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SPECTRA AND COLORS OF EARLY-TYPE STARS NEAR THE NORTH GALACTIC POLE

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ABSTRACT

Slit spectrograms of 84 stars to a limiting magnitude of about 12 and of type F2 and earlier in a north galactic pole zone were taken with the Mount Wilson 60-inch and 100-inch telescopes in order to obtain spectral types, radial velocities, and axial-rotation velocity estimates. U, B, V observations of most of these stars were made with the McDonald 36-inch and 82-inch telescopes.

The principal results are the following: (1) The majority of stars considered belong to the "older population I." The percentage of halo population II stars to the limiting magnitude of this study is small. (2) Sixteen new metallic-line stars were found. The relationship between the spectral classification parameters and the colors of these stars is discussed. (3) Considering only the normal population I stars, the estimated rotational velocities suggest that axial rotation may be less at high galactic latitudes than for stars of similar spectral type in the neighborhood of the sun. (4) The spectra of 10 of the stars considered show decided population II characteristics. These include hot subdwarfs, F- and G-type subdwarfs and horizontal-branch stars. Some of these have large radial velocities, but none shows axial rotational line broadening. The position of these and other stars on the two-color diagram is discussed.

I. INTRODUCTION

Since the discovery of a number of faint blue stars at high galactic latitudes by Humason and Zwicky (1947), there has been a considerable amount of interest in the early-type stellar representation in the galactic halo. Colorimetric, proper-motion, and objective-prism surveys have been carried out by a number of investigators, with special emphasis on the bluest stars. The spectrographic studies of Greenstein (1956, 1959) and Münch have shown that a variety of objects is to be found at large distances above the galactic plane, including hot subdwarfs, white dwarfs, horizontal-branch stars, F–G subdwarfs, and normal population I stars.

A finding list of 601 stars of spectral type F2 and earlier in a north galactic pole region was prepared by Slettebak and Stock (1959) from objective-prism plates taken with the Hamburg Schmidt telescope, in order to serve as a source for more detailed studies of the halo population. The present paper describes spectrographic results obtained at the Mount Wilson Observatory by one of us (A.S.) in 1958 and U, B, V photometry carried out by the remaining authors at the McDonald Observatory in 1960 for 84 stars in the finding list.

II. SPECTROGRAPHIC OBSERVATIONS AND PROCEDURE

The stars included in this study were selected in two ways: (1) All stars listed in the Hamburg survey as brighter than photographic magnitude 11.5 in a given zone were observed. The zone chosen covered $\alpha(1950) = 12^{h}28^{m}$ to $13^{h}0^{m}$ and $\delta(1950) = +30^{\circ}$ to $+50^{\circ}$ and included 60 stars. (2) A number of stars in and outside this zone, some of which are fainter than the afore-mentioned magnitude limit, were observed because they promised to have interesting spectra. Spectra of 24 such stars were obtained. Spectrographic observations were made with three telescopes:

1. With the exception of 10 faint objects, one spectrogram of each star was taken with the Mount Wilson 60-inch reflector. The 4-inch camera of the X spectrograph was employed, with a scale of 80 A/mm and a slit width of 20 μ at the plate. The latter were baked Kodak II*a*-O plates.

2. The spectra of 10 faint stars were obtained with the Mount Wilson 100-inch reflector. Baked Kodak II*a*-O plates were used with the 3-inch camera of the Newtonian-focus spectrograph. The scale was 85 A/mm and the slit width at the plate 27 μ.

3. The Perkins 69-inch reflector was employed to obtain spectrograms of 12 of the brighter stars. The Pα camera on the two-prism spectrograph gives a dispersion of 28 A/mm at Hγ, with a projected slit width of 22 μ. Kodak 103*a*-O plates were used.

a) *Spectral Classification*

The primary objective of this investigation was to analyze the early-type stellar population at large distances above the galactic plane, in order to determine the relative importance of the disk and halo stars. This meant, first, that a set of spectrograms suitable for spectral classification, including standard stars, had to be obtained. These spectrograms were taken with the Mount Wilson 60-inch telescope and were widened to 0.4 or 0.5 mm on the plate (depending on the brightness of the star). The MK standard stars, plus standards for metallic-line and peculiar A-type stars, are listed in Table 1. In addition to these, spectrograms of the F-type subdwarf HD 140283; of the intermediate-population, high-velocity, A-type star HD 161817; and of RR Lyrae at maximum and minimum light were taken for comparison with population II objects.

TABLE 1

STANDARD STARS

I. *MK standards:*			
B3 V,	16 Peg	A1 V,	HR 7784
B5 V,	ρ Aur	A2 V,	θ Leo
B5 V,	λ Cyg	A3 V,	λ Gem
B5 V,	κ Hya	A4 V,	δ Leo
B6 V,	30 Sex	A5 V,	80 UMa
B7 V,	α Leo	A7 V,	ι UMa
B8 V,	ζ Peg	A7 V,	21 L Mi
B9 V,	α Del	F0 V,	ρ Gem
A0 V,	α Lyr	F2 V,	σ Boo
A0 V,	HR 3314	F2 V,	78 UMa
A0 V,	109 Vir	F5 V,	45 Boo
A0 V,	γ UMa	F5 V,	ι Peg
A0 IV,	γ Gem	F7 V,	θ Boo
A0 III,	α Dra		
II. *Metallic-line star standards:*			
ζ UMa B		ζ Lyr A	
ϵ Ser		15 Vul	
III. *Peculiar A-type standards:*			
α CVn A		73 Dra	
χ Ser		γ Equ	

The spectral types are listed in Table 2. In most cases only one 60-inch spectrogram was used, as indicated by a single Xf plate number. The classification of some of the brighter stars was based also on 69-inch spectrograms; these also have a Pα plate number in Table 2. Those stars for which only a 100-inch plate was available are indicated by a B plate number. The classification of the latter stars is uncertain because no standard stars were taken with the same spectrograph for comparison purposes and because the spectrograph was not in perfect adjustment.

Table 2

SPECTRAL TYPES, ROTATIONAL VELOCITIES, RADIAL VELOCITIES AND COLORS OF EARLY-TYPE STARS IN A NORTH GALACTIC POLE ZONE

No.	BD	HD or Design.	Plate	α (1950)	δ (1950)	Sp. Type	v sin i (km/sec)	R.V. (km/sec)	p.e. of R.V. (km/sec)	V	B-V	U-B
1	+50°1766		Xf 3512	10^{h}43^m.1	+49°34'	A3V	100	- 2	± 10	10^m.37	+^{m}.08	+^{m}.06
2	+41 2143		Xf 3525	10 55.1	+40 31	Am	≤ 50	+18	± 9	10.62	+.15	+.10
3	+41 2144		Xf 3524	10 55.5	+40 56	A2p	≤ 50	- 4	± 3	10.58	+.04	+.05
4	+45 1887(ft)	95768(ft)	Xf 3523	11 0.8	+44 36	Am	75	- 1	± 3	9.60	+.27	+.13
5	+45 1887(br)	95768(br)	Xf 3522	11 0.8	+44 36	G8III-IV	≤ 50	- 5	± 2	7.34	+.87	+.55:
6	+33 2070		B 1317	11 0.8	+33 26	AlVp?	≤ 50			11.56	+.10	+.09:
7	+42 2209	99831	Xf 3561	11 26.7	+42 22	Am	≤ 50	-15	± 6	8.91	+.30	+.10
8	+25 2399		B 1308	11 36.0	+25 18	AOp				11.66*	-.12	-.49
9		NGP 23	B 1310	11 41.7	+40 50	sdF-G	≤ 50			11.95:*	+.48	-.18
10	+32 2188		Xf 3513	11 44.5	+32 7	Hor.-br.	≤ 50	+100	± 6	10.74	-.08:	-.29:
11	+32 2217		Xf 3528	12 2.4	+31 37	Am	≤ 50	+ 1	± 5	10.52	+.28	+.10
12		NGP 96	B 1315	12 10.4	+49 21	sdF-G		-300:		11.56	+.47	-.22
13	+31 2340	106223	Xf 3554	12 10.8	+30 34	pec.	100	-17*		7.44	+.30	-.08
			Pα 11897									
14	+47 1940	106420	Xf 3562	12 11.9	+47 20	B7V	≤ 100	+13	± 6	8.21	-.14	-.45
15	+25 2478		Xf 3529	12 14.0	+24 53	AOV	200	-40	± 7	10.65	-.03	-.05
16		NGP 122	B 1311	12 16.5	+47 54	sdF	≤ 75			12.42:*	+.41	-.23
17	+26 2331	107427	Xf 3565	12 18.4	+26 12	A3V	150	- 8.6*		9.09*	+.10	+.09
18	+49 2137		Xf 3530	12 22.6	+49 25	B7V	300	+135	± 19	10.64	-.15	-.60
19*	+37 2284		Xf 3539	12 28.0	+37 21	Am	100	-28	± 7	9.75	+.20	+.08
20	+26 2359	109030	Xf 3570	12 29.1	+26 9	AOp	≤ 50	+ 7.3*		7.92	+.02	+.03
21*	+46 1791	109068	Xf 3642	12 29.2	+45 30	A7V	100:	+ 5	± 8	7.66*	+.20	+.08
22*	+46 1793	109268	Xf 3643	12 30.8	+45 37	A2V	≤ 50	-12	± 5	9.06*	.00	.00
23*	+32 2255 SE	109269 SE	Xf 3575	12 30.9	+32 19	F3V	≤ 50	+ 9	± 5	9.5		
24*	+32 2255 NW	109269 NW	Xf 3576	12 30.9	+32 19	F3V	≤ 50	+12	± 8	9.7		
25*	+31 2384		Xf 3571	12 31.7	+30 56	A3V	≤ 50	+ 7	± 4	11.00*	+.17	+.07
26*	+44 2207		Xf 3639	12 32.0	+43 40	A7V	150	+22	± 6	10.65:	+.21	+.09
27*	+42 2323		Xf 3674	12 32.3	+42 2	FOV	≤ 50	+28	± 5	9.78	+.28	-.04
28*	+48 2038		Xf 3640	12 32.9	+47 31	A3V	≤ 50	-51	± 6	10.94	+.18	+.04
29*		NGP 177	B 1316	12 33.4	+42 40	sdB				12.00:	-.26	-.94
30*	+40 2551	109615	Xf 3533	12 33.4	+39 55	AlV	≤ 50	-11	± 5	7.31	-.06	-.08
31*	+49 2151	109680	Xf 3652	12 33.8	+49 28	FOV	≤ 50	-10	± 5	8.78	+.29	+.05
32*	+32 2260	109691	Xf 3574	12 34.0	+32 28	AlV	250	+ 8	± 5	8.89	-.04	-.08
33*	+33 2257	109762	Xf 3538	12 34.6	+33 18	Am	≤ 50	+ 6	± 4	8.58	+.27	+.11
34	+25 2534		Xf 3684	12 34.9	+25 20	sdO	≤ 75	+ 3	± 6	10.51	-.30	-1.08
			Xf 3514									
35*	+46 1802	109838	Xf 3650	12 35.2	+45 32	F2V	≤ 50	- 2	± 3	8.04	+.31	.00
36*	+33 2258	109845	Xf 3584	12 35.3	+32 49	F3V	≤ 75	+ 1	± 4	8.73	+.33	+.02
37*	+39 2541		Xf 3534	12 35.8	+38 57	FOV	≤ 75	+ 7	± 5	10.11	+.30	+.07
38*	+41 2312	9 CVn	Xf 3551	12 36.4	+41 9	A5V	250	-16*		6.37	+.18	+.07
			Pα 12694									
39*	+40 2558	109995	Xf 3537	12 36.4	+39 35	AOV	30	-133	± 2	7.61	+.04	+.09
			Pα 12680									
40*	+47 1977	110012	Xf 3663	12 36.4	+47 3	A3V	100	-66	± 5	9.84	+.05	+.06

Table 2 (Continued)

No.	BD	HD or Design.	Plate	α (1950)	δ (1950)	Sp. Type	v sin i (km/sec)	R.V. (km/sec)	p.e. of R.V. (km/sec)	V	B-V	U-B
41*	+36°2295	110066	Xf 3552	$12^h36^m.9$	+36°14'	A2p	≤ 25	-14.8*		$6^m.55$	$+^m.04$	$+^m.02$
			Pα 12695									
42*	+35 2362	110085	Xf 3540	12 36.9	+34 29	A7V	150	- 5	± 7	9.14	+.20	+.08
43*	+48 2045		Xf 3646	12 37.1	+48 3	F2V	≤ 50	+18	± 10	11.10:	+.26	+.03
44*	+37 2306	110166	Xf 3531	12 37.5	+37 16	B7V	150	-64	± 8	8.77	-.13	-.39
			Pα 12351									
45*	+49 2153		Xf 3647	12 37.6	+49 6	Am	≤ 50	- 8	± 5	9.64	+.29	+.12
46*	+31 2396	110248	Xf 3581	12 38.1	+30 39	Am	≤ 50	- 9	± 2	7.67	+.30	+.16
47*	+31 2397	110326	Xf 3582	12 38.7	+30 43	Am	50	- 8.6*		6.99	+.28	+.04
			Pα 12703									
48		NGP 193	B 1309	12 39.7	+31 12	A0V				11.92:*	+.46	-.06
49*	+46 1814	110500	Xf 3583	12 39.9	+46 9	Am	100	- 8.0*		7.04	+.24	+.09
50*	+38 2360		Xf 3557	12 40.7	+38 22	F0p	≤ 75	+ 8	± 4	9.70	+.33	-.01
51*	+38 2361		Xf 3564	12 40.8	+38 20	Am	75	-22	± 4	9.83:	+.24	+.07
52*	+36 2305	110787	Xf 3541	12 41.7	+36 3	Am	75	-24	± 4	7.10	+.31	+.09
53		NGP 203	B 1313	12 42.3	+35 16	sdG				12.26:*	+.50	-.13
54*	+36 2306	110854	Xf 3542	12 42.4	+35 55	A0V	≤ 50	-18	± 7	8.28	-.04	-.09
55*	+48 2052		Xf 3651	12 42.8	+48 18	A7V	≤ 50	- 2	± 3	10.92	+.26	+.04
56*		NGP 206	Xf 3543	12 42.9	+41 2	A2Vp?	≤ 50	+15	± 6	11.14	+.14	+.11
57*	+50 1946 NE	111041 NE	Xf 3644	12 43.7	+50 6	F6IV	≤ 50	- 8	± 4	9.5		
58*	+50 1946 SW	111041 SW	Xf 3645	12 43.7	+50 6	F5IV	≤ 50	-18	± 5	9.5		
59*	+43 2260		Xf 3653	12 46.1	+43 24	F3V	≤ 50	+12	± 3	9.22	+.29	+.02
60*	+49 2163	11 CVn	Xf 3649	12 46.4	+48 44	Am	40	- 1.9*		6.27	+.17	+.16
			Pα 12681									
61*	+44 2225	111422	Xf 3664	12 46.5	+44 26	A5V	≤ 75	+11	± 4	9.80	+.17	+.10
62*	+42 2343	111525	Xf 3661	12 47.2	+42 20	A7V	≤ 50	-11	± 7	8.58	+.19	+.10
63*	+49 2164	111573	Xf 3685	12 47.4	+48 31	F0V	75	-13	± 4	9.16	+.32	.00
64*	+38 2373	111604	Xf 3553	12 47.8	+37 47	A2III	200	-11*		5.90	+.16	+.07
			Pα 12679									
65*	+38 2374		Xf 3566	12 48.7	+37 40	F0V	≤ 50	-26	± 4	9.36	+.30	+.03
66*	+32 2283		Xf 3572	12 48.9	+32 12	A2V	100	- 1	± 5	10.25	+.11	+.06
67*	+41 2337	111859	Xf 3563	12 49.6	+40 31	F3V	75	+ 1	± 5	8.10	+.36	+.01
68*	+43 2271		Xf 3654	12 51.1	+43 25	F2V	100	0	± 8	10.30	+.34	-.01
69*	+31 2419		B 1320	12 51.3	+31 29	A2V	≤ 100			11.59:	+.11	+.06
70*	+32 2289		B 1319	12 51.3	+31 30	F5V:p				11.16:	+.47	-.05
71*	+34 2369	112171	Xf 3544	12 51.8	+33 48	A5V	120	+ 5.3*		6.27	+.19	+.08
			Pα 12702									
72*	+47 2001		Xf 3675	12 52.3	+46 39	A2V	≤ 100	+ 8	± 7	9.98	+.04	+.04
73		NGP 232	B 1312	12 53.6	+28 23	sdF		-250:		12.74:*	+.11	-.71
74*	+39 2580(br)	α CVn(br)	Xf 3696	12 53.7	+38 35	A0p	40	- 3.3*		2.89	-.12	-.32
			Pα 6289									
75*	+39 2580(ft)	α CVn(ft)	Xf 3687	12 53.7	+38 35	F0V	≤ 25	- 3.1*		5.64	+.32	-.03
			Pα 11123									

Table 2 (Continued)

No.	BD	HD or Design.	Plate	α (1950)	δ (1950)	Sp. Type	v sin i (km/sec)	R.V. (km/sec)	p.e. of R.V. (km/sec)	V	B-V	U-B
76*	+40°2596	112431	Xf 3556	$12^h53^m.9$	+40° 1'	Am	⩽ 75	- 7	± 7	$8^m.91$	$+^m.22$	$+^m.10$
77*	+32 2301	112487	Xf 3577	12 54.3	+32 13	A3V	⩽ 75	-22	± 7	9.66	+.11	+.09
78*	+44 2234	112501	Xf 3671 Rα 12704	12 54.3	+43 49	Am	50	- 8.8*		6.98	+.10	+.12
79*		NGP 235	Xf 3676	12 54.3	+47 35	A4V	200	+ 9	± 8	11.45	+.15	+.05
80*	+46 1832(br)	112515(br)	Xf 3672	12 54.5	+45 53	F2Vp?	⩽ 50	- 8	± 4	8.52	+.33	+.11
81*	+46 1832(ft)	112515(ft)	Xf 3673	12 54.5	+45 53	F6V	⩽ 50	-13	± 4	9.56	+.46	.00
82*	+47 2008	112940	Xf 3655	12 57.4	+46 44	Am	⩽ 75	-16	± 3	9.04	+.31	+.09
83*	+48 2073		Xf 3662	12 58.4	+48 29	F0V	⩽ 75	-15	± 7	10.68	+.34	-.04
84	+39 4926		Xf 3573 Xf 3648	22 43.9	+39 51	Hor.-br.	⩽ 50	-27	± 3	9.26:	+.21:	+.12:

Stars designated by an asterisk in Column 1 are those included in the zone ($\alpha = 12^h28^m$ to 13^h0^m; $\delta = +30^\circ$ to $+50^\circ$) in which all early-type stars were observed.

An asterisk following the radial velocity indicates that the value was obtained from the General Catalogue of Stellar Radial Velocities (Wilson 1953).

An asterisk following the V magnitude indicates that only one observation of the magnitude and colors was made. Magnitudes expressed only to the nearest one-tenth are based on values in the AGK2.

Remarks

2. A3 K-line, A5V Balmer lines, A7 metallic lines.
3. Peculiar A-type star: 73 Draconis type.
4. BDS 5655(ft.). A5 K-line, A7V Balmer lines, F2 metallic lines.
5. BDS 5655(br). CN appears to be weak.
6. Mg II 4481 weak or absent.
7. A4 K-line, A7V Balmer lines, F5 metallic lines.
8. Spectrum resembles α CVn(br): feature at λ4128; Balmer lines weaker than at luminosity class V; Mg II weak or absent.
9. All lines very weak relative to late F-type or G-type Balmer lines.
10. See text.
11. A4 K-line, A7V Balmer lines, F2 metallic lines.
12. All lines very weak relative to late F-type or G-type Balmer lines. Companion $13^m.5$, 300°, 3".
13. See text.
16. All lines weak relative to early F-type Balmer lines. A2 K-line.
19. A7 K-line, A7V Balmer lines, F2 metallic lines.
20. Peculiar A-type star: X Serpentis type.
23. ADS 8595 SE.
24. ADS 8595 NW.
29. See text.
33. A3 K-line, A8V Balmer lines, F2 metallic lines.
34. See Text.

Table 2

Remarks (Continued)

39. Spectrum very similar to α Lyrae. Metallic lines are somewhat weak.
41. Peculiar A-type star: 73 Draconis type. AOp in H.D.
43. Metallic lines appear somewhat weak.
45. A3 K-line, A7V Balmer lines, F3 metallic lines.
46. A3 K-line, A8V Balmer lines, F4 metallic lines.
47. A3 K-line, A8V Balmer lines, FO metallic lines. Spectroscopic binary.
48. The spectrum appears to be that of a normal AOV star and does not correspond to the B-V color.
49. A3 K-line, A7V Balmer lines, F5 metallic lines.
50. Peculiar F-star: β Cr B type.
51. A6 K-line, A8V Balmer lines, F2 metallic lines.
52. A7 K-line, A8V Balmer lines, F3 metallic lines.
53. All lines very weak relative to G-type Balmer lines.
56. Balmer lines and Mg II 4481 somewhat weak for this type. Spectrum similar to that of HD 161817.
57. ADS 8661 NE.
58. ADS 8661 SW.
60. A6 K-line, A7V Balmer lines, F3 metallic lines.
70. May be subluminous: metallic lines appear to be weak for this type.
73. All lines very weak relative to F-type Balmer lines. Iriarte-Chavira No. 139 = 673 (Bol. Obs. Tonantzintla y Tacubaya, No. 16, 1957).
74. ADS 8706(br). Peculiar A-type star and spectrum variable. Magnitude and colors from Johnson and Morgan (1953).
75. ADS 8706(ft). Spectral type from Johnson and Morgan (1953).
76. A3 K-line, A7V Balmer lines, F2 metallic lines.
78. A3 K-line, A5V Balmer lines, FO metallic lines.
80. ADS 8714(br). Metallic spectrum too strong for Balmer-line type. Appears in metallic-line star region of two-color diagram.
81. ADS 8714(ft).
82. A3 K-line, A8V Balmer lines, F5 metallic lines.
84. See text.

b) Radial Velocities

Despite the fact that only one low-dispersion (80 A/mm) spectrogram per star was available for most of the stars included in this study, it was decided to measure radial velocities for all stars not included in the *General Catalogue of Stellar Radial Velocities* (Wilson 1953). Although the accuracy of a given radial-velocity determination is not high, these measures should have some significance in the mean and also permit the segregation of stars of especially high velocity.

Since most of the stars are of A type, the number of spectral features which can be used for radial-velocity measures with low-dispersion spectrograms is limited. For most of the stars five Balmer lines, plus the Ca II K line when the latter was visible, were used. In addition, the He I 4026 and 4471 lines were measured for a few of the early-type stars, and the Mg II 4481 plus one or two strong Fe I lines for some of the later-type and metallic-line stars. Those brighter stars for which 69-inch spectrograms were available and which are not in the *General Catalogue* were also measured on Pα plates.

A comparison of the 4-inch camera X spectrograph radial-velocity determinations for 12 stars with radial velocities listed in the *General Catalogue* showed that a correction of +13.5 km/sec to the measured values was necessary to reduce them to the system of the *General Catalogue*. Although the correction is large, it is in line with similar corrections determined by Dr. Helmut Abt for the 8-inch and 16-inch cameras of the X spectrograph in 1959–1960: −7.0 km/sec for 4 plates taken with the 8-inch camera and +3.2 km/sec for 16 plates taken with the 16-inch camera (Abt 1960). The corrected radial velocities and the corresponding probable errors of the determinations are listed in Table 2.

c) Rotational Velocities

Rotational velocities for the stars in this survey were estimated by comparing line profiles visually with those of stars with measured rotational velocities. The stars in Table 1 were used as standards of axial rotation (Slettebak 1954, 1955; Slettebak and Howard 1955) for the Xf plates, and a number of additional standards used for the Pα plates.

It was determined that stars with $v \sin i \simeq 50$ km/sec could not be distinguished from sharp-lined stars on most Xf plates but that a rotational velocity of about 75 km/sec was usually discernible. Most stars with apparently sharp lines have therefore been listed with $v \sin i \leq 50$ km/sec in Table 2, although the upper limit was raised to 75 and even 100 km/sec in a few cases of inferior plate quality. For Pα plates, values of $v \sin i$ near 25 km/sec are just on the threshold of detectability for good-quality plates.

III. PHOTOMETRY

During January and February, 1960, U, B, V observations for all but a few stars in Table 2 were made with the 36-inch and 82-inch reflecting telescopes of the McDonald Observatory. All stars were observed twice, with the exception of 10 stars which are marked with an asterisk in Table 2. Although all the nights used were not of the first quality, the internal agreement for stars with two observations is good. The blue-ultraviolet colors for the standard stars did not transform well from the instrumental system to $U - B$, resulting in an uncertainty in the zero point of $\pm 0\overset{m}{.}02$, although the scale should be accurate. For the stars which were observed twice, the mean errors for one observation are the following: $V : \pm 0\overset{m}{.}011$; $B - V : \pm 0\overset{m}{.}007$; $U - B : \pm 0\overset{m}{.}008$. The two-color diagram for the stars observed is shown in Figure 1.

IV. RESULTS AND DISCUSSION

a) Spectra and Colors of Population I Objects

1. A glance at Table 2 shows that the majority of stars included in this survey are normal stars which are on, or somewhat above, the main sequence plus a number of

metallic-line stars and peculiar A-type and F-type stars. In the terminology of the Vatican Conference on Stellar Populations (O'Connell 1958), these stars may be classified as "older population I" objects. The two-color diagram shown in Figure 1 corroborates the spectral classification on this point: most of the stars lie along the curve for normal main-sequence stars (except for the metallic-line stars, which lie in their usual place beneath the curve for main-sequence stars) and show no color peculiarities. Evidently the percentage of halo population II stars at high galactic latitudes is small to a limiting photographic magnitude of 11.5.

2. Sixteen new metallic-line stars are listed in Table 2, of which 12 are located in the zone in which all early-type stars were observed. A comparison of the number of metallic-

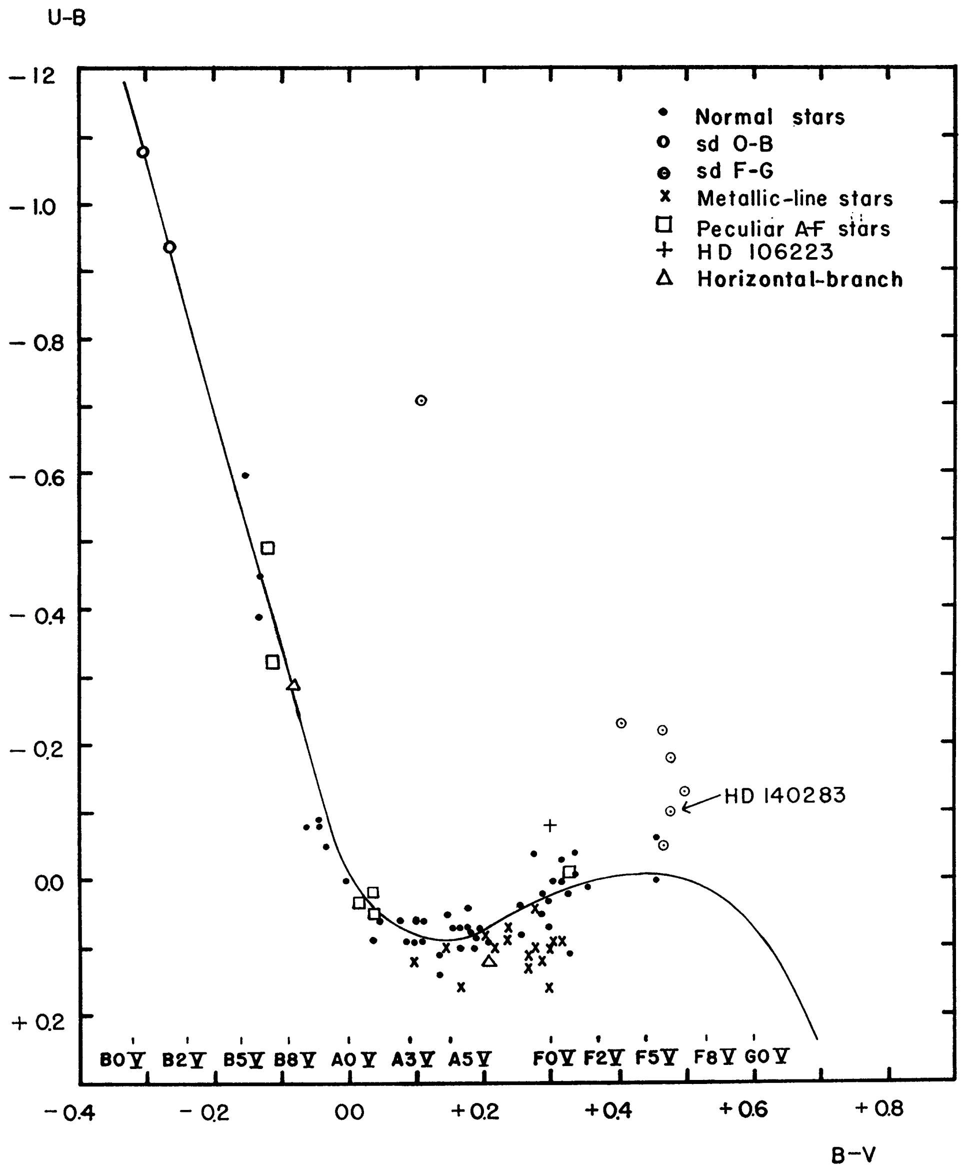

FIG. 1.—The two-color diagram for the galactic pole stars included in this study. The solid line represents the unreddened main sequence

line stars relative to the number of population I stars of equivalent K-line type in this zone with the corresponding ratio for stars near the sun (Slettebak 1954, 1955) shows a higher percentage of metallic-line stars at high galactic latitudes (Slettebak 1960). When the comparison is made with normal main-sequence stars of equivalent absolute magnitude, however, so that the figures refer essentially to equal volumes of space, the percentage of metallic-line stars at high galactic latitudes is found to be only slightly higher than in the neighborhood of the sun. In view of the small sample considered, it must be concluded that the present study presents insufficient evidence to suppose that the relative numbers of metallic-line stars near the sun and at high galactic latitudes are different.

Plots of the K-line, Balmer-line, and metallic-line types versus the $B - V$ and $U - B$ colors were made. The best correlation was found to exist between the Balmer-line types and $B - V$ colors, as shown in Figure 2. Much of the scatter in this diagram can probably be understood in terms of the difficulty of assigning Balmer-line types with an accuracy within one-tenth spectral class. A similar diagram in which metallic-line

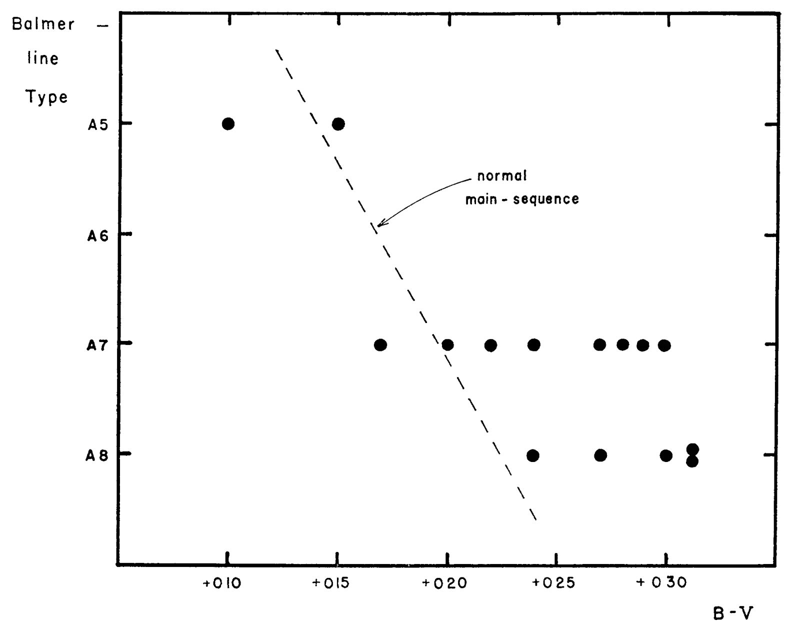

FIG 2 —The correlation between Balmer-line types and $B - V$ colors for the galactic pole metallic-line stars (the spectroscopic binary HD 110326 is omitted)

types are plotted against $B - V$ colors shows a mild correlation in the same sense as in Figure 2, but the scatter is much larger. The plots of the K-line versus $B - V$ colors, as well as those showing all three classification parameters versus $U - B$ colors, show no correlation whatsoever.

The correlation between $B - V$ colors and Balmer-line types for metallic-line stars in the neighborhood of the sun was pointed out by C. and M. Jaschek (1957, 1959). Their results indicate that metallic-line stars of a given Balmer-line type have very nearly the same $B - V$ colors as normal main-sequence stars of that spectral type. As may be seen in Figure 2, the present results suggest that metallic-line stars of a given Balmer-line type are somewhat redder than main-sequence stars of that type. They are considerably too blue for their metallic-line types, however, and, in view also of the smaller scatter with $B - V$ of their Balmer-line types, the latter would still seem to be physically the most significant.

b) Spectra and Colors of Stars Showing Population II Characteristics

The spectra of ten of the stars in Table 2 show one or more of the following population II characteristics: weakened metallic lines, large radial velocity, and little or no axial rotation. Three additional stars show these characteristics to a lesser degree. The population nature of some of these stars is confirmed by their positions in the two-color diagram in Figure 1. A discussion of these stars follows.

1. *Hot subdwarfs.*—Two of the stars in Table 2 are hot subdwarfs: NGP 177 and BD+25°2534. The former was independently discovered by Feige (1958) and is No. 65 in his list, while the latter was first noted as very blue by Malmquist (1927) and is No. 299 in his catalogue and also No. 66 in Feige's list.

NGP 177 shows the weak, broad, diffuse Balmer lines that are typical of the hot subdwarf, together with the presence of He I 4471 and, more faintly, He I 4026. The last visible Balmer line is H12, and the ultraviolet continuum is quite strong, with no evidence of the Balmer discontinuity. The Ca II K line is not visible on our plate. Estimates of the radial velocity and rotational velocity of this star were not possible.

The spectrum of +25°2534 is similar to that of NGP 177 but differs in particulars. The Balmer lines appear to be somewhat weaker, and the last visible Balmer line is H11 on our plates. Hγ and possibly Hδ appear to have sharp absorption cores, much like the Balmer lines in certain B-type shell stars. The helium lines at λ 4026 and λ 4471 are stronger than in NGP 177, and faint features are visible near λ 4200 and λ 4686 which are probably due to He II. A broad and diffuse feature is weakly present at the position of the Ca II K line. The He I 4471 line looks sharp and suggests a low rotational velocity ($\leq$ 75 km/sec). The radial velocity of +25°2534 was measured as +3 km/sec. Although this is not an accurate determination in view of the small plate scale, it seems certain that the star does not have a very large radial velocity.

Both these stars are very blue, as may be seen in the two-color diagram in Figure 1. They lie very close to the curve for the normal main sequence and do not show the ultraviolet excesses referred to by Feige (1958). It would seem to be impossible to segregate stars such as these from normal unreddened early-type stars purely by the colorimetric approach.

2. *F- and G-type subdwarfs.*—Stars Nos. 9, 12, 16, 53, and 73 (and, to a lesser extent, 70) in Table 2 show the typical spectra of the later-type subdwarfs. Spectral types assigned to these stars on the basis of the absolute intensities of the Balmer lines would all fall in the range early F to G, and in every case the metallic lines are very weak relative to the Balmer-line types. Although it was not always possible to make a rotational-velocity determination, none of these stars showed any conspicuous line broadening. Radial-velocity measurements for two of the stars (Nos. 12 and 73) show large negative radial velocities.

All these stars show the ultraviolet excesses that are characteristic of the later-type subdwarfs, as may be seen in the two-color diagram in Figure 1. The well-known F-type subdwarf HD 140283 is plotted in the diagram for comparison purposes (Roman 1955). Of special interest is No. 73 (NGP 232) with a $B - V$ color like that of a middle A-type star and a corresponding ultraviolet excess of about 0.8 mag. Although it is set apart from the other late-type subdwarfs on the two-color diagram, its spectrum is very similar to the others and shows no outstanding peculiarities on our plates.

3. *Horizontal-branch stars.*—During the course of objective-prism surveys at the Hamburg Observatory (Slettebak and Stock 1957, 1959; Hardorp, Rohlfs, Slettebak, and Stock 1959), two rather faint stars at high and intermediate galactic latitudes were found which showed the sharp density break at the Balmer limit that is characteristic of supergiant stars of A type. The two stars are Nos. 10 (BD+32°2188) in the galactic pole zone, and 84 (BD+39°4926) in Lacerta. Both stars show spectra that are decidedly not normal and also unlike those of the other population II stars considered thus far.

Like A-type supergiant stars, they show the sharp Balmer break already referred to and weak Balmer lines. All metallic lines are weak, however, including the Fe II and other lines that are characteristic of high-luminosity stars. Unlike the hot subdwarfs, the Balmer lines are sharp and deep and are visible to H19 in $+32°2188$ and to H20 in $+39°4926$, on our plates.

The more extreme of the two stars is $+32°2188$, whose Balmer lines are similar to those of an F2 V star. Only a few metallic lines are visible, including very weak features near Mg II 4481 and Fe II 4233 and a weak and diffuse feature near the Ca II K line. He I 4026 also appears to be faintly present.

The Balmer lines of $+39°4926$ are similar in strength to those of an A7 V star but without the Stark wings of the latter. The only metallic line that is clearly visible is a very sharp Ca II K line which is equal in strength to that in an A0-type star.

The spectra of these two stars most nearly resemble those of the globular-cluster horizontal-branch stars. In 1958, Dr. Guido Münch very generously permitted one of us (A.S.) to examine his spectrograms of a number of stars to the blue of the RR Lyrae gap in the horizontal branches of the globular clusters M10, M13, M15, and M92. The majority of his stars show the sharp and deep Balmer lines, the sharp density break at the Balmer limit, and the general weakness of metallic lines that characterize the spectra of $+32°2188$ and $+39°4926$. Greenstein (1959) has found other stars of this type in the galactic halo.

In the two-color diagram in Figure 1, $+32°2188$ lies on the normal main-sequence line at a $B - V$ color corresponding to about type B8, while $+39°4926$ is redder, with a slight ultraviolet deficiency. The colors of both stars are somewhat uncertain, however.

Additional population II characteristics of these stars are their rotational and radial velocities. Both stars have sharp lines on our plates ($v \sin i \leq 50$ km/sec), in agreement with observations showing that objects of this type are characterized by small axial rotation (Greenstein 1956). The radial velocity of $+32°2188$ is $+100$ km/sec, making this a high-velocity object. The radial velocity of $+39°4926$ is smaller, -27 km/sec.

4. *HD 106223.*—The star HD 106223 (No. 13 in Table 2) was noted by Bidelman (1951) as showing the spectroscopic characteristics of the A-type subdwarfs. Later, the Burbidges (1956) studied the star as one of five which showed some population II characteristics. The spectrum of HD 106223 is not unlike that of the horizontal-branch star $+32°2188$, in that the Balmer lines correspond to spectral type early F, while the metallic lines are much too weak for this type. There are important differences, however: HD 106223 does not show a sharp and strong Balmer jump; it does show axial rotation ($v \sin i \simeq 100$ km/sec); it is not a high-velocity object (Burbidge and Burbidge 1956); and it occupies a different place in the two-color diagram. Figure 1 shows the star with a $B - V$ color corresponding to spectral class F0 and an ultraviolet excess for that class. HD 106223 is seen to occupy an adjacent position to the F-type subdwarfs in the two-color diagram, and there are spectroscopic resemblances also, but again differences in axial rotation and space motions exist. It would seem that this star represents a mixture of population I and II characteristics, as the Burbidges (1956) have pointed out.

c) Axial Rotation

1. Considering only the normal population I stars in Table 2, the estimated rotational velocities suggest that axial rotation may be less at high galactic latitudes than for stars of similar spectral type in the neighborhood of the sun. The 19 normal A0–A7 V stars in Table 2 in the magnitude range between 8.0 and 11.6 have a mean observed $v \sin i$ of 91 km/sec. This figure may be compared with a corresponding value of 138 km/sec for 99 A0–A7 V stars in the neighborhood of the sun (Slettebak 1954, 1955). Since the galactic pole sample is very small and the rotational-velocity estimates are based on low-dispersion plates, this suggestion must be considered as tentative, to say the least.

2. No star with population II characteristics in Table 2 shows rotational line broaden-

ing on our plates, with the exception of HD 106223, which was discussed in Section IV, *b*, 4.

d) Radial Velocities

1. The existence of large radial velocities for some of the population II stars (F-type subdwarfs, horizontal-branch stars) in Table 2 has already been dissussed. These stars are not present in sufficient numbers in this study to permit a statistical discussion.

2. Attention should be called to three stars with apparently normal population I main-sequence spectra which have quite large radial velocities. The B7 V stars +49°2137 and HD 110166 have measured radial velocities of +135 and −64 km/sec, respectively, but both show considerable axial rotation and have normal spectra. The A0 V star HD 109995 has a measured radial velocity of −133 km/sec. The metallic lines are somewhat weak for this type, but the spectrum is not unlike that of α Lyrae.

3. A comparison of the distribution of radial velocities of the fainter normal A-type stars in Table 2 with that of similar stars close to the galactic plane shows that both the average radial speed and the radial-velocity dispersion are larger for the former. The faint normal A-type stars included in this study appear to have intermediate-velocity characteristics. No such effect was found for the fainter normal F-type stars in Table 2, which appear to have velocity characteristics similar to stars of corresponding type near the galactic plane. In both cases the sample is quite small, however.

In conclusion, one of us (A.S.) would like to thank Dr. I. S. Bowen for courtesies extended at the Mount Wilson and Palomar Observatories as a guest investigator in the spring of 1958. I am also indebted to Dr. Guido Münch for permission to examine his plates, and to Drs. Münch, A. D. Code, J. Greenstein, and Helmut Abt for helpful discussions. Dr. W. W. Morgan very kindly read the manuscript and made a number of valuable suggestions. Mrs. Rosemary Mardis assisted with the radial-velocity reductions. A grant from the National Science Foundation in support of the spectroscopic portion of this investigation is gratefully acknowledged.

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