A SEARCH FOR FAINT BLUE STARS*

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ABSTRACT

Four-color photography has been used in a search for faint blue stars with the 18-inch Schmidt telescope at Palomar, undertaken in the hope of finding new white dwarfs. In this *Contribution* the results are given for stars brighter than magnitude 15.0 pg in two regions: (*a*) the Hyades cluster; (*b*) the region of the north galactic pole. Spectroscopic observations have been made with the 100-inch reflector.

In the Hyades region fourteen blue stars were found, with spectral types ranging from B0 to B5. Proper motions are known for ten of these stars. From their motions and spectra, four are shown to be white dwarfs, three of them physical members of the cluster. Absorption lines are wide and shallow in the spectra of two others, whose motions are not known—an indication that they also may be white dwarfs.

In the region of the north galactic pole thirty-one blue stars were found. Their spectra range from B0 to A0. Proper motions are available for only four stars, one of which, from its motion and spectrum, is a white dwarf. Two other stars, whose motions are unknown, have spectra similar to those of the white dwarfs. The spectra of the remaining twenty-eight stars appear normal; if these objects are high-luminosity blue stars, their distances are exceedingly large. Possibly they belong to the type of stellar population shown in the Hertzsprung-Russell diagram for globular clusters and designated by Baade as "Type II." If so, their absolute magnitudes are about 0.0, and their distribution in space would be similar to that of the globular clusters and cluster-type variables.

I. GENERAL OUTLINE OF THE SEARCH PROGRAM

Schmidt telescopes of large apertures are well suited for search programs because they give uniform definition over considerable fields and because they are practically achromatic and allow the effective use of full-size objective prisms and gratings. As part of the work of the 18-inch Schmidt telescope at Palomar, a survey of the sky in different colors has been conducted during the past few years. Large areas of the sky were photographed in the infrared, red, yellow, blue, and near ultraviolet parts of the spectrum with the intention of selecting different types of interesting stars from the relative intensities in various parts of their spectra. In the present paper some results are given for a number of faint blue stars found during a search for white dwarfs. The search part of the program covered in this report was carried on during the years 1939–40 and was concentrated in two regions, namely, (*a*) the Hyades cluster of stars and (*b*) the neighborhood of the northern galactic pole. The reasons for these choices are as follows: J. M. Ramberg had announced the discovery of two white dwarfs among the physical members of the Hyades cluster.[1] A further search for white dwarfs among the faint members would be of particular interest in connection with the evolution of star clusters. It was expected also that, if apparently faint blue stars were found at the northern galactic pole, they might be white dwarfs, as the main-sequence stars of types O, B, and A are highly concentrated along the plane of the Milky Way.

For practical reasons the search was limited to stars brighter than about the fifteenth apparent photographic magnitude. To identify short-period variable stars, each field was photographed four times within a few hours on clear nights. The four types of photographs are as follows:

1. One exposure of 10 minutes on Agfa Supersensitive Panchromatic film with an intervening Minus Red 2 Gelatin filter, covering the region λλ 3500–5400.

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[1] *A.N.*, **265**, 111, 1938; *Stockholms Obs. Medd.*, No. 37, 1938; *Stockholms Obs. Ann.*, **13**, No. 9, 90, 1941.

2. One exposure of 30 minutes on Agfa Supersensitive Panchromatic film with an Áero 2 Gelatin filter or a GG 11 glass filter of 2-mm thickness, covering the region λλ 4900–7000.

3. One exposure of 10 minutes on Agfa Commercial noncolor-sensitive film, covering the region λλ 3500–5200.

4. One exposure of 60 minutes on Agfa Supersensitive Panchromatic film with a 2-mm UGI glass filter, covering the region λλ 3500–3900.

All the films were developed for 7 minutes with Rodinal 1:20 at 65° F. The yellow exposure, No. 2, was then compared with the violet exposure, No. 4; blue stars could be identified with relative ease if no strong Balmer continuum in absorption was present. The blue exposures, Nos. 1 and 3, were compared to rule out short-period variable stars. A succession of fields was chosen, centered around guide stars 5° apart in right ascension and declination. Since the diameter of the field for the Schmidt telescope is slightly greater than 9°, most of the stars were included in different fields, and additional checks were obtained. This check is necessary because some of the photographs are not of the very best quality. The films sometimes move slightly in the plateholder because of the effects of humidity and differences in temperature, especially during the longer exposures. Also dust specks on the filters may interfere with a star image, and inequalities may occur in the process of development. Some difficulties were encountered because of variable red sensitivity of the panchromatic films.

II. PRELIMINARY LIST OF FAINT BLUE STARS

In Table 1 we give the results for fifteen stars in the region of the Hyades cluster and thirty-three stars near the northern galactic pole. Eighteen fields, each about 9° in diameter, were searched. The nine fields in the Hyades are centered on the intersections of three hour-circles having right ascensions 3^h56^m, 4^h16^m, and 4^h36^m, with three declination-circles at $+10°29'$, $+15°29'$, and $+20°29'$ (1940). The nine fields at the northern galactic pole are centered on the intersections of three hour-circles having right ascensions 12^h11^m, 12^h36^m, and 13^h1^m, with three declination-circles at $+31°18'$, $+36°18'$, and $+41°18'$ (1940). The apparent photographic magnitudes were estimated relative to the nearest available selected areas. The color classification is not quantitative but is divided into three classes: blue, decidedly blue, and very blue, referring to approximate ranges in the color index from $+0.3$ to -0.1, -0.1 to -0.3, and -0.3 to -0.6, respectively. These ranges were first established through tests on some brighter, unobscured A and B stars and later checked on fainter stars for which K. G. Malmquist[2] has determined the color indices. The co-ordinates given in Table 1 refer to the epoch 1855 and were measured relative to the nearest BD stars. Stars with known and large proper motions have been designated as white dwarfs by the letter "D," as proposed by W. J. Luyten.[3] Absorption lines in the spectra of stars referred to as having wide lines appear on our small-scale spectra to be from 20 to 80 angstroms wide.

In Table 2 is shown the distribution in colors and magnitudes of stars in the region of the Hyades cluster.

The distribution in colors and magnitudes of the stars near the northern galactic pole is shown in Table 3.

The list is complete to stars of about the fifteenth photographic magnitude. In view of the very small number of stars involved in these counts, the indicated increase in the number of stars per unit magnitude interval is probably not significant.

Spectra.—The spectral types of the forty-eight stars in Table 1 have been estimated from low-dispersion spectrograms obtained from 1940 to 1944 with the 100-inch reflector of the Mount Wilson Observatory. With the exception of seven stars, the dispersion used was 220 A/mm at $H\gamma$. Numbers 5, 7, 13, 28, 32, 33, and 34 were taken with a dispersion

[2] *Stockholm Obs. Ann.*, Vol. 12, No. 7, 1936.

[3] *Ap. J.*, **101**, 131, 1945.

TABLE 1

PRELIMINARY LIST OF FAINT BLUE STARS

(Asterisks refer to notes on following page)

No.	R.A. 1855	Decl. 1855	m_{pg}	Color	Spectrum
	In the Region of the Hyades Cluster				
1	$4^h41^m.8$	+17° 27′	12.7	Very blue	B2
2*	4 4.8	11 30	13.7	Very blue	B5
3*	3 45.6	10 19	13.0	Very blue	DB1
4*	3 47.4	9 20	14.8	Blue	DB3
5	3 44.0	6 43	14.7	Decidedly blue	B5
6	4 3.5	15 00	14.6	Blue	B3
7*	4 25.7	12 23	14.5	Decidedly blue	B3
8	4 41.0	13 35	14.6	Blue	B3
9*	4 24.0	17 26	14.1	Blue	DB3
10*	4 1.8	17 39	14.4	Decidedly blue	DB5
11	4 21.7	7 23	14.7	Decidedly blue	B2
12	4 16.3	8 12	12.8	Blue	B3
13*	4 39.8	7 33	14.6	Blue	G0
14	4 33.0	10 42	13.5	Decidedly blue	B2
15	4 32.8	+ 8 25	12.8	Blue	B5
	In the Region of the North Galactic Pole				
16	$11^h50^m.6$	+30° 46′	14.4	Blue	A0
17	11 57.8	40 57	14.4	Blue	B2
18	12 1.6	37 51	15.1	Decidedly blue	B2
19*	12 5.5	34 42	12.8	Blue	B5
20*	12 5.4	43 28	14.9	Decidedly blue	B3
21	12 6.6	33 44	14.2	Very blue	B0
22	12 7.5	37 28	12.7	Decidedly blue	B3
23	12 10.1	32 58	14.2	Blue	A0
24	12 17.5	39 57	11.4	Blue	B8
25*	12 18.2	36 47	10.0	Very blue	B5
26	12 21.5	29 9	13.7	Blue	B5
27	12 24.6	39 48	12.5	Blue	A0
28*	12 25.4	42 17	15.2	Decidedly blue	B3
29*	12 27.8	38 26	13.6	Decidedly blue	B0
30	12 30.2	39 23	13.4	Decidedly blue	B5
31*	12 35.9	32 52	12.8	Blue	A0
32	12 44.1	37 58	15.2	Blue	B1
33	12 44.1	34 25	14.6	Blue	A0
34	12 48.4	38 20	14.7	Decidedly blue	B0
35	12 46.3	30 54	15.0	Decidedly blue	B2
36	12 49.4	33 13	14.3	Blue	A0
37	12 55.9	39 14	12.0	Decidedly blue	B8
38	12 52.4	28 20	13.9	Very blue	B0
39	12 57.8	28 54	14.8	Blue	B0
40	13 6.8	37 44	13.8	Decidedly blue	B2
41*	13 10.5	39 49	13.3	Blue	F0
42	13 6.4	32 8	14.2	Blue	B5
43*	13 9.5	29 52	12.5	Blue	DB0
44	13 17.0	36 53	11.0	Very blue	B2
45	13 19.3	40 53	12.4	Decidedly blue	B5
46*	12 50.0	33 13	14.7	Blue	F
47	12 52.4	28 8	14.7	Decidedly blue	B5
48	12 53.0	+41 48	13.6	Blue	A0

NOTES TO TABLE 1

No. 2.—Small proper motion in R.A. The spectral lines are shallow and very wide, indicating a white dwarf.

No. 3.—Van Maanen's measure of the proper motion indicates that this is a member of the Hyades cluster and therefore a white dwarf. The continuous spectrum extends far into the violet. Absorption lines are extremely weak and narrow.

No. 4.—Van Maanen's proper motion makes this a Hyades star and a white dwarf. Spectral lines are shallow and very wide.

No. 7.—Small proper motion in R.A. As the lines are shallow and very wide, the spectrum indicates a white dwarf.

No. 9.—Van Maanen and Luyten have both measured the proper motion; their results indicate that the star is a member of the Hyades cluster and therefore a white dwarf. Luyten's proper motion was measured previous to our discovery, and his designation is L 1239-16. Luyten informs us that E. G. Ebbighausen has measured a proper motion of 0".08 for this star. The spectral lines are very shallow and extremely wide. The continuous spectrum extends far into the violet. Suspected of being variable in light, and possibly in color.

No. 10.—Van Maanen's proper motion in R.A. is small. Luyten finds a measurable negative proper motion in both components. The spectrum lines are shallow and very wide. Probably white dwarf. Not a member of the Hyades cluster.

No. 13.—The indication that this star is blue may possibly be due to a defective spot on one film. Identification has been checked and found correct.

No. 19.—Malmquist No. 11.

No. 20.—Malmquist No. 33.

No. 25.—Malmquist No. 161; BD+36°2268.

No. 28.—The spectrum indicates that this star is possibly a white dwarf, as the lines are shallow and very wide.

No. 29.—Malmquist No. 132.

No. 31.—Malmquist No. 338.

No. 41.—Color measures show this star bluer than the spectrum would indicate.

No. 43.—Previously found by Luyten from the proper motion and designated by him as L 1409-4. The proper motion makes this star a white dwarf. The spectrum appears nearly continuous on small-scale spectrograms, which makes the classification uncertain. May be O type. A fifteenth-magnitude companion is 2″ preceding.

No. 46.—Coincident with an anonymous extragalactic nebula.

TABLE 2

DISTRIBUTION IN COLOR AND MAGNITUDE OF FAINT BLUE STARS IN THE REGION OF THE HYADES CLUSTER

RANGE IN m_{pg}	NUMBER OF STARS			TOTAL
	Blue	Decidedly Blue	Very Blue	
10.0–10.5	.....	.....	.....	.....
10.5–11.0	.....	.....	.....	.....
11.0–11.5	.....	.....	.....	.....
11.5–12.0	.....	.....	.....	.....
12.0–12.5	.....	.....	.....	.....
12.5–13.0	2	.....	2	4
13.0–13.5	.....	1	.....	1
13.5–14.0	.....	.....	1	1
14.0–14.5	1	2	.....	3
14.5–15.0	4	2	.....	6
15.0–15.5	.....	.....	.....	.....

of 500 A/mm at $H\gamma$. Classification was made by comparison with stars of known spectral type whose spectra had been obtained with the same dispersion and under the same conditions as those in the table. Comparison stars consisted of several high-luminosity stars of types O, B, and A, and known white dwarfs. The uncertainty in the spectral classification is probably not greater than three-tenths of a spectral division for those stars in Table 1 whose spectra appear normal. For several stars with shallow and very wide absorption lines or with spectra which appear nearly continuous, the uncertainty is greater. In some stars this uncertainty may be as large as a whole spectral division.

Of the forty-eight stars in Table 1, six—Nos. 2, 3, 4, 7, 9, and 10—in the Hyades region and two—Nos. 28 and 43—in the region of the north galactic pole have spectra similar in appearance to such well-known white dwarfs as Wolf 485, Wolf 1346, and AC+70°8247. Two stars—Nos. 13 (G0) and 41 (F0)—have types which do not correspond to the color indicated by the Schmidt photographs. The identifications of both stars have been checked and found correct, and the discrepancy is possibly due to defective spots on the Schmidt photographs. Star 46 is centrally superimposed on an anonymous extragalactic nebula, which may account for the overestimation of blueness.

TABLE 3

DISTRIBUTION IN COLOR AND MAGNITUDE OF FAINT BLUE STARS NEAR THE NORTHERN GALACTIC POLE

RANGE IN m_{pg}	NUMBER OF STARS			TOTAL
	Blue	Decidedly Blue	Very Blue	
10.0–10.5	.....	.....	1	1
10.5–11.0	.....	.....	1	1
11.0–11.5	1	.....	.....	1
11.5–12.0	.....	1	.....	1
12.0–12.5	2	1	.....	3
12.5–13.0	2	1	.....	3
13.0–13.5	1	1	.....	2
13.5–14.0	2	2	1	5
14.0–14.5	5	.....	1	6
14.5–15.0	3	4	.....	7
15.0–15.5	1	2	.....	3

Color.—Of the forty-five blue stars, thirty-six have been classified as B5 or earlier; two as B8; and seven as A0. The stars in the Hyades region show no correlation between color and spectral type. At the northern galactic pole, mean values of color and spectral type show only a slight correlation. Whether the lack of correlation between color and spectrum at the galactic pole indicates reddening in a region relatively free from absorbing material is doubtful. More likely the cause is a combination of errors in the assigned color values and spectral types.

Proper motions.—Preliminary measures of the proper motions of the first ten of our stars in the Hyades region were made by the late Dr. A. van Maanen on plates having an interval of from 1 to 3 years. Dr. W. J. Luyten, at the University of Minnesota, has measured the motions of four of our stars in the Hyades region and four in the region of the north galactic pole. Luyten's measures were made on Harvard plates having a scale of 60″ per mm and an interval of 30–35 years. The values obtained by van Maanen and Luyten are in Table 4.

Discussion.—In the region of the Hyades cluster, fourteen faint blue stars have been found. Three of these stars—Nos. 3, 4, and 9—have proper motions corresponding to that of the Hyades cluster and are therefore members of the cluster. Since their apparent magnitudes thus imply absolute magnitudes with values from approximately +11 to +12, they are undoubtedly white dwarfs. A fourth star—No. 10—has, according to Luyten, a considerable motion, but not in the direction of the cluster. Van Maanen's measure in μ_α yields a motion only one-third as great as Luyten's. These four stars all have spectra similar to those of known white dwarfs. All absorption lines are shallow and about 20–80 angstroms wide; or, as in star 3, the lines are so extremely weak that the spectrum appears almost continuous. The spectra of stars 2 and 7 might indicate that they, too, are white dwarfs, but van Maanen's measures of μ_α show no appreciable motion. As the interval for van Maanen's plates is only 1 year for star 2 and 2 years for

TABLE 4

KNOWN PROPER MOTIONS

	Star	van Maanen		Luyten	
		μ_α	μ_δ	μ_α	μ_δ
Hyades region	1	+0″.002±0″.026	.....	+0″.006	−0″.011
	2	− .021± .036	.....	.....	.....
	3	+ .090± .015	−0″.010±0″.009	.....	.....
	4	+ .140± .011	− .016± .011	.....	.....
	5	+ .002± .011	.....	.....	.....
	6	− .020± .011	.....	+ .004	− .008
	7	+ .018± .010	.....	.....	.....
	8	+ .014± .008	.....	.....	.....
	9	+ .104± .016	−0.020±0.006	+ .101	− .038
	10	+0.027±0.015	.....	− .076	− .082
North galactic pole	16	.....	.....	+ .024::	− .019::
	26	.....	.....	+ .012	+ .011
	39	.....	.....	− .001	− .014
	43	.....	.....	−0.143	−0.072

star 7, it is possible that future measures on plates having a longer interval will show an appreciable proper motion. In the spectra of the remaining eight stars in the Hyades region, all the absorption lines appear to be slightly wider and weaker than normal. Because of the small scale of our spectra, it is difficult to decide whether this peculiarity is real. If real, it may be caused by rotation, since the lines of all elements are affected.

In the fields searched at the north galactic pole, thirty-one faint blue stars were found. Of the four stars whose proper motions have been measured by Luyten, one—No. 43—has so large a motion that it is almost certainly a white dwarf. One other star whose proper motion is unknown—No. 28—may possibly be a white dwarf, as the absorption lines are wide and shallow. The spectra of the remaining twenty-nine stars appear normal. These stars form an interesting group if we consider their absolute magnitudes and distances. Unlike the objects found in the Hyades region, they appear in a region free from absorption and, although their motions are as yet unknown, their spectra indicate that they are not white dwarfs. If they are stars of normal luminosity, these distances would be very great. If the mean absolute magnitude of a normal B3 star is −2.2, as determined by Stebbins, Huffer, and Whitford,[4] the distance moduli for stars of twelfth and

[4] *Mt. W. Contr.*, No. 621; *Ap. J.*, **91**, 20, 1940.

fifteenth apparent magnitude are as shown in the accompanying tabulation. Consequently, a fifteenth-magnitude normal B3 star would be at the same distance as the Small Magellanic Cloud. Considering also that our observations go only to apparent magnitude 15 and that Table 3 indicates an increase in the number of stars per unit magnitude interval, we should expect to observe B stars as faint as the seventeenth and eighteenth magnitudes. Such stars would be as distant as the Andromeda galaxy, in which B-type stars actually appear in large numbers at the seventeenth and eighteenth apparent magnitudes. It is therefore obvious that any assumption that the luminosities of these B stars are normal is wrong. The difficulty just mentioned disappears, however, if we identify them with the B-type stars of Baade's population II, as shown in the Hertzsprung-Russell diagram for globular clusters.[5] These stars are at the blue end of the horizontal branch and have the absolute magnitude 0. Since they have the same absolute

Apparent Magnitude	Modulus	Distance
$m=12$	$m-M=14.2$	6,600 pc
$m=15$	$m-M=17.2$	27,000 pc

magnitude as the cluster-type variables, we should expect to find them scattered thinly in all directions, forming an almost spherical system. Additional evidence that these are stars of intermediate brightness is furnished by the observation by Baade and Minkowski of the spectra of two Type II blue stars in the globular star cluster M3. The spectral types of these two stars are O and B2, respectively, and the absolute magnitudes about 0.

The velocities of all the stars in Table 1 have been measured; but, because of the small dispersion used and the resulting large probable error, the results are not listed. Most of the velocities are small, however, and for that reason it seems improbable that the stars have moved out of the plane of the Milky Way. The outstanding exceptions are velocities of +200 km/sec for star 8 in the Hyades region, and −220 km/sec for star 17 in the region of the north galactic pole.

Because of the uncertainty in the absorption factor for the Hyades region, no assumption has been made in regard to the absolute magnitudes of stars with small proper motions in that region.

We wish to thank Dr. Luyten for his proper-motion measurements of four stars in the Hyades region and four in the region of the north galactic pole.

[5] *Mt. W. Contr.*, No. 696; *Ap. J.*, **100**, 137, 1944.