109	4.3	10	0.40	sd(T)	43(8)
	64	G63-44	13 35.6	0.68	0.18	-50	-14	-57	8	11	0.16	-	-
	66	G63-46	13 37.5	0.58	0.19	-77	-26	-49	7	12	0.26	sg(R)	
	79*	G19-27	17 28.8	0.67	0.16	-16	-15	+26	7	10.2	0.19	-	24(7)
	84*	$+34^o3239$	18 32.7	0.50	0.17	+40	+ 7	-30	9	12	0.14	ms(J)	-5(8)
	86*	G22-6	18 51.9	0.59	0.18	-77	-70	-16	5	11	0.37	sg(J)	16(7)
	88*	G23-1	19 25.9	0.79	0.16	+ 6	+32	-31	10	15	0.20	-	-
	100*	G126-19	21 37.3	0.77	0.17	+47	-59	+73	5.8	10.5	0.29	-	-

Notes

6 Must be sg if Jones is correct.

30 Main sequence according to Jones. Low U V and W raises the possibility of a contaminating companion affecting δ(0.6).

39 Must be sg near M_V= +1.7 if Jones is correct. This gives U= -264, V= -375, W= +69. Trigonometric π is very uncertain.

60 Must be sg if trig. π is correct. Dwarf of photometric π=0.067 which is impossible on basis of π trig.

63 Trig π velocities are tabulated. Photometric π removes the mild anomaly.

79 Trig π not conclusive.

84 Trig π not conclusive. If a sg at M_V=3.2, the δ is not consistent with Figure 1.

86 Trig π not conclusive. Jones gives M_V=4.0 but such a sg with δ=0.18 is not consistent with Figure 1.

88 If a sg like 47 Tuc at M_V= +1.3, then E>O and V= +144. Mild sg at M_V≃+3 is a possible solution.

100 If a sg like 47 Tuc at M_V= +1.5, then E>O and V= +113. Mild sg at M_V≃+3 is a possible solution.

(9) and (10) of Table 5 are the perigalacticon and the apogalacticon distances as estimated from Figure 3. Column (11) shows the resulting value of *e*. Column (12) lists independent estimates of the luminosity class, either from Jones (*J*) or, where available, from the trigonometric parallaxes (*T*) given in column (13).

Table 5 does not exhaust the possibilities for subgiants in Table 3. Many more undoubtedly exist, as indicated by the estimates made in § IV and by Jones's results for other stars in Table 3. In this connection, it should be emphasized that the distribution of stars in Figure 3 is highly biased, not only because the sample in Tables 1 and 3 is not complete per volume of space but also because more stars undoubtedly exist on the left side of the diagram than are shown, due to the fact that the figure is plotted as if the stars were all dwarfs. Because of these selection effects, no valid estimate of the angular momentum of the halo population can be made from any sample of high-velocity stars now available. But the *trend* of the correlations in Table 4 is not affected by these biasing effects, because stars with all values of δ exist in the sample, which itself was not preselected on the basis of the U-, V-, or W-values.

VII. HIGH-ANGULAR-MOMENTUM STARS WITH LARGE $\delta(0.6)$

On the ELS galactic-collapse picture, stars with highly eccentric orbits and with angular momenta equal to or greater than the Sun ($h = 25$ in units of 100 kpc km sec^{-1}) should exist. This follows because, if the Galaxy did indeed collapse, matter with $h \geq 25$ was at large distances ($R > 10$ kpc) from the center before the equilibrium galaxy was formed and was falling toward the center. That such matter did exist is proved by the matter now in the Galaxy known to have $h \geq 25$, albeit presently moving in nearly circular orbits at or outside the Sun's orbit. Stars formed from such matter during the collapse will still have $h \geq 25$, but will move in eccentric orbits (i.e., $|U| > 0$). No stars of this type ($h \geq 25$, $\delta \gtrsim 0.16$) were known to ELS (1962, Fig. 6, e.g.), and a discussion on this point was made.

Such stars, if they exist, will occur in Figure 3 to the *right* of the line $V' = 0$. They will lead the Sun in its rotation by amounts up to $V' = +160$ km sec^{-1}, which is the escape velocity on the Lynden-Bell model.

The number of such stars now in the solar neighborhood, and listed in catalogs of high proper motion, is expected to be small for at least three reasons: (1) Because the perigalactica for such stars are all greater than $R_2 \simeq 5$ and are more likely to be greater than $R \simeq 7$ (for $|U| \leq 200$ km sec^{-1} according to Fig. 3), they were all formed in regions of low density, far from the center, and there will presumably be few of them. (2) All such stars in the solar neighborhood will be near perigalacticon and will be moving through the solar neighborhood near their maximum velocity. The time spent near the Sun will be a minimum. (3) In most regions of Figure 3 with $V' > 0$, the stars do not have a particularly high velocity relative to the Sun. They will, therefore, be biased against in catalogs listed according to proper motion. And because they are so rare per volume of space due to reasons (1) and (2), a large volume must be surveyed to find a few, a circumstance which further reduces the proper motion.

Such stars do exist, however. There are thirteen in the present sample, seven of which have $\delta(0.6) \geq 0.16$. Others have been found by Eggen (1968*c*), such as Bruce Proper Motion numbers 46420, with $\delta(0.6) = 0.20$ and $V' = +64$, and 46491, with $\delta(0.6) = 0.21$ and $V' = +78$. Several bright nearby stars have $V' > 0$, the most interesting of which is γ Pav, whose parameters are listed at the end of Table 3 under running number 113. The trigonometric parallax for γ Pav is large ($0\overset{''}{.}111 \pm 0\overset{''}{.}006$), and the proper motion and radial velocity are well determined, giving $V' = +59$ at $\delta(0.6) = 0.18$.

The stars with $V' > 0$ in the present program are listed in Table 6. Most of these stars are relatively bright and, therefore, nearby, as they must be to have large enough proper motions (their space motions relative to the Sun are small) to have been chosen here. The U, V, and W vectors listed in Table 6 have been calculated as if the stars were dwarfs, therefore giving *minimum* distances and space motions. Some of the stars will not have $V' > 0$ if they are subgiants, because the increased distance will cause V' to become negative. The only certain cases for $V' > 0$ are those whose dV/dr values are positive, such as numbers 3, 5, 52, 84, 88, and 103 and γ Pav. If any of these are subgiants, V' becomes even more positive, and the star moves farther to the right in Figure 3.

The present material is not sufficient to test adequately if the metal weakening increases systematically with increasing positive values of $(V'^2 + U'^2)^{1/2}$. The stars with $V' > 0$ have apogalactica which become progressively larger as $(V'^2 + U'^2)^{1/2}$ increases and must therefore have increasingly eccentric orbits. If the collapse picture is right in its most elementary prediction, $\delta(0.6)$ must correlate with increased distance from the 0,0 origin for $V' > 0$ in the Bottlinger diagram.

Figure 3 suggests that this may be the case. The four stars with $V' > 0$ which lie close to the line $R_1 = 20$ kpc all have $\delta(0.6) \geq 0.16$, whereas most other stars closer to

TABLE 6

STARS WITH $V + 15 > 0$ IF ASSIGNED THE MAIN-SEQUENCE LUMINOSITY

No	Name	$B-V$	δ(0 6)	μ_α	μ_δ	ρ	U'	V'	W'	dV/dr
3..	G70−35	0.80	0.08	−0.191	−0.116	− 17.1	− 37	+13	+ 4	+0.094
5 .	−2°181	0.69	11	− .196	− .086	− 9.9	− 33	+22	− 2	+0.230
10	G72−60	0.56	.18	+ .220	− .027	+127.6	+147	+14	−42	−0.737
20	G8−51	1.08	.06	− .233	− .254	0.0	− 18	+10	−28	−0.261
48	+55°1362	0.70	24	+ .130	− .034	− 40.0	− 51	+ 4	−16	−0.062
										possible sg
52	−14°3322	0.58	.21	− .114:	+ .256:	+ 11.4	+ 86	+52	+65	+0.493
54..	G13−1	0.58	.16	+ .107	− .190	− 23.0	− 54	+ 6	−39	−0.408
										possible sg
68 .	−2°3811	0.57	.07	+ .100	− .112	+ 28.8	− 67	+ 3	− 7	−0.082
78 .	+25°3252	0.51	.11	+ .051	− .183	+ 31.7	− 47	+27	+ 5	−0.317
84	+34°3239	0.50	.17	+ .210	+ .201	− 37 0	+ 40	+ 7	−30	+0.729
										possible sg
88..	G23−1	0.79	.16	+ .232	+ .031	+ 3.6	+ 6	+32	−31	+0.408
93..	G24−13	0.61	.19	.000:	− .335:	+101.5	−138	+10	−87	−1.069
103 .	G27−44	0.49	.13	+ .157	+ .343	− 28.8	+ 44	+29	+37	+0.948
113 .	γ Pav	0.49	0 18	+0.088	+0.800	− 30.2	+ 4	+59	+ 6	+3.454

$V' = U' = 0$ have $\delta(0.6) \leq 0.16$. But the sample must obviously be increased by new and special observations.

Candidates for stars of this type can be found as follows. If $V' > 0$, the stars are moving *away* from the high-velocity antapex at $l^{II} \simeq 270°$, $b^{II} \simeq 0°$ (or $\alpha \simeq 9^h10^m$, $\delta \simeq -48°$ [1950]), and are therefore unusual. Many of them can be located in proper-motion catalogs by selecting those which have proper motions in the "forbidden" quadrant away from the high-velocity antapex. Few such stars exist, as can be seen by inspection of the *Bruce Proper Motion Survey* (Luyten 1963), the Lowell fields, or, for example, *The Radcliffe Catalogue of Proper Motions in the Selected Areas* (Knox-Shaw and Barrett 1934), and many of those which do exist will be nearby white dwarfs with small motion. But, depending on the radial velocity, the remainder are good candidates for stars with $V' > 0$. Most of the stars in Table 6 do, in fact, have unusual values of the direction of proper motion for their positions in the sky.

It seems probable that many stars which lead the Sun can be located in this way, especially if proper-motion catalogues are used whose limits are smaller than $\mu \simeq 0''.20$ year^{-1}. The results to be expected from sufficient material of this type are (1) a firmer determination of the escape velocity of the Galaxy and (2) a test of whether $\delta(0.6)$ increases toward the leading boundary of Figure 3. A search for such stars has been started.

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APPENDIX

NORMALIZATION OF OBSERVED ULTRAVIOLET EXCESSES TO CORRECT FOR THE GUILLOTINE

The shapes of the blanketing vectors in the $(U - B, B - V)$ diagram are such that stars with different $B - V$ values with the same metal abundance will show different ultraviolet-excess values. For red stars, $\delta(U - B)$ is partially guillotined because the blanketing line is nearly parallel to the intrinsic Hyades line. Corrections to the observed δ are needed if metal abundances are to be compared among stars of different colors.

The guillotine can be seen in Figure 2. The upper line is considered to be the envelope for the maximum abundance effect. Although taken from a different source (the photometric catalog discussed in § I), the guillotine agrees well with an independent determination by Eggen (1968*a*) who used different methods.

Table 1A gives the relevant data. Column (2) shows the Hyades fiducial line, column (3) gives

TABLE 1A

$\delta = f(B - V)$ FOR VARIOUS $\delta(0.6)$ VALUES

			Observed δ				δ Correction Factor			
$(B-V)_0$ (1)	Hyades $(U-B)_H$ (2)	Limit $(U-B)_M$ (3)	δ_M (4)	$\delta_{0.75M}$ (5)	$\delta_{0.5M}$ (6)	$\delta_{0.25M}$ (7)	$\delta(0.6)/\delta_M$ (8)	$\delta(0.6)/\delta_{0.75M}$ (9)	$\delta(0.6)/\delta_{0.5M}$ (10)	$\delta(0.6)/\delta_{0.25M}$ (11)
0 35	0.03	−0.22	0.25	0.17	0.11	0.055	1.24	1 23	1.18	1.1
0.40	.01	− .25	.26	.17	.11	.055	1.19	1.23	1.18	1.1
0.45	.00	− .27	.27	.18	.11	.055	1.15	1.17	1.18	1.1
0.50	.03	− .25	.28	.19	.12	.055	1.11	1.10	1.08	1.1
0.55	.08	− .22	.30	.20	.12	.06	1.03	1.00	1.04	1.0
0.60	.13	− .18	.31	.21	.13	.06	1.00	1.00	1.00	1.0
0.65	.19	− .11	.30	.21	.13	.06	1.03	1.00	1.00	1.0
0.70	.25	− .03	.28	.20	.12	.06	1.10	1.05	1.04	1.0
0.75	.34	+ .08	.26	.20	.12	.055	1.19	1.08	1.08	1.0
0.80	.43	+ .19	.24	.19	.12	.055	1.29	1.10	1.08	1.0
0.85	.54	+ .32	.22	.18	.12	.06	1.41	1.17	1.08	1.0
0.90	.64	+ .44	.20	.16	.12	.06	1 55	1.31	1.12	1.0
0.95	.74	+ .55	.19	.15	.11	.06	1.63	1.40	1.18	1.0
1.00	.84	+ .67	.17	.14	.10	.06	1.82	1.50	1.30	1.0
1.05	.94	+ .79	.15	.12	.09	.055	2.06	1.75	1.44	1.1
1.10	0.99	+0.87	0.12	0.09	0.06	0.04	2.58	2.33	2.2:	1.5:

the coordinates of the maximum abundance line, column (4) is the excess of this line from the Hyades, and column (8) is the ratio of the excess at $(B - V)_0 = 0.60$ (where δ is a maximum) to δ at any other $(B - V)_0$.

For underabundance less than the maximum, similar ratios can be obtained by drawing the blanketing vectors from Wildey *et al.* (1962, eq. [9]) in Figure 2 and marking off proportional distances along these vectors for all $U - B$ (cf. Arp 1962). The δ from the $(U - B, B - V)$ lines for 0.75, 0.50, and 0.25 of the maximum blanketing are listed in columns (5), (6), and (7) of Table 1A. The corresponding correction factors from which δ (0.6) can be found are given in columns (9), (10), and (11).

Table 1A can be used with interpolation in columns (1) and (4)–(7), respectively to obtain $\delta(0.6)$ for any star whose values of $(B - V)_0$ and δ are known.

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