

A SEARCH FOR UNDERLUMINOUS HOT STARS

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ABSTRACT

A new list is given of 114 faint blue stars in the galactic polar regions. Spectra and photoelectric colors of a small fraction indicate that these are largely halo and subluminous stars, with relatively high radial velocities. Some interesting hot subdwarfs and possible white dwarfs are included.

Faint blue stars ranging from 11 to 17 mag. were found by Zwicky (Humason and Zwicky 1947) during a survey of 800 square degrees near the north galactic pole and near the Hyades. Low-dispersion spectra obtained by Humason for a good number showed that early-type or peculiar stars were involved. In recent years, photographic surveys by Luyten (1953, 1954, 1955) and Iriarte and Chavira (1957) have revealed a large number of faint blue stars. Luyten and Miller (1951) give proper motions of some of the HZ stars, as do Pels, Perek, and Blaauw (1951, 1953). Some photoelectric color indices of the HZ stars were available, kindly communicated in advance of publication by D. L. Harris III, and there exist a large number of approximate photographic colors of other faint blue stars. Harris' three-color work showed that all but the bluest of the HZ white dwarfs could be recognized colorimetrically, in most cases, and that the other blue stars (hot subdwarfs in particular) frequently showed $U-B$ excesses. Thus the existence of various types of faint blue stars was shown to be very probable. From spectra obtained by Greenstein (1956) and unpublished (see Zwicky 1957), a number of categories were recognized: remote main-sequence stars, horizontal-branch and galactic-halo stars, underluminous hot stars, and white dwarfs. Some objects belonging to the last group can be identified with three-color photometry alone, but spectra and three-color photometry will both be needed to distinguish between the other classes.

I have been interested in finding more stars of these peculiar kinds, and for this purpose, while a student at the California Institute of Technology, I undertook in 1956 a systematic search for faint blue stars limited mostly to stars brighter than 14 mag., i.e., accessible to detailed spectroscopic study. The survey was made on the plates of the National Geographic—Palomar Sky Survey. The colors were blue, 103a-O plates without filter (including a good deal of ultraviolet) and red, 103a-E and red plexiglas centered near $H\alpha$. The north galactic polar areas were fully covered as well as part of the south polar region, and three objects were found during searches for other purposes. From a search on a blink comparator a first selection of blue stars was made; this was refined later to eliminate dubious cases. The main difficulty was that the exposure times for the Survey plate pairs were designed to give approximately equal images near type G0; stars of all earlier types appear blue, and the stars here selected are the very bluest. Rough estimates of apparent magnitude were made, using step-scales suitable for the average Survey plate; these scales, fundamentally, refer to a calibration based on Selected Area 57.

The present survey covers 3600 square degrees, mostly at galactic latitudes higher than $+55^\circ$, and about 2400 square degrees at galactic latitudes south of -45° and at declinations north of -15° . Table 1 contains the data for identification of these objects,

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TABLE 1*
CO-ORDINATES AND PRELIMINARY DATA ON 114 FAINT BLUE STARS

FEIGE NUMBER	1950		m_{pg}	C I (mag)	$B-V$ (mag)	$U-B$ (mag)	SPECTRAL TYPE	V (km/sec)
	α	δ						
1	0 ^h 09 ^m 4	+11° 49'	12 7	-0 15				
2	0 09 8	+15 06	13 1	- 4				
3	0 17 2	- 9 34	15 0	- 3				
4	0 17 4	+13 36	14 0	- 7				
5	0 17 7	- 3 15	13 5	- 25				
6	0 40 5	- 9 02	14 7	- 25				
7	0 41 2	-10 17	15 0	- 35				
8	0 44 1	+13 06	14 2	- 15				
9	0 52 1	- 4 33	14 0	- 2				
10	0 56 4	- 5 41	9 8	- 2				
11	1 01 7	+ 3 58	11 5	- 5			A0p	
12	1 19 0	+12 26	12 7	- 15				
13	1 27 8	- 9 55	13 3	- 2				
14	1 45 6	- 6 11	12 5	- 5			sdB	
15	1 46 5	+13 18	10 6	- 15				
16	1 52 1	- 7 01	11 0	- 2				
17	1 55 1	+ 6 57	15 0	- 2				
18	1 56 3	- 5 03	9 3	- 15				
19	2 08 3	+ 1 34	14 4	- 15				
20	2 09 4	+ 8 33	14 0	- 15				
21	2 14 8	+ 4 01	14 1	- 1				
22	2 27 7	+ 5 03	12 4	- 4				
23	2 29 7	+ 2 47	11 9	- 15				
24	2 32 5	+ 3 31	12 3	- 25	-0 25	-1 23		
25	2 36 0	+ 5 15	11 6	- 25				
26	2 37 5	+ 3 43	12 9	- 5				
27	2 37 6	+ 8 48	11 4	- 25				
28	2 52 5	- 4 01	11 5	- 2				
29	2 55 3	- 2 12	10 3	- 2			B3 III	+2
30	2 58 2	-11 38	13 0	- 15				
31	3 02 0	+ 2 46	15 0	- 3				
32	3 05 1	-11 56	14 0	- 15				
33	3 05 1	-10 57	13 5	- 2				
34	10 36 7	+43 21	10 9	- 5			WD?	
35	10 42 6	+25 08	12 7	- 2				
36	11 01 8	+24 56	12 5	- 3	- 25	-1 02		
37	11 08 2	+ 7 36	14 3	- 15				
38	11 14 2	+ 7 16	12 9	- 25				
39	11 15 3	+44 33	13 4	- 2				
40	11 18 9	+11 36	11 1	- 2	- 12:	-0 62:	B6	
41	11 23 3	+ 6 47	11 0	0	+ 09	-0 02		
42	11 25 7	+39 44	12 7	- 35				
43	11 26 5	+38 28	14 1	- 5			WD	
44	11 30 2	+15 34	14 4	- 2				
45	11 33 5	+29 18	14 8	- 3				
46	11 34 9	+14 27	13 1	- 5			sdO	+170
47	11 35 4	+45 13	16 6	- 65				
48	11 44 5	+61 33	13 1	- 25				
49	11 45 0	-15 49	11 8	- 6			B1	+67
50	11 47 8	+52 50	11 9	- 1				
51	11 51 7	+18 53	10 2	- 3			B5	
52	11 56 0	+12 31	12 9	- 1				
53	11 59 8	+50 12	11 7	- 1				
54	12 00 1	-19 24	15 0	- 2				
55	12 02 5	+60 51	13 3	- 3				
56	12 04 1	+11 57	10 9	- 4			B5	
57	12 06 3	+ 7 44	13 0	-0 2	-0 02	-0 07		

* Numbers 113 and 114 are near the Veil and Network nebulae.
The following stars are in the BD: 10 = -6°17'; 15 = +12°23'; 18 = -5°35'; 28 = -4°49'; 29 = -2°52'; 51 = +19°25'15"; 66 = +25°25'34" = Malmquist 299; 67 = +18°26'47"; 71 = +30°23'55"; 82 = +32°23'59"; 86 = +30°24'31"; 99 = +20°30'04"; 100 = +19°28'36"; 107 = -14°6'357"; 111 = +7°50'93".

TABLE 1—*Continued*

FEIGE NUMBER	1950		m_{pg}	C I (mag)	$B-V$ (mag)	$U-B$ (mag)	SPECTRAL TYPE	V (km/sec)
	α	δ						
58	12 ^h 11 ^m 4	+ 2° 17	11 8	+0 1	+0 18	+0 07	B9	
59	12 14 4	+15 51	11 6	— 2				
60	12 16 5	+15 24	13 1	— 1				
61	12 19 3	+48 04	11 9	— 1				
62	12 20 1	+57 09	13 8	— 35				
63	12 21 4	+57 57	13 5	— 15			A0p sdO sdOp, WD?	+34 +22
64	12 27 8	+46 53	12 3	— 2				
65	12 33 4	+42 39	11 9	— 2				
66	12 34 9	+25 21	10 0	— 3				
67	12 39 4	+17 49	11 5	— 5	— 34	—1 26		
68	12 39 8	+16 41	12 2	— 2	+ 05	+0 10	B9	
69	12 41 4	+16 12	12 7	— 1				
70	12 52 3	+52 01	11 8	0				
71	12 59 5	+29 51	10 4	— 15				
72	13 03 0	+ 6 15	11 0	0				
73	13 04 5	+49 06	13 8	— 2			Bp, WD? sdBp A0	
74	13 05 0	+19 53	11 6	— 25				
75	13 13 5	+13 14	14 2	— 1				
76	13 14 8	+13 03	15 0	— 1				
77	13 16 4	+29 02	15 0	— 25				
78	13 17 4	+29 40	13 8	— 15			B3p B9	+148 ..
79	13 17 4	+56 55	16 0	— 3				
80	13 17 6	+12 20	11 3	— 2	— 10	—1 00		
81	13 29 4	+15 56	13 3	— 5				
82	13 29 6	+32 02	10 4	— 15	+ 01	—0 01		
83	13 30 2	+53 38	13 4	— 1			B9	
84	13 32 8	+13 43	11 9	— 3				
85	13 34 7	+ 8 35	15 0	— 1				
86	13 36 1	+29 37	9 3	— 3				
87	13 38 1	+61 07	12 8	— 2				
88	13 52 6	+11 58	15 0	— 25			B9	
89	14 03 6	+ 7 02	14 2	0				
90	14 05 4	+ 5 22	13 9	0				
91	14 06 9	+59 55	13 9	— 2				
92	14 10 0	+50 21	11 2	— 25				
93	14 15 3	+13 16	15 0	— 35	— 24:	—1 09:	sdB2	
94	14 21 0	+21 03	12 0	0				
95	14 26 3	+21 20	13 0	— 5	— 23	—1 06		
96	14 28 0	+21 30	13 3	— 25				
97	14 33 8	+30 20	12 0	0				
98	14 36 2	+27 43	11 7	— 1			B5p	
99	14 37 2	+19 39	10 0	— 2	— 13	—0 54		
100	14 37 4	+19 21	11 6	— 1				
101	14 38 4	+18 07	11 5	— 2	— 05	—0 22		
102	14 41 4	+51 56	16 0	— 5				
103	14 49 3	+11 52	13 0	— 15			B8p	
104	14 49 8	+55 49	13 8	— 1				
105	14 53 1	+12 57	13 9	0				
106	22 40 2	— 4 27	14 0	— 4				
107	22 47 8	—13 34	12 0	— 2				
108	23 13 6	— 2 07	13 2	— 1				
109	23 14 9	+ 7 35	13 6	— 2				
110	23 17 4	— 5 26	11 5	— 4	—0 31	—1 18		
111	23 49 0	+ 8 25	11 2	— 15				
112	7 49 1	—14 35	12 8	— 2				
113	20 46 8	+30 05	12 0	— 3			B8p	
114	20 47 6	+29 54	12 5	—0 4				

including estimated magnitudes and colors on the international scale. The magnitudes should be accurate to ± 0.4 mag., and the colors to ± 0.15 mag. The available colorimetric data plotted in Figure 1 show the comparison of my estimated colors with available photoelectric colors; these are unpublished but were kindly supplied by W. G. Tift and a few by H. C. Arp. A large majority of the negative color indices in Table 1 must be real, indicating that the list contains mostly O, B, or early A stars.

The spectra in Table 1 were supplied by Greenstein, with a few by G. Münch and G. Wallerstein. The spectral types are consistent with the $U-B$, $B-V$ color indices of the six stars for which both sets of data exist. The types are preliminary. A large majority of the stars have peculiar spectra, and their classification is difficult. Peculiarities in-

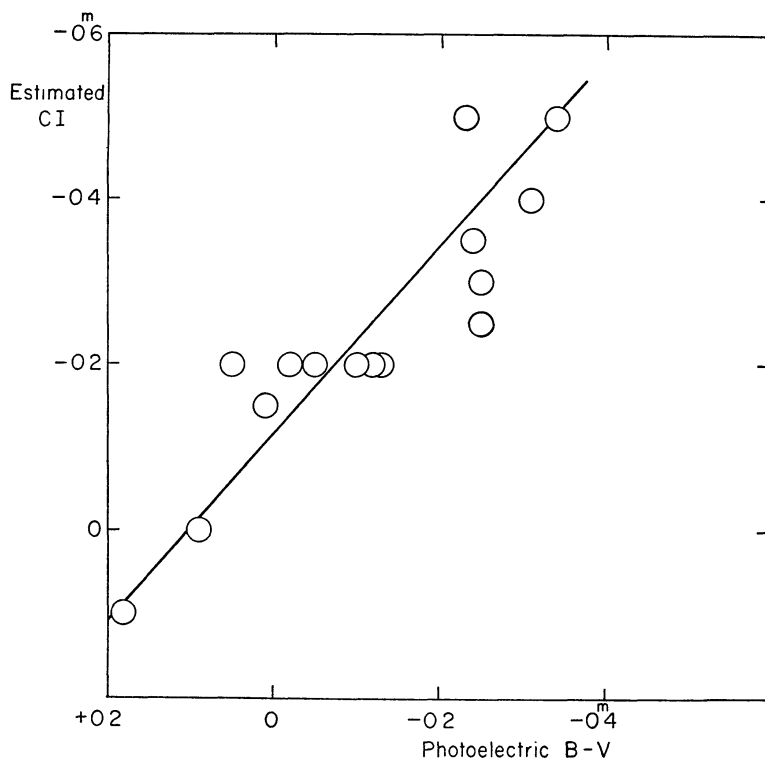


FIG. 1—Comparison of estimated color, C.I., with photoelectric $B-V$ colors

clude the presence of B stars with very weak lines of He I and A or late B stars with no Mg II. Some blue stars classified here as sdB show nothing but shallow hydrogen lines with a small Balmer discontinuity; others which show strong He I (or He II) lines are classified as sdO. There is considerable uncertainty in the spectroscopic distinction between the sdO, sdB, and possible very hot white dwarfs. A similar uncertainty occurs in the purely colorimetric approach; Figure 2 shows the location of those stars for which $U-B$, $B-V$ colors are available, with respect to the standard three-color relation. Note that stars Feige 24, 80, 93, 95, and possibly some others show an ultraviolet excess. Three Humason-Zwicky sdO stars found by Greenstein and HD 127493 found by Münch are plotted and show similar ultraviolet excesses. The excess of HZ3, however, is mostly interstellar reddening, which must also affect some of the stars of the present survey, since even subdwarfs are farther from the galactic plane than the bulk of the absorbing material.

The spectrum of star No. 67 has been investigated by G. Münch. This object is so hot

that the absorption line $\lambda 4686$ of He II is the only strong feature visible. According to Greenstein, an object like +28°4211 shows both He II and H lines, while the very hot probable white dwarf, HZ 21, shows both He II and He I. From its color and spectrum, Feige 67 is one of the hottest stars known.

An independent search in the 400 square degrees near the north galactic polar region covered originally by the Humason-Zwicky program showed that my survey was complete there to about 13.5 mag. However, evidence exists for statistical incompleteness in my list, from the distribution over the sky of the stars fainter than 12 mag. This may arise from small differences in the quality of individual Survey plates. None of the stars listed in Table 1 have been found by Iriarte and Chavira.

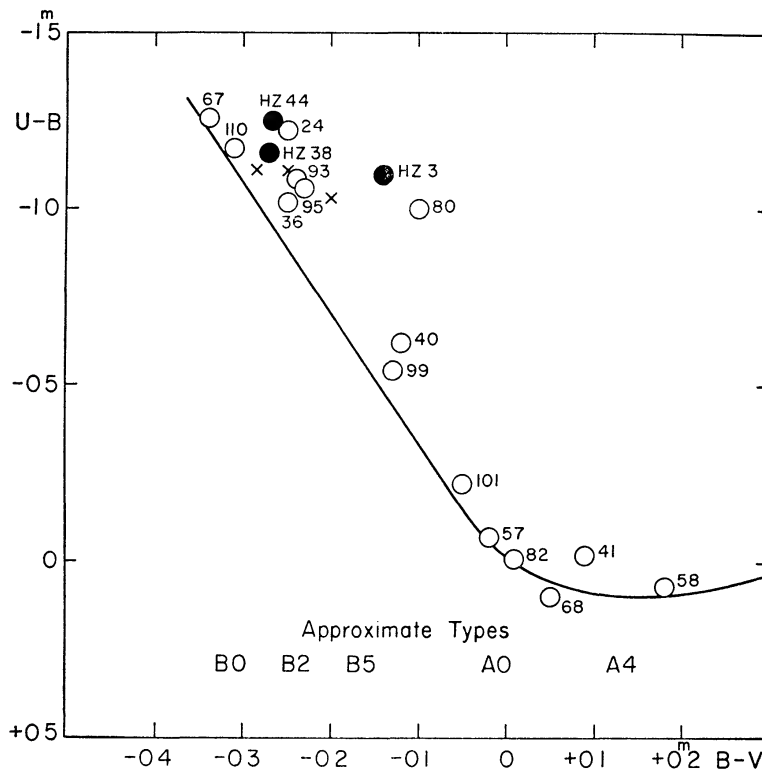


FIG. 2—The $U - B$, $B - V$ relation for the Feige stars designated by numbered open circles, the hot subdwarfs HZ 3 (reddened), HZ 38, HZ 44 (dots), and some standards (crosses). The upper end of the normal relation is not accurately defined.

The radial velocities by Greenstein, given in Table 1, show that they are high-velocity objects and represent in their majority the blue sequence of halo population II. Some exceptions, however, were noted spectroscopically. The star numbered 29 is a distant object, probably belonging to population I, showing strong Si II, normal He I, and N II lines. Star 49 has strong lines of Si IV and He I and some rotational broadening, again indicating population I, although the radial velocity is high (+67 km/sec). Population I early B stars at these magnitudes are very distant from the galactic plane, and such stars may be "runaway," normal main-sequence stars. If the latter hypothesis is correct, such stars must have a high average z -component of velocity. Consider the case of star 49, listed as normal B1, which has a distance modulus of 15.0 and a height of 7000 psc above the galactic plane. An evolutionary life-span of 35 million years then

requires an average velocity in the z -direction of the order of 200 km/sec, which is not inconsistent with the present residual radial velocity of $+67$ km/sec.

The data concerning proper motions are practically non-existent, and those on absolute luminosities and radial velocities are too scarce yet to permit any more detailed discussion of this promising field of research.

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