ULTRAVIOLET OBSERVATIONS OF WEAK-HELIUM STARS

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ABSTRACT

Ultraviolet filter photometry with the Wisconsin experiment package aboard OAO-2 has been carried out for the weak-helium stars 3 Cen A, 3 Sco, HD 144334, HD 21699, HD 144844, α Scl, HR 8535, HR 8770 and HD 144661. The flux distribution is compared with that of B3 to B8 main sequence and giant stars in terms of color-color diagrams.

When allowance is made for line blocking shortward of 2800 Å due to lines of P II, Ga II, Si II, Si III, Ti II and Sr II we find that most of the weak-helium stars have normal fluxes in good agreement with their ground-based colors. It is difficult to consider HR 8535, HR 8770 and HD 144661 as having a normal flux distribution and the suggestion is made they may be brighter than normal at 3320 Å.

The star α Scl is a light and spectrum variable. The strengthening of Ti II and Sr II lines around 2400 Å appears to redistribute flux longward of the Balmer discontinuity. The flux distribution indicates an effective temperature about 1500°K higher than previously determined which would increase the apparent helium underabundance.

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I. INTRODUCTION

Reporting observations in the unknown ultraviolet region for a number of the little understood weak-helium stars of Population I is *per se* of interest. We explore how the ultraviolet photometry may clarify whether or not these stars have normal fluxes. Most of these stars are given a late B spectral type and sometimes a luminosity class III [Garrison (1967), Bernacca (1968), Jaschek, Jaschek and Arnal (1969), Molnar (1971), Ciatti and Bernacca (1971), and Schild and Chaffee (1971)], although their colors imply a spectral type as early as B3 to B5. The stars selected for this investigation and the data reduction procedure are described in the next two sections. In § IV the results are discussed in terms of the color indices $m_\lambda(1920\ Å) - m_\lambda(3320\ Å)$, $m_\lambda(2460\ Å) - m_\lambda(3320\ Å)$ and $m_\lambda(4250\ Å) - m_\lambda(3320\ Å)$ by comparing the weak-helium stars with a sample of main sequence and giant stars of spectral type B3 to B8.5. The conclusions in § V show how line blocking may play an important role in these stars and that a few cases of abnormal flux distribution may exist.

II. PROGRAM STARS AND OBSERVATIONS

The stars considered in this investigation are listed in Table 1 where the meaning of the columns is evident. The star 3 Cen A was reported by Bidelman (1960) as having strong phosphorous lines. Later it was found that most of the apparent helium abundance (~ 0.01 by number) is due to He^3 [Jugaku and Sargent (1963), Hardorp (1967)]. Bertiau (1958) has given the type B5 III and A. de Vaucouleurs (1957) B5 IV for 3 Cen A. Alpha Scl has been described as helium deficient and classified as nearly B4 V by Jugaku and Sargent (1961); HR 8535 and HR 8770 have recently been found by Molnar (1971) and the peculiarity of the other stars has been noted by Garrison (1967). The La Plata Catalogue of stars classified on the MK system (Jaschek, Conde, De Sierra 1964) contains estimates of spectral type for 3 Sco (B7 IV, B8 IV), HD 144334 (B8 V, B9 III), HD 14461 (B7 IV, B7 V) and HD 144844 (B9 V).

A number of main sequence and giant stars are listed in Table 2 and have been selected as comparison stars. It should be recalled that 20 Tau was considered to be "weak-helium" by Searle and Sargent (1964). Because it is a rather anomalous star, we will not consider it further. In addition, 41 Eri is a double-lined spectroscopic binary where both components are Mn-stars according to Searle and Sargent (1967). The (B-V) color excess in Table 2 is based on the photometric classification S_Q and the standard colors given by Johnson (1966).

Table 1. Weak-Helium Stars

Star	V	B-V	U-B	S_Q	Sp. Type	Region	Remarks
3 Cen A	4.31	-0.13	-0.59	B4	B5 Vp	Sco-Cen Assn	1
α Scl	4.30	-0.14	-0.52	B5	B8 III	Field	2
3 Sco	5.86	-0.06	-0.58	B3	B8 p	Sco-Cen Assn	3,7
HR 8535	6.16	-0.12	-0.56	B5	B8 IIIp	Field	4
HR 8770	(6.39)	-0.08	-0.56	B4	B9 III	Field	4
HD 21699	5.48	-0.10	-0.58	B4	B8 III	α Per cl.	5,6
HD 144334	5.92	-0.08	-0.56	B4	B8 p	Sco-Cen Assn	3,8
HD 144661	6.32	-0.06	-0.52	B5	B7 III(p?)	Sco-Cen Assn	3
HD 144844	5.88	+0.02	-0.32	B7	B9 IV(p?)	Sco-Cen Assn	3,6,9

Remarks:

1. Spectral type by Slettebak (1963); visual binary; the secondary is B9 V ($\Delta m = 1.6$).
2. Spectral type quoted in Jugaku and Sargent (1961); ADS 16474 ($\Delta m = 3.2$).
3. Garrison (1967).
4. Molnar (1971); Hg II λ3984 strong in HR 8535.
5. Peculiarity noted by Garrison (1967); spectral type by Roman and Morgan (1950).
6. Reported as suspected variable in Hoffleit (1964).
7. Photometry from Garrison (1967).
8. Possible spectrum variable (Norris 1971).
9. SB2 ($\Delta m \approx 1.6$); the secondary is ~A0 (Norris 1971).

Table 2. Comparison Stars

Star	S_Q	Sp. Type	E(B-V)*
35 Ari	B3	B3 V	0.07
HD 142990	B3	B3 V	0.11
ι Her	B3	B3 V	0.02
HD 68324		B3 V	(0.00)
114 Tau	B2.5	B3 V	0.04
ρ Aur	B4	B5 V	0.03
115 Tau	B5	B5 V	0.05
HD 67341		B5 Vn	(0.00)
16 Pup	B5	B5 V	0.01
HD 93194	B4	B5 V	0.04
19 Tau	B6	B6 V	0.02
HD 21362	B6	B6 V	0.10
17 Tau	B7	B6 III	0.01
16 Tau	B7.5	B7 IV	0.05
η Tau	B7.5	B7 III	0.01
20 Tau	B7	B7 III	0.04
τ^5 Eri	B7.5	B8 V	0.01
ι Lep	B7.5	B8 V	0.00
18 Tau	B7.5	B8 V	0.02
27 Tau	B7.5	B8 III	0.02
41 Eri	B8	B8.4 V	0.00

*The color excess is based on the photometric spectral type S_Q except when in parentheses.

The photometry in Tables 1 and 2 has been taken from Blanco, Demers, Douglass and Fitzgerald (1968) or from Garrison (1967).

The Wisconsin Experiment Package (WEP) flown in the OAO-2 has been described by Code, Houck, McNall, Bless and Lillie (1970). The first column of Table 3 lists the photometers and the filters used in this investigation. Columns 2 and 3 present the effective wavelengths for constant energy and the bandpass at half maximum sensitivity. Our observations range roughly from 1750-4700 Å. Following Code (1971) the net count rates from each filter have been normalized to filter S1F1 (3320 Å) and relative fluxes have been derived as a function of wavelength using the correction factors Δ listed in the fourth column of Table 3.

Table 3. WEP Filter Characteristics

Photometer + Filter	λ_{eff}(Å)	$\delta\lambda$(Å)	Δ
S3F1	1913	260	43.70
S2F5	2386	330	2.890
S3F2	2462	380	6.540
S2F2	2945	440	1.102
S1F4	2985	420	1.330
S1F1	3317	540	1.000
S1F3	4252	840	0.208

III. REDDENING CORRECTION AND OBSERVATIONAL DATA

When estimating the reddening correction, two sources of uncertainty are encountered. In Table 4 we have derived E(B-V) for the weak-helium stars by matching the standard colors (Johnson 1966) with the photometric classification S_Q (case a) and with the spectral types of Table 1 (case b). If one considers case (a) to give the true color excess, one has assumed *a priori* that the flux measured in U, B and V is normal. However, using case (b) causes more difficulties. The stars HR 8535, HR 8770, HD 21699 and α Scl must then be assumed to be unreddened and the remaining Sco-Cen stars become the least reddened stars in that region (*c.f.* Garrison 1967). The mean color excess for the α Per Cluster is 0.08 mag (Mitchell 1960), which agrees with the value derived from the S_Q for HD 21699. We have adopted case (a) for all stars.

Table 4. Color excess of the weak-helium stars derived on the basis of S_Q, case (a), and spectral type, case (b)

Star	E(B-V) a	E(B-V) b
3 Cen A	0.05	0.02
α Scl	0.02	-0.04
3 Sco	0.14	+0.04
HR 8535	0.04	-0.02
HR 8770	0.10	-0.02
HD 21699	0.08	0.00
HD 144334	0.10	+0.02
HD 144661	0.10	+0.06
HD 144844	0.14	+0.08

A second source of uncertainty is the shape of the reddening curve in the ultraviolet. Since Stecher's relation (shown in Figure 1 by a broken line) for the Perseus region (Stecher 1969) was derived, it has been found (Bless and Savage 1970, 1972) that the ultraviolet reddening curve can change drastically for different areas of the sky. Therefore, we have decided not to treat the data below 1920 Å where the variations are the greatest. For the region above 1920 Å we have adopted the 'mean' curve of Bless and Savage (1971) (shown in Figure 1 by the solid line). The difference between the two curves at 1920 Å will bear on the interpretation of the results. In Figure 1 both curves are normalized to E(B-V) = 1. The observed data are presented in Table 5. Under each wavelength, the observed flux, its standard deviation, the flux corrected for reddening and the corresponding standard deviation are entered in order. Errors are generous estimates computed on the basis of the fluctuation in the count rates only. They could be reduced by a factor of about $\sqrt{6}$ quite safely. Entries following the star names give the number of observations.

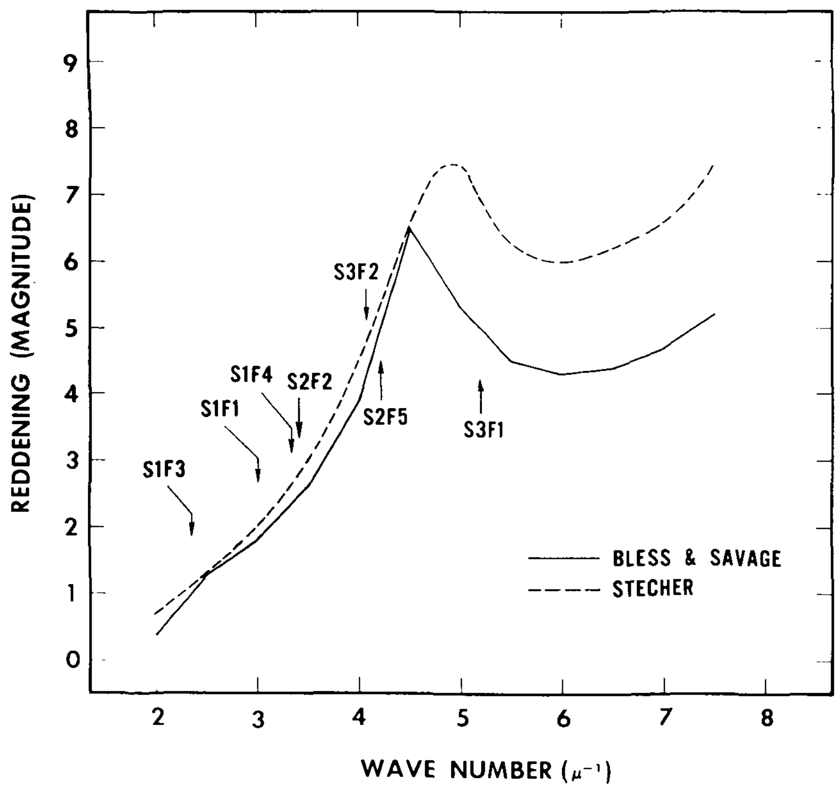

Figure 1.—Stecher's (1969) reddening curve (dashed line) and Bless and Savage's (1972) "mean" reddening curve (solid line) as a function of wavelength. Both curves are normalized to E(B-V) = 1. The arrows point out the effective wavelength of the various photometers.

Table 5. Observed and unreddened relative fluxes as a function of wavelength for the peculiar and comparison stars.

Star	No. of obs.	Effective wavelength (Å) 1913	2386	2462	2945	2985	3317	4252
3 Cen A	6	3.43	2.19	1.95	1.29	1.36	1.00	0.75
		0.02	0.01	0.01	0.00	0.00	0.00	0.00
		3.96	2.54	2.18	1.33	1.40	1.00	0.73
		0.02	0.01	0.01	0.00	0.00	0.00	0.00
Alpha Scl	2	3.17	1.98	1.88	1.24	1.27	1.00	0.86
		0.03	0.01	0.01	0.01	0.01	0.00	0.00
		3.36	2.10	1.96	1.26	1.28	1.00	0.85
		0.03	0.02	0.01	0.01	0.01	0.00	0.00
Alpha Scl	4	3.07	1.82	1.70	1.25	1.25	1.00	1.08
		0.02	0.01	0.01	0.01	0.00	0.00	0.00
		3.26	1.93	1.78	1.27	1.27	1.00	1.07
		0.02	0.01	0.01	0.01	0.00	0.00	0.00
3 Sco	1	2.38	1.63	1.48	1.18	1.27	1.00	0.84
		0.10	0.05	0.03	0.03	0.03	0.00	0.01
		3.57	2.46	2.04	1.29	1.37	1.00	0.76
		0.14	0.07	0.05	0.03	0.03	0.00	0.01
HR 8535	2	2.63	1.88	1.66	1.25	1.26	1.00	0.88
		0.08	0.04	0.03	0.02	0.02	0.00	0.01
		2.95	2.11	1.82	1.28	1.28	1.00	0.86
		0.09	0.05	0.03	0.03	0.02	0.00	0.01
HR 8770	2	2.13	1.45	1.38	1.13	1.20	1.00	0.84
		0.10	0.05	0.03	0.03	0.03	0.00	0.01
		2.85	1.96	1.73	1.20	1.26	1.00	0.79
		0.13	0.07	0.04	0.03	0.03	0.00	0.01
HD 21699	2	2.64	1.87	1.76	1.25	1.28	1.00	0.85
		0.05	0.03	0.02	0.02	0.01	0.00	0.01
		3.33	2.37	2.11	1.31	1.34	1.00	0.80
		0.07	0.03	0.03	0.02	0.02	0.00	0.01
HD 144334	2	2.70	1.86	1.64	1.24	1.30	1.00	0.88
		0.08	0.04	0.03	0.02	0.02	0.00	0.01
		3.60	2.50	2.06	1.31	1.37	1.00	0.82
		0.10	0.05	0.04	0.02	0.02	0.00	0.01

Table 5 (continued)

Star	No. of obs.	1913	2386	2462	2945	2985	3317	4252
		Effective wavelength (Å)						
HD 144661	2	2.26		1.37		1.25	1.00	0.87
		0.09		0.03		0.03	0.00	0.01
		3.02		1.72		1.31	1.00	0.81
		0.12		0.04		0.03	0.00	0.01
HD 144844	2	2.15	1.54	1.35	1.12	1.21	1.00	1.18
		0.09	0.04	0.03	0.03	0.03	0.00	0.02
		3.23	2.33	1.86	1.22	1.31	1.00	1.07
		0.13	0.07	0.04	0.03	0.03	0.00	0.02
35 Ari	2	3.85	2.12	1.99	1.34	1.33	1.00	0.76
		0.04	0.02	0.01	0.01	0.01	0.00	0.00
		4.71	2.61	2.34	1.39	1.38	1.00	0.73
		0.05	0.02	0.02	0.01	0.01	0.00	0.00
HD 142990	1	3.17	1.73	1.72	1.27	1.28	1.00	0.78
		0.08	0.03	0.03	0.02	0.02	0.00	0.01
		4.36	2.39	2.21	1.36	1.36	1.00	0.72
		0.11	0.05	0.03	0.02	0.02	0.00	0.01
Iota Her	1	4.30	2.50	2.17	1.40	1.41	1.00	0.63
		0.04	0.02	0.01	0.01	0.01	0.00	0.00
		4.55	2.65	2.27	1.42	1.43	1.00	0.62
		0.04	0.02	0.01	0.01	0.01	0.00	0.00
HD 68324	1	4.45		2.55		1.51	1.00	0.56
		0.07		0.03		0.01	0.00	0.00
		4.45		2.55		1.51	1.00	0.56
		0.07		0.03		0.01	0.00	0.00
114 Tau	1	4.23	2.21	2.10	1.42	1.39	1.00	0.68
		0.06	0.02	0.02	0.01	0.01	0.00	0.00
		4.75	2.49	2.29	1.45	1.42	1.00	0.66
		0.07	0.03	0.02	0.01	0.01	0.00	0.00
Rho Aur	3	3.92	2.19	2.04	1.34	1.34	1.00	0.85
		0.04	0.02	0.02	0.01	0.01	0.00	0.00
		4.28	2.39	2.19	1.37	1.36	1.00	0.83
		0.05	0.02	0.02	0.01	0.01	0.00	0.00

Table 5 (continued)

Star	No. of obs.	Effective wavelength (Å) 1913	2386	2462	2945	2985	3317	4252
115 Tau	2	3.50	1.94	1.84	1.34	1.29	1.00	0.89
		0.06	0.03	0.02	0.02	0.01	0.00	0.01
		4.05	2.25	2.06	1.39	1.33	1.00	0.86
		0.07	0.03	0.02	0.02	0.01	0.00	0.01
HD 67341	1	2.88		1.92		1.34	1.00	0.79
		0.13		0.05		0.03	0.00	0.01
		2.88		1.92		1.34	1.00	0.79
		0.13		0.05		0.03	0.00	0.01
16 Pup	1	4.03	2.17	2.08	1.28	1.36	1.00	0.84
		0.05	0.02	0.02	0.01	0.01	0.00	0.00
		4.15	2.23	2.13	1.29	1.37	1.00	0.84
		0.05	0.02	0.02	0.01	0.01	0.00	0.00
HD 93194	1	3.99	2.21	2.11	1.37	1.34	1.00	0.82
		0.06	0.03	0.02	0.02	0.01	0.00	0.01
		4.48	2.49	2.31	1.40	1.37	1.00	0.80
		0.07	0.03	0.02	0.02	0.01	0.00	0.01
19 Tau	1	2.55		1.59		1.28	1.00	0.95
		0.04		0.02		0.01	0.00	0.01
		2.70		1.66		1.29	1.00	0.93
		0.05		0.02		0.01	0.00	0.01
HD 21362	2	2.48	1.77	1.57	1.18	1.27	1.00	1.02
		0.07	0.03	0.02	0.02	0.02	0.00	0.01
		3.32	2.38	1.97	1.25	1.35	1.00	0.95
		0.09	0.04	0.03	0.02	0.02	0.00	0.01
17 Tau	1	2.62		1.58		1.37	1.00	0.89
		0.03		0.01		0.01	0.00	0.00
		2.70		1.62		1.38	1.00	0.89
		0.03		0.01		0.01	0.00	0.00
16 Tau	1	2.26		1.39		1.20	1.00	1.13
		0.09		0.03		0.03	0.00	0.02
		2.62		1.55		1.23	1.00	1.09
		0.10		0.04		0.03	0.00	0.02

Table 5 (concluded)

Star	No. of obs.	Effective wavelength (Å) 1913	2386	2462	2945	2985	3317	4252
Eta Tau	4	2.19		1.40		1.22	1.00	0.84
		0.01		0.00		0.00	0.00	0.00
		2.25		1.43		1.22	1.00	0.84
		0.01		0.00		0.00	0.00	0.00
20 Tau	1	2.11		1.32		1.26	1.00	0.97
		0.03		0.01		0.01	0.00	0.01
		2.37		1.44		1.29	1.00	0.94
		0.04		0.01		0.01	0.00	0.00
Tau 5 Eri	1	2.71		1.68		1.26	1.00	1.05
		0.05		0.02		0.01	0.00	0.01
		2.79		1.72		1.27	1.00	1.05
		0.05		0.02		0.01	0.00	0.01
Iota Lep	1	2.79		1.73		1.29	1.00	1.03
		0.05		0.02		0.01	0.00	0.01
		2.79		1.73		1.29	1.00	1.03
		0.05		0.02		0.01	0.00	0.01
18 Tau	1	2.32		1.47		1.24	1.00	1.10
		0.10		0.04		0.03	0.00	0.02
		2.46		1.54		1.25	1.00	1.09
		0.10		0.04		0.03	0.00	0.02
27 Tau	1	2.37		1.35		1.21	1.00	0.97
		0.03		0.01		0.01	0.00	0.00
		2.51		1.41		1.22	1.00	0.96
		0.03		0.01		0.01	0.00	0.00
41 Eri	3	2.59		1.59		1.26	1.00	0.99
		0.02		0.01		0.00	0.00	0.00
		2.59		1.59		1.26	1.00	0.99
		0.02		0.01		0.00	0.00	0.00

IV. RESULTS AND DISCUSSION

The data of Table 5 are presented as color-color diagrams in Figures 2 and 3. The horizontal bars in Figure 3 indicate the shift of the weak-helium line stars if Stecher's reddening curve had been adopted. The shift of the comparison stars would not be larger than 0.1 mag except for HD 142990 (B3 V) and HD 21362 (B6 V). The dashed line joins different observations of α Sculptoris.

The color indices $m_\lambda(1920\ \text{Å}) - m_\lambda(3320\ \text{Å})$ and $m_\lambda(2460\ \text{Å}) - m_\lambda(3320\ \text{Å})$ are essentially temperature dependent. The color $m_\lambda(4250\ \text{Å}) - m_\lambda(3320\ \text{Å})$ is related to the Balmer discontinuity which for B type stars is related to the effective temperature. Thus, by using the color-color diagrams we can perform an interesting comparison between inferences about temperature from different parts of the spectrum.

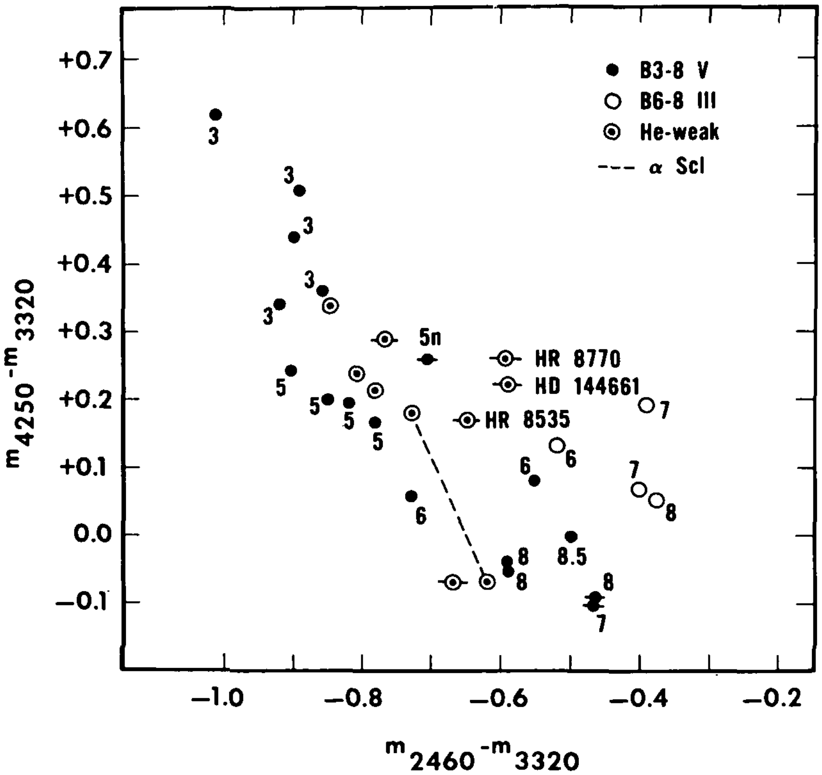

Figure 2.—Plot of the color index $m_\lambda(4250) - m_\lambda(3320)$ vs. $m_\lambda(2460) - m_\lambda(3320)$. The symbols are explained in the inset. The number near a dot indicates the spectral class. The dashed line joins observations of α Scl at two epochs (see Figure 6).

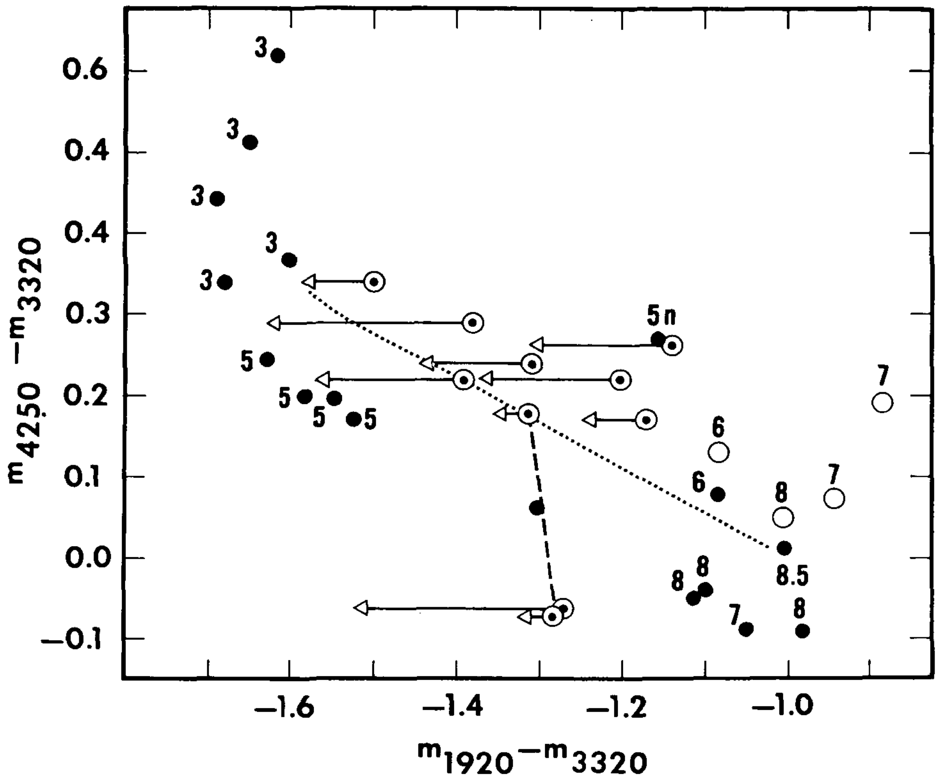

Figure 3.—The Balmer discontinuity is plotted against $m_\lambda(1920)$ - $m_\lambda(3320)$. Symbols are the same as in Figure 2. The arrows indicate the position of the weak-helium stars according to Stecher's reddening curve. The broken curve is assumed as the upper edge of the main sequence band.

Identification of the weak-helium stars may be achieved by reference to Table 6. On both diagrams dwarf stars form a scattered sequence. A distinction between B3, B5 and B8 stars is clearly evident and enables us to infer a photometric classification from the ultraviolet spectrum. The spread in m_λ(4250 Å) - m_λ(3320 Å) is of the order of 0.1 mag. The giants, as a group, have a smaller Balmer discontinuity than their main sequence counterparts and are fainter at 2460 Å. Underhill (1972) has shown clear evidence of line blocking around 2400 Å for stars later than B5 due mainly to the second spectrum of the metals. The effect is certainly enhanced in the spectra of the giant stars and accounts for their location in Figure 3.

In Figures 4 and 5 we have schematically represented the distribution in wavelength of the multiplets of most of the elements known to be strong in the weak-helium stars. The

Table 6. Color indices of the weak-helium stars corrected by means of the Bless and Savage reddening curve

Star	m(4250)-m(3320)	m(2460)-m(3320)	m(1920)-m(3320)
3 Cen A	0.343	-0.847	-1.495
α Scl	0.179*	-0.733*	-1.315*
3 Sco	0.294	-0.774	-1.380
HR 8535	0.166	-0.650	-1.174
HR 8770	0.261	-0.596	-1.136
HD 21699	0.242	-0.810	-1.305
HD 144334	0.216	-0.784	-1.392
HD 144661	0.225	-0.591	-1.200
HD 144844	-0.074**	-0.671	-1.272

*on January 23, 1971
**not corrected for duplicity

dashed curves show the sensitivity curves of photometers S3F1 (1920 Å) and S3F2 (2460 Å) as a function of wavelength.

a) The Weak-Helium Stars at 2460 Å

In Figure 6 the flux of α Scl at two epochs is compared with the flux from a hydrogen line-blanketed model atmosphere (Klinglesmith 1971). We can infer an effective temperature of at least 16000°K which may be compared with 14600 ± 200°K determined by Norris (1971). It can be shown that Norris' measurements of the continuous energy fit a hydrogen line-blanketed model of about 14000°K so that the difference of about 1500°K appears to be real.

The appearance of the depression in the continuum at 2400 Å on July 10, 1970 may be attributed to strengthening of Ti II and Sr II lines (see Figure 5) which have been observed to be strong in the ground-based spectrum of this star. Alpha Scl has been reported as a possible spectrum variable by Jugaku and Sargent (1961). The flux removed from the 2400 Å region is redistributed longward of the Balmer discontinuity. The black dot at 4250 Å in Figure 6 can be fitted to a model atmosphere of 14000°K in better agreement with Norris' estimate.

The stars 3 Cen A, 3 Sco, HD 144334 and HD 21699 are the hottest weak-helium stars. Their location in Figure 2 in the range B3-B5 agrees well with the photometric temperature classification (Table 1). We note, in addition, that 3 Sco and HD 144334 have strong Si II and Si III lines (Norris 1971) and

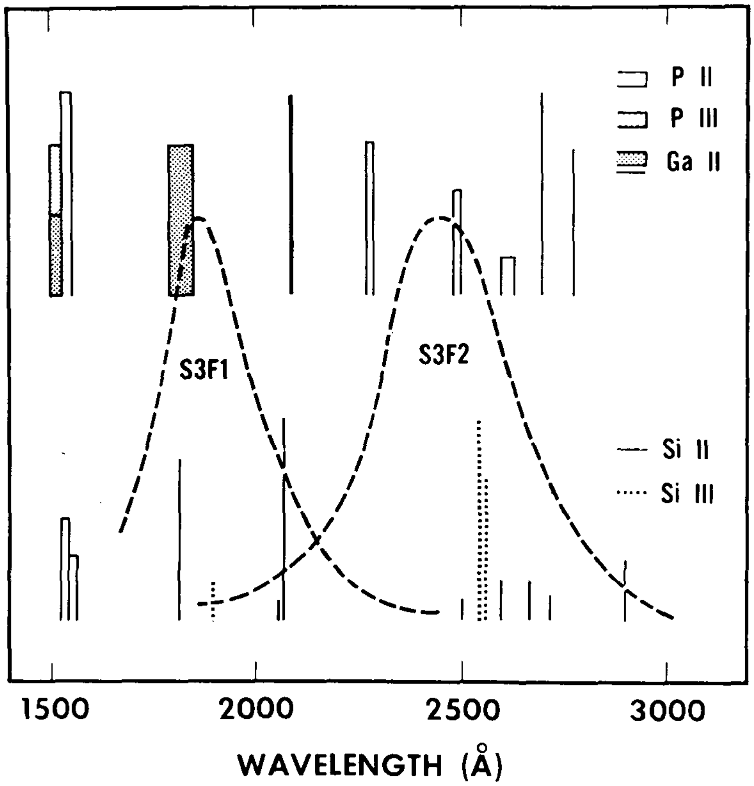

Figure 4.—The distribution in wavelength of the lines of the elements with spectra strong in the weak-helium stars is shown behind the sensitivity curves of photometers S3F1 (1920 Å) and S3F2 (2460 Å). Ordinates are in arbitrary units.

phosphorous is overabundant in 3 Cen A (e.g. Hardorp 1967). Figure 4 shows that the filter S3F2 is affected by line blocking due to the above elements. This effect supports further the conclusion that the stars considered have normal fluxes at 2460 Å.

The stars HR 8770, HD 144661 and possibly HR 8535 seem to be peculiar. They are either considerably fainter at 2460 Å than expected according to their ground-based colors or if they have types B7 to B9 III they have an excess of radiation at 2460 Å.

We have two good spectrograms of HR 8770 and one each for HR 8535 and HD 144661 at a dispersion of 40 Å/mm. They have been obtained using the GSFC 36-inch telescope, employing a blue sensitive Carnegie Image Tube and a IIa-O emulsion behind a BG-12 filter. The spectra of both HR 8535 and HD 144661 are similar in H, Mg, Si II and He I line strengths. The ratio Mg II λ4481/He I λ4471 would indicate B8. However, the ratio He I λ4026/Ca II-K excludes B8 or a later type. The line

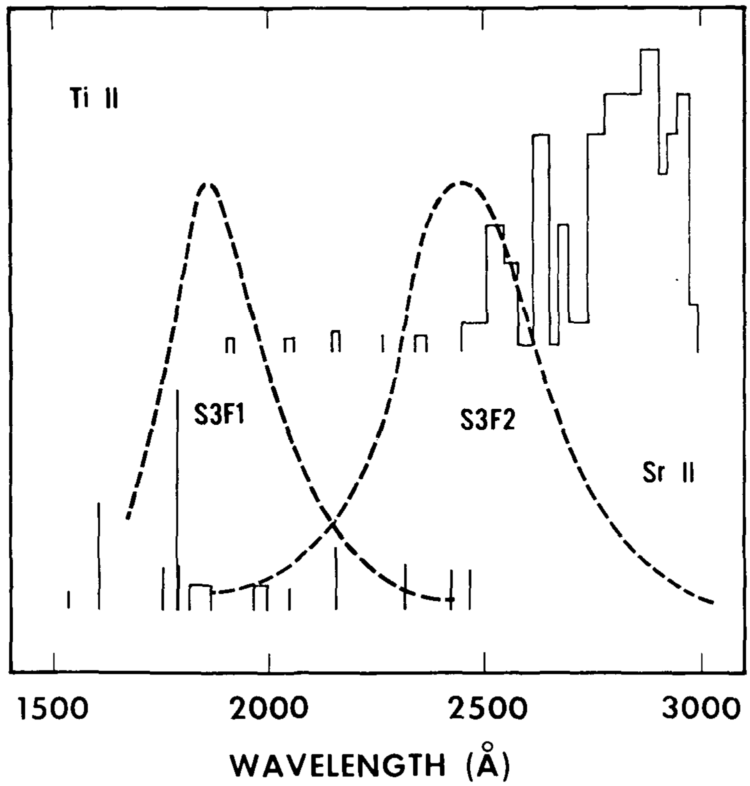

Figure 5.—The meaning is the same as in Figure 4.

Hg II λ3984 in HR 8535 observed by Molnar (1971) is not obviously present on our spectrograms. This star may be a spectrum variable.

The star HR 8770 has fainter helium lines and stronger Si II λ4128-30 than the above two stars. The Balmer lines are somewhat sharper and Si II λ4200 may be present on one of the spectrograms. The ratio λ4026/K excludes type B9. The faintness of the K-line and Mg II λ4481 in all three stars places some doubt on considering them as giants around B7-8. We cannot exclude that HR 8770 may be related to the silicon stars. Norris (1971) suspects the presence of P II lines in the spectrum of HD 144661. Hence line blocking around 2400 Å due to silicon and phosphorous cannot be discounted for explaining the flux deficiency of HR 8770 and HD 144661. The evidence, however, is not as clear as for the hottest weak-helium stars discussed above. We do not have data on B5 III and B6 III stars with which to support the inference that HR 8770 and HD 144661 are giants of earlier type than B7 in analogy with the location of the late B-type giants on the diagram. We may suggest as an alternative hypothesis that these two stars are brighter at 3320 Å than normal.

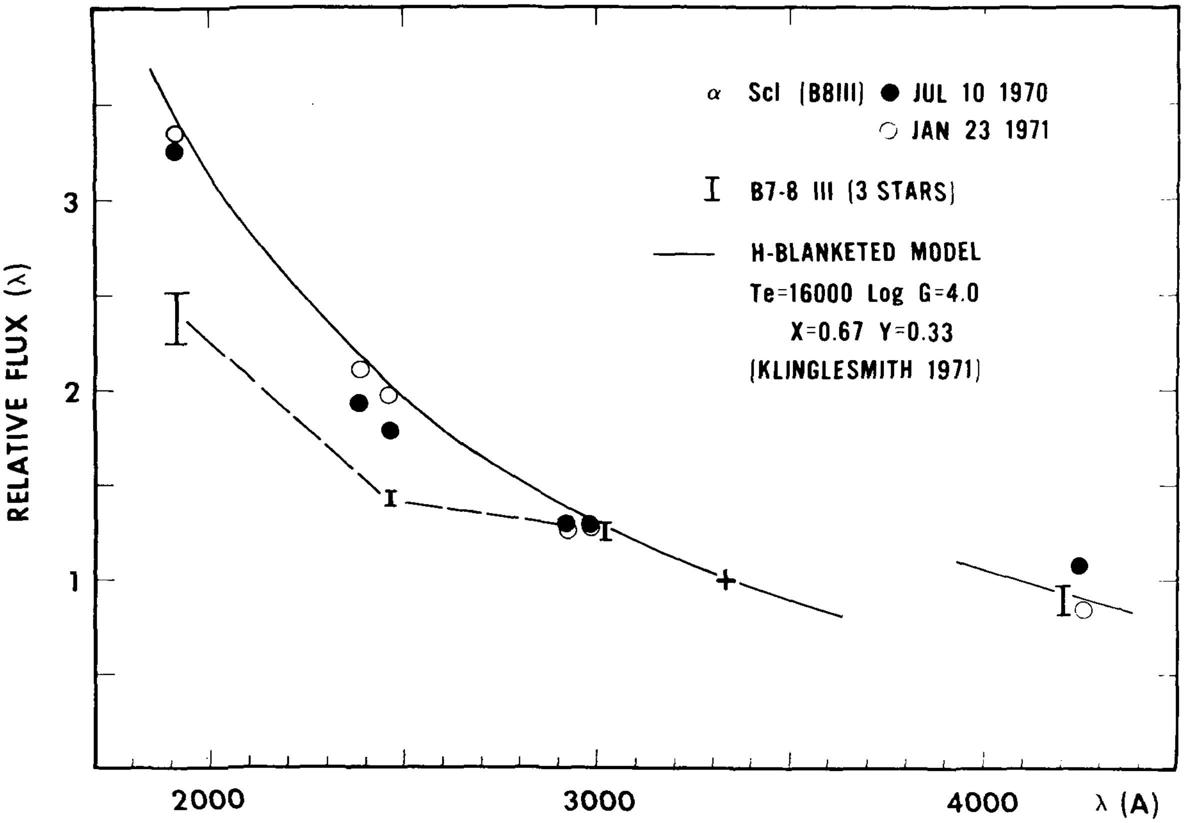

Figure 6.—The observations of α Scl at two epochs are compared with the flux of a hydrogen line blanketed model atmosphere (Klinglesmith 1971). The observations of three stars of the same spectral type as α Scl are shown by the vertical bars. The flux is normalized to 3320 Å.

We conclude the discussion of Figure 2 by noting that HD 144844 is on the lower edge of the main sequence band. One would expect to find a strong deficiency at 2460 Å because of blanketing due to P II, Ga II, Si II and Fe II lines which have been observed in the ground-based spectrum by Norris (1971). We may argue as follows: first, the E(B-V) is rather large (see Table 4) so that the correction for reddening may be over-estimated. Second, HD 144844 is a double-lined spectroscopic binary. According to Norris (1971) the secondary is three times fainter and of spectral type A0 or slightly earlier. If we assume T_e = 12000°K for the secondary, Klinglesmith's models give $F_\lambda(4250)/F_\lambda(3320)$ = 1.35. The ratio of 1.07 observed for the mixed components (Table 5) requires a ratio of 1.0 for the primary if we assume the secondary to be three times fainter in S1F1. Thus, $m_\lambda(4250$ Å$) - m_\lambda(3320$ Å$) \simeq 0.0$

might be a more correct color index for the brighter star alone. Third, we wonder whether we have observed HD 144844 in a phase similar to that of α Scl on July 10, 1970. Its location in Figure 2 agrees with that of α Scl when the star has an increased Balmer discontinuity.

In summary, when allowance is made for the uncertainties due to a qualitative accounting for line blocking around 2400 Å, the following picture emerges:

a. Most of the program weak-helium stars appear to have normal fluxes corresponding to the range of the hot stars.
b. The temperature determination and hence, helium abundance derived from ground-based observations may be affected by large uncertainties. In α Scl the apparent helium underabundance is probably larger than previously reported.
c. It is difficult to interpret HR 8770, HD 144661 and perhaps HR 8535 as having a normal flux distribution on the basis of the present knowledge of their spectra.

b) The Weak-Helium Stars at 1920 Å

The weak-helium stars are fainter at 1920 Å than main sequence stars of the same color in Figure 3. If we assume 0.1 mag as the natural width of the main sequence band in m_λ(4250 Å) - m_λ(3320 Å), we see that α Scl and HD 144334 are on the upper edge as defined by the broken line, thus not necessarily peculiar. Moreover, we have seen that the continuum of α Scl fits nicely to a model atmosphere. For HD 144334 we may advocate line blocking around 2000 Å from Si II and Si III (see Figure 4). By reference to Figure 4, the position of 3 Cen A may be attributed to the overabundance of gallium (c.f. Hardorp 1967).

The discrepancy could also be removed for 3 Sco if we consider both line blocking by Si II and Si III and the possibility of having underestimated the reddening. Finally, we can shift HD 21699 to within the main sequence band since Stecher's curve is likely to represent more correctly the reddening law for the Perseus region than does the law we have adopted.

The position of HD 144844 is still embarrassing. If, for consistency, we admit that line blocking due to P II, Ga II, Si II and Fe II plays a role in filter S3F1, we should conclude that this star is brighter at 1920 Å for its color (B7) and much brighter for its spectrum (B9) than expected. We feel, however, that the evidence is not strong enough to suggest an excess of radiation.

The stars HR 8535 and HR 8770 are "peculiar" in Figure 3 even when their position corrected according to Stecher's reddening curve is considered. We note that HD 144661 and

HD 144844 are relatively close in the Sco-Cen association, so that it is reasonable to assume they undergo the same reddening law. The fact that the Bless and Savage curve seems more reliable for HD 144844 supports the conclusion that HR 8535, HR 8770 and HD 144661 may form a separate group from the other weak-helium stars. They have comparable color indices and are fainter by about 0.4 mag at 1920 Å than their colors would predict. The possible presence of P II in the spectrum of HD 144661 cannot account for line blocking in filter S3F1 (Figure 4); it is not ascertained whether Si II lines may play a role in HR 8770, although the effect is expected to be stronger than at 2460 Å (Figure 4).

New spectrograms and the ultraviolet photometry show that all three stars are definitely earlier than B8. If their position on the diagram is to be explained by giantism in analogy with the B6-8 III stars, their type is possibly about B6 III. Contrary to this hypothesis we note, however, that Norris (1971) has determined log g = 3.95 for HD 144661, a value typical of dwarf stars, and that HR 8535 has a similar spectrum to that of HD 144661.

V. SUMMARY AND CONCLUSIONS

We should emphasize that the conclusions that we can draw from the previous sections are certainly biased by the qualitative character of the analysis and by selection effects in the choice of the comparison stars.

Do the program weak-helium stars have normal fluxes? We feel the answer is affirmative for 3 Cen A, 3 Sco, HD 144334, HD 21699, α Scl and possibly HD 144844, after allowance is made for line blocking shortward of 2800 Å due to the abnormal strength of lines from the heavier elements. The existence of blanketing is likely to distort the continuum longward of the Balmer discontinuity, as in the case of α Scl, placing an uncertainty on the temperature and helium abundance derived from ground-based observations. The effective temperature and helium underabundance of α Scl are probably higher by a significant factor than previously reported.

Norris (1971) has found that a number of weak-helium stars on the (θ_e, log g)-plane are beyond the helium-ionization convective boundary which is thought to constitute the limit for the Ap stars (Searle and Sargent 1967). If line blocking in the ultraviolet redistributes energy longward of the Balmer discontinuity as in α Scl, the hottest weak-helium stars could be given a higher temperature, which would support Norris' discussion about the mechanism of the Ap phenomenon.

It is difficult to interpret HR 8535, HR 8770 and HD 144661 as having a normal flux distribution. New spectrograms and the ultraviolet photometry exclude that they are later than B7 and of luminosity higher than V. However, they are fainter at 1920 Å and 2460 Å than the UBV photometry and the color index m_λ(4250 Å) - m_λ(3320 Å) would predict by about 0.4 mag and 0.2 mag respectively. Only as a suggestion we have mentioned the possibility that they are brighter at 3320 Å than normal, which would account for the smaller Balmer discontinuity and the apparent faintness shortward of 2800 Å. For HR 8770 line blocking by Si II lines cannot be excluded.

We have discussed the important role of metal line blocking only. We might add that metal continuous opacity sources are negligible in the weak-helium stars. These stars have temperatures of B3 to B5 stars and the important continuous opacity sources such as Si I will be completely ionized. The uncertainty in the reddening correction for each star places a restriction on any finer analysis of the observational material presented in this investigation.

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