THE ASTROPHYSICAL JOURNAL, 278:208–214, 1984 March 1

HIGH-DISPERSION SPECTROSCOPIC INVESTIGATION OF FIELD HORIZONTAL-BRANCH, HIGH-LUMINOSITY, AND MAIN-SEQUENCE STARS

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Received 1982 June 10; accepted 1983 August 9

ABSTRACT

High-dispersion spectra (12.5 Å mm^{-1}) were taken of 11 early-type stars with the Cassegrain image-tube spectrograph on the CTIO 4 m telescope, in order to improve previous classifications based on low-dispersion and/or photometric studies. Atmospheric parameters were determined, as well as interstellar reddenings and radial velocities. Five of the stars were classified as field horizontal-branch stars, two as high-luminosity stars, three as main-sequence stars, and one as an RR Lyrae variable star.

Abundances of 11 elements were derived for the five field horizontal-branch stars and for one moderate high-luminosity star. A wide range of variation in [Ca/Fe] was detected, and its implications are discussed briefly.

Subject headings: stars: abundances — stars: atmospheres — stars: horizontal-branch

I. INTRODUCTION

One of the present authors (A. G. D. P.) has been carrying out surveys for early-type field horizontal-branch stars (FHB) by means of four-color photometric measures of candidates obtained from objective-prism spectroscopy (Philip 1967, 1968, 1969*a*, *b*, 1970*a*, 1973; Philip and Sanduleak 1968; Bond and Philip 1973).

In the present high-dispersion investigation we measured FHB stars from the candidate list, high-luminosity stars, and a few main-sequence stars, all of early type, as well as two of the classical FHB stars, HD 2857 and HD 161817, in order to determine their atmospheric parameters and to derive chemical abundances for confirmed FHB stars. The star HD 161817 was used as a standard because its spectrum has been studied extensively (Kodaira 1964, 1973, 1975 [KK]). This work was done in connection with a spectroscopic investigation of blue horizontal-branch (BHB) stars in globular clusters, to be published separately.

II. OBSERVATION AND REDUCTION

The photometric properties of the program stars are summarized in Table 1, together with references concerning the surveys. In most cases the *uvby* photometry has been done by A. G. D. P. and partially supplemented by our observations during the same observing run at CTIO when the spectra were obtained in 1980 July.

The spectrograms were taken with the Cassegrain image-tube spectrograph on the 4 m reflector at CTIO. The combination of grating No. 380 and hypersensitized IIIa-J emulsion gives spectra at 12.5 Å mm^{-1} over 3850–4300 Å.

TABLE 1

PHOTOMETRIC PROPERTIES

Star	V	Sp.	$(b-y)$	c_1	m_1	n	References[a]
HD 2857	9.8	A2	0.133	1.215	0.116	94	Ph, GD
HD 14829	9.9	A0	0.037	1.243	0.133	17	Ph
HD 107369	9.2	A0	0.144	1.620	0.087	22	Mc, BP
HD 130095	8.6	B8	0.061	1.241	0.120	14	GD, BM, Mc, Ob
HD 130156	9.1	A3	0.262	0.744	0.209	12	Mc
HD 161817	6.9	A0	0.125	1.208	0.118	99	Kd, Ph
HD 184779	9.2	A3	0.173	0.784	0.134	10	BP
HD 202759	8.8	B9	0.165	1.174	0.117	5	Mc
HD 214539	7.4	B5	0.053	1.093	0.064	4	Mc
PS 37 II	11.3	A	0.110	0.835	0.218	2	PS
PS 53 II	12	B	0.000	1.212	0.134	5	PS

[a] Ph = Philip 1968, 1969*a*, *b*, 1970*a*, 1973; GD = Graham and Doremus 1968; Ob = Oblak *et al.* 1976; Mc = MacConnell *et al.* 1971; BP = Bond and Philip 1973; Kd = Kodaira 1964; PS = Philip and Sanduleak 1968; BM = Bond and MacConnell 1971.

TABLE 2

SPECTROSCOPIC PROPERTIES

Star	R.V. (km s^{-1})	(n)	D(0.2) (Å)	W_λ(Ca II K) (Å)	Note about Metallic Lines	Spectrogram[a] (exposure time) (min.)
Field horizontal branch:						
HD 2857	−151 ± 6	(13)	11.7	1.36, 0.12	similar to std.	F1727-14(11), 1732-14(4.5), 1732-20(5)
HD 14829	−178 ± 10	(4)	12.3	0.22	fewer than std.	F1732-26(12)
HD 130095	+83 ± 6	(9)	14.0	0.41	weaker than std.	F1728-14(1.5)
HD 161817	−361 ± 6	(13)	10.6	1.48, 0.02	standard	F1729-14(2), 1729-20(1.3)
PS 53 II	+126 ± 6	(11)	11.0	0.29	fewer than std.	F1732-08(50)
High luminosity:						
HD 107369	−45 ± 3	(21)	9.7	1.72	slightly stronger than std.	F1728-08(4)
HD 214539	+325 ± 6	(10)	3.5	0.20, 0.01	fewer than std.	F1726-14(0.8), 1726-20(0.6), 1731-32(1)
Variable:						
HD 202759	+24 ± 6	(16)	10.2	0.90, 0.13	weaker than std.	F1726-26(4), 1726-232(2), 1731-20(2.5)
Main sequence:						
HD 130156	−18 ± 3	(19)	10.0	2.96	stronger than std.	F1728-20(6.5), 1728-26(4)
HD 184779	−26 ± 6	(12)	10.5	2.66, 0.18	richer and stronger than std.	F1725-26(2), 1725-32(4), 1731-14(2.5)
PS 37 II	−4 ± 10	(10)	16.0	2.99	broader and stronger than std.	F1727-08(41)

[a] F1725–F1727 were taken on 1980 July 5, and F1728–F1732 were taken on 1980 July 7.

The wavelength calibration was done with the help of a He-Ne-Ar hollow-cathode tube, and the intensity calibration was done with the Hoag-Schoening projection sensitometer at CTIO through filter 5-75 and wedge No. 11. The plates were developed in D19, and the spectra have a width of at least 0.4 mm.

A brief journal of the observations is included in Table 2. The radial velocities were measured with a Grant-type machine at the Tokyo Astronomical Observatory and the spectra were traced with a microdensitometer at the Department of Astronomy, University of Tokyo. The equivalent widths were measured by both authors in Tokyo. The main spectroscopic properties are given in Table 2. (These properties include the heliocentric radial velocity with the number of lines measured in parentheses, the half-width of Hδ at a depth of 0.2, the equivalent width of the stellar Ca II K line, and the results of visual inspection of the metallic-line spectra compared to that of the standard star HD 161817.) Probable errors are given for the radial velocity, and the maximum internal differences for W_λ(Ca II K) whenever more than one spectrum is available. The accuracy of D(0.2) is given in Table 3. The program stars in Table 2 are grouped according to their nature. Some remarks about individual stars are made in this section.

HD 107369.—MacConnell *et al.* (1971) included this star in their list of new probable FHB stars.

HD 130095.—Przybylski and Kennedy (1965) reported $B-V$ and $U-B$ colors of +0.08 and +0.05 mag, respectively, and possible variability of the radial velocity ($V_R = +46.0$, +61.0, and +42.9 km s^{-1}). Note that the present value of the radial velocity ($V_R = 83 \pm 6$ km s^{-1}) is definitely higher than the previously quoted values, confirming that this star really is a velocity variable. Bond and MacConnell (1971) classified this star as a FHB star and noted that it had a variable radial velocity.

HD 130156.—MacConnell *et al.* (1971) included this star in their list of new probable FHB stars.

HD 184779.—Bond and Philip (1973) suggested that this star was a FHB star on the basis of two measures that placed the c_1 index at 0.86 mag. The average of 10 observations now places the c_1 index at 0.78 ± 0.05 mag, closer to the main sequence value.

HD 202759.—Przybylski and Bessell (1974) reported light variations of amplitude of 0.08 mag, with a quasi-period of

TABLE 3

Hδ PROFILE

Star	Δλ(Å) 0	1	2	4	6	8	10	12	14	16	18	20	NOTE[a]
HD 2857	0.21	0.33	0.43	0.55	0.64	0.71	0.76	0.80	0.83	0.86	0.88	0.90	A
HD 14829	0.19	0.29	0.36	0.47	0.58	0.66	0.73	0.79	0.83	0.86	0.89	0.91	B
HD 107369	0.16	0.28	0.38	0.52	0.64	0.73	0.81	0.86	0.90	0.93	0.94	0.96	A
HD 130095	0.16	0.22	0.31	0.42	0.53	0.63	0.70	0.78	0.83	0.87	0.90	0.93	B
HD 130156	0.24	0.33	0.43	0.57	0.67	0.74	0.80	0.84	0.87	0.89	0.91	0.92	B
HD 161817	0.22	0.36	0.48	0.57	0.66	0.73	0.78	0.82	0.85	0.87	0.90	0.91	A
HD 184779	0.31	0.43	0.50	0.62	0.69	0.75	0.79	0.82	0.85	0.87	0.89	0.90	A
HD 202759	0.23	0.39	0.49	0.61	0.69	0.76	0.80	0.83	0.86	0.88	0.90	0.92	A
HD 214539	0.26	0.49	0.65	0.83	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00	B
PS 37 II	0.26	0.30	0.36	0.49	0.58	0.64	0.69	0.74	0.77	0.80	0.82	0.84	C
PS 53 II	0.18	0.27	0.37	0.50	0.62	0.71	0.77	0.83	0.87	0.90	0.92	0.94	A

[a] The range of scattering among data from different wings and spectrograms; A: <0.01, B: <0.02, C: <0.03.

12 hours, $V_R = -12$ km s^{-1}, and W_λ(Ca II K) = 0.81. Their analysis led to atmospheric parameters $T_{\rm eff} = 7400$ K and log $g = 3.1$, suggesting that this star may lie on the blue edge of the RR Lyrae strip. The present spectra yield W_λ(Ca II K) = 0.90 ± 0.13, compatible with theirs, but $V_R = +24 \pm 6$, higher than theirs. The radial velocity shows no significant variation among the present three spectra which were taken at a separation of 48 hours; this separation corresponds nearly to 4 times the quasi-period. MacConnell *et al.* (1971) included this star in their list of new possible FHB stars.

HD 214539.—Przybylski (1969) carried out a coarse spectral analysis of this metal-poor A0 Ib star to find a deficiency of between 13 and 30 for the iron-group elements. He cited the values $T_{\rm eff} \sim 9100$ K and log $g \sim 1.5$ as suggested by Newell, but adopted $T_{\rm eff} \sim 8900$ K, assuming that the star lies above the blue horizontal branch in the H-R diagram.

The high-velocity nature of the FHB stars in Table 2 is apparent. As for the standard star HD 161817, the present value of $V_R = -361 \pm 6$ km s^{-1} is consistent with $V_R = -363 + 0.3$ km s^{-1} obtained by Kodaira (1964) from high-dispersion spectra and with -364 km s^{-1} obtained by Philip (1969*c*, 1970*b*) from low-dispersion spectra taken at Mount Wilson and Kitt Peak. (One discordant value for HD 161817 was obtained with the image tube system at Kitt Peak.)

The equivalent width W_λ(Ca II K) = 1.48 ± 0.02 is somewhat smaller than the value of 1.90 found in the previous study, probably due to the ambiguity in measuring the line wings. The profiles of the Hδ lines of the program stars are given in Table 3. In comparing the present profiles of HD 161817 with those of Kodaira (1964), we find that the present profiles are slightly shallower than the previous ones. Although there may be some minor systematic deviations in the present CTIO data, we use this star as the standard in reducing all the present data on a uniform basis. The results of the following analyses should be interpreted relative to those of the standard star.

III. ATMOSPHERIC PARAMETERS

The atmospheric parameters, $T_{\rm eff}$ and log g, and the reddening $E(b-y)$ are determined in principle by the variable-reddening method described in Kodaira (1975) (see also Newell, Rodgers, and Searle 1969), using the photometric indices $b-y$, c_1, and m_1, and, in place of $D(0.2)$, the line depth of Hδ at $\Delta\lambda = 2$, 6, and 14 Å. In this method the observed quantities are compared with the theoretical ones given for a grid of model atmospheres, allowing the value of $E(b-y)$ to vary. The fittings of observations to theory of the relations c_1 versus $(b-y)$ and m_1 versus $(b-y)$ and of Hδ depths provide six curves in the ($T_{\rm eff}$, log g)-plane, and their converging point determines the atmospheric parameters, $T_{\rm eff}$ and log g, together with the $E(b-y)$; see Figure 1. We used the model grid by Kurucz (1979) with the mixing length of convection $l = 2H_p$. The value of l/H_p is subject to theoretical ambiguity; thus we must emphasize again that the results should be interpreted relative to those of the standard star.

The resulting atmospheric parameters and the reddenings are given in Table 4. As for the abundance of heavy elements, represented by log A, we use models for log $A = 0$ and log $A = -1$, and the final model used (consistent with the metallic-line analysis) is given in Table 4. Changes of the parameter values by a change in log A from 0 to -1 are roughly $0 > \Delta T_{\rm eff}/\Delta$ log $A > -100$ K and $0.1 > \Delta$ log g/Δ log $A > 0$, for the parameter ranges in question. The degree of the convergence of the curves in the ($T_{\rm eff}$, log g)-plane is also noted in Table 4. An example of good convergence is shown in Figure 1. The parameters of the standard star HD 161817, determined by the present method, are consistent with those derived in a detailed analysis by Kodaira (1964). The convergence is found to be generally poor for stars with log $g \gtrsim 4$ and log $A = 0$, probably because of insufficient inclusion of line-blocking effects in the theoretical models. The convergence may be poor in the case of variable stars because

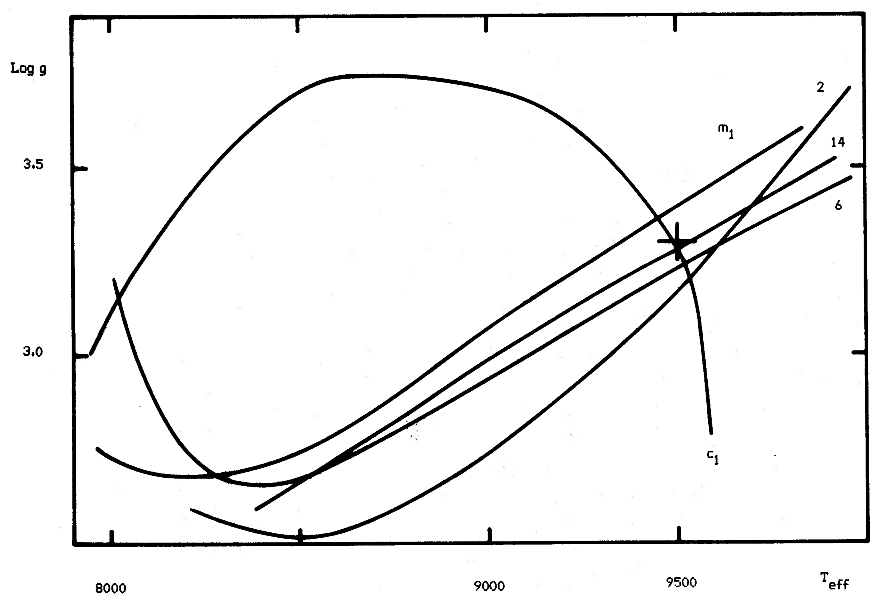

FIG. 1.—Log g–$T_{\rm eff}$ diagram for PS 53 II. An example is shown of good convergence of the curves which determine the atmospheric parameters. The family of ($T_{\rm eff}$, log g) curves are shown which reproduce the observed photometric data and Balmer line profile. The labels on the curves indicate the photometric indices and the wavelengths from the Hδ line center. The cross indicates the adopted model point.

TABLE 4

ATMOSPHERIC PARAMETERS AND INTERSTELLAR ABSORPTION

Star	T_{eff}	log g	$E(b-y)$	W_λ(ISK) (mÅ)	R.V. ISK (km s^{-1})	Convergence	log A
Field horizontal branch:							
HD 2857	7700	2.9	0.02	191	+7	good	−1
HD 14829	9300	3.35	0.04	79	+4	good	−1
HD 130095	9200:	3.4:	0.06:	142	−3	fair	−1
HD 161817	7700	2.9	0.01	80	−12	good	−1
PS 53 II	9500	3.3	0.01	99	+2	good	−1
High luminosity:							
HD 107369	8000	2.1	0.10	not separable		good	0
HD 214539	9800:	1.6:	0.05:	153	−3	fair	−1
Main sequence:							
HD 130156	7700::	4.2::	0.12::	not separable		poor	0
HD 184779	7500:	4.0:	0.00:	not separable		fair	0
PS 37 II	8100::	4.2::	0.00::	not separable		poor	0
Variable:							
HD 202759	7400:	2.8:	0.01:	not separable		fair	−1

NOTE.—Colons indicate uncertain values.

the observational data used are not always obtained at the same phase of variation.

Concerning the particular stars in this study, the uncertain parameters of the variable star HD 202759 are compatible with the findings of Przybylski and Bessell (1974) that this star is located within the RR Lyrae variable strip. The metallic lines are weaker in HD 202759 than in HD 161817 in spite of the lower temperature of the former, indicating that the value of [Fe/H] for HD 202759 may be less than that of HD 161817 (−1.3). The velocity variable HD 130095 shows less consistent behavior than the other FHB candidates, indicating that the resulting atmospheric parameters are not fully reliable. HD 214539 is found to be much hotter (see Table 4) than Przybylski (1969) assumed ($T_{eff} \approx 8900$ K).

The program stars are reclassified, in Table 4, according to their parameters. The resulting values of $E(b-y)$ are compatible with the photometric data and locations in the Galaxy, except for the relatively large and uncertain values [$E(b-y) \geq 0.06$] for HD 130095 and HD 130156. The large, but still tolerable, values of $E(b-y)$ are forced on these stars by the poor consistency among the observed quantities mentioned above.

The equivalent widths and heliocentric radial velocities of the interstellar Ca II K line are given in Table 4 whenever the interstellar component is separable from the stellar one. This is the case for all of the FHB stars in the present program; the interstellar component of Ca I λ4226 may be present at the corresponding radial velocity, but its equivalent width is generally small and subject to a large ambiguity.

Concerning the measure of the abundance of calcium in HD 161817, the abundance derived in the present paper from Ca I λ4226 (log $\epsilon = 4.32$) deviates from that (log $\epsilon =$ 5.01) in Kodaira (1964) while the abundance derived from Ca II (5.03) is close to that (5.13) measured in Kodaira (1964). We suspect that the equivalent width of Ca I λ4226 might be underestimated by as much as $\Delta W_\lambda = 50$ mÅ in the present study due to complex blending features. The simple mean value (4.71) of log ϵ(Ca I) and log ϵ(Ca II) is adopted in Table 6.

IV. CHEMICAL ABUNDANCE OF FHB STARS

Fine analyses of metallic-line spectra of the five FHB stars were undertaken, using the model atmosphere program ATLAS6 and the abundance analysis program WIDTH6 by Kurucz (1979). The possible supergiant HD 107369, which has a surface gravity slightly lower than those of the FHB stars, was added to the objects selected for the fine analysis. Another supergiant, HD 214539, could not be included in the further analysis because the convergence of the iterative procedure in the computing of the model atmosphere is disturbed by its very low surface gravity and relatively high temperature. The equivalent widths of metallic lines were measured on the intensity tracings and are given in Table 5, together with atomic data and the resulting abundances. Corrections due to blends were taken into account, if necessary. The probable error of W_λ is estimated to be about ±30 mÅ for lines of $W_\lambda \approx 100$ mÅ. We estimate the upper limit of the equivalent width to be about 30 mÅ when the absorption line is not recognized with certainty on the present tracings; the corresponding upper limit of the abundance is given in Table 5 whenever it is found to be meaningful.

The *gf*-values are adopted from the collection by Kurucz and Peytremann (1975), except for those of Si II which are not included in the collection in which case we used Schulz-Gulde (1969). Comparisons of Kurucz-Peytremann *gf*-values with those of Bridges and Kornblith (1974) for Fe I, those of Kurucz (1981) for Fe II, and those of Biémont *et al.* (1981) for Fe II, show that discrepancies between them are small ($|\Delta \log gf| < 0.1$) and without any clear systematic trend.

The present equivalent widths for HD 161817 turn out to be systematically slightly larger than those measured by Kodaira (1964); log W_λ(CTIO) − log W_λ(1964) = 0.13 for line of $W_\lambda \approx$ 100 mÅ. This may be caused by the image-tube characteristics and/or the slight difference in setting the continuum level, leading to an apparent increase of the so-called microturbulence velocity by $\Delta \log \xi_t \leq 0.2$. Model atmospheres with the parameters in Table 4 are generated for $l = 2H_p$,

TABLE 5

LINE DATA

Line		$\chi_{r,s}$	log gf	HD 2857 W_λ	HD 2857 log ε	HD 14829 W_λ	HD 14829 log ε	HD 130095 W_λ	HD 130095 log ε	HD 161817 W_λ	HD 161817 log ε	PS 53-II W_λ	PS 53-II log ε	HD 107369 W_λ	HD 107369 log ε
AlI(1)	3944	0.00	-0.75	56	4.37	<30	<5.46	18:	5.09:	150	5.36	30	5.62	119	5.49
	3961	0.01	-0.45	113	5.32	<30	<5.26	<30	<5.05	132	4.85	<30	<5.33	124	5.25
SiI(3)	3905	1.90	-0.71	174	5.55	46:	6.04:	26:	5.80:	184	6.40	100	7.1	140	6.25
SiII(1)	3856	6.83	-0.34	109	6.30	—	—	74	5.85	—	—	<166	<7.0	174	6.75
	3862	6.83	-0.83	88	6.55	<30	<5.84	63	6.30	80:	6.47:	—	—	180	7.32
(3)	4128	9.79	-0.55	29	6.42	32	6.08	51:	6.40:	—	—	63	6.48	59	6.42
	4130	9.80	-0.60	51	6.73	45	6.27	29	5.95	—	—	44	6.12	81	6.66
CaI(2)	4226	0.00	0.20	212	4.60	<30	<5.30	—	—	111	4.32	—	—	212	5.25
CaII(1)	3933	0.00	0.15	1355	4.95	220	3.36	405	4.93	1475	5.03	286	4.50	1594	5.33
ScII(7)	4246	0.31	0.26	131	1.75	32	1.89	73	2.33	171	2.30	25:	1.91	240	3.05
TiII(11)	4012	0.57	-1.73	87	3.89	21	4.13	40	4.43	110	4.11	21	4.24	199	5.21
(20)	4287	1.08	-1.90	47	4.00	<30	<4.79	<30	<4.74	55	4.09	77:	5.4:	154	5.11
	4294	1.08	-1.05	104	3.73	<30	<3.94	—	—	105	3.74	65	4.45	184	4.70
(34)	3900	1.13	-0.27	180	4.06	<30	<3.29	—	—	138	3.44	—	—	—	—
	3913	1.11	-0.37	185	4.23	<30	<3.32	147	4.58	225	4.92	48	3.66	341	6.02
(41)	4290	1.16	-0.97	157	4.32	—	—	—	—	120	3.88	115:	4.70:	226	5.15
	4300	1.18	-0.47	188	4.32	—	—	—	—	155	3.81	—	—	233	4.76
(87)	4028	1.88	-0.92	85	4.05	41	4.50	<30	<4.29	51	3.69	—	—	194	5.31
	4053	1.88	-1.32	57	4.16	<30	<4.73	100:	5.48:	82	4.42	61	5.23	168	5.20
(105)	4163	2.58	-0.15	113	4.07	20:	3.78:	<30	<3.95	50	3.42	—	—	230	5.49
	4171	2.59	-0.33	73	3.86	35	4.25	<30	<4.13	66	3.79	30:	4.25:	127	4.38
VII(10)	3951	1.47	-0.80	44	3.12	<30	<3.90	<125	<4.90	71	3.43	<30	<3.96	108:	3.82:
CrI(1)	4274	0.00	-0.16	42	4.01	35:	5.57:	<30	<5.36	89	4.51	<30	<5.69	66	4.86
FeI(4)	3859	0.00	-0.79	191	6.46	—	—	<30	<5.97	—	—	100:	7.11:	130	6.03
	3920	0.12	-1.81	78	6.05	<30	<7.18	58	7.43	117	6.45	21:	7.20:	110	6.93
	3922	0.05	-1.70	94	6.05	<30	<7.03	<30	<6.90	58	5.67	<30	<7.23	164	7.38
	3927	0.11	-1.60	90	5.95	<30	<5.97	104	7.68	86	5.91	19	6.94	67	6.30
	3930	0.09	-1.57	93	5.93	<30	<6.92	72	7.32	136	6.42	<30	<7.12	132	6.89
(42)	4202	1.48	-0.43	114	6.03	—	—	—	—	71	5.59	92	7.54	204	7.63
	4250	1.55	-0.59	114	6.23	36	6.92	<30	<6.71	125	6.36	30:	7.02:	195	7.70
	4271	1.48	0.19	199	6.61	64:	6.45:	161	7.41	—	—	85:	6.85:	195	6.87
(43)	4005	1.55	-0.54	84	5.91	69	7.30	—	—	127	6.37	<30	<6.99	221	8.20
	4045	1.48	0.25	141	5.69	55	6.30	41:	6.01:	173	6.18	<30	<6.15	260	7.87
	4063	1.55	0.01	124	5.77	26:	6.17:	—	—	108	5.59	30:	6.43:	250	8.00
	4071	1.60	-0.03	124	5.85	65:	6.77:	23:	6.05:	159	6.34	<30	<6.50	234	7.84
	4132	1.60	-0.59	63	5.76	31	6.89	<30	<6.75	120	6.36	<30	<7.05	128	6.93
	4143	1.55	-0.41	111	6.03	44	6.87	<30	<6.54	149	6.51	<30	<6.84	165	7.16
(71)	4282	2.17	-0.69	45	6.07	<30	<7.31	—	—	68	6.33	<30	<7.49	162	7.81
(359)	4062	2.83	-0.68	31	6.36	—	—	—	—	<30	<6.34	<30	<7.89	30	6.88
FeII(3)	3938	1.66	-4.19	109	7.32	—	—	92	8.00	—	—	<30	<7.34	132	7.54
(27)	4128	2.57	-3.53	34	6.49	<27	<7.13	70	7.67	—	—	29:	7.19:	110:	7.30:
	4173	2.69	-2.60	68	6.06	39	6.45	70	6.67	80	6.19	—	—	192	7.39
	4233	2.57	-1.92	108	5.69	<30	<5.56	40	5.79	158	6.29	95	6.38	280	7.80
(28)	4178	2.57	-2.95	45	6.06	33	5.59	113	7.52	88	6.52	58:	7.02:	137	7.10
SrII(1)	4077	0.00	0.17	121	0.73	30	1.43	47	1.55	180	1.60	47	1.88	241	2.65
	4215	0.00	-0.14	70	0.49	<30	<1.71	27	1.54	119	0.99	22:	1.78:	148	2.38
YII(14)	4177	0.41	-0.24	<30	<1.12	<30	<2.50	<30	<2.42	<30	<1.12	<30	<2.68	89	1.98
ZrII(41)	4149	0.80	-0.13	51	2.06	62:	3.32:	<30	<2.85	39:	1.91:	<30	<3.02	30:	1.86:
	4048	0.80	-0.39	<30	<2.03	16:	2.86:	<72	<3.65	43:	2.23:	21:	3.11:	33	2.20
	4050	0.71	-0.96	<30	<2.54	<30	<3.63	<30	<3.63	<30	<2.54	<30	<3.81	75	3.18

NOTE.—Colons indicate uncertain values.

and the abundances are calculated for three different cases of constant microturbulence velocity, $\xi_t = 0$, 2, and 4 km s^{-1}. The last case ($\xi_t = 4$ km s^{-1}) was found to be most reasonable for all stars with sufficient Fe I lines; therefore we assumed $\xi_t = 4$ km s^{-1} for all stars. Kodaira (1964) found $\xi_t = 2$ km s^{-1} at the surface for HD 161817 which increases to $\xi_t = 4$ km s^{-1} at unit Rosseland-mean optical depth $\tau \sim 1$. The ionization equilibrium Fe I/II is realized roughly in the adopted models, while the equilibria Si I/II and Ca I/II are often not. The possible causes of this are the low accuracy of measured equivalent widths and the scarcity of available lines of Si I, Ca I, and Ca II. Nevertheless, the abundances are derived also for those elements of which only one or two lines are available, just to indicate the rough level of abundance.

Finally, the adopted element abundances are given in Table 6, relative to those of the Sun mainly according to Aller (1968) (cf. Kodaira 1973). The values given in Table 6 are derived by a weighted mean, with meaningful upper-limit values being taken into account. The probable error may be about $\Delta \log \epsilon = \pm 0.2$ for Fe, ± 0.3 for Ti, and ± 0.5 for the other elements. The major error sources are uncertainties of the measured equivalent widths and the scarcity of observed lines. Since most of the metallic elements are in the singly ionized state for the temperature range in question, the abundances derived from lines of ionized elements are insensitive to the uncertainties of atmospheric parameters, except for Ca, Sr, and Y which have relatively small second ionization potentials ($\chi \leq 12$ eV). For these elements, a typical uncertainty of $\Delta T_{\rm eff} = 200$ K corresponds to an error of $\Delta \log \epsilon \approx \pm 0.3$. In the cases of Al and Cr whose abundances were derived from neutral lines, the same uncertainty of $T_{\rm eff}$ as above leads to an error of $\Delta \log \epsilon \approx \pm 0.2$. When the atmospheric parameters are poorly determined (HD 130095), errors in $\log \epsilon$ may exceed the values cited above.

V. DISCUSSION

Among the 11 program stars, the four stars HD 2857, 14829, 130095, and PS 53 II have the characteristics of FHB stars. These stars all have a high radial velocity and the atmospheric parameters which are appropriate for blue horizontal branch (BHB) stars. HD 2857 is similar to the standard HD 161817, lying close to the blue edge of the RR Lyrae gap, while the others are substantially hotter than these two: $T_{\rm eff} \geq 9200$ K. The iron deficiency varies from the small value of [Fe/H] ≈ -0.5 for HD 130095 and PS 53 II to the moderate one of [Fe/H] ≈ -1.3 for HD 2857. The results for HD 130095, however, should be accepted with caution because of its possible variability in radial velocity. No light variation has been reported for this star; more photometric and spectroscopic observations are necessary. The high-luminosity star HD 107369 may have almost normal iron abundance, but since the radial velocity ($V_R = -45 \pm 3$ km s^{-1}) is relatively large if this star is a Population I star, we are inclined to assume that it might be in a stage evolved from the blue horizontal branch.

Cohen (1978, 1979, 1980) , Pilachowski, Canterna, and Wallerstein (1980), and Pilachowski, Sneden, and Green (1981) found enhancement in aluminum, calcium, and titanium relative to iron for red giants in globular clusters. We find moderate enhancement in titanium but suppression in aluminum and calcium relative to iron for the stars in Table 6. The relative deficiency in calcium is especially remarkable in hot FHB stars, reaching an enormous value of [Ca/Fe] $= -2.3$ for HD 14829. Although the calcium abundance of hot FHB stars was derived from the Ca II K line only, we feel that the relative deficiency is beyond the ambiguities involved in the analyses. Since the hot BHB stars show relative suppression in light elements, including calcium and scandium, compared with HD 161817 and HD 2857, this might be related to the Am (or Ap) phenomenon (cf. Smith 1971). Model atmosphere calculations by Michaud, Vauclair, and Vauclair (1983) based on the diffusion theory suggest that calcium may become highly underabundant in hot FHB stars if the thin outer envelope can be well mixed. They suggest also that the same diffusion mechanism may induce overdeficiency of strontium and overabundances of yttrium and zirconium. The present results seem to be compatible with their prediction. If the diffusion mechanism is in operation in the envelopes of the stars analysed here, the observed iron abundances indicate only the upper limits of the intrinsic values, according to Michaud, Vauclair, and Vauclair (1983).

TABLE 6

CHEMICAL ABUNDANCES[a]

Star	HD 2857	HD 14829	HD 130095	HD 161817	PS 53 II	HD 107369	Sun
$T_{\rm eff}$	7700	9300	9200:[b]	7700	9500	8000	...
log g	2.87	3.35	3.45:	2.87	3.30	2.10	...
Al	−1.4(2)[b]	< −1.0(2)	−1.3(1)	−1.2(2)	−0.9(1)	−0.9(2)	6.3
Si	−1.2(5)	−1.3(5)	−1.5(5)	−1.1(2)	−0.7(4)	−0.8(5)	7.5
Ca	−1.6(2)	−3.0(1)	−1.5(1)	−1.7(2)	−1.9(1)	−1.1(2)	6.4
Sc	−1.3(1)	−1.0(1)	−0.7(1)	−0.7(1)	−1.1(1)	+0.1(1)	3.0
Ti	−0.5(11)	−0.3(4)	−0.3(7)	−0.7(11)	0.0(7)	+0.5(10)	4.6
V	−1.0(1)	< −0.2(1)	< +0.8(1)	−0.7(1)	< −0.1(1)	−0.3(1)	4.1
Cr	−1.2(1)	+0.4:(1)	< +0.2(1)	−0.7(1)	< +0.5(3)	−0.3(1)	5.2
Fe	−1.3(21)	−0.7(10)	−0.6(16)	−1.3(16)	−0.5(10)	−0.1(21)	7.4
Sr	−2.3(2)	−1.5(1)	−1.4(2)	−1.6(2)	−1.1(2)	−0.4(2)	2.9
Y	< −0.5(1)	< +0.9(1)	< +0.8(1)	< −0.5(1)	< +1.1(1)	+0.4(1)	1.6
Zr	−0.6(2)	+0.5:(2)	< +0.3(3)	−0.6(3)	+0.3:(1)	−0.3(3)	2.7

[a] For all stars except the Sun, values are $\log \epsilon - \log \epsilon$(Sun); for the Sun, they are $\log \epsilon$.

[b] Number of used lines.

NOTE.—Colons indicate uncertain values.

The moderate excess of titanium relative to iron is observed for all analyzed stars and may have the same origin as that in red giants found by Cohen and by Pilachowski *et al.* Bessell (1982), however, found almost solar relative abundance [Ti/Fe] for three red giants in M71 and 47 Tucanae, questioning the previous findings. The remarkably low value of [Ca/Fe] of the hot FHB stars (≤ -1) would lead to a large underestimate of metallicity if the ΔS method were applied to these A-type stars. Objective prism surveys for FHB stars may show a selection effect for stars with the weakest Ca II K lines in the temperature range of $T_{\rm eff} > 9000$ K where other metallic lines are not prominent. Concerning this point a careful review might be worthwhile.

The authors thank the director of Cerro Tololo Inter-American Observatory for the assignment of telescope time to this project. We wish to thank C. Sneden for constructive suggestions in revising the manuscript.

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