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A LIBRARY OF STELLAR SPECTRA

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ABSTRACT

Spectra for 161 stars having spectral classes O–M and luminosity classes V, III, and I have been incorporated into a library available on magnetic tape. The spectra extend from 3510 to 7427 Å at a resolution of ~ 4.5 Å. The typical photometric uncertainty of each resolution element in the spectra is on the order of 1%, while broad-band variations are smaller than 3%.

Potential uses for the library include population synthesis of galaxies and clusters, tests of stellar atmosphere models, spectral classification, and the generation of color indices having arbitrary wavelength and bandpass.

Subject headings: spectrophotometry — stars: catalogs

I. INTRODUCTION

A comprehensive spectrophotometric library of stars covering the H-R diagram is an important tool for many areas of astronomy such as modeling stellar atmospheres and spectral classification of digital observations. It is especially important as the basis for the technique of spectral synthesis which is applied to the integrated light of composite systems to determine the fraction of light contributed by each of the main stellar groups comprising the system.

A number of filter photometric (Wood 1969; Faber 1973), photographic (Williams 1976), and spectrophotometric (Spinrad and Taylor 1971; O'Connell 1973; Breger 1976; Joly 1974; Pritchet and van den Bergh 1977; MacFarlane 1979; Gunn and Stryker 1982) stellar libraries exist in the literature, and recently an ultraviolet stellar library from *IUE* has been prepared (Wu *et al.* 1984). The filter photometry is useful for determining rough color groups, but contamination of colors by emission lines, the effect of redshift, the uncoupling of emission and underlying absorption features, and the nonlinear way in which broad-band colors add introduce uncertainties into the usage of these catalogs. Spectrophotometry reduces these problems, but current libraries are, in general, based on low-resolution scanner data which are restricted to or undersample major lines. However, synthesis techniques often work best when the spectral features are oversampled (Peck 1984).

We therefore undertook spectrophotometric observations of a large number of stars at moderate resolution (~ 4 Å) with the intention of constructing a comprehensive library of stellar spectra. For population synthesis completeness in the stellar types is crucial since the synthesis techniques cannot identify a missing but necessary stellar component (Peck 1980). In addition, a long-wavelength baseline is desirable, as is a selection of different metallicities. In practice, however, observing time is limited. The library we present below consists of spectra covering 3510–7427 Å for 161 stars of spectral types O–M and luminosity classes V, III, and I. The stars are mainly of solar metallicity, although two stars specifically chosen for low metallicity are included.

II. THE DATA

a) *Observations*

The data were obtained on 26 nights from 1980 December to 1981 December using the Intensified Reticon Scanner (IRS) on the No. 1 90 cm telescope at Kitt Peak. The instrument is a dual-beam spectrophotometer which measures sky and object simultaneously. Data are taken in a "beam switch" mode where the object is alternately observed through one aperture and then through the other. Apertures of 13″ diameter spaced 61″ apart were used.

Although the instrument was still undergoing development until 1981 February, we see no evidence in our data suggesting that any instrumental effects persist. The primary concern is for the presence of fixed pattern noise. The spectra obtained during the period in question were carefully examined to verify their quality.

Each spectrum presented in this paper was taken in three overlapping segments: (1) blue, grating No. 35 (600 l mm^{-1}) in second order with copper sulfate and Schott WG3 blocking filters to cover 3430 or 3500 Å to 4870 or 4950 Å (depending on the exact instrumental setup); (2) green, grating No. 56 (600 l mm^{-1}) in second order with either a Schott GG455 or Corning 3-75 blocking filter to cover from 4760 to 6220 Å;

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and (3) red, grating No. 36 (1200 l mm^{-1}) in first order with either a Schott GG15 or WG2 blocking filter to cover from 6000 to 7450 Å. The instrumental profile can be adequately represented by a Gaussian function. The full width at half-maximum is ~ 4.5 Å, although this varies slightly across the spectrum and due to seeing variations, but by less than 10%.

The object stars were chosen from the literature according to their spectral types (see references to Table 2). Stars with the least amount of interstellar reddening were preferred. Stars brighter than about $V = 8$ could not be observed with the IRS without neutral density filters. Therefore, to minimize the observing time required per star while avoiding the use of neutral density filters, objects closest to the bright limit were preferred. No stars fainter than approximately $V = 11$ were observed. Integration times were chosen to provide better than 1% photon statistics in each pixel of the spectrum. The blue end of the spectra of red stars has somewhat poorer statistics (see, for e.g., the M star spectra shortward of 4500 Å).

b) Reductions

The data were placed on linear wavelength and flux scales using the Kitt Peak Interactive Image Processing System software. On each night we obtained spectra of a helium-neon-argon line source, a continuum source, and three to eight flux standards to remove the instrumental signature. The mean Kitt Peak extinction curve was used, and the fluxes were placed on the system of Hayes and Latham (1975) through observations of stars having known fluxes (Barnes and Hayes 1982). The mean extinction function was modified after these data were reduced and represents a change in flux at 3500 Å of ~ 7% for an air mass of 1.2 which is somewhat greater than our average value. At 7500 Å, the effect is only 2%.

In the red spectra a strong absorption feature near 6850 Å (the *b* band) interferes with the calibration for instrumental sensitivity. The affected calibration point was replaced with a reasonable estimate based on a smooth instrument response through this spectral region. A similar problem occasionally appeared at 3800 Å in the blue spectra due to the deep absorption lines in some of the A-type standards. The resultant calibration has residual errors typically smaller than ~ 3% throughout the library.

Some of the data were obtained through thin clouds and therefore were not of photometric quality. The effects of the clouds on the colors of the stars were negligible. When the three spectra (blue, green, red) for each star were joined, they were normalized to the component having the highest flux level. Although this procedure reduces the number of affected stars, we cannot guarantee that even the highest flux level spectrum was not observed through some clouds. Therefore, the absolute flux levels of the spectra in the library generally should be considered uncertain.

The V magnitudes were numerically synthesized from the spectra. The zero-point transformation was determined from ~ 50 stars for which high quality observed magnitudes are available in the literature. In Figure 1 we plot the observed magnitudes against the transformed synthesized V magnitudes for 119 of the library stars. One can see from the figure that, except for about a dozen stars possibly affected by clouds, the relationship has little scatter.

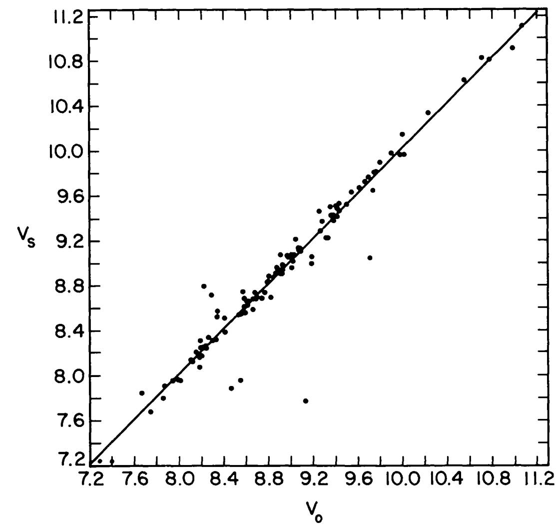

FIG. 1.—V magnitudes given in the literature (V_0) vs. those synthesized from the spectra using the transformations given in the text (V_s). Solid line represents $V_0 = V_s$.

With some of the data (63 stars) obtained by D.A.H. there was a problem due to overlapping orders in the green and red spectra. The Corning 3-75 filter used in the green permitted 3750–4130 Å light to enter in third order (appearing at 5575–6200 Å), and the WG2 filter used in the red allowed 3500–3700 Å to pass in second order (7000–7400 Å). These data required special processing.

Each affected star was first flux calibrated with the standard stars (O–F) closest in spectral type to it. Then an additional multiplicative factor was applied. This factor was a function of wavelength and was determined from the blue spectrum of the object and standard stars and the blocking filter transmission curve. The intensity ratio of the third-order light to second-order light for the green spectra was determined by measuring the ratios of the hydrogen absorption lines at 3970 and 4101 Å (Hϵ and Hδ) appearing in the green spectrum of A-type stars. For the red spectra, this factor was determined by comparison with spectra of stars of similar spectral type which did not suffer from the problem.

For stars exhibiting residual Balmer line absorption in the green spectrum arising from the overlap of the third order, contamination from Hϵ was removed and replaced with a polynomial fitted to the surrounding continuum. The region from 5938 to 5995 Å in A-type and some F-type stars should be avoided in the affected spectra (see, e.g., star 30 in Fig. 2). The stronger Hδ line was replaced during the combining of the red and green spectra; the H8 line was too weak to be significant.

A careful comparison was made between stars which were contaminated and those of nearly the same spectral type which were not. In general, the correction procedure worked well; a few stars were rejected from the library when we felt that some residual deviations persisted. The stars subjected to the order correction processing are identified in the last column of Table 1 by "G" or "R."

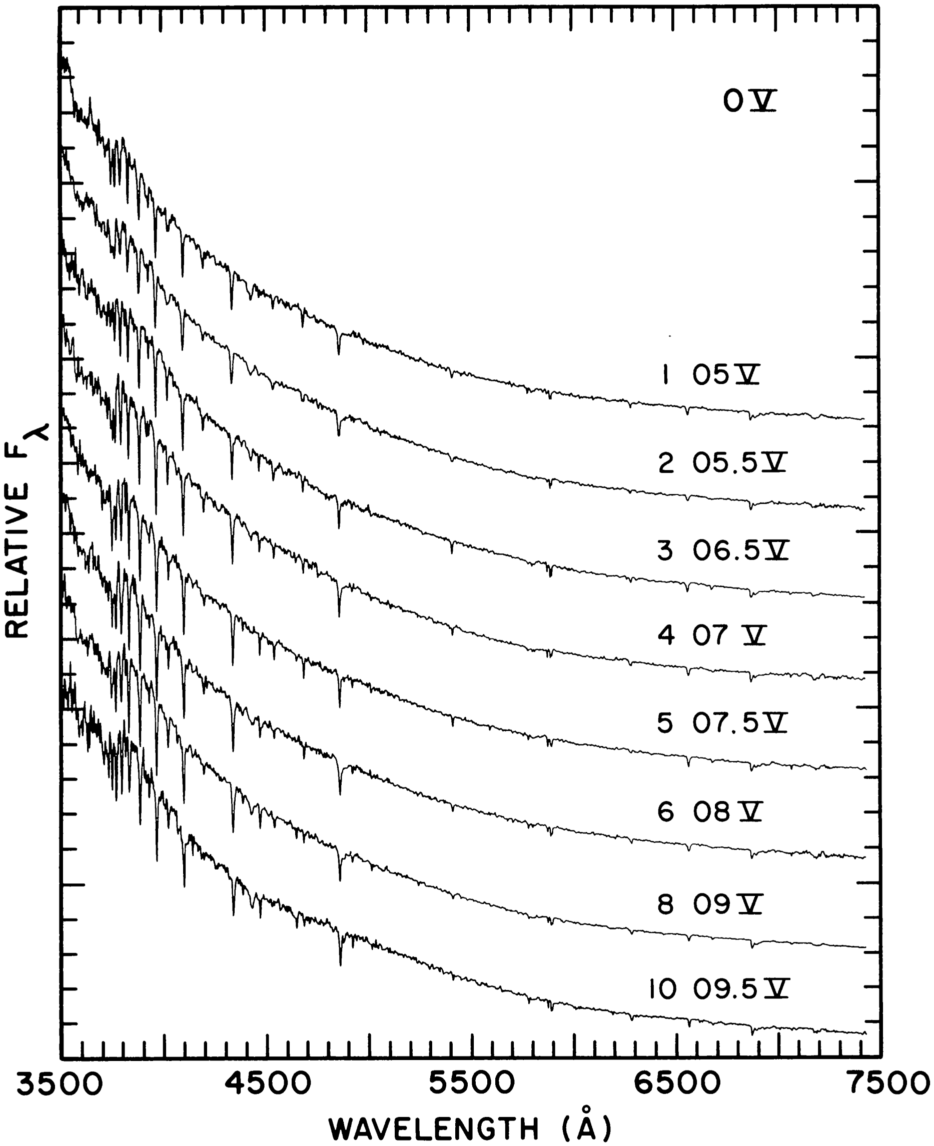

FIG. 2*a*

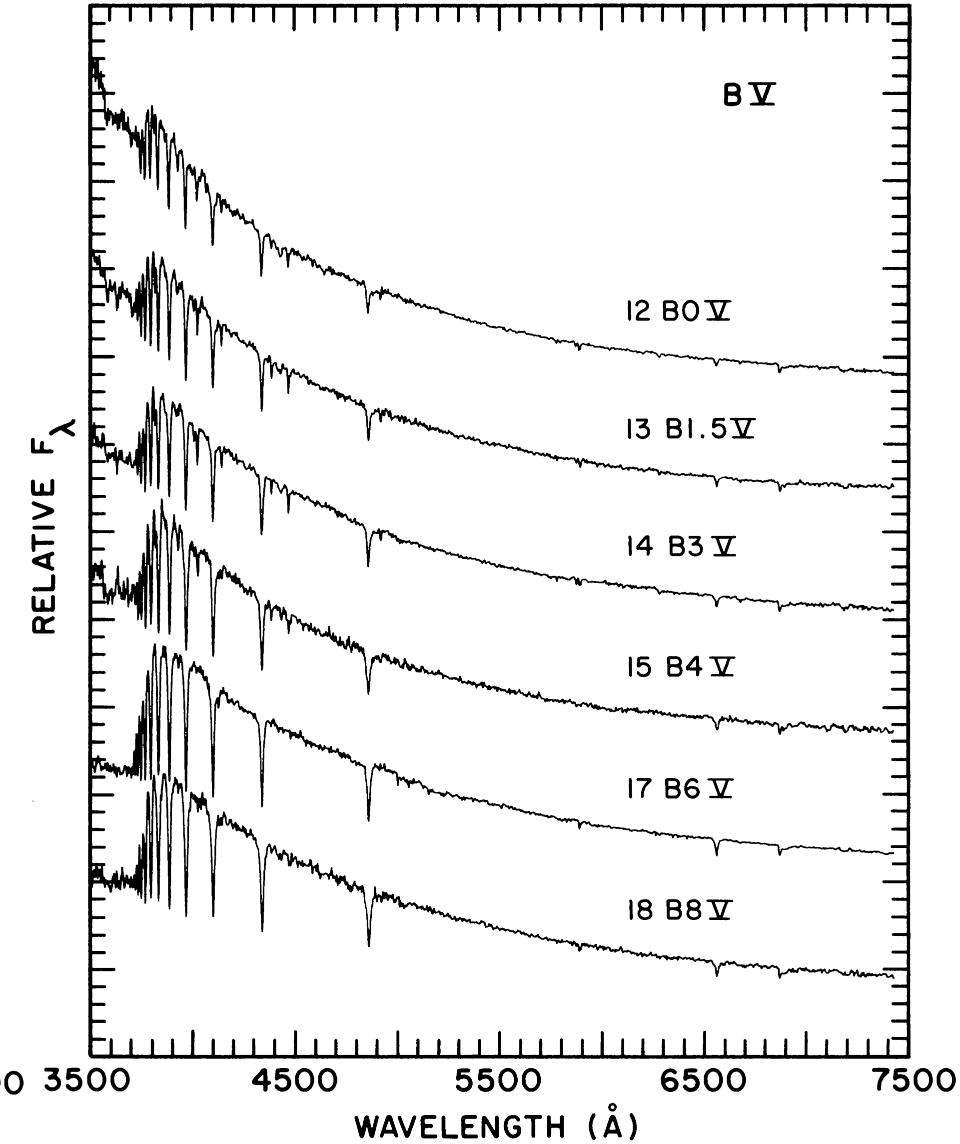

FIG. 2*b*

FIG. 2.—Stellar spectra grouped by spectral type: O–M and luminosity class V–I. Stars which duplicate spectral types and some emission-line stars are not illustrated. Each spectrum has been normalized to ~ 4200 Å or 6300 Å (red stars) and offset by a constant. Minimum and maximum values from Table 1 can be used to reconstruct the true F_λ scale.

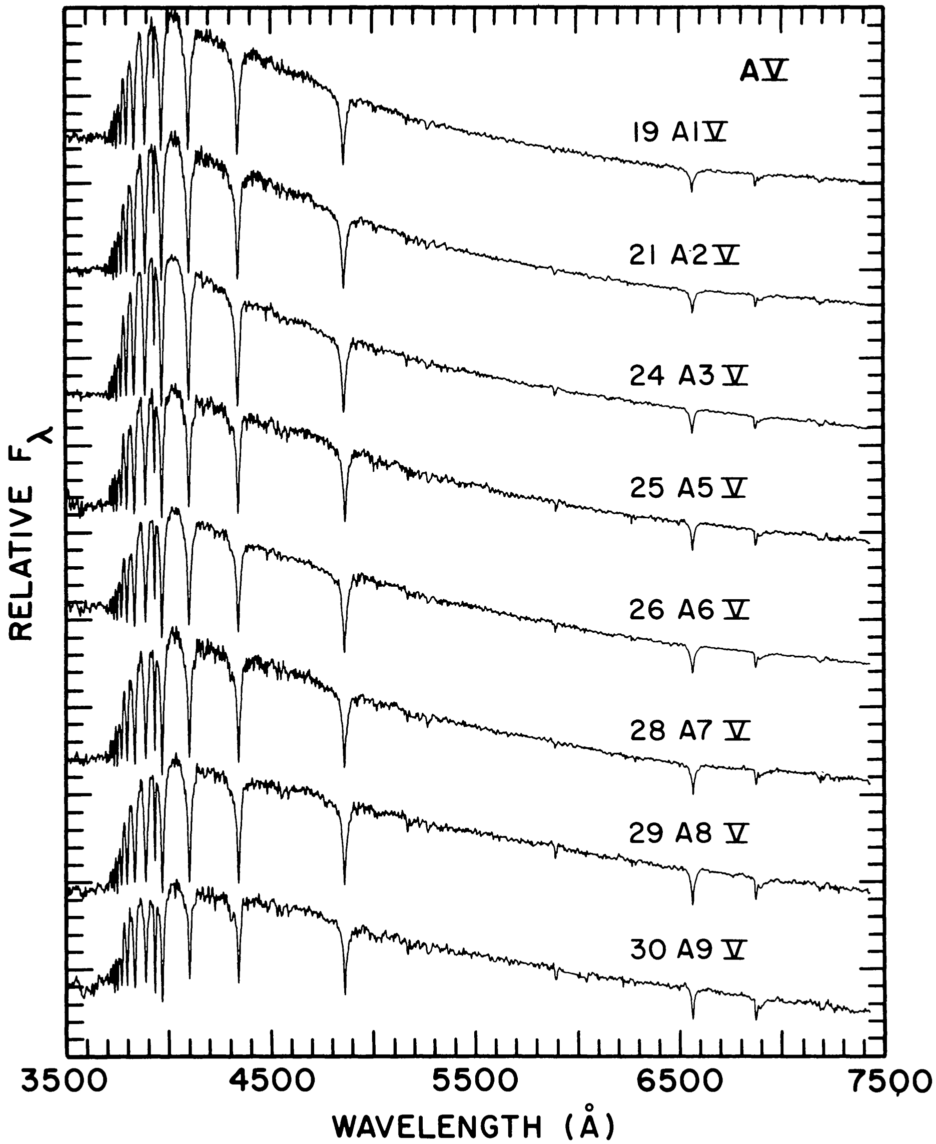
AV
19 A1V
21 A2V
24 A3V
25 A5V
26 A6V
28 A7V
29 A8V
30 A9V
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2c

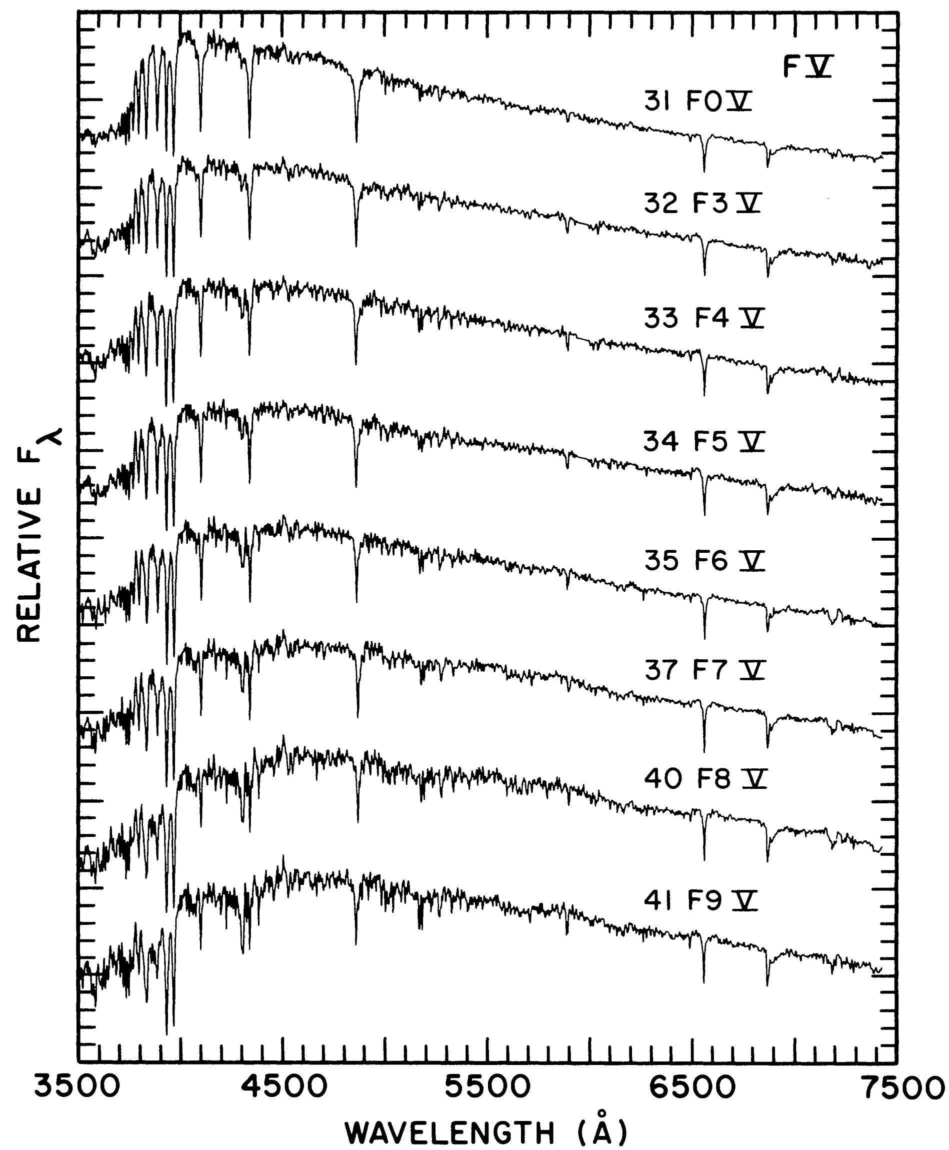
FV
31 F0V
32 F3V
33 F4V
34 F5V
35 F6V
37 F7V
40 F8V
41 F9V
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2d

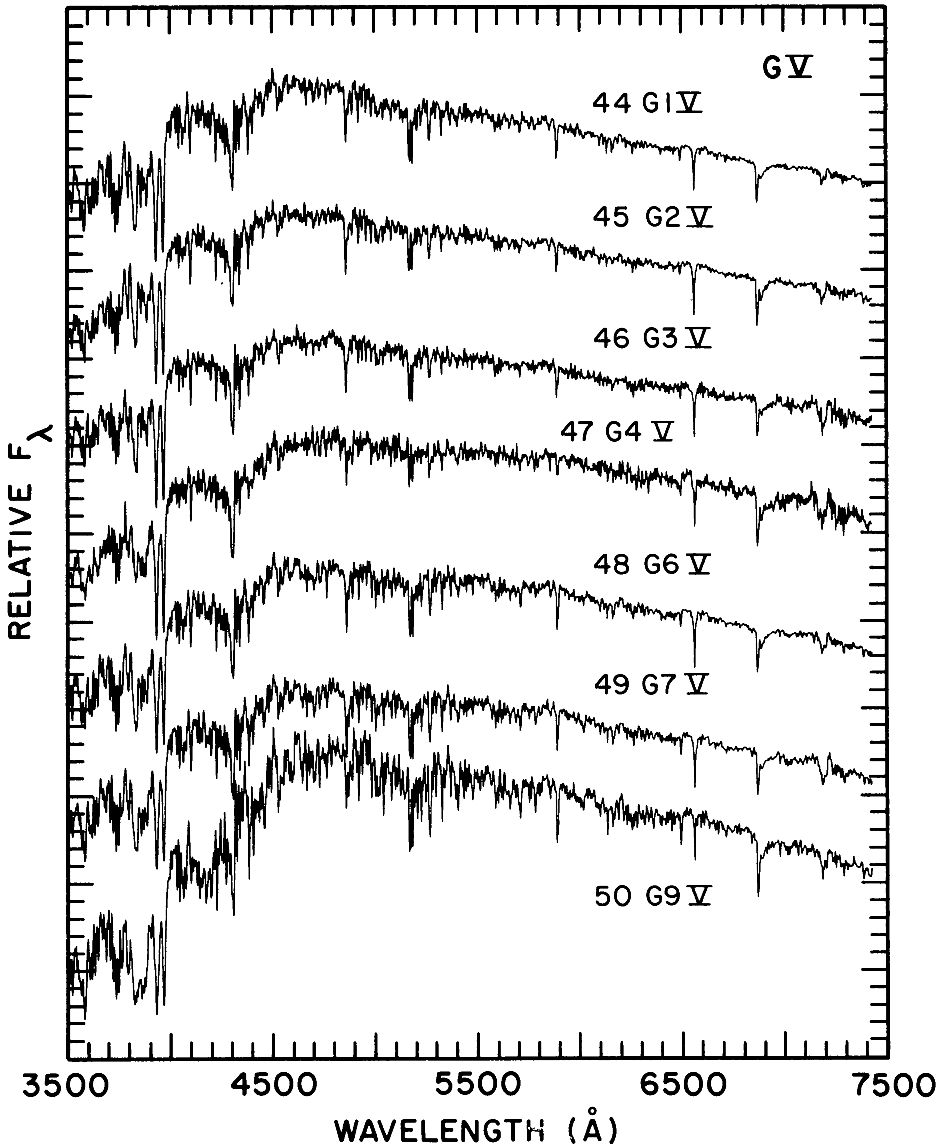
G V
44 G1 V
45 G2 V
46 G3 V
47 G4 V
48 G6 V
49 G7 V
50 G9 V
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2e

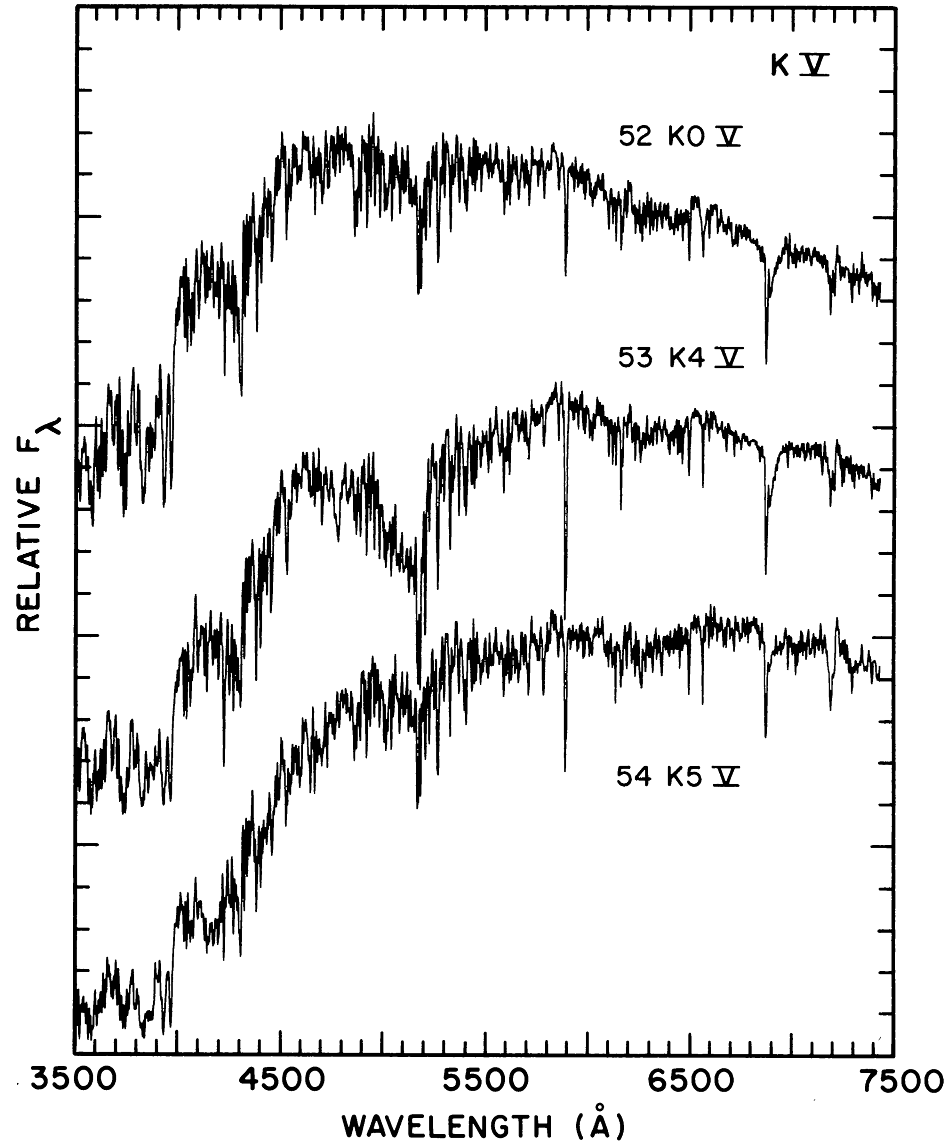
K V
52 K0 V
53 K4 V
54 K5 V
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2f

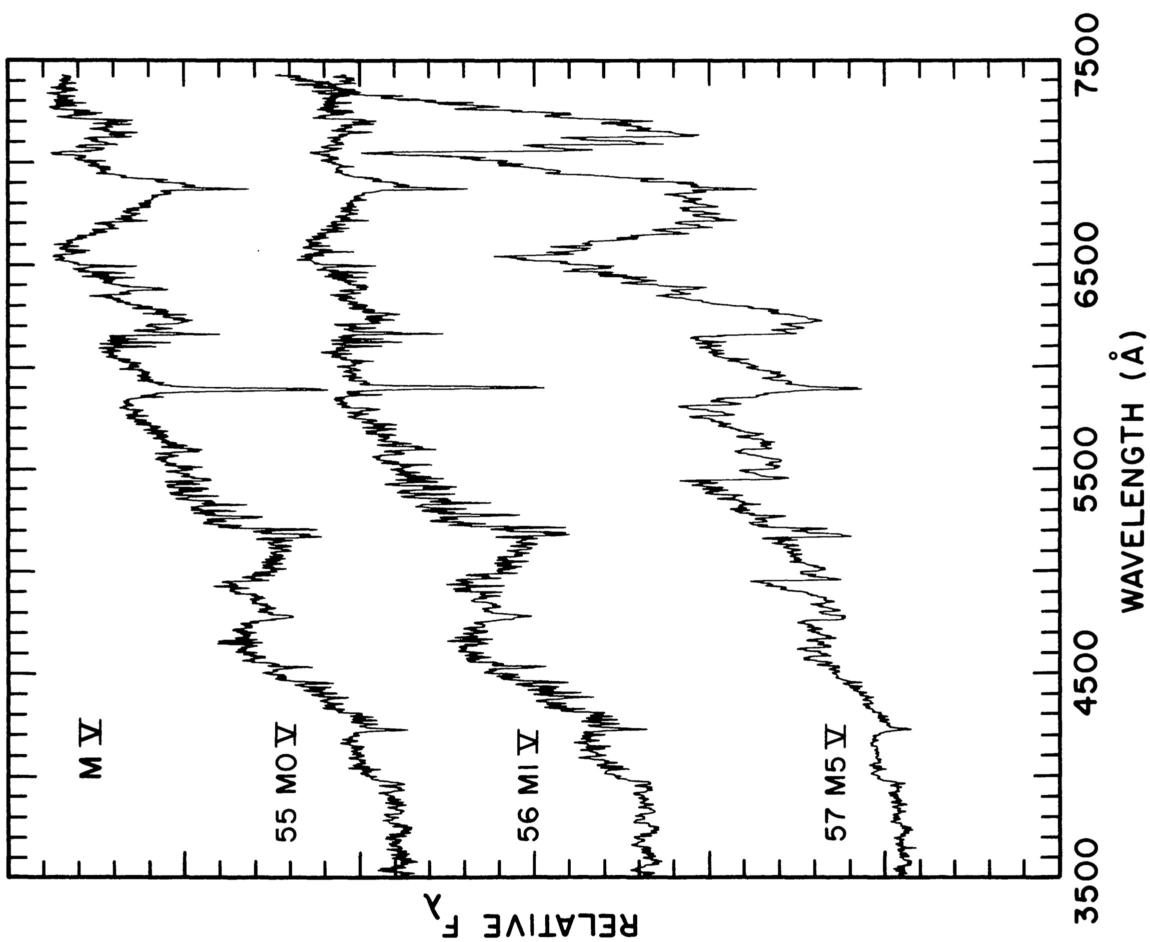
M V
55 MO V
56 MI V
57 M5 V
RELATIVE F_λ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2g

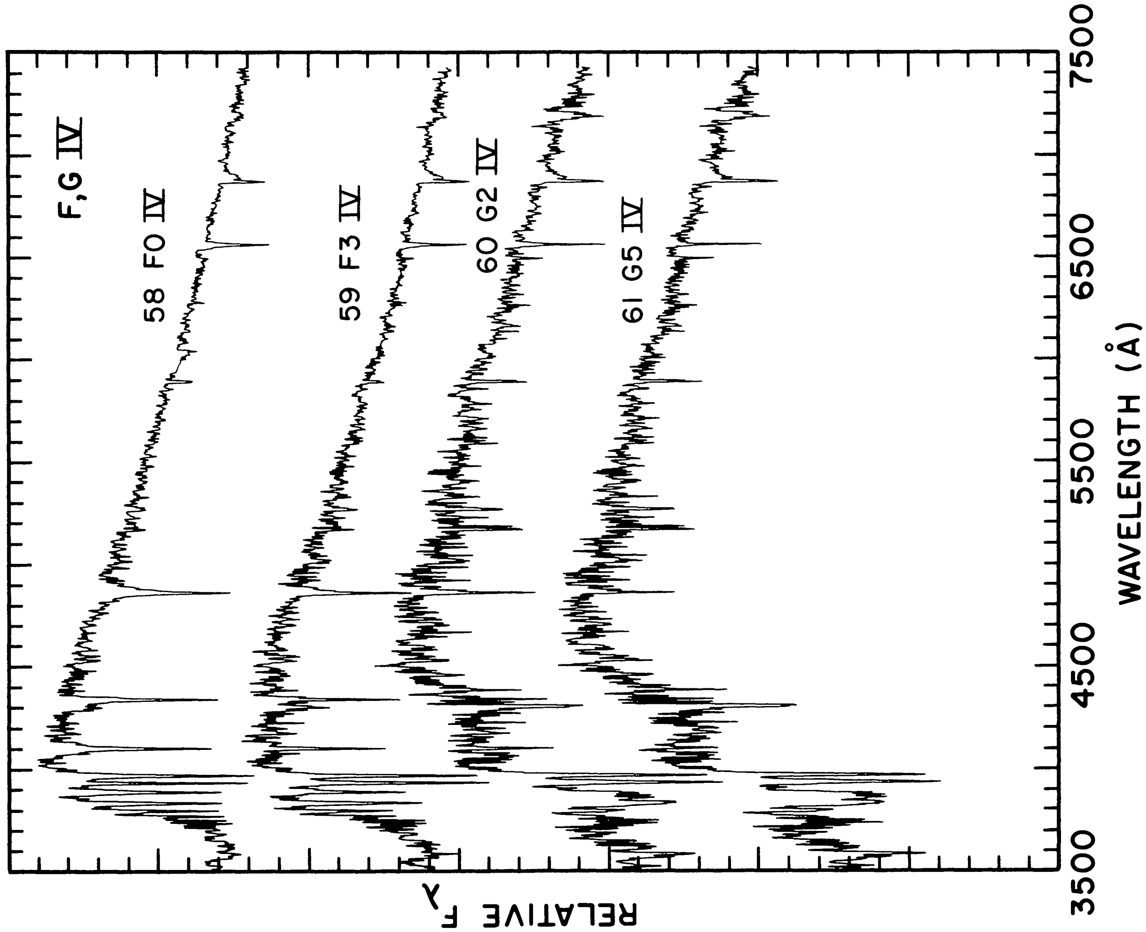
F,G IV
58 FO IV
59 F3 IV
60 G2 IV
61 G5 IV
RELATIVE F_λ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2h

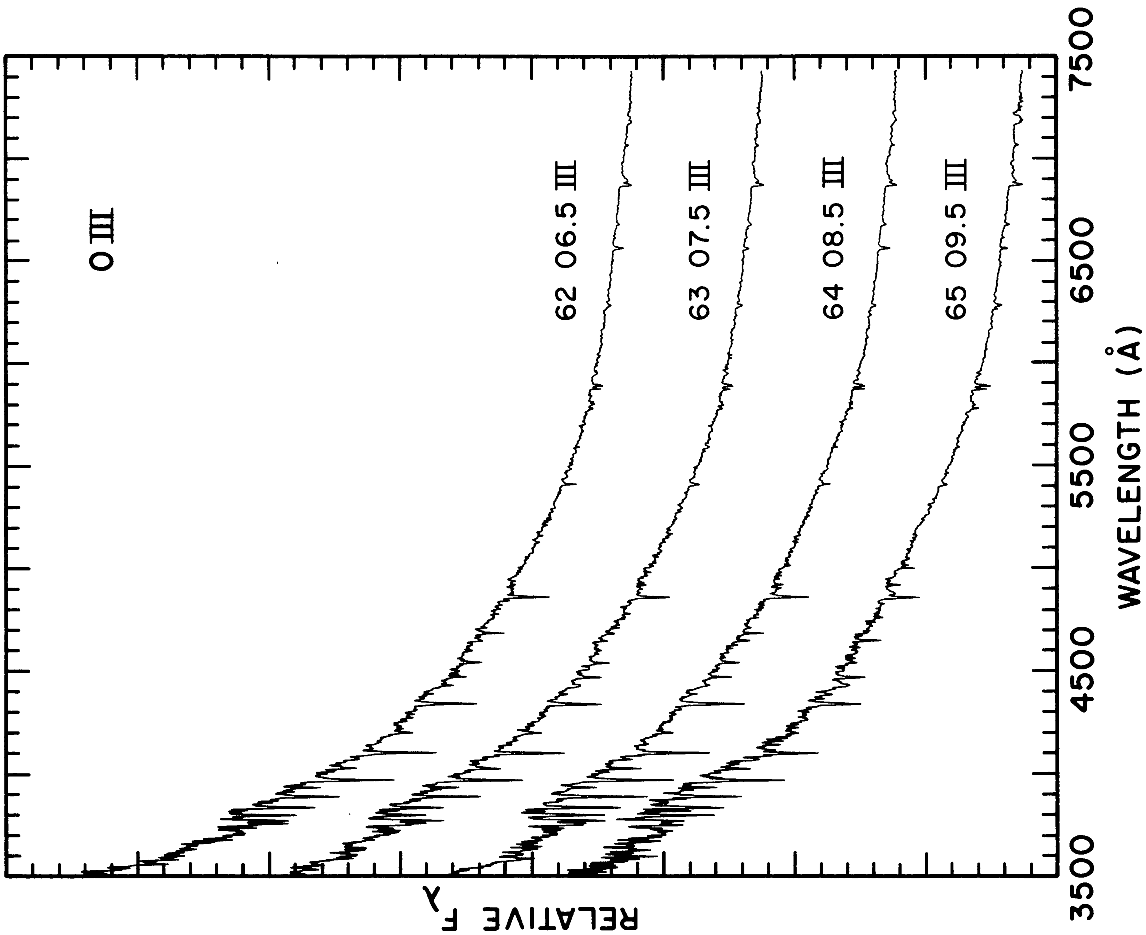
O III
62 O6.5 III
63 O7.5 III
64 O8.5 III
65 O9.5 III
RELATIVE F_λ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2*i*

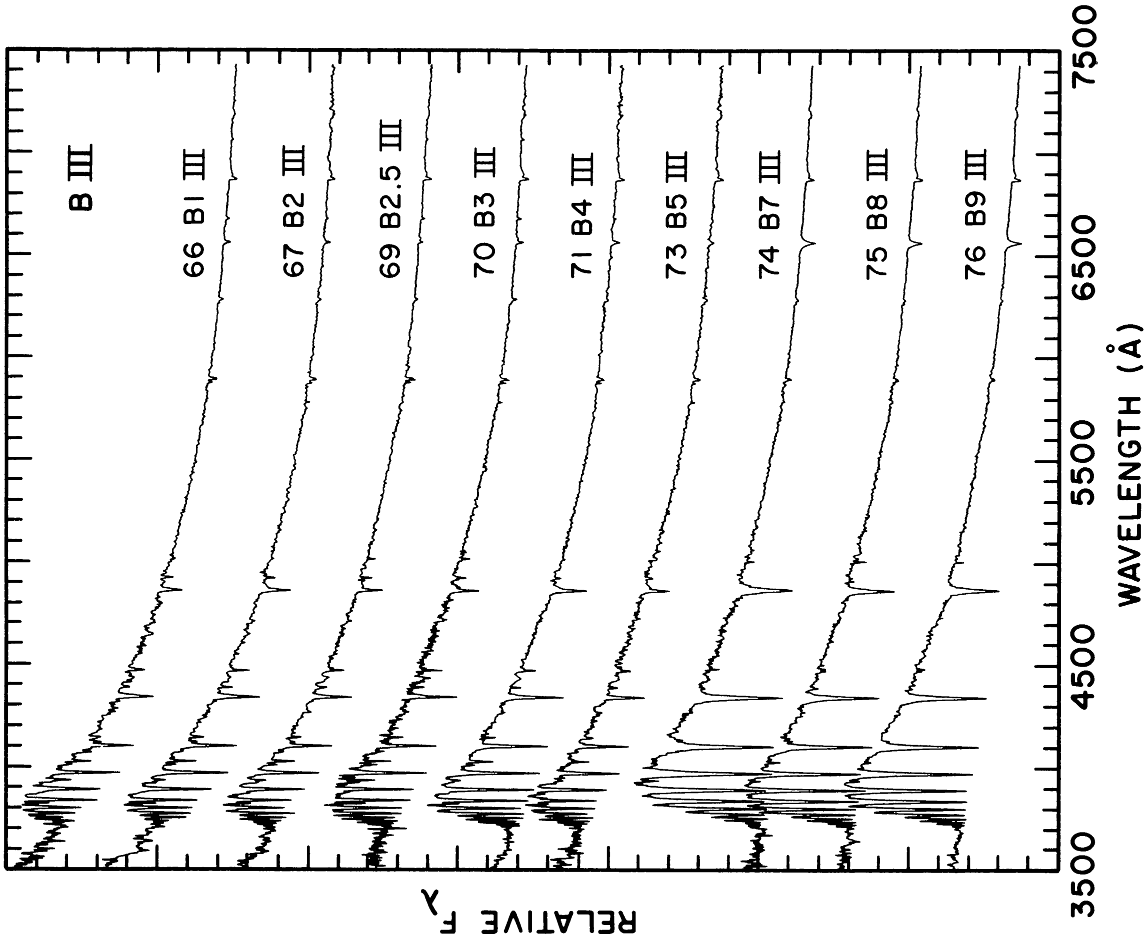
B III
66 B1 III
67 B2 III
69 B2.5 III
70 B3 III
71 B4 III
73 B5 III
74 B7 III
75 B8 III
76 B9 III
RELATIVE F_λ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2*j*

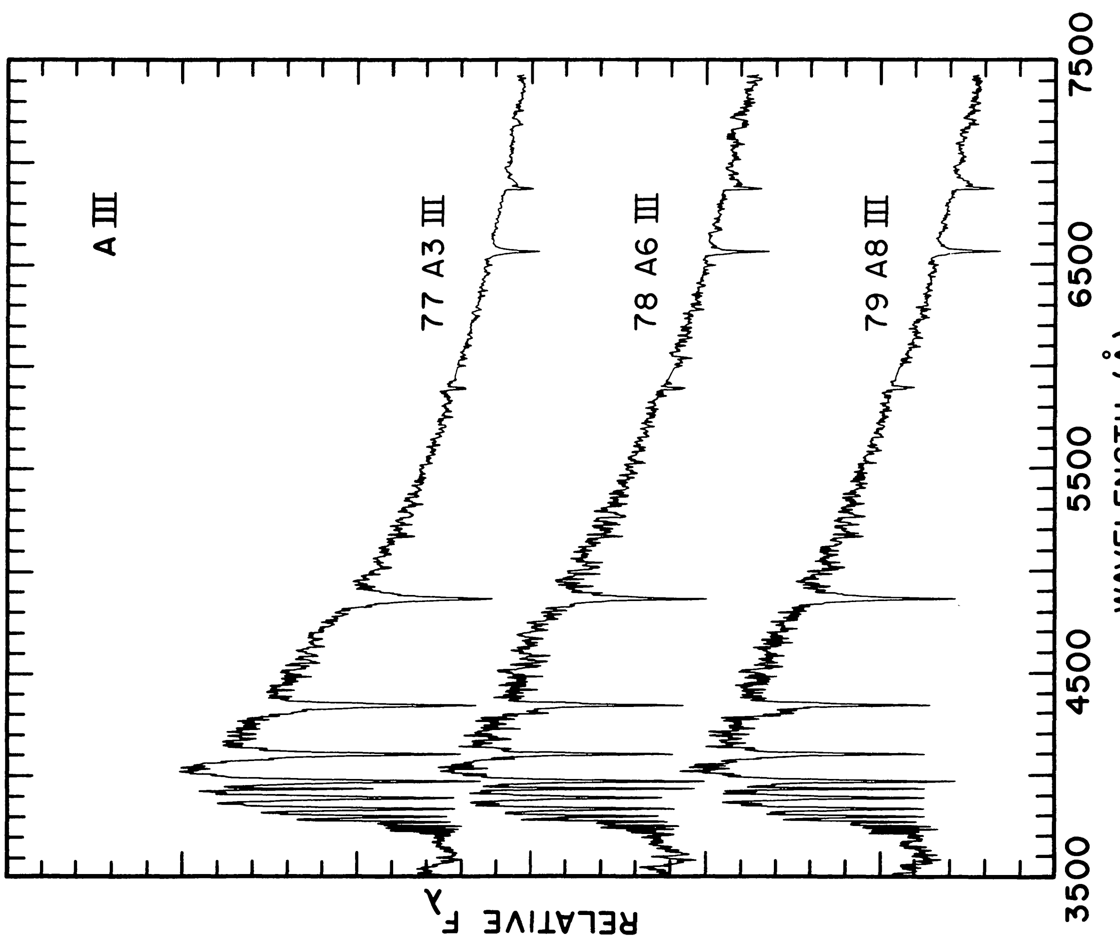
A III
77 A3 III
78 A6 III
79 A8 III
RELATIVE Fλ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2k

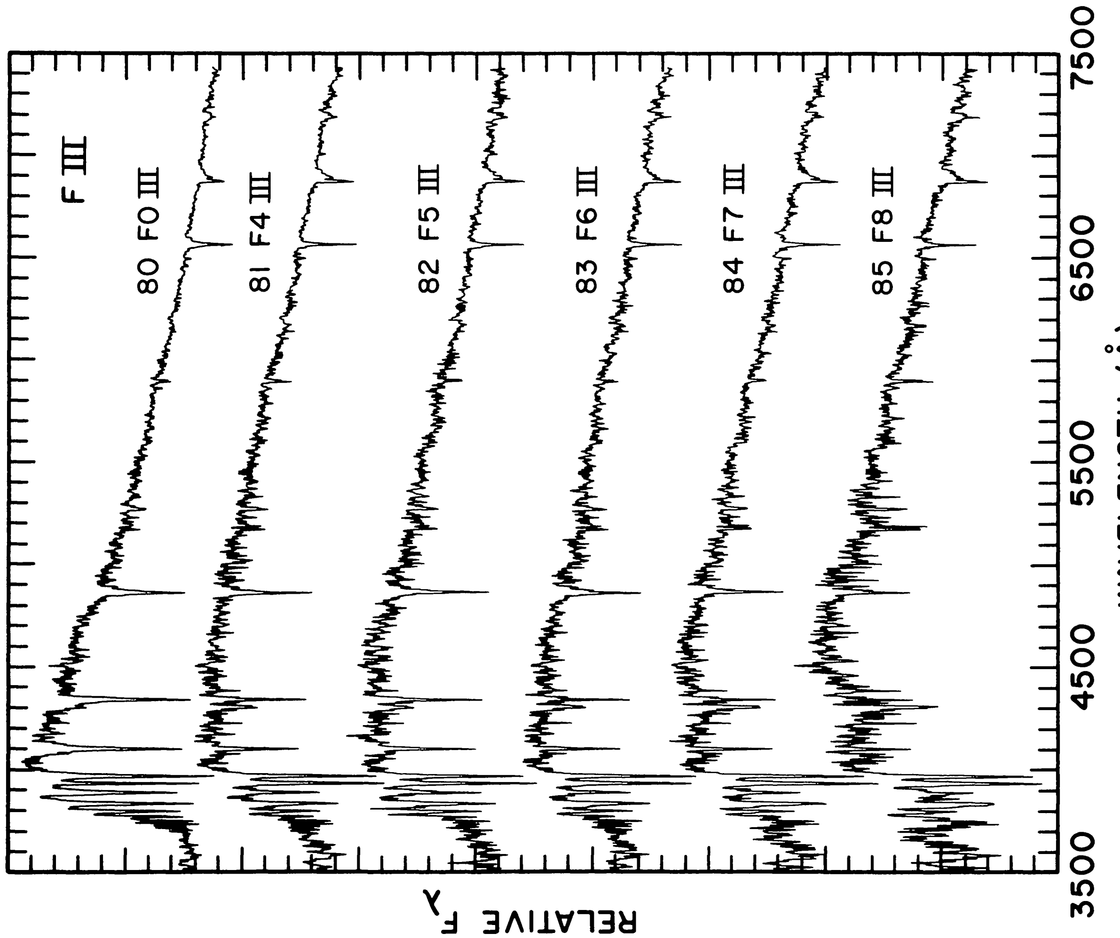
F III
80 F0 III
81 F4 III
82 F5 III
83 F6 III
84 F7 III
85 F8 III
RELATIVE Fλ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2l

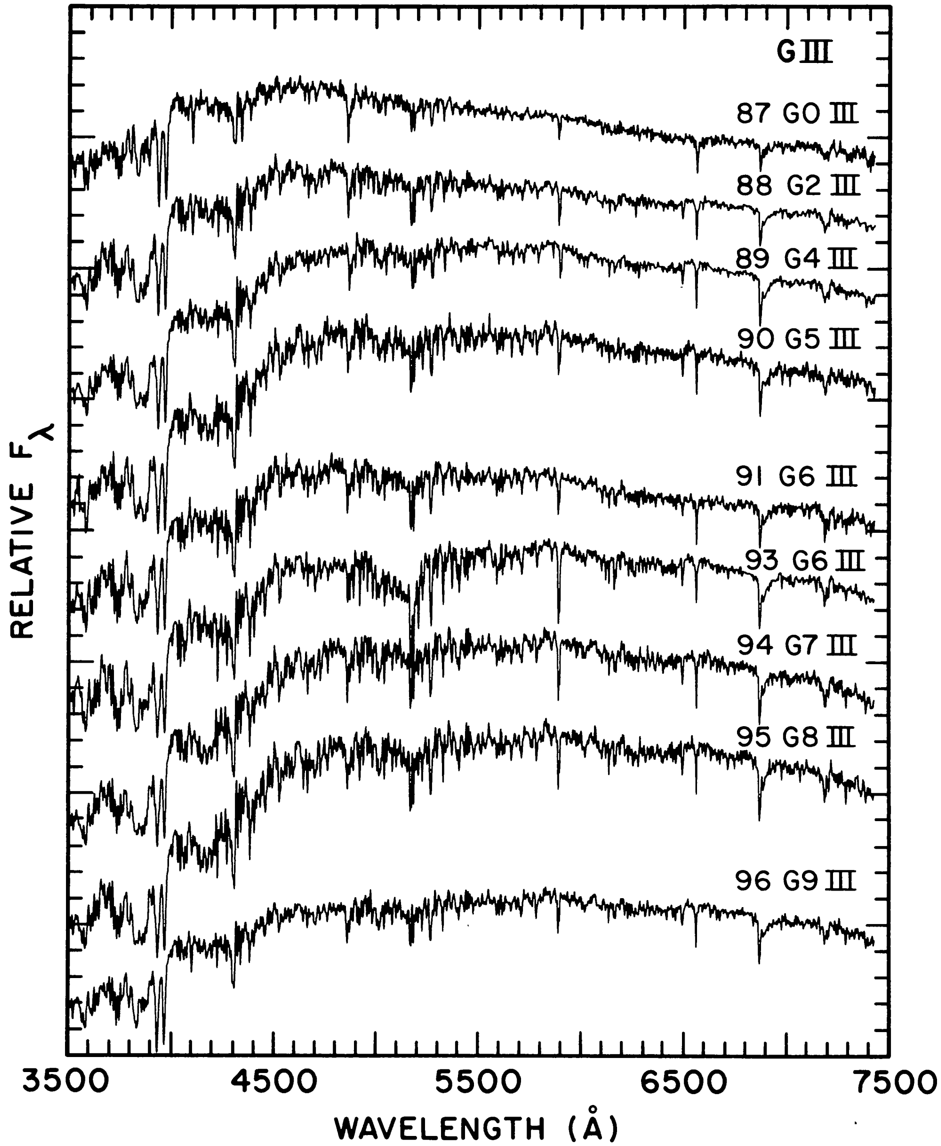
G III
87 G0 III
88 G2 III
89 G4 III
90 G5 III
91 G6 III
93 G6 III
94 G7 III
95 G8 III
96 G9 III
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2*m*

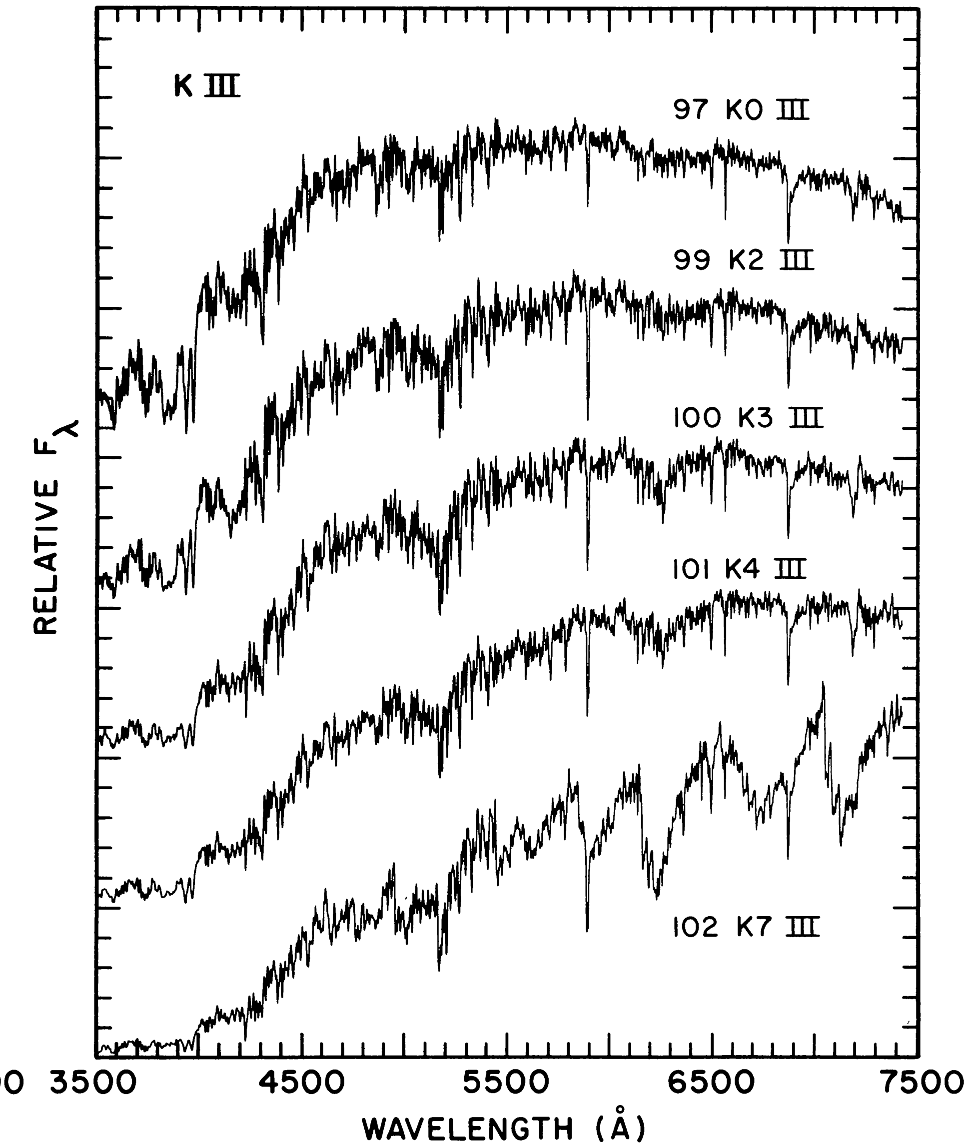
K III
97 K0 III
99 K2 III
100 K3 III
101 K4 III
102 K7 III
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2*n*

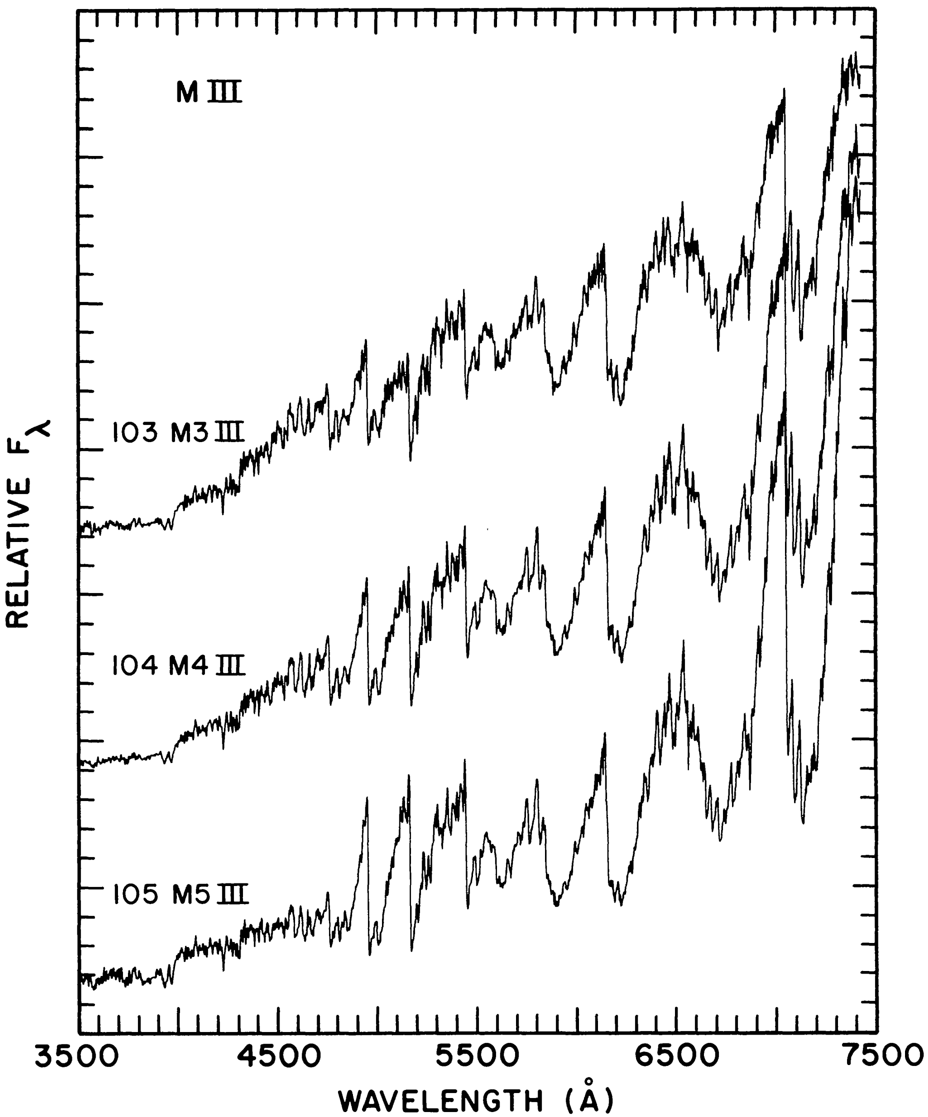
M III
103 M3 III
104 M4 III
105 M5 III
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2*o*

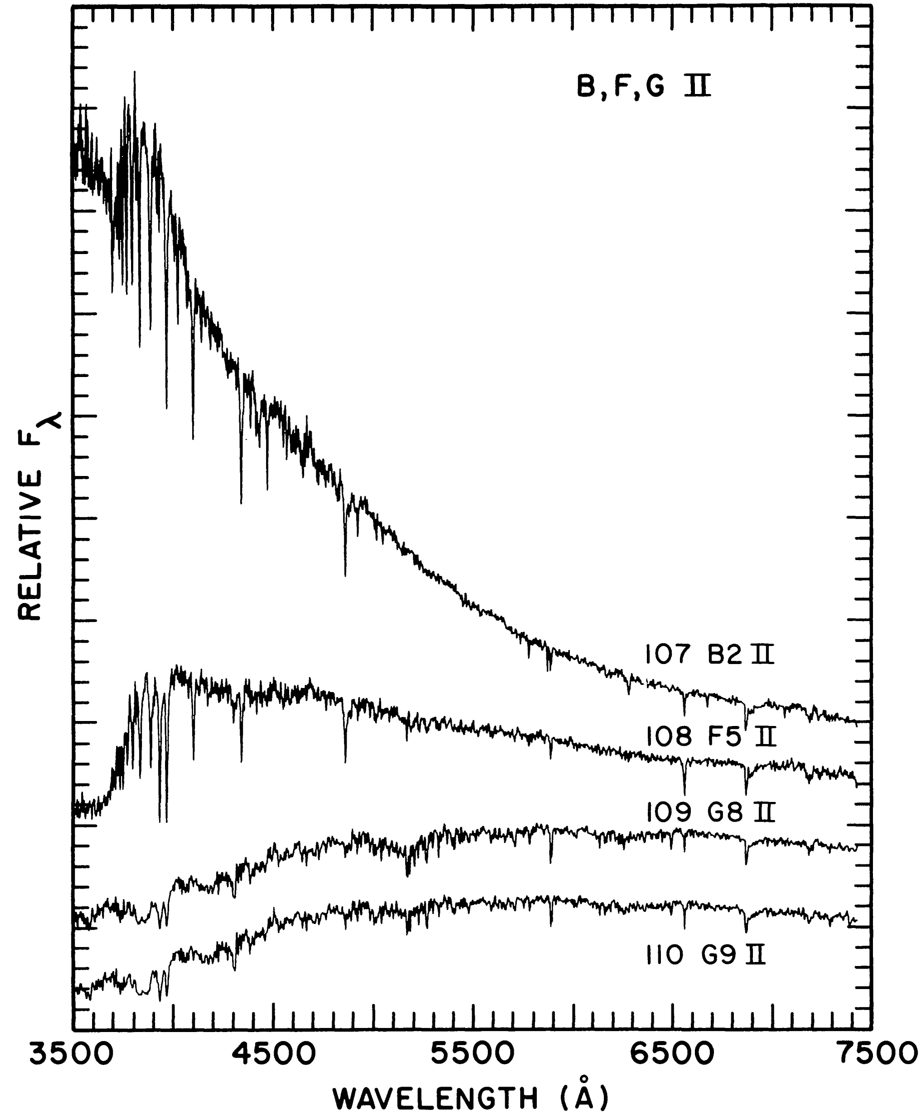
B, F, G II
107 B2 II
108 F5 II
109 G8 II
110 G9 II
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2*p*

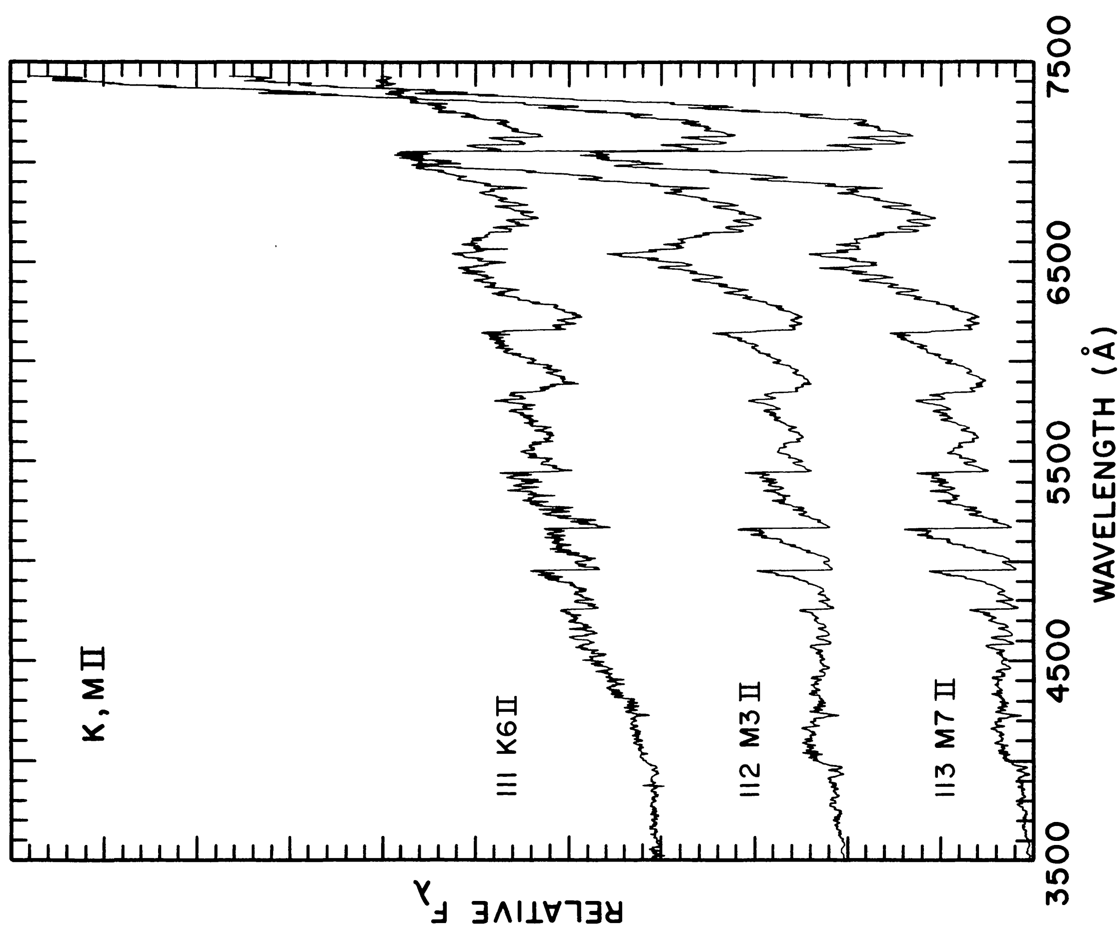
K, M II
111 K6 II
112 M3 II
113 M7 II
RELATIVE F_λ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2q

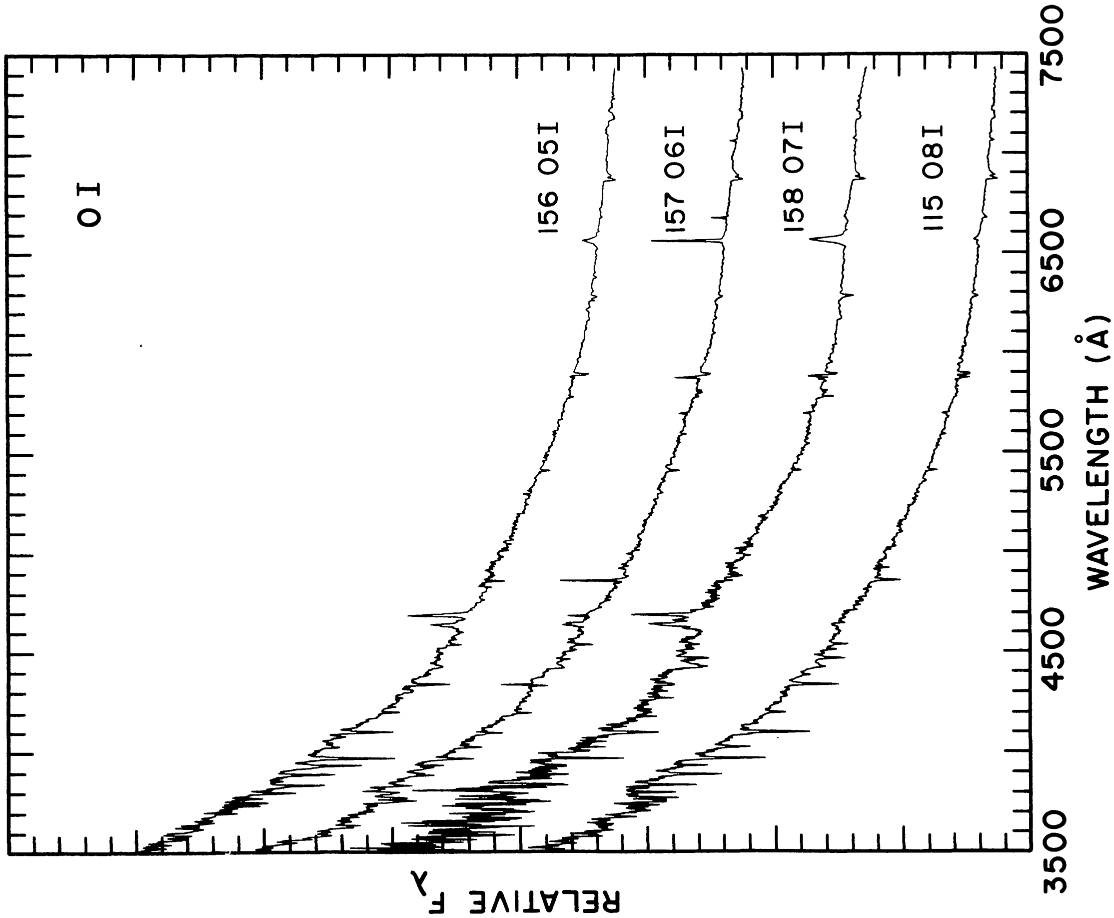
O I
156 O5 I
157 O6 I
158 O7 I
115 O8 I
RELATIVE F_λ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2r

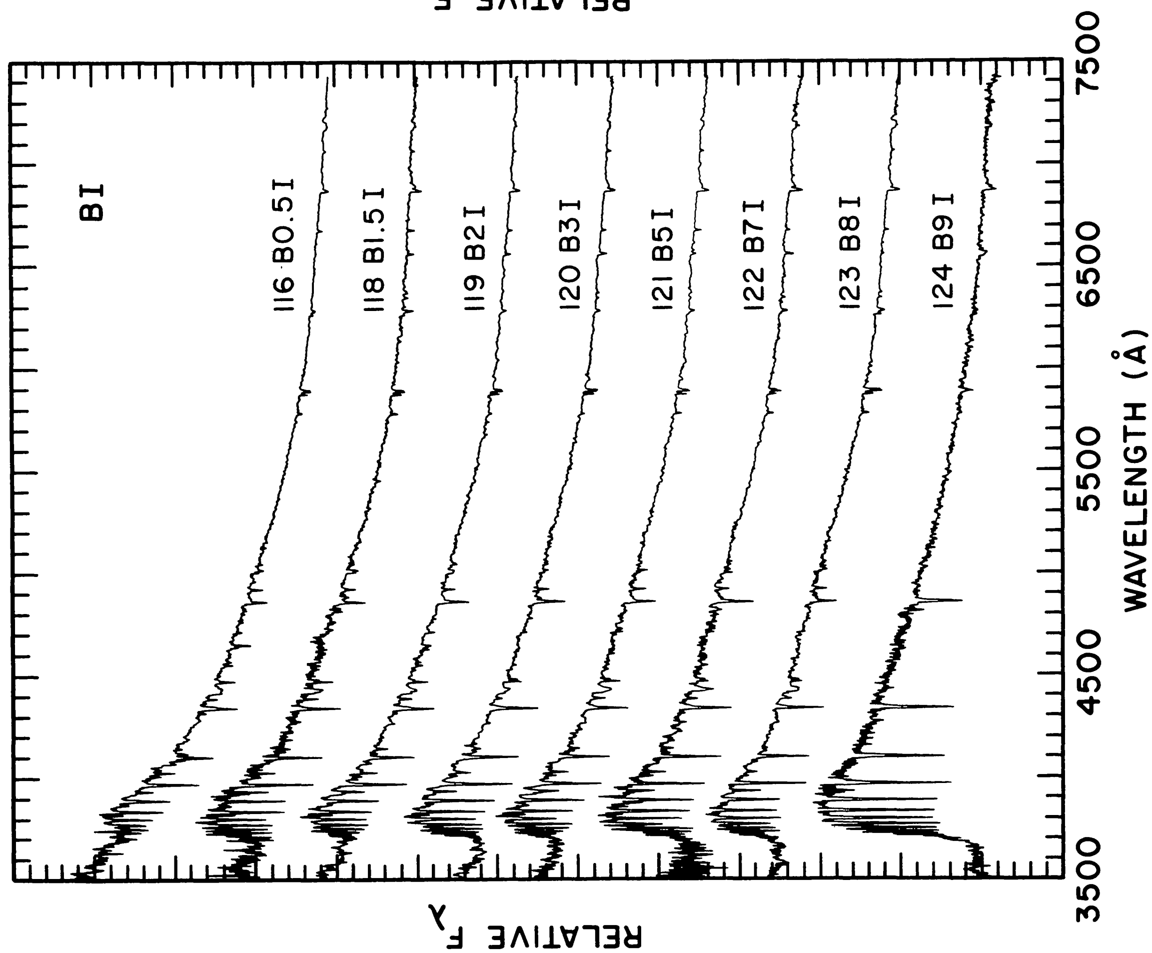
B I
116 B0.5 I
118 B1.5 I
119 B2 I
120 B3 I
121 B5 I
122 B7 I
123 B8 I
124 B9 I
RELATIVE F_λ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2s

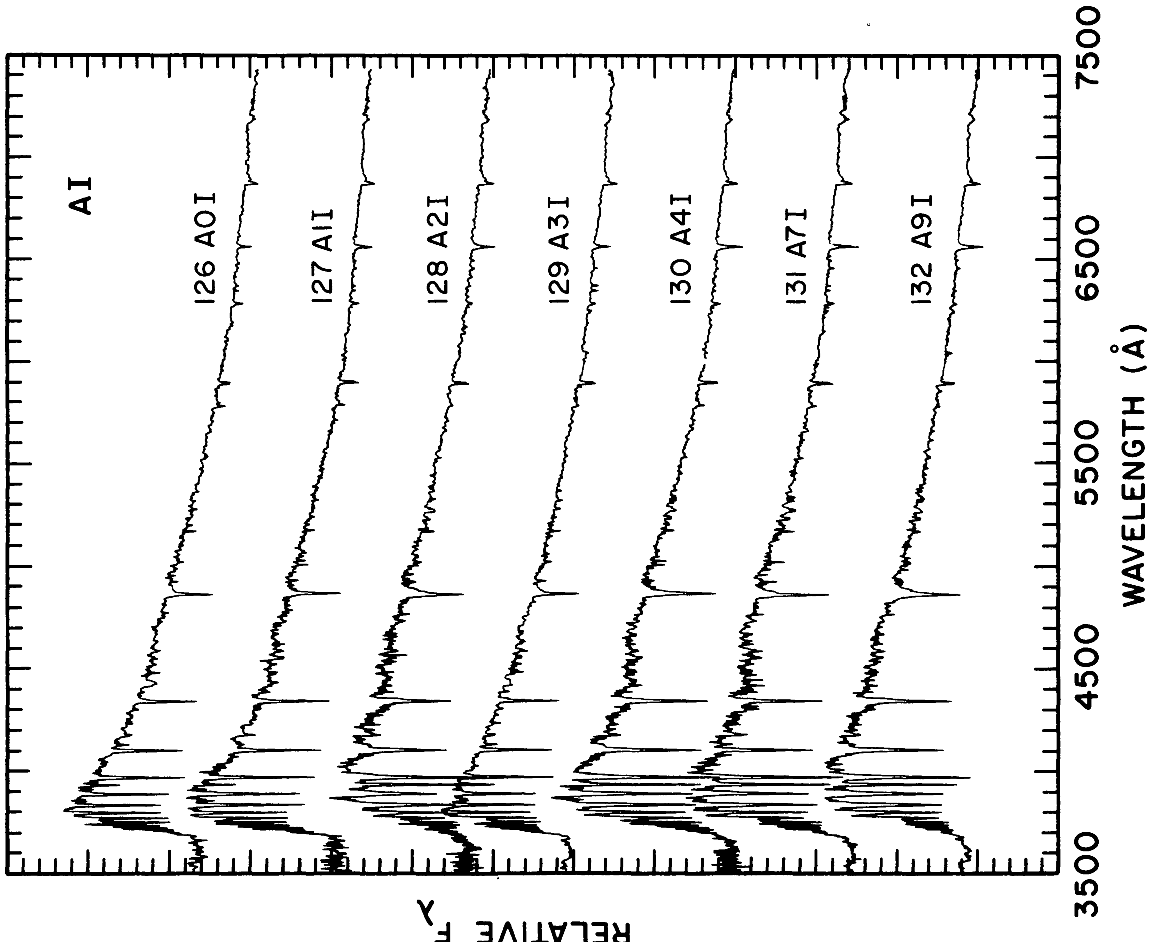
A I
126 A0 I
127 A1 I
128 A2 I
129 A3 I
130 A4 I
131 A7 I
132 A9 I
RELATIVE F_λ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2t

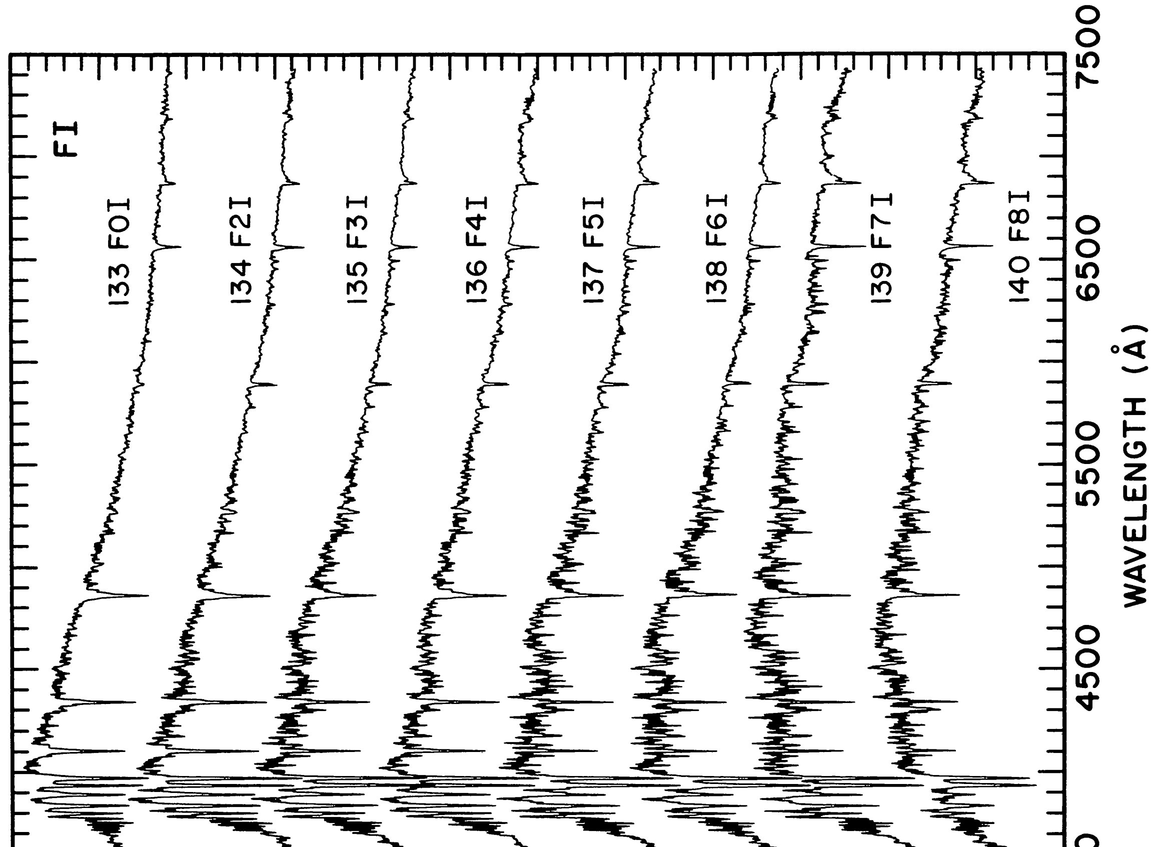
FI
133 F0I
134 F2I
135 F3I
136 F4I
137 F5I
138 F6I
139 F7I
140 F8I
RELATIVE F_λ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2*u*

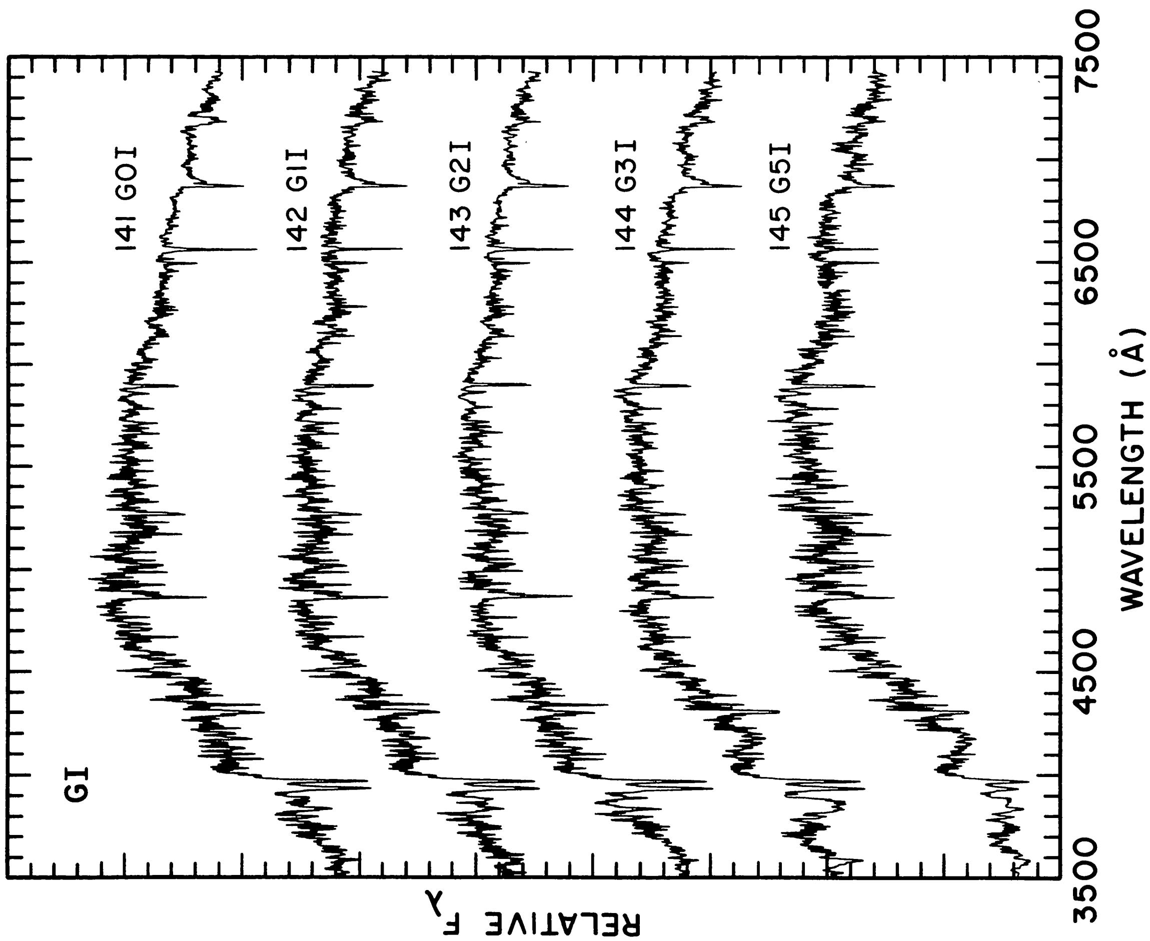
GI
141 G0I
142 G1I
143 G2I
144 G3I
145 G5I
RELATIVE F_λ
WAVELENGTH (Å)
3500
4500
5500
6500
7500

FIG. 2*v*

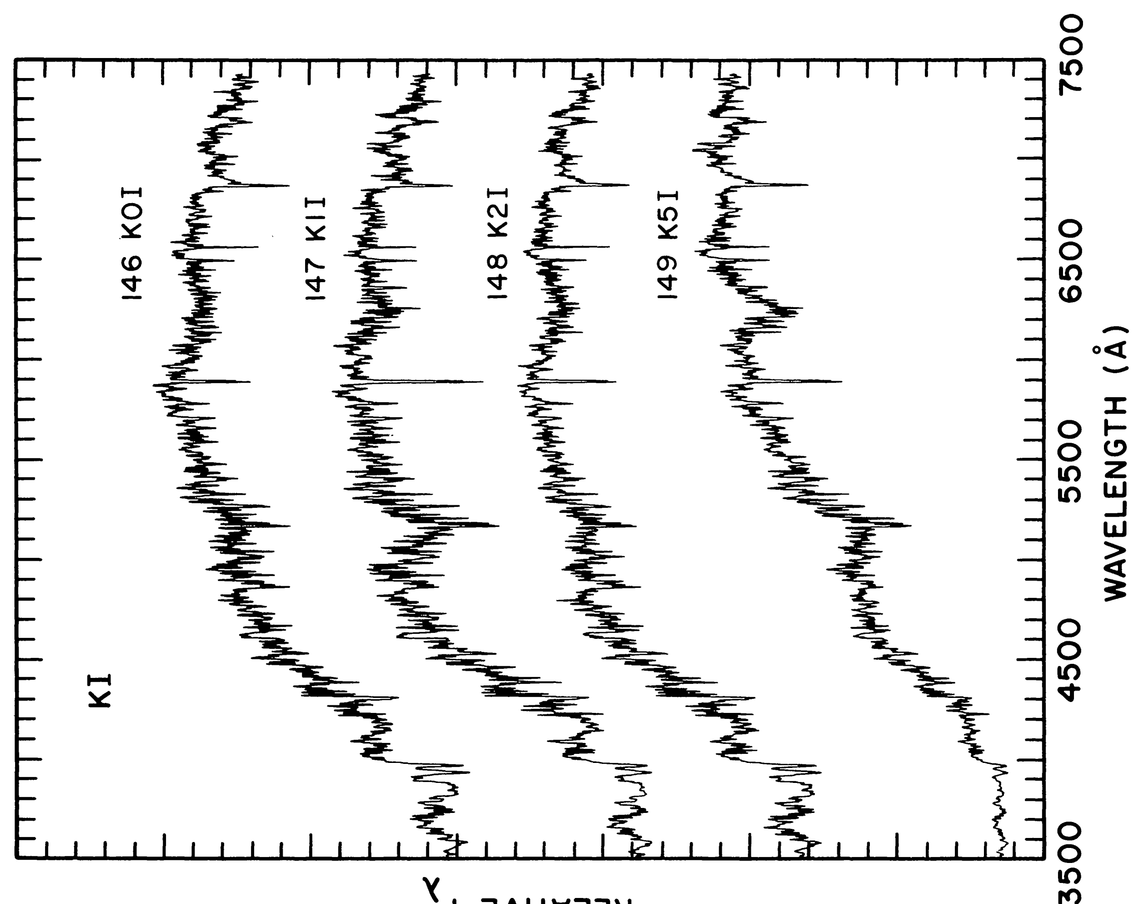
KI
146 K0I
147 K1I
148 K2I
149 K5I
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2w

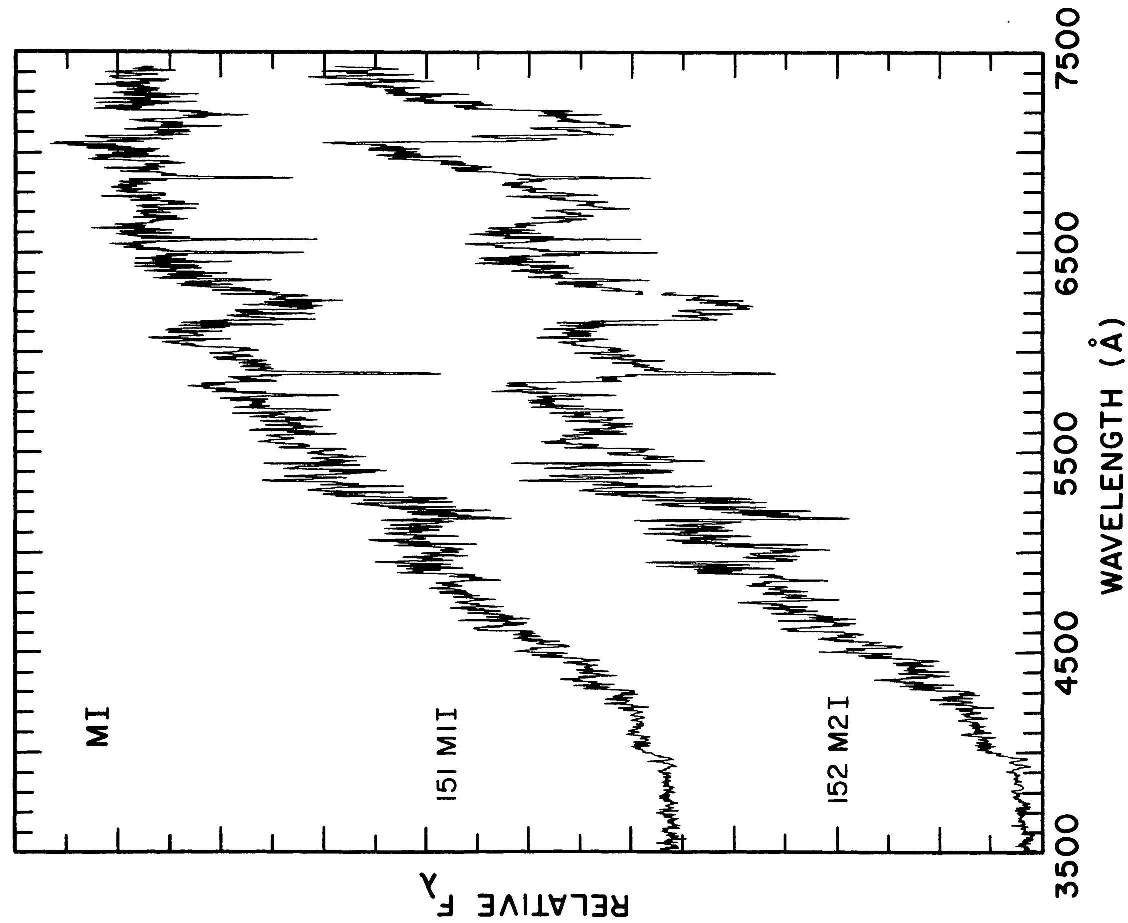
MI
151 M1I
152 M2I
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2x

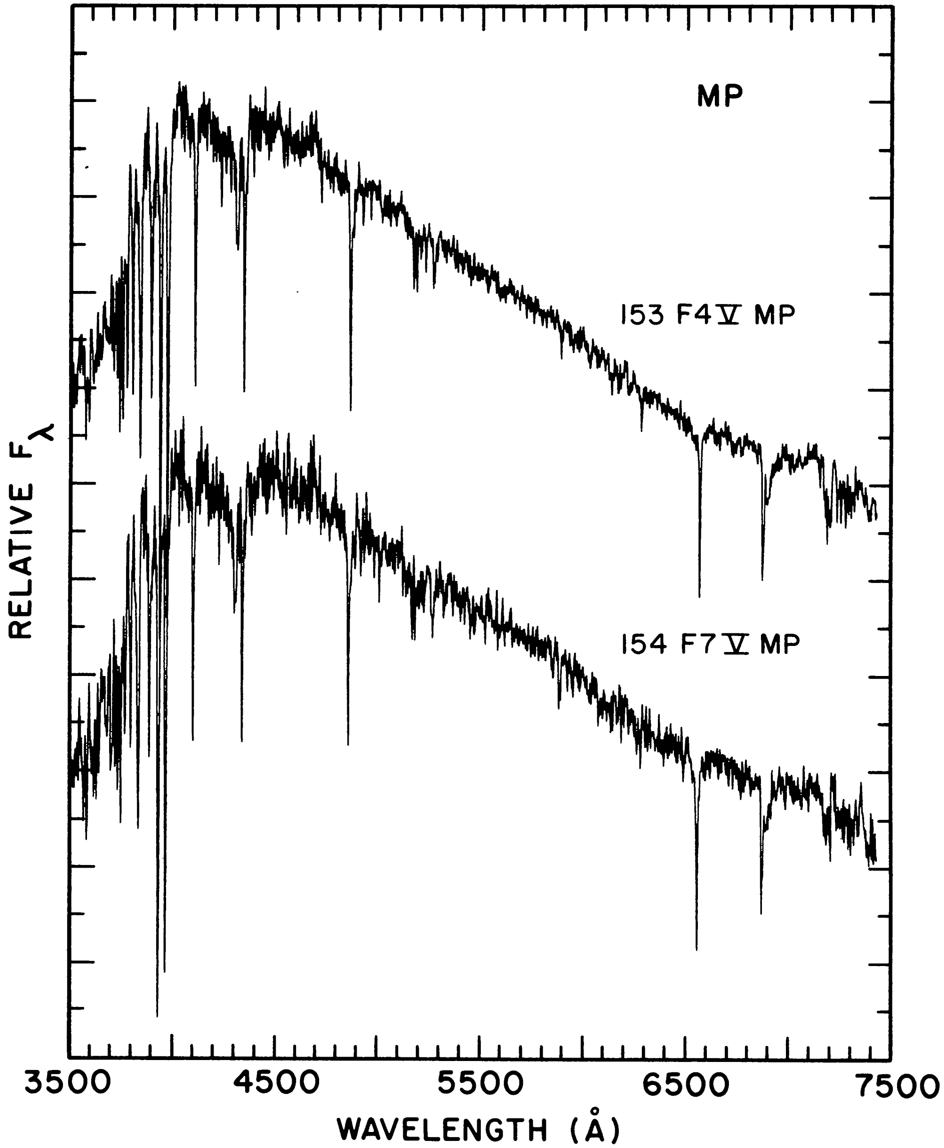
MP
153 F4 V MP
154 F7 V MP
RELATIVE F_λ
3500
4500
5500
6500
7500
WAVELENGTH (Å)

FIG. 2y

TABLE 1

Library Stars

Star	SAO	HD	BD	Other	Adopted Spectral Type	Published Spectral Type	$E(B-V)$	F_{min} (E-12)	F_{max} (E-12)	Notes
1	...	242908	33°1023	...	O5 V	...	0.60	1.82	29.90	R
2	34810	215835	57 2607	...	O5.5 V	...	0.65	2.79	52.47	G, R, Batten
3	22966	12993	57 0498	...	O6.5 V	...	0.52	1.24	22.73	
4	58048	35619	34 1046	...	O7 V	...	0.55	2.39	38.97	G, R, Aitken 4041
5	95633	44811	19 1335	...	O7.5 V	...	0.44	1.93	33.09	R
6	...	242935	33 1026	...	O8 V	...	0.52	0.95	16.60	R, Aitken 3943
7	22694	236894	57 0409	...	O8 V	...	0.53	0.88	15.31	
8	...	17520	59 0553	...	O9 V	...	0.63	3.40	65.59	
9	22862	12323	54 0441	...	O9 V	...	0.19	0.58	8.59	R
10	...	...	62 0249	...	O9.5 V	...	1.00	2.17	40.84	R
11	...	158659	...	...	B0 V	...	0.51	0.39	6.09	
12	12463	237007	50 0549	...	B0 V	...	0.63	1.16	21.58	R
13	57982	35215	30 0873	...	B1.5 V	B1 V	0.33	0.56	6.81	R
14	58354	37767	36 1236	...	B3 V	...	0.35	1.02	10.34	G, R, G abs
15	...	...	...	Feige 40	B4 V	...	0.15	0.08	0.83	R
16	20734	240344	59 2751	...	B4 V	B5 V	0.83	3.64	42.50	
17	39800	30584	44 1036	...	B6 V	...	0.41	1.63	15.46	
18	...	...	...	O 1015	B8 V	...	0.39	0.23	2.15	R
19	44595	116608	44 2271	...	A1 V	...	0.12	0.25	2.11	
20	...	...		Feige 41	A1 V	...	0.10	0.08	0.60	R
21	63984	124320	39 2731	...	A2 V	...	0.07	0.42	3.28	
22	...	...	−04 0495	Feige 28	A2 V	...	0.06	0.07	0.54	R
23	69382	190785	34 3866	...	A2 V	A4 V	0.04	0.94	6.27	G, R, G abs
24	20709	221741	60 2578	...	A3 V	...	0.19	0.61	4.41	
25	37324	9547	45 0379	...	A5 V	A3 III	0.18	0.37	2.15	
26	38904	21619	40 0954	...	A6 V	...	0.09	0.58	3.49	
27	76231	23863	23 0559	Hz 885	A7 V	...	0.02	0.90	4.47	G, R, G abs
28	44342	111525	42 2343	...	A7 V	...	0.00	0.49	2.90	
29	11895	9972	60 0297	...	A8 V	...	0.00	0.36	1.55	
30	76210	23733	23 0549	Hz 693	A9 V	...	0.06	1.03	3.83	G, R, G abs
31	37400	10032	40 0337	...	F0 V	...	0.04	0.72	2.78	
32	...	...	...	Hz 948	F3 V	...	0.02	0.46	1.29	G, R, G abs
33	76177	23511	23 0526	Hz 388	F4 V	...	0.04	0.36	1.14	G, R, G abs
34	...	...	...	Hz 227	F5 V	...	0.07	0.32	1.03	G, R, G abs
35	57199	...	31 0769	...	F6 V	...	0.02	0.27	1.14	
36	24277	24189	52 0720	...	F6 V	...	0.06	0.59	2.48	
37	11511	5702	61 0191	...	F7 V	...	0.00	0.33	1.45	
38	82235	107132	25 2486	...	F7 V	F9 V	0.00	0.47	1.70	R
39	82243	107214	25 2488	...	F7 V	G0 V	0.08	0.43	1.73	R
40	11547	6111	61 0198	...	F8 V	...	0.02	0.30	1.52	
41	39853	31084	43 1117	...	F9 V	...	0.02	0.40	2.06	
42	82256	107399	26 2330	...	F9 V	G0 V	0.00	0.27	1.13	R
43	93936	28099	16 0601	...	G0 V	...	0.03	0.82	3.21	
44	38396	17647	45 0669	...	G1 V	G5 V	0.10	0.44	2.37	Aitken 2173
45	6424	66171	72 0395	...	G2 V	...	0.00	0.47	2.41	
46	...	...	58 1199	...	G3 V	...	0.00	0.08	0.41	
47	...	...	...	Tr A14	G4 V	...	0.13	0.09	0.69	R
48	38976	22193	41 0714	...	G6 V	...	0.00	0.38	2.19	Aiken 2630
49	93895	27685	16 0585	...	G7 V	G4 V	0.00	0.71	3.54	
50	131817	33278	−02 1149	...	G9 V	G9 V	0.36	0.34	5.20	
51	76664	29050	22 0715	...	G9 V	K1 V	0.00	0.24	1.26	G, R
52	24232	23524	51 0777	...	K0 V	...	0.00	0.30	1.45	Aitken 2768
53	11483	5351	68 0060	...	K4 V	...	0.03	0.08	1.19	
54	76803	...	...	...	K5 V	...	0.55	0.16	5.50	5150 A line weak
55	...	260655	...	...	M0 V	...	0.16	0.04	1.39	
56	...	...	63 0137	...	M1 V	...	0.00	0.05	1.52	
57	...	...	05 1668	Yale 1755	M5 V	...	0.00	0.01	1.72	
58	23048	13505	58 402	...	F0 IV	...	0.00	0.68	2.29	G, R, G abs
59	6933	83140	78 315	...	F3 IV	...	0.06	0.59	2.22	
60	80653	78277	28 1696	...	G2 IV	...	0.04	0.45	2.85	
61	80124	70178	29 1739	...	G5 IV	...	0.16	0.47	3.61	
62	...	227018	34 3128	...	O6.5 III	...	0.70	2.41	46.44	G, R
63	11810	...	60 0261	...	O7.5 III	...	0.62	2.61	43.93	G, R
64	49280	191978	40 4050	...	O8.5 III	...	0.41	2.46	41.97	R
65	12383	16429	60 0541	...	O9.5 III	...	0.87	11.26	171.70	Aitken 2018
66	23043	13494	55 0543	...	B1 III	...	0.44	0.80	10.15	
67	22920	12727	56 0425	...	B2 III	...	0.32	0.79	10.53	R, Aitken 1648
68	...	...	...	O 2311	B2 III	...	0.54	0.95	13.56	R
69	11885	...	...	...	B2.5 III	B2 III	0.47	1.84	22.13	G, R

TABLE 1—*Continued*

Star	SAO	HD	BD	Other	Adopted Spectral Type	Published Spectral Type	$E(B-V)$	F_{min} (E-12)	F_{max} (E-12)	Notes
70	...	166125	−14 4908	...	B3 III	...	0.68	2.13	23.89	
71	58518	39136	32 1111	...	B4 III	B3 III	0.27	0.91	9.09	G, R, G abs
72	152619	56183	−13 1982	...	B4 III	...	0.09	0.48	5.49	
73	95626	256413	19 1331	...	B5 III	...	0.51	1.57	16.28	R
74	...	...	61 0339	...	B7 III	...	0.39	0.38	4.07	
75	57294	28696	31 0790	...	B8 III	...	0.46	0.74	14.70	
76	38671	20023	46 0713	...	B9 III	...	0.09	1.09	9.99	
77	55163	12027	36 0378	...	A3 III	...	0.13	1.00	6.90	G, R, G, abs Aitken 1573
78	35403	240296	57 2736	...	A6 III	...	0.30	0.69	3.71	G, R, G abs
79	12086	12161	59 0380	...	A8 III	...	0.01	1.10	5.06	G, R, G abs, Aitken 1599
80	116066	64191	01 1932	...	F0 III	...	0.04	0.31	1.48	
81	21831	5211	59 0141	...	F4 III	...	0.06	0.38	1.43	
82	...	...	61 0367	...	F5 III	F6 III	0.11	0.20	0.68	
83	96705	56030	15 1522	...	F6 III	...	0.00	0.58	1.82	
84	20603	...	...	...	F7 III	...	0.08	0.32	1.40	
85	37391	9979	44 0338	...	F8 III	...	0.18	0.30	1.51	Aitken 1278
86	55660	15866	30 0410	...	G0 III	...	0.02	0.57	3.37	G, R
87	...	...	30 2347	...	G0 III	...	0.00	0.05	0.23	
88	76462	25894	27 0635	...	G2 III	...	0.00	0.53	3.35	
89	21431	2506	58 0060	...	G4 III	...	0.13	0.39	3.98	
90	...	...	28 1885	...	G5 III	...	0.10	0.07	0.71	
91	63279	112872	31 2431	...	G6 III	...	0.00	0.07	0.57	
92	76499	26514	23 0642	...	G6 III	...	0.15	1.02	9.81	
93	76728	29883	27 0688	...	G6 III	K5 III	0.00	0.37	2.97	
94	...	249240	...	...	G7 III	...	0.11	0.19	1.92	
95	58259	245389	32 1053	...	G8 III	...	0.20	0.14	2.04	
96	55155	...	...	...	G9 III	...	0.00	0.14	0.97	
97	55164	...	37 0448	...	K0 III	...	0.03	0.08	1.15	
98	112496	33506	−00 0870	...	K2 III	F0 III	0.03	0.07	1.56	
99	77849	...	...	...	K2 III	...	0.06	0.03	1.12	
100	76530	26946	25 0690	...	K3 III	...	0.36	0.28	10.87	
101	56436	21110	31 0597	...	K4 III	...	0.13	0.16	9.72	
102	21753	...	59 0128	...	K7 III	...	0.17	0.03	3.30	G, R
103	63349	...	...	...	M3 III	...	0.00	0.00	1.28	
104	82478	110964	27 2167	...	M4 III	...	0.00	0.01	3.72	
105	62808	...	40 2491	...	M5 III	...	0.00	0.05	2.98	
106	23227	14357	56 0555	...	B2 II	...	0.56	15.92	163.40	
107	...	...	−14 4956	...	B2 II	...	0.70	2.02	23.62	
108	...	...	−00 3227	...	F5 II	...	0.39	0.24	1.11	
109	...	249384	...	...	G8 II	...	0.38	0.77	11.84	
110	...	250368	...	...	G9 II	...	0.10	0.05	0.81	
111	...	249826	...	...	K6 II	...	0.45	−0.05	3.86	
112	...	...	19 1947	...	M3 II	...	0.00	0.03	12.28	
113	...	...	36 1963	...	M7 II	...	0.04	0.04	15.38	
114	...	...	−11 4586	...	O8 I	...	1.23	8.24	134.00	
115	10952	225160	61 2585	...	O8 I	...	0.56	3.38	58.43	G, R
116	23569	16808	57 0622	...	B0.5 Ib	...	0.78	4.29	56.12	
117	...	167451	−13 4897	...	B0.5 Ib	...	0.94	9.98	126.40	
118	...	...	−14 5030	...	B1.5 Ia	...	1.14	6.36	63.42	
119	34012	209678	52 3088	...	B2 Ib	...	0.55	3.05	31.26	G, R
120	20899	...	62 2313	...	B3 I	...	0.62	2.57	23.49	G, R
121	49374	192832	41 3675	...	B5 Ia	...	0.98	9.69	83.14	G, R
122	...	...	61 0220	...	B7 I	...	0.96	3.37	25.02	
123	23607	17145	57 0634	...	B8 Ia	...	0.84	9.21	66.52	
124	...	...	...	LSI V P24	B9 Ib	...	0.23	0.10	0.77	
125	34034	209900	52 3095	...	A0 Ib	...	0.45	1.92	13.22	G, R, G abs
126	11344	...	61 0153	...	A0 Ib	...	0.84	3.52	25.01	R
127	12149	...	...	...	A1 I	...	0.94	4.53	27.58	
128	...	...	...	42 LSI	A2 I	...	0.55	0.76	4.10	
129	87716	...	27 3513	...	A3 Ia	A2 Ia	0.33	2.01	11.83	G, R, G abs
130	12096	...	...	...	A4 I	...	0.96	4.25	38.23	
131	11801	9167	60 0257	...	A7 I	F1 II	0.90	10.99	65.51	
132	21214	842	55 0021	...	A9 I	...	0.37	3.19	17.82	G, R, G abs
133	37370	...	45 0394	...	F0 Ib	...	0.22	0.69	3.39	R
134	...	...	58 0204	...	F2 I	...	0.55	1.02	5.53	
135	22943	12842	57 0487	...	F3 I	F6 I	0.64	2.82	18.84	
136	21536	...	58 0077	...	F4 I	...	0.64	2.68	11.27	R
137	11893	9973	60 0296	...	F5 Iab	...	0.60	11.36	74.99	G, R

TABLE 1—*Continued*

Star	SAO	HD	BD	Other	Adopted Spectral Type	Published Spectral Type	$E(B-V)$	F_{min} (E-12)	F_{max} (E-12)	Notes
138	22328	8992	58 0249	...	F6 Ib	...	0.68	4.60	37.99	
139	...	17971	...	...	F7 I	F5 I	0.51	3.04	18.78	
140	105303	187428	19 4165	...	F8 Ib	...	0.23	1.43	6.93	G, R
141	24392	25361	58 0694	RX Cam	G0 Ia	...	0.54	2.28	21.05	
142	21446	...	...	...	G1 I	...	0.51	0.39	3.89	
143	...	...	56 0084	...	G2 I	...	0.22	0.19	2.73	
144	88209	191010	25 4103	...	G3 Ib	...	0.08	0.34	3.08	G, R
145	87740	187299	24 3889	...	G5 I	...	0.60	3.87	38.41	G, R
146	124982	186293	09 4226	...	K0 I	...	0.01	0.17	3.57	G, R
147	37325	...	45 0380	...	K1 Ib	...	0.26	0.12	4.23	R
148	11069	1069	59 0019	...	K2 I	...	0.20	0.37	7.38	G, R
149	11095	1400	61 0032	...	K5 I	K7 I	0.00	0.18	10.35	G, R
150	23217	14330	56 0551	...	M1 Iab	...	0.59	0.17	26.58	G, R
151	23888	...	54 0651	...	M1 I	...	0.89	−0.12	17.95	R
152	22994	13136	55 0529	...	M2 Ib	...	0.61	0.26	38.01	
153	81555	94028	21 2247	...	F4 V	...	0.00	0.84	2.56	Metal poor
154	102986	...	18 3423	...	F7 V	...	0.00	0.17	0.61	Metal poor
155	81292	...	20 2465	...	M4.5 Ve	...	0.02	0.04	2.68	R, emission
156	23550	16691	56 0693	...	O5 If	...	0.77	3.74	66.52	emission
157	10973	108	62 2363	...	O6 If	...	0.39	4.41	83.22	R, emission
158	...	...	40 4220	...	O7 If	...	2.00	114.20	1923.00	G, emission
159	12165	13256	60 0447	...	B1 Ia	...	1.39	28.71	395.80	emission
160	114524	50064	00 1651	...	B1 Ia	B6 Ia	0.96	12.52	139.50	emission
161	...	...	51 0710	...	B5 Ib	...	0.68	1.38	13.20	R, emission

c) *Combining the Spectra*

It is desirable to join the three spectra (blue, green, red) for each star to create a single effective spectrum. Because the data were obtained using three different gratings, the wavelength dispersion characteristics for the individual observations are all slightly different. For the sake of uniformity, all observations were mapped to a single wavelength grid extending from 3510 to 7427.2 Å in increments of 1.4 Å. The boundary wavelengths are chosen for the maximum wavelength coverage common to all stars, and the wavelength increment is approximately that of the original raw data. Nearly all remapping algorithms in common use also smooth the original data (Stover 1980). The algorithm chosen here is a fifth-order polynomial interpolator applied to the data in its F_λ form. This is a simple and reasonably fast technique which preserves the high-frequency information contained in the spectra to an acceptable degree.

After remapping and scaling the three spectrum segments to the segment having the highest flux, the three individual observations were joined to form a single spectrum. The segments were not averaged in the overlap region but rather were butted together at a common wavelength which was chosen to avoid strong lines and variations near the edges of the spectrum segments. The result is a single spectrum sampled at 2799 points. No attempt was made to correct the alignment of the spectra for the radial velocities of the stars. As a check, we measured the position of Hγ for 12 stars and found the average variation from the rest wavelength to be 0.5 Å.

d) *Interstellar Reddening*

The *UBV* colors were used to correct for the effects of interstellar reddening to derive the intrinsic spectrum of the star; however, because observed colors were not always available in the literature, it was necessary to synthesize colors from the spectra. The U_3, B_2, and B_3, and V response curves from Buser and Kurucz (1978) were used. Following their recommendations for reproducing the effective filter response curves, U_3 and B_2 were computed with atmospheric extinction convolved at an air mass of 1.3. Since our data begin at 3510 Å and the U filter continues blueward to the atmospheric cutoff, the synthesized U magnitudes are inferior to the B and V magnitudes. The transformations used were

$$V=1.002V_s-13.711, \tag{1}$$

$$B-V=0.994(B_3-V)_s+0.736, \tag{2}$$

$$U-B=1.140(U_3-B_2)_s-1.880, \tag{3}$$

where the subscript s refers to the quantities synthesized.

The transformation relations were determined from a subset of ~50 stars with good observed colors, although the relationships determined by all of the stars are not significantly different. The uncertainties in the synthesized V, $B-V$, and $U-B$ are estimated to be 0.05, 0.03, and 0.06 mag, respectively, based on the scatter in the comparison of transformed colors to all observed ones. There are ~12 stars having large discrepancies between observed and synthesized V magnitudes which could be attributed to clouds. There are also three stars with widely differing $B-V$ colors. We can offer no explanation for these.

The spectral types for the stars given in the literature (Jaschek 1978; references in Table 2) were assumed initially, and the color excesses $E(B-V)$ and $E(U-B)$ were calculated using FitzGerald's (1970) tables of intrinsic colors. When available, observed colors from the literature were used rather

TABLE 2

COLORS

STAR	NAME	OBSERVED U − B	OBSERVED B − V	SYNTHESIZED U − B	SYNTHESIZED B − V	DEREDDENED, SYNTHESIZED U − B	DEREDDENED, SYNTHESIZED B − V	OBSERVED V	SYNTHESIZED V	DEREDDENED V	REFERENCE
1	HD 242908	−0.72	0.28	−0.67	0.29	−1.11	−0.30	9.04	9.07	7.11	1
2	HD 215835	−0.65	0.33	−0.61	0.30	−1.08	−0.33	8.59	8.61	6.48	1
3	HD 12993	−0.80	0.20	−0.71	0.18	−1.08	−0.33	8.98	9.08	7.37	2, 3
4	HD 35619	−0.69	0.23	−0.64	0.22	−1.04	−0.32	8.60	8.56	6.75	1
5	HD 44811	−0.80	0.13	−0.75	0.15	−1.07	−0.29	8.42	8.38	6.94	1
6	HD 242935	−0.73	0.20	−0.69	0.21	−1.07	−0.30	9.43	9.41	7.70	1
7	HD 236894	−0.76	0.19	−0.67	0.22	−1.05	−0.30	9.37	9.50	7.76	1
8	HD 17520	−0.68	0.32	−0.63	0.27	−1.08	−0.35	8.27	8.33	6.26	4
9	HD 12323	−0.93	−0.12	−0.88	−0.05	−1.01	−0.24	8.90	8.93	8.30	4
10	BD62 0249	−0.34	0.70	−0.34	0.70	−1.09	−0.27	10.04	9.96	6.69	1
11	HD 158659	−0.72	0.22	−0.66	0.22	−1.02	−0.29	10.25	10.33	8.66	5
12	HD 237007	−0.60	0.33	−0.59	0.31	−1.05	−0.31	9.45	9.46	7.40	1
13	HD 35215	−0.66	0.08	−0.64	0.10	−0.87	−0.23	9.40	9.42	8.34	1
14	HD 37767	−0.48	0.15	−0.47	0.16	−0.71	−0.19	8.94	8.93	7.79	1
15	Feige 40	−0.62	−0.14	−0.58	−0.04	−0.68	−0.18	11.1	11.07	10.58	6
16	HD 240344	−0.07	0.57	−0.11	0.65	−0.71	−0.15	8.89	8.95	6.24	7
17	HD 30584	0.01	0.28	−0.14	0.27	−0.42	−0.13	8.35	8.57	7.23	7
18	O 1015	−0.10	0.28	−0.18	0.28	−0.46	−0.10	10.57	10.62	9.34	8
19	HD 116608	0.05	0.14	0.03	0.14	−0.06	0.03	9.45	9.53	9.14	7
20	Feige 41	0.09	−0.02	−0.06	0.12	−0.13	0.03	11.0	10.90	10.57	6
21	HD 124320	0.10	0.12	0.06	0.12	0.01	0.06	8.86	8.87	8.64	7
22	Feige 28	0.09	0.13	0.02	0.11	−0.03	0.05	10.8	10.80	10.61	6
23	HD 190785	...	0.06	0.01	0.09	−0.02	0.05	8.19	8.07	7.94	3
24	HD 221741	...	0.17	0.12	0.27	−0.01	0.09	8.88	8.90	8.28	7
25	HD 9547	...	0.30	0.12	0.33	−0.01	0.15	9.42	9.51	8.92	7
26	HD 21619	0.20	0.26	−0.08	0.26	−0.14	0.18	8.75	8.68	8.38	3
27	HD 23863	0.13	0.22	0.05	0.22	0.03	0.20	8.11	8.13	8.07	9
28	HD 111525	0.09	0.20	0.08	0.20	0.08	0.20	8.59	8.60	8.57	3
29	HD 9972	...	0.27	0.18	0.34	0.18	0.34	8.92	9.07	9.07	7
30	HD 23733	0.11	0.36	0.04	0.36	−0.01	0.30	8.25	8.26	8.06	9
31	HD 10032	...	0.30	0.04	0.36	0.01	0.33	8.41	8.50	8.37	5
32	Hz 948	0.02	0.43	−0.02	0.44	−0.03	0.42	9.08	9.13	9.06	9
33	HD 23511	0.03	0.46	0.00	0.50	−0.03	0.46	9.28	9.28	9.15	9
34	Hz 227	0.11	0.52	0.06	0.53	0.01	0.47	9.43	9.48	9.25	9
35	SAO 57199	−0.01	0.48	0.03	0.50	0.02	0.49	9.06	9.21	9.15	10
36	HD 24189	...	0.54	0.01	0.53	−0.04	0.48	8.35	8.51	8.31	7
37	HD 5702	...	0.49	0.06	0.55	0.06	0.55	8.81	8.83	8.30	7
38	HD 107132	0.01	0.50	0.01	0.52	0.01	0.52	8.83	8.69	8.69	5, 11
39	HD 107214	0.04	0.58	0.06	0.59	0.00	0.52	9.02	8.95	8.69	5, 11
40	HD 6111	...	0.55	0.19	0.62	0.17	0.60	8.85	8.86	8.79	7
41	HD 31084	...	0.58	0.17	0.61	0.16	0.59	8.56	8.54	8.47	7
42	HD 107399	0.03	0.56	0.07	0.58	0.07	0.58	9.10	9.10	9.10	5, 11
43	HD 28099	0.20	0.66	0.14	0.56	0.11	0.53	8.12	8.11	8.01	3
44	HD 17647	0.11	0.72	0.27	0.70	0.19	0.61	8.62	8.63	8.31	3
45	HD 66171	0.05	0.61	0.20	0.63	0.20	0.63	8.20	8.24	8.24	3, 12
46	BD 58°1199	...	...	0.13	0.64	0.13	0.64	...	10.15	10.15	
47	TR A14	0.33	0.79	0.36	0.86	0.25	0.74	10.00	9.96	9.54	13
48	HD 22193	0.16	0.68	0.31	0.71	0.31	0.71	8.34	8.31	8.31	3
49	HD 27685	0.22	0.68	0.33	0.70	0.33	0.70	7.86	7.79	7.79	3
50	HD 33278	...	0.80	1.10	1.12	0.79	0.80	8.67	8.58	7.42	
51	HD 29050	0.35	0.72	0.45	0.78	0.45	0.77	8.82	8.88	8.88	7
52	HD 23524	0.28	0.77	0.46	0.79	0.46	0.79	8.69	8.73	8.73	7
53	HD 5351	0.88	1.03	1.07	1.08	1.04	1.05	9.10	9.13	9.03	3, 10
54	SAO 76803	...	...	1.85	1.70	1.34	1.24	...	9.06	7.31	
55	HD 260655	1.18	1.50	1.32	1.53	1.18	1.39	9.63	9.67	9.17	3
56	BD 63°0137	...	...	1.43	1.38	1.43	1.38	...	8.98	8.98	
57	Yale 1755	1.12	1.56	1.19	1.56	1.19	1.56	9.82	9.89	9.89	13
58	HD 13505	...	0.32	0.02	0.38	0.02	0.38	8.54	8.53	8.53	7
59	HD 83140	...	...	0.05	0.45	0.01	0.40	...	8.71	8.52	
60	HD 78277	...	...	0.38	0.68	0.35	0.64	8.20	8.24	8.11	12
61	HD 70178	...	...	0.56	0.86	0.43	0.72	8.20	8.30	7.78	12
62	HD 227018	−0.62	0.38	−0.63	0.34	−1.14	−0.35	8.99	9.04	6.74	1
63	SAO 11810	−0.67	0.31	−0.63	0.29	−1.08	−0.32	8.63	8.66	6.62	1
64	HD 191978	−0.78	0.14	−0.71	0.10	−1.00	−0.30	8.02	7.95	6.61	1
65	HD 16429	−0.38	0.62	−0.40	0.62	−1.04	−0.23	7.67	7.84	5.00	3
66	HD 13494	−0.65	0.18	−0.63	0.21	−0.94	−0.22	9.30	9.37	7.93	3
67	HD 12727	−0.72	0.08	−0.71	0.08	−0.94	−0.24	9.03	9.01	7.96	1

TABLE 2—*Continued*

Star	Name	Observed $U-B$	Observed $B-V$	Synthesized $U-B$	Synthesized $B-V$	Dereddened, Synthesized $U-B$	Dereddened, Synthesized $B-V$	Observed V	Synthesized V	Dereddened V	Reference
68	O 2311	−0.54	0.30	−0.54	0.29	−0.93	−0.24	9.38	9.42	7.65	8
69	SAO 11885	...	...	−0.53	0.25	−0.87	−0.21	...	8.56	7.02	
70	HD 166125	−0.31	0.52	−0.29	0.48	−0.78	−0.19	9.08	9.11	6.88	1
71	HD 39136	−0.45	0.09	−0.48	0.08	−0.67	−0.18	8.80	8.82	7.93	1
72	HD 56183	−0.61	−0.12	−0.60	−0.10	−0.66	−0.18	8.78	8.73	8.44	5
73	HD 256413	−0.37	0.35	−0.41	0.36	−0.77	−0.14	8.93	8.90	7.23	1
74	BD 61°0339	...	0.23	0.02	0.27	−0.25	−0.11	9.92	9.97	8.69	3
75	HD 28696	...	0.41	−0.11	0.36	−0.43	−0.09	8.59	8.74	7.24	5
76	HD 20023	−0.17	0.01	−0.29	0.01	−0.35	−0.08	7.95	7.95	7.66	5
77	HD 12027	0.13	0.22	0.03	0.19	−0.06	0.07	8.25	8.24	7.81	7
78	HD 240296	...	0.47	0.15	0.50	−0.07	0.22	9.34	9.22	8.25	7
79	HD 12161	...	0.27	−0.02	0.28	−0.02	0.27	7.88	7.90	7.87	7
80	HD 64191	...	...	0.07	0.30	0.04	0.26	...	9.32	9.19	
81	HD 5211	...	0.47	0.08	0.54	0.04	0.49	9.02	9.07	8.88	7
82	BD 61°0367	...	0.46	0.08	0.54	−0.01	0.43	10.02	10.14	9.78	3
83	HD 56030	...	0.45	−0.10	0.44	−0.10	0.44	8.67	8.67	8.67	13
84	SAO 20603	...	...	0.08	0.56	0.02	0.48	...	9.18	8.92	
85	HD 9979	...	0.50	0.26	0.70	0.12	0.54	9.27	9.46	8.88	5
86	HD 15866	0.26	0.66	0.31	0.66	0.29	0.64	8.00	7.96	7.90	7
87	BD 30°2347	0.11	0.58	0.16	0.58	0.16	0.58	10.73	10.83	10.83	5
88	HD 25894	0.17	0.71	0.42	0.72	0.42	0.72	8.47	7.88	7.88	
89	HD 2506	...	...	0.72	1.01	0.61	0.89	...	8.01	7.59	
90	BD 28°1885	0.78	1.02	0.81	1.00	0.73	0.91	9.77	9.81	9.49	
91	HD 112872	0.46	0.80	0.55	0.80	0.55	0.80	9.71	9.76	9.76	3
92	HD 26514	0.71	1.06	0.82	1.07	0.69	0.94	7.19	7.09	6.61	
93	HD 29883	...	...	0.60	0.89	0.60	0.89	8.56	7.95	7.95	
94	HD 249240	...	...	0.89	1.05	0.80	0.95	...	8.75	8.40	
95	HD 245389	...	1.12	1.02	1.15	0.84	0.98	8.94	8.98	8.34	3
96	SAO 55155	...	...	0.32	0.83	0.32	0.83	...	9.14	9.14	
97	SAO 55164	0.82	1.03	0.97	1.04	0.94	1.01	9.04	9.06	8.96	10
98	HD 33506	...	0.43	1.34	1.19	1.31	1.16	8.23	8.79	8.69	5
99	SAO 77849	...	...	1.45	1.22	1.40	1.17	...	9.26	9.06	
100	HD 26946	...	...	2.13	1.62	1.79	1.32	9.13	7.76	6.62	7
101	HD 21110	1.66	1.52	1.95	1.56	1.83	1.45	7.29	7.24	6.83	5
102	SAO 21753	...	1.70	2.16	1.69	2.00	1.55	8.92	8.91	8.37	7
103	SAO 63349	...	...	1.98	1.54	1.98	1.54	...	9.77	9.77	
104	HD 110964	1.69	1.59	1.86	1.56	1.86	1.56	9.72	9.04	9.04	7
105	SAO 62808	1.41	1.48	0.86	1.45	0.86	1.45	9.56	9.63	9.63	
106	HD 14357	−0.52	0.31	−0.47	0.40	−0.88	−0.15	8.52	6.58	4.75	1
107	BD −14°4956	...	...	−0.39	0.49	−0.90	−0.19	...	9.25	6.96	
108	BD −00°3227	...	...	0.38	0.77	0.09	0.40	...	10.56	9.30	
109	HD 249384	...	...	1.16	1.37	0.83	1.03	...	7.68	6.46	
110	HD 250368	...	...	0.98	1.12	0.89	1.04	...	9.65	9.33	
111	HD 249826	...	...	2.45	1.90	2.02	1.53	...	9.90	8.47	
112	BD 19°1947	...	...	0.79	1.39	0.79	1.39	9.20	9.05	9.05	12
113	BD 36°1963	...	...	1.17	1.54	1.13	1.51	8.30	8.71	8.58	12
114	BD −11°4586	−0.14	1.00	−0.14	0.94	−1.08	−0.26	9.40	9.40	5.40	1
115	HD 225160	−0.72	0.27	−0.67	0.24	−1.07	−0.31	8.19	8.17	6.33	7
116	HD 16808	−0.47	0.56	−0.42	0.56	−0.99	−0.20	8.60	8.68	6.13	3
117	HD 167451	−0.27	0.79	−0.27	0.73	−0.97	−0.19	8.23	8.24	5.18	1
118	BD −14°5030	0.03	1.03	0.01	0.96	−0.85	−0.15	9.52	9.52	5.81	1
119	HD 209678	−0.47	0.39	−0.47	0.38	−0.87	−0.15	8.42	8.38	6.58	1
120	SAO 20899	−0.25	0.49	−0.30	0.50	−0.74	−0.11	8.82	8.84	6.81	1
121	HD 192832	−0.02	0.89	−0.06	0.88	−0.79	−0.08	8.62	8.60	5.42	1
122	BD 61°0220	0.13	0.92	0.07	0.92	−0.65	0.00	9.68	9.72	6.60	1, 3
123	HD 17145	−0.01	0.82	−0.02	0.82	−0.65	0.02	8.16	8.20	5.47	3
124	LSIV P24	...	...	−0.13	0.23	−0.28	0.01	...	11.05	10.30	
125	HD 209900	0.23	0.45	0.04	0.44	−0.27	0.01	8.71	8.69	7.22	1
126	SAO 11344	0.33	0.84	0.17	0.86	−0.44	0.06	9.33	9.22	6.50	1
127	SAO 12149	...	...	0.30	0.97	−0.38	0.07	...	9.41	6.37	
128	42 LSI	...	...	0.32	0.69	−0.08	0.17	...	10.05	8.26	2
129	SAO 87716	0.01	0.39	−0.14	0.41	−0.37	0.09	8.31	8.30	7.23	1
130	SAO 12096	...	...	0.60	1.04	−0.09	0.13	...	9.07	5.95	
131	HD 9167	...	...	0.60	1.03	−0.05	0.18	...	8.14	5.23	2
132	HD 842	...	...	0.25	0.49	−0.01	0.14	...	7.86	6.65	7
133	SAO 37370	...	...	−0.03	0.37	−0.19	0.16	...	9.10	8.38	12
134	BD 58°0204	...	...	0.40	0.73	0.00	0.21	...	9.65	7.87	2

TABLE 2—*Continued*

Star	Name	Observed $U-B$	Observed $B-V$	Synthesized $U-B$	Synthesized $B-V$	Dereddened, Synthesized $U-B$	Dereddened, Synthesized $B-V$	Observed V	Synthesized V	Dereddened V	Reference
135	HD 12842	...	...	0.45	0.83	−0.03	0.23	...	8.56	6.48	2
136	SAO 21536	...	...	0.44	0.90	−0.04	0.30	...	9.03	6.95	12
137	HD 9973	...	0.86	0.50	0.87	0.05	0.30	...	6.83	4.89	4
138	HD 8992	...	...	0.62	0.94	0.10	0.31	...	7.78	5.57	
139	HD 17971N	0.90	1.06	0.66	1.07	0.27	0.60	7.75	7.67	6.03	3
140	HD 187428	...	...	0.36	0.78	0.17	0.56	...	7.89	7.15	12
141	HD 25361	...	...	1.11	1.36	0.65	0.88	...	7.58	5.84	2
142	SAO 21446	...	...	1.10	1.36	0.66	0.91	...	9.29	7.65	
143	BD 56°0084	...	...	0.82	1.10	0.64	0.90	...	8.72	8.01	2
144	HD 191010	...	...	0.76	1.00	0.69	0.93	...	8.15	7.89	12
145	HD 187299	1.37	1.60	1.48	1.62	0.93	1.11	...	7.12	5.21	13
146	HD 186293	...	...	1.15	1.19	1.14	1.18	...	7.83	7.80	12
147	SAO 37325	...	...	1.88	1.46	1.64	1.25	...	8.44	7.61	12
148	HD 1069	...	...	1.43	1.37	1.25	1.19	...	7.62	6.98	7
149	HD 1400	...	...	1.87	1.56	1.87	1.56	...	6.88	6.88	7
150	HD 14330	...	...	2.74	2.23	2.15	1.76	...	7.92	6.06	7
151	SAO 23888	...	...	3.14	2.54	2.24	1.82	...	9.26	6.47	12
152	HD 13136	...	...	2.66	2.19	2.05	1.70	...	7.62	5.68	
153	HD 94028	−0.19	0.47	−0.16	0.45	−0.16	0.45	8.23	8.25	8.25	3, 14
154	SAO 102986	...	...	−0.11	0.47	−0.11	0.47	9.79	9.81	9.81	14
155	SAO 81292	1.06	1.54	1.18	1.55	1.16	1.54	9.4	9.37	9.31	15
156	HD 16691	−0.57	0.48	−0.53	0.47	−1.09	−0.29	8.70	8.69	6.17	3
157	HD 108	−0.79	0.18	−0.79	0.09	−1.07	−0.30	7.40	7.23	5.95	7
158	BD 40°4220	0.58	1.70	0.56	1.63	−1.04	−0.27	9.20	8.99	2.54	1
159	HD 13256	−0.01	1.20	0.00	1.19	−1.08	−0.15	8.61	8.65	4.14	3
160	HD 50064	−0.26	0.77	−0.28	0.79	−1.00	−0.14	8.21	8.17	5.05	3, 16
161	BD 51°0710	−0.18	0.59	−0.24	0.60	−0.74	−0.06	9.75	9.64	7.42	1

REFERENCES.—(1) Hiltner 1956. (2) Hardorp *et al.* 1959. (3) Blanco *et al.* 1968. (4) Wildey 1964. (5) Buscombe 1977. (6) Sargent and Searle 1968. (7) Kennedy and Buscombe 1974. (8) Schild 1965. (9) Mendoza 1956. (10) Dickow *et al.* 1970. (11) Abt and Levato 1977. (12) Buscombe 1980. (13) Johnson 1965. (14) Peterson 1980. (15) MacFarlane 1979. (16) Humphreys 1970.

than synthesized ones. The quantity $E(U-B)$ was converted to $E(B-V)$ using the formulae of Heintze (1973) for O stars and Buser (1978) for the rest. On the basis of these two color excesses, adjustments were made as necessary to the spectral type, although discrepancies smaller than 0.1 mag were not considered significant. The final $E(B-V)$ was that derived from the $B-V$ color only.

The interstellar reddening law given in Table 2 of Schild (1977) was used to deredden the stars. We used a simple linear interpolation between points so the original data can be easily recovered if necessary. It is well known that the reddening curve varies slightly from place to place in the Galaxy, and in particular there is considerable structure in the curve from 4000 to 7000 Å (see Schild 1977). Many of the heavily reddened stars, and particularly the supergiants, show structure in their spectra of up to 10% which does not change smoothly with spectral type; these features may be associated with variations in the reddening curve. For example, HD 9167 (star 131) exhibits structure in its spectrum and has an $E(B-V)$ of 0.90. It is also in the direction of the clusters Tr 1 and NGC 581 which are known to deviate from a standard reddening law. Alternatively, we may be seeing the effects of interstellar absorption bands which are not adequately represented by the broad-band reddening law.

We reviewed the list of stars contained in the library by Gunn and Stryker (1982), but found no stars in common. Consequently, we were unable to compare the photometric quality of the two catalogs.

c) *The Library*

Tables 1 and 2 present information about the stars, and Figure 2 presents representative spectra. The stars are arranged in order of spectral type: O to M and luminosity class V to I. Stars having unusual characteristics such as low metallicity or emission-line spectra are placed at the end of the list.

The columns in Table 1 have the following meaning: (1) the ordinal of the star in the library; (2)–(5) designations for the stars as they appear in various catalogs; (6) the adopted spectral type; (7) the spectral type as it appears in the literature if different from that adopted; (8) the color excess $E(B-V)$ used to deredden the spectrum; columns (9)–(10) the minimum and maximum flux (ergs cm^{-2} s^{-1} $Å^{-1}$) for each spectrum. These are provided so that the flux scales in Figure 1 can be recovered if desired; and column (11) notes concerning the spectrum. The letters "G" and "R" identify the spectra that have been corrected for the problems with the order blocking filters (see § II*b*) in the green and the red, respectively. The notation "G abs" refers to the modification of the spectra in the region 5938 to 5995 Å (see § II*b*). One star is noted as having an unusual bend in its spectrum in the red as compared to other stars of similar spectral type. Ten stars are noted as being in Aitken's (1932) catalog of binary stars, and one star is a spectroscopic binary (Batten 1968); however, we see no abnormality in the spectra of these stars.

Table 2 contains color information including those found in the literature, those synthesized from the spectra, and those synthesized after dereddening. Any deviations of the dereddened colors from a smoothly changing sequence as a function of spectral type are due to the fact that the observed colors found in the literature were used to determine $E(B-V)$ in many cases, and there exist some small differences between the observed and synthesized colors.

Figure 2 depicts spectra representative of the different stellar types in the library; where types are duplicated in the library, only one star is illustrated. Each panel of the figure was constructed by normalizing each star to 4200 or 6300 Å (for red stars), and adding a constant. The minimum and maximum fluxes given in Table 1 can be used to reconstruct the scale of the figure if desired.

The entire library of spectra is available on magnetic tape. To obtain a copy, complete an order form published in any issue of the *Astronomical Data Center Bulletin* (or send a letter with tape specifications: density, internal coding [EBCDIC or ASCII], and maximum allowable block size [physical record length]) and forward it along with one 2400 foot (732 m) blank (preferably new) magnetic tape to: Dr. Wayne H. Warren, Jr.; Astronomical Data Center; NASA Goddard Space Flight Center; Code 601; Greenbelt, MD 20771 USA. Appendix A contains a description of the tape format.

III. APPLICATIONS

A spectrophotometric library of stars has many applications. We illustrate here only a few of the many uses. These are intended merely as examples of what can be done and are not presented as exhaustive research projects in themselves.

a) *Population Synthesis*

Population synthesis is a technique applied to the integrated light of composite systems to determine the fraction of light contributed by each of the main stellar groups comprising the system. This technique has been used in a variety of forms by a number of investigations in the study of, for example, binary stars (Beavers, Cook, and Ficke 1978), nuclei of galaxies (Turnrose 1976; Pritchet 1977), elliptical galaxies (Faber 1972; O'Connell 1976; Gunn *et al.* 1981), and late-type galaxies (Morgan and Osterbrock 1969; O'Connell 1970; Peck 1980; Hunter, Gallagher, and Rautenkranz 1982). The temperature mix of a system determined in this way can then be used to explore its evolutionary history through, for example, the luminosity function, ratios of different stellar age groups, and the presence and size of a young component, and to predict the flux of the system at additional wavelengths as a test of the synthesis (see Huchra *et al.* 1983; Lamb *et al.* 1984). Furthermore, population synthesis is a means for correcting observed emission-line strengths for underlying stellar absorption (see Turnrose 1976; Hunter, Gallagher, and Rautenkranz 1982; Keel 1983).

b) *Stellar Clusters*

One interesting use of the library, and one which is similar to population synthesis, is the fabrication of a spectrum representing the integrated light from clusters of stars or galaxies based on theoretical or empirical parameters such as stellar evolutionary tracks and an initial mass function (IMF). For example, we have constructed the spectra for clusters of stars initially formed with a Miller and Scalo (1979) IMF and having ages of 0, 10^7, 10^8, and 10^9 yr. These spectra are shown in Figure 3. We used the absolute visual magnitudes of Mihalas (1968) to place the library stars at a common distance. Then for an age of 0 yr, we simply add up the spectra of the main-sequence stars from the library in the proportions prescribed by an IMF extending from 0.1 to 50 M_0.

To evolve the model cluster to a particular age, we noted where stars should appear along their evolutionary tracks on the basis of the theoretical models of Brunish (1981), Becker (1981), and Mengel *et al.* (1979). At any given age there is a mass below which there are stars still on the main sequence and a mass above which all stars have died. In between these two limiting masses is a small range of stellar masses which are evolving and which are assigned as either giants or supergiants according to the theoretical luminosities and temperatures indicated by the evolutionary tracks. We sampled the evolutionary tracks by dividing them into four segments: the main sequence, to maximum luminosity during core helium burning, to the first red giant maximum, and to the tip of the red giant branch. We then computed the time spent and the time-averaged luminosities and temperatures in each segment as a function of the initial mass of the star. We then divided the range of evolving stars under consideration into four or five bins by mass and noted which evolutionary stage each of those stars would occupy at the time in question. We can then infer the average spectral type and luminosity class of the star.

Because real clusters are thought to form over a finite period (10^7–10^8 yr), which is nonnegligible compared to the ages of our models, we have added several clusters together having a small spread in age. Thus, for the model cluster having an age of 10^7 yr we combined clusters evolved to ages of 5×10^6, 10^7, and 3×10^7 yr. The model cluster having an age of 10^8 yr is a sum of clusters evolved to ages of 7×10^7, 10^8, and 1.3×10^8 yr. The zero age and 10^9 yr clusters are single-age models.

As one expects, the brightest stars dominate the integrated light. But one can see in Figure 3 features entering the spectra which reveal their composite nature. The evolution is treated here in a very simple fashion for illustrative purposes. Clearly more care is needed to follow properly the rapid evolution of the more massive stars.

There are real galactic star clusters for which the spectral types of the brightest member stars are known. We have synthesized the integrated spectrum for a few of these clusters by adding up the light contributed by the spectral types in the published lists. Figure 3 also shows the synthesized spectra for the Pleiades (Abt and Levato 1978) and Coma Berenices (Abt and Levato 1977). The Pleiades are considered to be $\sim 6\times10^7$–2×10^8 yr old, and the spectrum does resemble that in Figure 3 for the 10^8 yr model. Coma Berenices, at an age of 5×10^8 yr, resembles the 10^9 yr model.

We have also synthesized but not illustrated α Per (Morgan, Hiltner, and Garrison 1971) which is 10^7 yr old. The α Per cluster is dominated by a single F5 supergiant but to a much greater degree than our model cluster at 10^7 yr. The statistics of the small number of stars in real clusters is likely the cause of the disagreement. Our model indicates that only 0.06% of

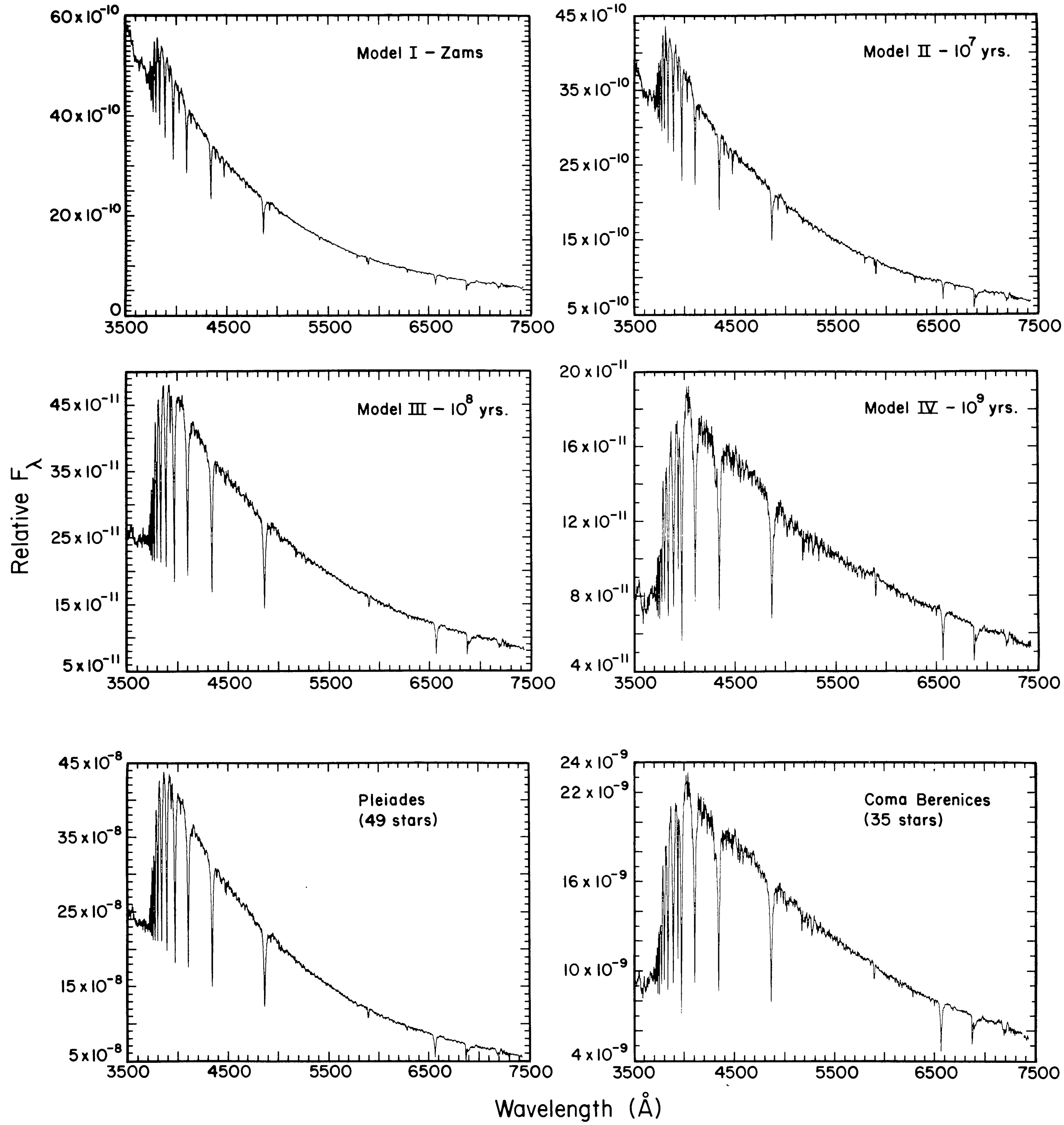

FIG. 3.—Spectra of the stellar clusters. Upper four spectra are models synthesized from the library by evolving a Miller and Scalo (1979) IMF to four different ages (see text). Lower two spectra are constructions based on the observed membership of the galactic clusters.

the bright stellar population should be supergiants; the real cluster contains a single supergiant, or $\sim 1\%$ population. If we remove the F5 supergiant from our synthesis, then the spectrum resembles the 10^8 yr model cluster. We caution that our models are intended to be instructive in the use of the library, and the above discussion of cluster ages should not be considered conclusive.

c) Line Indices and Colors

Another use for this library is the synthesis of color indices at arbitrary wavelengths for filters of arbitrary bandwidth. By numerically convolving any user-defined transmission curve with the spectral library, new color relations can be investigated.

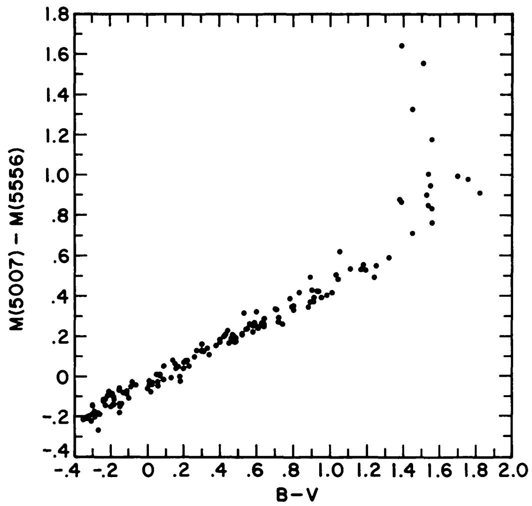

FIG. 4

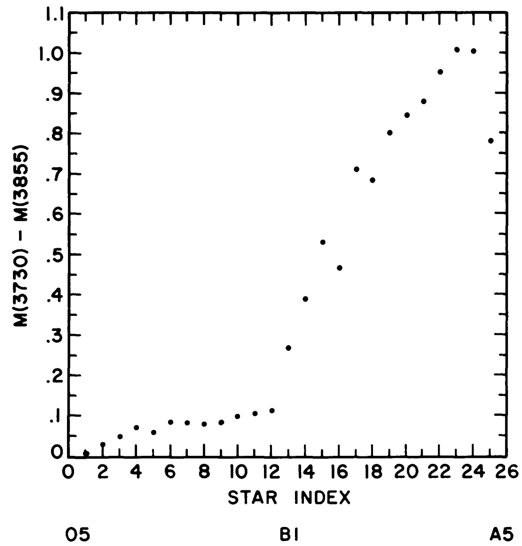

FIG. 5

FIG. 4.—Color index $m(5007)-V$ vs. $B-V$ for all stars in the library. The 5007 Å simulated filter has a FWHM of 25 Å.

FIG. 5.—Color index $m(3730)-m(3855)$ derived from the spectra of the first 25 stars in the library. This provides a measure of the Balmer jump as a function of spectral type for O–A dwarf stars. The FWHM of the simulated filters at 3730 and 3855 Å is 30 Å.

Consider an example in which a stellar field containing B and V standards is observed through a narrow band [O III] λ5007 filter with the intention of deriving fluxes in this nebular emission line. Although the standard stars do not have measured magnitudes at 5007 Å, an excellent relation for $m(5007)-V$ as a function of $B-V$ can be derived from the library. Figure 4 shows this relationship for the case where the filter has a 25 Å FWHM. Clearly a very good relation exists for the regime $B-V<1.3$; for $B-V>1.3$, the effects of molecular bands become important.

Similarly, one can investigate a variety of indices sensitive to stellar temperature and luminosity. For example, Figure 5 shows the synthesized narrow-band index $m(3730)-m(3855)$ as a function of spectral type for hot luminosity class V stars. This index measures the height across the Balmer jump and is very sensitive to temperature for stars of class B1–A3. It is also marginally useful for some hotter stars. From Figure 5 it appears that the library stars numbered 5, 16, and 18 may be classified as too cool by as much as one subclass.

We have also considered the use of certain line strengths as luminosity discriminants. Following Pritchet and van den Bergh (1977), we have considered the line indices for MgH λ4619, MgI + MgH λ5174, NaI + TiO λ5891, and CaH λ6820. We find generally good agreement with their results (see also O'Connell 1973). In particular, the most sensitive indicator of these four is that of MgI + MgH λ5174. For stars later than mid-G, this index provides good luminosity discrimination, especially for supergiants. It also provides a good temperature index, especially for stars earlier than mid-G. It therefore is an excellent reddening-free spectral class index.

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APPENDIX A

STELLAR LIBRARY TAPE FORMAT

The library is distributed as a card image nine-track magnetic tape. The tape may be written according to user specifications for the blocking factors and the character set (ASCII or EBCDIC). Each spectrum is 2799 points long and consists of 352 cards, and there are 161 spectra in the library. The data are given as F_λ(ergs cm^{-2} s^{-1} Å^{-1}).

There are no special records, headers, or trailers between spectra. The entire library is terminated with the usual double end-of-file mark.

The first two cards in the spectrum contain descriptive information about the star. Each element in the card image format, including the actual pixel values , is allocated 10 columns. Thus, there are eight information elements per card. The header cards are formatted as follows.

Card 1

1–10 Star name (usually HD...)
11–20 Spectral type (first seven characters only)
21–30 Spectral type as given in literature if different

31–40 $E(B-V)$ derived
41–50 $U-B$ observed
51–60 $B-V$ observed
61–70 $U-B$ after dereddening
71–80 $B-V$ after dereddening

Card 2
1–10 $U-B$ in literature
11–20 $B-V$ in literature
21–30 Wavelength of first pixel (= 3510 Å)
31–40 Wavelength increment per pixel (= 1.40 Å)
41–80 Blank

The data cards follow a similar format, starting with card 3 and continuing through card 352.

Card 3
1–10 Flux(pixel 1)
11–20 Flux(pixel 2)
⋮
71–80 Flux(pixel 8)

The subsequent cards, 4–352, follow the pattern of card 3 for all 2799 pixels in the spectrum. The format of the data on these cards is the FORTRAN 1P8E10.3. That is, each value occupies 10 columns, using exponential notation, has four digits precision, and there are eight pixel values per card. For example, a value might be 1.234E-11, right justified in the 10 columns.

The format of the header information is equivalent to FORTRAN F10.2 for all numerical values. The first three elements, star name, and the spectral types are left-justified alphanumeric, or A10 FORTRAN format.

Approximately half a 600 tape is needed to contain all the spectra when recorded at 1600 BPI.

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