FAINT SPECTROPHOTOMETRIC STANDARD STARS

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ABSTRACT

Absolute spectral energy distributions for 25 stars have been measured with the Double Spectrograph on the 5 m Hale telescope. They have been selected to be spectrophotometric standards for use with the *Hubble Space Telescope* and with ground-based telescopes carrying out *HST* related work. More than half of these stars have absolute fluxes measured in the ultraviolet with the *International Ultraviolet Explorer* (*IUE*). Spectra are shown and smoothed absolute fluxes at continuum points are listed. Comparisons of these fluxes with those determined elsewhere show that the ones in this paper are systematically brighter by 0.04 mag.

I. INTRODUCTION

Anticipated observations with the *Hubble Space Telescope* along with corresponding ground-based observations make it desirable to have spectrophotometric standard stars at optical and ultraviolet wavelengths which are already tied together. Present standard stars such as the cool subdwarfs measured by Oke and Gunn (1983) are not satisfactory because the UV flux in these stars is very low and calibration spectra taken with *HST* would require a very long time to obtain. Furthermore, these cool subdwarfs are too bright for use with pulse-counting systems on larger telescopes.

A new set of potential spectrophotometric standards was chosen with the following properties. (a) They should be distributed around the sky. (b) Some of them should be faint enough so that they can be observed with pulse-counting devices without having to introduce neutral-density filters. (c) Some of them should be hot with high UV fluxes so they can be observed quickly with *HST*. (d) They should be stars which have been well observed with *IUE* so that absolute fluxes in the UV are already known on a well-defined system. (e) The stars should have relatively simple spectra with a large number of wavelengths where accurate fluxes can be defined.

Using these criteria a selection of 25 stars was chosen. Absolute fluxes from 3200 to 9200 Å have been determined for these stars to complement the existing UV data (Bohlin *et al.* 1990). The results are discussed in this paper.

II. OBSERVATIONS

The objects selected for observation are listed in Table I along with their epoch 2000 coordinates, spectral types, and visual magnitudes. Coordinates, finding charts, etc. are given by Turnshek *et al.* (1989). One of the stars, G24-9, may be an eclipsing binary (Carilli and Conner 1988).

Previous absolute calibration work such as that by Oke and Gunn (1983) was done using photomultiplier tubes and instruments such as the Multichannel Spectrometer (Oke 1969). Such detectors have a long history of reliability, stability, and linearity. But such spectrometers are very slow and inefficient by present-day standards and to calibrate 25 stars, some relatively faint, would take a very large amount of observing time. It was therefore decided to use the Double Spectrograph (Oke and Gunn 1982) on the 5 m Hale telescope along with its CCDs if the detectors could be verified to be satisfactory for an absolute calibration task. The Double Spectrograph has two Texas Instruments thinned back-illuminated 800×800 pixel CCDs. These detectors have been verified to be linear to at least 0.2% over the range of signal normally used.

To carry out absolute spectrophotometry it is necessary to work with large apertures or slits and to work in moderately good seeing. In our case, the Double Spectrograph was used with 10-arcsec-wide and occasionally 8-arcsec-wide entrance slits. Observations made of standard stars throughout photometric nights, and reduced using standard atmospheric extinction coefficients, verified that the stability of the CCDs was similar to that of photomultiplier tubes used with the Multichannel Spectrometer. (A problem in the ultraviolet was later found which is described below.) The repeatability of the standards was about 1% over most of the spectral range and a little larger in the ultraviolet and near infrared.

The Double Spectrograph separates the spectrum with a dichroic filter. The one used for the present observations switches at approximately 4800 Å. The blue side of the instrument was set up to cover the spectral range from about 3150 Å to nearly 4800 Å while the red side was set for 4650 to 9400 Å. The standard observing technique was to observe one of the cool subdwarf standards HD 19445, HD 84937, BD + 26°2606, or BD + 17°4708 (Oke and Gunn 1983) several times during the night at a variety of zenith distances. The unknowns were observed near the meridian. If the unknowns were bright, several exposures in quick succession were made, usually observing first in the blue side of the spectrometer and then in the red side. Blue and red exposures were done separately since optimum exposure times were substantially longer in the blue than in the red. For fainter objects the blue and red sides were observed simultaneously a few times in succession. Wavelengths were determined using emission-line comparison lamps observed through a narrow slit; all slits in the Double Spectrograph have identical slit centers. Wavelengths for the star spectra are always slightly uncertain when observations are made with a very wide slit because the star images may not be at the exact center of the slit. This lack of centering can also be a function of wavelength due to atmospheric dispersion. This was minimized in later observations by always placing the slit vertical in the sky (Filippenko 1982).

The small uncertainty in the wavelength, as large as 2 Å in the blue and 6 Å in the red, causes three problems. First, the spectral lines are shifted relative to each other so that when standard deviations are calculated from multiple exposures they tend to be larger in the lines than outside the lines. Second, the atmospheric extinction corrections when they change suddenly as in the A and B bands, will be in error.

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TABLE I. Program stars.

Star No.	Name	α(2000)	δ(2000)	Sp. Type	V	AB (λ5460)
1	G158-100	00 33 54.3	-12 07 57	sdG	14.89	14.82
2	HZ 4	03 55 21.7	+09 47 19	DA4	14.52	10.47
3	G191B2B	05 05 30.6	+52 49 54	DAO	11.78	11.72
4	G193-74	07 53 27.4	+52 29 36	DC	15.70	15.58
5	BD+75°325	08 10 49.3	+74 57 57	O5p	9.54	9.52
6	Feige 34	10 39 36.7	+43 06 10	DO	11.18	11.13
7	HD 93521	10 48 23.5	+37 34 13	O9Vp	7.04	6.96
8	HZ 21	12 13 56.4	+32 56 31	DO2	14.68	14.67
9	Feige 66	12 37 23.6	+25 04 00	sdO	10.50	10.43
10	Feige 67	12 41 51.8	+17 31 20	sdO	11.81	11.78
11	G60-54	13 00 09.5	+03 28 56	DC	15.81	15.73
12	HZ 44	13 23 35.4	+36 08 00	sdO	11.66	11.65
13	GRW+70°5824	13 38 51.8	+70 17 08	DA3	12.77	12.72
14	BD+33°2642	15 51 59.9	+32 56 55	B2IV	10.81	10.74
15	G138-31	16 27 53.6	+09 12 24	DA7	16.14	16.07
16	G24-9	20 13 56.0	+06 42 55	DC	15.72	15.77
17	BD+28°4211	21 51 11.1	+28 51 52	Op	10.51	10.47
18	BD+25°4655	21 59 39.3	+26 25 42			9.65
19	LTT 9491	23 19 35.0	-17 05 30	DC	14.04	14.06
20	Feige 110	23 19 58.4	-05 09 56	DOp	11.82	11.81
21	GD 248	23 26 06.7	+16 00 21	DC	15.09	15.08
22	GD 50	03 48 50.1	-00 58 30	DA2	14.06	14.06
23	SA95-42	03 53 43.7	-00 04 33		15.61	15.60
24	GD 108	10 00 47.3	-07 33 31	sdB?	13.56	13.57
25	NGC 7293	22 29 38.5	-20 50 13		13.51	13.48

Third, the instrument calibration will be incorrect in places where the sensitivity is changing very rapidly with wavelength, e.g., near the dichroic crossover point.

Standard stars and unknowns were reduced in the same way by (a) subtracting the appropriate erase level, (b) flattening the two-dimensional spectra, (c) subtracting the sky background, (d) summing all the observed spectrum along the slit, and (e) correcting for extinction using a standard atmospheric extinction law (Oke and Gunn 1983).

All the observations in the red were made with the regular TI CCD. In the blue the original TI CCD was used for more than half of the observations. Its problem is that the quantum efficiency below 4000 Å, even after UV flooding is only a few percent. In 1987 a different TI CCD was put into service. This CCD, called No. 8, has a platinum flashgate on the surface which eliminates the need for a UV flooding procedure. After oxygen soaking it has a quantum efficiency of over 40% throughout the 3100–4000 Å range (Oke, Harris, and Oke 1988). This CCD, however, has numerous small flaws in the central part of the chip and these are not corrected by flatfielding. Since it is impossible to avoid all of these the resulting spectra with this CCD have flaws in the 4000–4500 Å spectral range. The smallest of these can be corrected, but the larger ones cannot. The way in which these spectra were handled is described below. The dates on which observations were obtained are listed in Table II along with the quality of the night as judged during the observing session. The slit widths used are also tabulated.

III. ABSOLUTE STANDARDS

The instrument has been calibrated absolutely by making observations of the four cool subdwarf spectrophotometric standard stars mentioned above (Oke and Gunn 1983). This system is referred to as AB79 and is based on Multichannel Spectrometer observations made with passbands of typically 20 or 40 Å. When one tries to use these standards to calibrate observations made with a resolution of a few Angstroms several problems arise which are discussed below.

In the original absolute calibration of α Lyrae no attempt was made to measure fluxes within the Balmer lines and no measurements were made between 3700 and 4000 Å where the Balmer lines are badly blended. In the AB79 calibration these regions were still excluded in the cool subdwarfs except that an attempt was made to estimate the absolute fluxes at midpoints between late members of the Balmer series. In the cool subdwarfs there are additional regions where absorption lines make it impractical to define an absolute calibration. These regions include the Ca II H and K lines, the G band, a region near 3580 Å where there are a number of strong metal lines, and the Mg-b band. The full list of wavelength gaps in the cool subdwarfs where absolute fluxes cannot easily be defined are given in Table III.

Over most of the spectrum the subdwarf calibrations, called AB79, are used directly. Small changes of 0.02–0.05 mag have been made at points adjacent to Hα, Hβ, and Hγ. Between 3594 and 4160 Å an attempt has been made to esti-

TABLE II. Log of observations.

Date yr/mo/da	Quality	Slit Width Used (arcsec)	Camera
85/02/08	Photometric	10	Regular Blue CCD
85/02/10	Photometric	10	"
85/08/31	Clouds	6,8	"
85/09/01	Photometric	8	"
85/09/02	Photometric	8	"
86/02/27	Photometric	8	"
86/02/28	Photometric	6,8	6 arcsec for BD+75°325*
86/12/10	Photometric	10	"
86/12/11	Photometric	8,10	"
86/12/12	Photometric	6,8	"
86/12/13	Photometric	6,8	"
87/10/04	Photometric	6,8	uv sensitive CCD
88/01/28	Some Cloud	8	"
88/01/29	Cloud, then fairly clear	10	"
88/01/30	Clouds	10	"
88/06/26	Low Haze	6,8	"

*Has a faint companion 4" SW.

mate a better set of fluxes than was done in AB79. Two points have been defined between each pair of Balmer lines. The values of AB for these points have been chosen so that the instrument sensitivity function is smooth and spectra of objects which have very few features in this region are also smooth and reasonable. Many of the points in this region must be defined with a wavelength accuracy 1–2 Å and, therefore, the radial velocities of the cool subdwarf standards which range from $+32$ to -295 km s^{-1} (Eggen 1964) are relevant. The velocity effects have not, however, been taken into account in the present work.

TABLE III. Gaps where OB − AB is not defined.

Feature	lower λ	Upper λ
Metal	3561	3593
H15	3706	3712
H14	3716	3722
H13	3727	3735
H12	3742	3754
H11	3760	3776
H10	3783	3813
H9	3823	3859
H8	3869	3903
Ca II K	3912	3946
H, Hε	3951	3993
Hδ	4080	4124
g-band,Hγ	4270	4364
Hβ	4836	4878
Mg-b	5150	5205
Hα	6531	6585

In Table IV the absolute fluxes used for the cool subdwarf standards are listed where they differ from those published by Oke and Gunn. The main changes are in the 3594–4160 Å region where many points have been added as described above.

The instrument calibration is determined by calculating the difference OB − AB between the extinction corrected observed magnitude OB and the absolute value of AB for the subdwarf. Points within the gaps listed in Table III are filled by interpolating with a second-order equation from existing points on either side of each gap. Where gaps are very close, points may come from wavelengths well beyond the individual gap. This process yields a smooth calibration without any absorption-line features from the standard star spectrum. Such a curve is generated for every standard star observation.

IV. DATA REDUCTION

a) Instrument Calibration

The first step in the reduction is to look at the instrument sensitivity using the values of OB − AB from the standard star observations. If (a) the instrument is stable, (b) the atmospheric transparency is constant, (c) the extinction law is correct, and (d) the standard stars are all calibrated correctly, then all the OB − AB curves will be identical apart from photon noise. A comparison of OB − AB curves therefore tests all four assumptions together; in practice when everything is working properly the curves really indicate the photometric quality of the night. On most nights which were judged to be photometric, it was found that OB − AB was indeed constant over all wavelengths to a precision of about 0.01 mag. On some other nights, however, there was a slow

TABLE IV. Values of AB for cool subdwarf standard stars.

Wavelength Å	AB 19445	84937	26°2606	17°4708
3594	9.010	9.290	10.720	10.510
3607	9.010	9.290	10.720	10.510
3640	8.979	9.269	10.698	10.487
3680	8.945	9.243	10.670	10.452
3705	8.946	9.220	10.657	10.432
3713	8.920	9.210	10.650	10.423
3715	8.918	9.205	10.649	10.421
3723	8.950	9.190	10.635	10.405
3726	8.950	9.180	10.630	10.400
3736	8.895	9.155	10.630	10.380
3741	8.885	9.145	10.620	10.370
3755	8.865	9.065	10.540	10.290
3759	8.845	9.040	10.530	10.270
3777	8.770	8.930	10.460	10.180
3782	8.750	8.920	10.450	10.200
3814	8.680	8.830	10.340	10.070
3822	8.700	8.860	10.380	10.170
3860	8.605	8.730	10.230	9.950
3866	8.600	8.725	10.260	10.020
3905	8.590	8.730	10.240	9.978
3911	8.585	8.680	10.223	9.950
3947	8.590	8.670	10.180	10.010
3953	8.605	8.695	10.225	9.990
3993	8.490	8.620	10.140	9.860
4020	8.460	8.600	10.116	9.830
4060	8.430	8.590	10.092	9.810
4080	8.430	8.610	10.080	9.840
4120	8.418	8.585	10.060	9.800
4160	8.395	8.570	10.040	9.790
4200	8.375	8.555	10.020	9.765
4270	8.342	8.535	10.000	9.750
4365	8.300	8.500	9.970	9.720
6540	7.870	8.190	9.570	9.328
6580	7.887	8.190	9.577	9.324

drift of OB − AB, usually nearly independent of wavelength, which was as large as 0.05 mag. In most cases this drift indicated that the transparency was improving during the night. The usual procedure on nights such as these was to break up the nights into two or three parts. This should reduce errors, both absolute and wavelength dependent, to no more than 0.02 mag except in the extreme ultraviolet.

Late in the program, particularly when the blue CCD with high UV sensitivity was being used, a few nights when clouds or haze were present were used. The evidence in these cases indicated that the extinction was substantial at times but nearly grey in character.

b) Water-Vapor Absorption

In the red and near infrared there are numerous regions where atmospheric water-vapor absorption occurs. The worst of these are between 9000 and 9800 Å. In these regions extinction coefficients were used with a square-root extinction law to allow for the fact that the water-vapor lines are on the square-root part of the curve-of-growth. The water-vapor level was estimated by looking at the absorption in the worst region in the standard stars. The level was found to usually be constant on any given night. The water-vapor extinction can only be taken out in an average way since the spectral resolution is far too low to resolve individual lines. Consequently, the uncertainties remain substantial even after the corrections are made. Above 9000 Å they can be 0.05 mag or greater. In the other regions they are about 0.02 mag. The limitations of these corrections are easily seen in the reduced spectra as slightly irregular continua.

c) Reduction of the Unknowns

Once the standards have been selected, the average value of OB − AB is derived for every pixel and AB for the unknown is calculated from its value of OB. Standard deviations sd0, based on photon counts, including sky counts, are calculated at every pixel.

When several spectra were obtained in close succession, they were averaged and a standard deviation sd1 was calculated for every observed pixel based on the agreement among the individual measurements. These errors reflect photon statistical errors, guiding errors, and errors in atmospheric transmission, but they do not reflect standard star errors, or changes in instrumental sensitivity since the observations span at most one hour and often only a few minutes.

It was usual to average all of the data for individual stars taken during an observing run of a few nights. Again, standard deviations sd2 were calculated based on agreement among the individual observations or averages from the different nights. These errors now reflect errors in atmospheric transmission, standard star OB − AB errors, and instrument sensitivity changes if any.

d) Second-Order Contamination

Above 8800 Å the second-order spectrum above 4400 Å begins to be transmitted by the dichroic filter. As the wavelength increases the second-order contamination increases since that wavelength is closer to the switchover point of the dichroic. The problem is present but minor in cool stars such as the cool subdwarf standards, but becomes very serious for hot stars. For hot stars the second order at 9200 Å produces more signal than the first order. The contamination was calculated by taking a defined fraction of the absolute flux and applying a suitable correction for extinction. A program to remove the second-order leak at a much earlier stage of the reduction was tried but it did not give a significantly better result than the simple procedure described above. This second-order leak occurs at wavelengths where there are already problems with water-vapor absorption.

e) Combining of Spectra from Different Runs

At this point in the reductions we have absolute spectral energy distributions AB separately for the blue and the red sides of the spectrograph for each observing run or night. These must now be combined. When the spectra are compared it is found that there are small non-wavelength-dependent shifts even when the nights were judged to be photometric. In practice, the first set of nights from 8 February 1985–26 February 1986, but excluding 31 August 1985, were used as the reference levels since these seemed to be the most transparent nights. Small offsets were then applied to each spectral energy distribution so that on average it matched the reference spectrum. The shifts that were needed are listed in Table V with one entry for each averaged spectrum for a run. Numbers in parentheses are those used for spectra where there was clearly cloud or thick haze present. The shifts are all in magnitudes.

All of the blue or red measurements are combined to gen-

TABLE V. Offsets in magnitudes between observing runs.

Star No.	Blue Offsets	Red Offsets	Red to Blue Offsets
1	-0.09,-0.08	-0.02,-0.06	0.00
2	+0.00,+0.02,(-0.40)	-0.04,-0.05,-0.06	0.00
3	+0.01,+0.02,-0.02	-0.04,-0.05,-0.06	0.00
4	-0.04,-0.02	-0.05,-0.02	0.00
5	-0.01,-0.04	-0.02,-0.08	0.00
6	-0.02,(-0.12)	+0.01,(-0.14)	0.00
7	0.00,(-0.12)	+0.02,(-0.15)	0.00
8	+0.02,(-1.16),-0.03,-0.04	-0.02,(-1.20),-0.04,-0.04	0.00
9	(-0.08),(-1.37),(-0.60)	(-0.15),(10.53)	0.00
10	(-0.08),(-0.60),(-0.71)	(-0.11),(-0.63)	0.00
11	-0.32,-0.01,-0.04	-0.04,-0.03,-0.04	0.00
12	(-0.51),(-1.02),-0.08	(-0.53),(-0.96),-0.02	0.00
13	(-0.52),-0.07	(-0.46),-0.04	0.00
14	+0.02,-0.03	(-0.18),-0.06	-0.06
15	-0.07	-0.04,-0.05	0.00
16	-0.02	+0.02	0.00
17	-0.04,-0.03	-0.04,-0.01	0.00
18	-0.01,-0.03	-0.02,-0.02	0.00
19	-0.04,-0.06	-0.02,-0.03	0.00
20	-0.02,-0.00	-0.04,-0.00	0.00
21	+0.02	-0.02,-0.02	0.00
22	...	...	0.00
23	...	...	-0.03
24	+0.03	0.00	0.00

erate a single blue or red energy distribution. There are two complications at this point. First, the wavelengths of pixels do not coincide from one run to another. This is corrected by interpolating and tabulating values of AB at intervals of one-third pixel, averaging, and then recombining the averages in one pixel intervals. Second, for nights 4 October 1987 and later the CCD with high UV sensitivity was used. Since this CCD has flaws which affect the 4000–4500 Å interval, it was decided to use these spectra only below about 3850 Å. This requires averaging blue data in two intervals, one from 3200 to 3850 Å and the other from 3850 to 4700 Å. This procedure is workable since the offsets have been made very carefully. In the red, spectra are averaged in the same way but there is only one interval.

The various spectra are now combined into a single averaged spectrum. Standard deviations sd3 are calculated which are based on the agreement among the individual spectra being averaged. In most cases the individual spectra are already averaged. These standard deviations should now represent the real wavelength-dependent errors in the data, including all the sources of errors mentioned above. Because we have applied arbitrary offsets to spectra, the errors do not reflect the errors in the absolute levels.

The blue and the red spectra must finally be combined. This has been done usually at 4700 Å although the joins have been done as low as 4663 Å or as high as 4748 Å. The choice of the switch-over wavelength was made on the basis of the quality of the ABs in this region in the two sides of the spectrograph; these vary depending on the guiding accuracy. The shift needed to match the red to the blue spectrum is given in the last column of Table V. Since individual spectra have different wavelengths for each pixel the final averaged data are calculated at every integer wavelength from 3200.0 to 4700.0 Å and at every even wavelength between 4702.0 and 9200.0 Å. The final result for each star is an absolute spectral energy distribution AB going from 3200 to 9200 Å. The standard deviation which reflects the wavelength-dependent part of the error, is tabulated at every listed wavelength. Table VI gives a summary of these errors for all stars as a function of the wavelength. The final energy distributions are plotted in Fig. 1; AB, defined as

$$AB = -0.4 \log f_\nu - 48.60,$$

where f_ν is the flux density in ergs s^{-1} cm^{-2} Hz^{-1}, is plotted against wavelength in Angstroms.

f) Deficiencies in the Spectral Energy Distributions

There are still a few problems which generate obvious errors in the AB fluxes.

(1) Because the wavelengths and spectral resolution are not perfectly defined in slitless observations, the corrections for atmospheric extinction are not accurate near the A and B bands. We have simply replaced values of AB between 6847 and 6950 Å and 7550 and 7690 Å by values interpolated from just outside these regions. Standard deviations and weights have been set to zero to flag these points.

(2) No allowance was made in the reductions for the presence of a very weak absorption at the Mg-*b* band in the AB79 subdwarf standard stars. This produces an apparent emission feature in all the hot star spectra. It has been removed as in (1) above between 5150 and 5205 Å. This was not done for G158-100 (star number 1) which itself has this feature in absorption; the equivalent width of this line is too weak in the spectrum given in this paper.

(3) Problems still remain near 4700 Å where the blue and red spectra join. This is probably caused by abnormally large errors in the wavelength due to poor guiding. Nothing has been done about this problem since it is not clear how to correct for guiding errors. The errors can be as high a 0.03 mag.

(4) A few objects show apparent emission at a level of 0.03 mag near Hβ. This is caused by slight errors in AB in the subdwarf standard stars on the red side of the lines.

TABLE VI. Fractional wavelength-dependent standard deviations.

Star No.	3200/3400	3400/3600	3600/4600	4600/4800	4800/5000	5000/7000	7000/8600	8600/8900	8900/9200
1	0.05	0.03	0.02	0.03	0.02	0.01	0.02	0.02	0.03
2	0.01	0.01	0.01	0.03	0.04	0.01	0.01	0.02	0.02
3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.01	0.02
6	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
7	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
8	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03
9	0.03	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.04
10	0.04	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.04
11	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.03
12	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
13	0.04	0.02	0.01	0.03	0.03	0.01	0.02	0.02	0.02
14	0.02	0.01	0.02	0.02	0.01	0.01	0.02	0.02	0.03
15	0.03	0.02	0.02	0.03	0.02	0.01	0.02	0.03	0.03
16	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.03
17	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.03
18	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03
19	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.03
20	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.05
21	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03
22	0.05	0.03	0.01	0.01	0.01	0.01	0.02	0.02	0.02
23	0.03	0.02	0.02	0.03	0.02	0.01	0.02	0.03	0.05
24	0.02	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.01
25	0.04	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.02

(5) There are clearly errors which are not just noise in the region below 3400 Å. They arise from oscillations in individual spectra which have amplitudes as high as 0.2 mag and which are typically 50 Å long. These oscillations are seen in the flatfields, in the standard star spectra, and in the unknowns. They do not cancel out when flatfields are applied to the data but appear to change on scales of hours. The effects are similar in both CCDs which were used to obtain the blue spectra. Attempts to track down the problem have not succeeded. The problem is not caused by the Deuterium lamp which is used for the blue flatfields and it is not due to abnormal extinction effects caused by the UV ozone bands. It is also not in the star spectra. The problem roughly averages out between 3300 and 3400 Å but it remains below 3300 Å. It should be recalled that there is a He II line at 3202 Å which is seen in some of the spectra but which does not create this problem.

V. ERRORS IN THE ABSOLUTE FLUX LEVEL

The errors calculated above represent the errors which are wavelength-dependent or random errors from photon statistics, etc. The errors in the actual absolute flux level must come from the offsets which have already been discussed. Using the displacements in Table V on supposedly clear nights it is found that the average value is − 0.026 mag and the standard deviation of one averaged spectrum is 0.038 mag. The results in the blue and red are essentially the same. The negative average indicates that our choice of the nights to use as references was the correct one. The error in the absolute flux level relative to the four subdwarf standards should be no more than 0.04 mag. The consistency among the stars is probably better than this by up to a factor of 2 since observations in several runs have been averaged. An independent measure of the errors in the absolute flux may be obtained by making comparisons with other spectrophotometric data and broadband magnitudes. We begin by comparing the AB values for the four cool subdwarf standard stars with their measured V magnitudes (Carney 1983). To do this it is necessary to allow for the difference in slope of the flux through the V band. The best average wavelength for the V filter is obtained by using one of the cool subdwarf energy distributions since f_λ is approximately constant in the relevant spectral range. This gives 5465 Å. Comparing the values of AB at 5465 Å with V magnitudes, if the numbers are normalized to the same values for α Lyrae, then AB_{5465} is fainter than V by 0.02 mag for the very hot star Feige 34 and brighter than V by 0.02 mag for the cool subdwarf HD 19445. A comparison of AB_{5465} and V for the four cool subdwarf standards gives $V - AB$ values of + 0.05, + 0.03, + 0.04, and + 0.04. After applying the color term above the average difference is 0.02 mag in the sense that AB_{5465} is too bright by 0.02 mag.

Next, we compare the values of AB_{5465} in this paper with Landolt's measured values of V (see Turnshek *et al.* 1989). For the cooler stars, after applying the color term correction, the values of AB_{5465} are too bright on average by 0.04 mag. For the very hot stars AB_{5465} is again too bright on average by 0.05 mag. A comparison of the present AB values with those of Stone (1977) for the four stars in common (Feige 110, BD + 28°4211, BD + 33°2642, and Feige 34) shows our values to be brighter than Stone's by 0.06 mag. There are also slight differences in color.

Finally, a comparison of *IUE* fluxes (Bohlin *et al.* 1989) and fluxes in this paper near 3200 Å where the data nearly overlap suggests that the present AB values are too bright by 0.04 mag. The fact that three independent comparisons all suggest that our values of AB are too bright by 0.04 mag is strong evidence that our data have a systematic absolute flux error. It is difficult to understand where this error comes from. Half of it is already present in the cool subdwarfs.

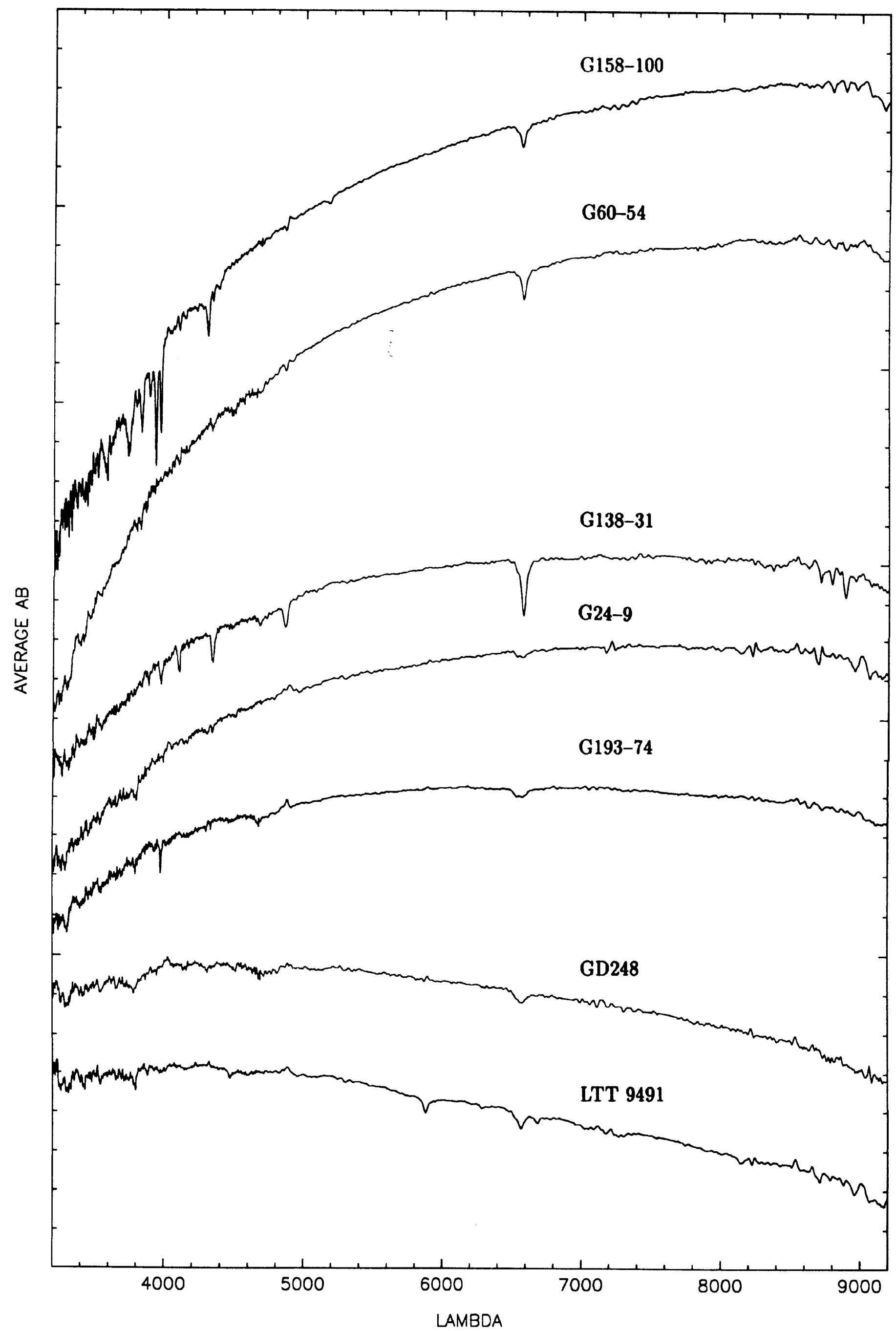

FIG. 1. Absolute spectral energy distributions AB in magnitudes as a function of the wavelength in Angstroms. Spectra have been displaced vertically by arbitrary amounts. The spacing between vertical ticks is 0.2 mag.

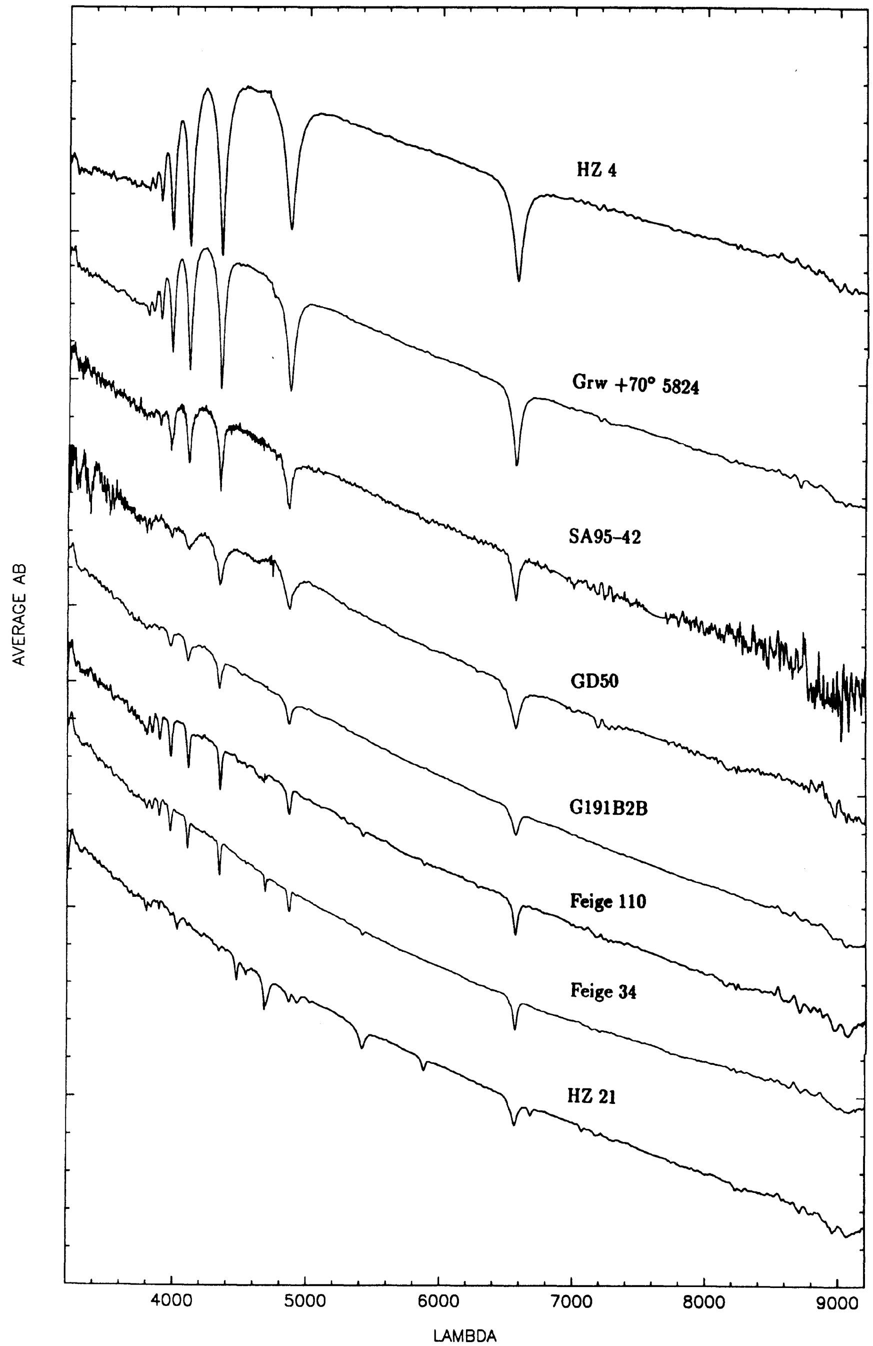

FIG. 1. (continued)

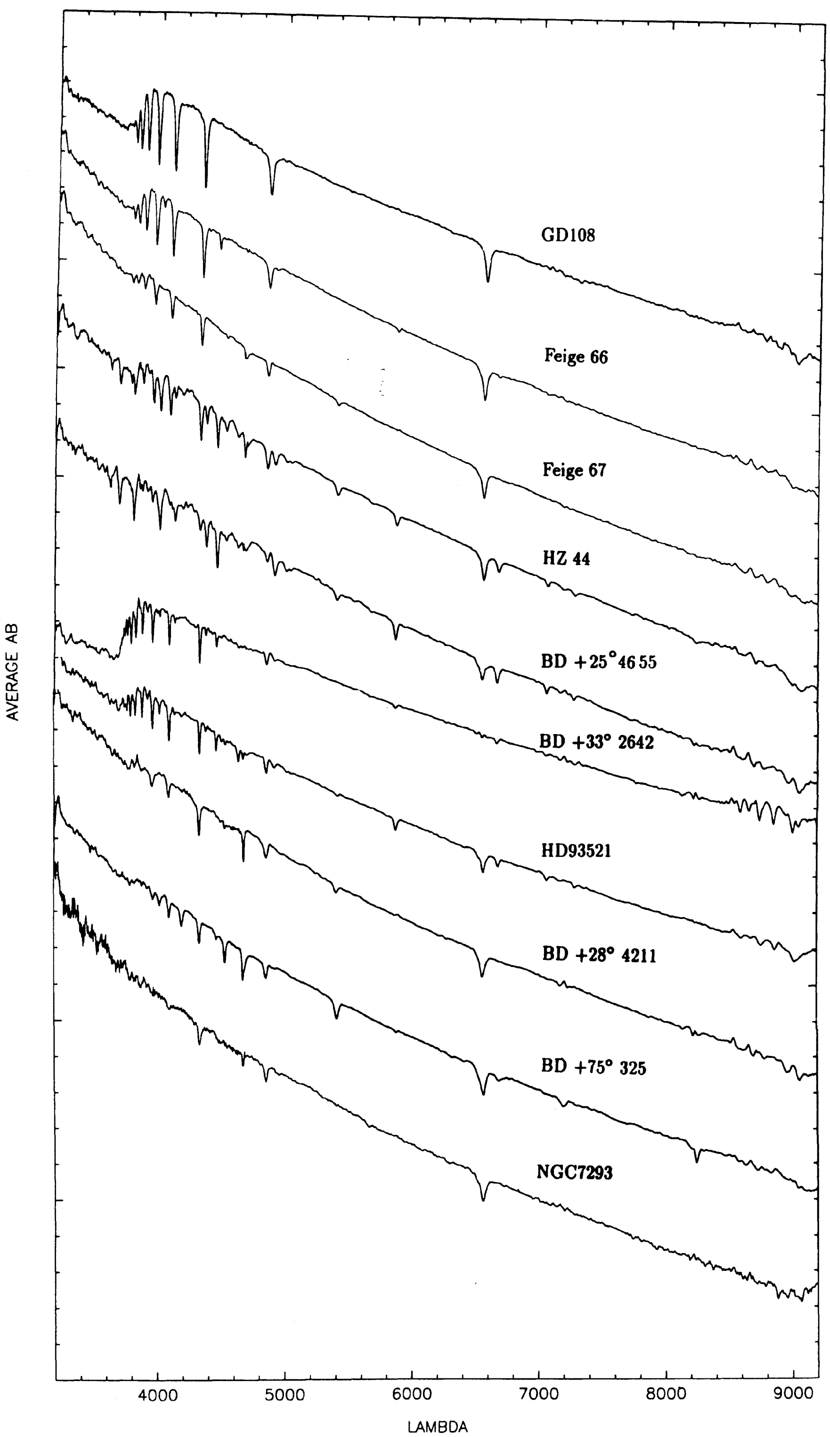

FIG. 1. (continued)

TABLE VII. Smoothed energy distributions AB.

	Star Number												
λ	3	4	5	6	8	10	15	16	17	19	20	21	24
3220	10.74	16.24	8.45	10.06	13.62	10.70	17.08	16.77	9.41	14.05	10.87	15.21	13.02
3280	10.78	16.21	8.50	10.10	13.66	10.75	17.03	16.72	9.45	14.04	10.91	15.20	13.06
3310	10.80	16.19	8.52	10.12	13.68	10.77	17.00	16.69	9.47	14.04	10.93	15.19	13.07
3340	10.82	16.17	8.54	10.14	13.70	10.79	16.98	16.66	9.49	14.04	10.94	15.19	13.08
3360	10.83	16.16	8.55	10.15	13.71	10.80	16.97	16.65	9.50	14.04	10.95	15.18	13.09
3440	10.88	16.11	8.61	10.21	13.77	10.87	16.90	16.58	9.56	14.03	11.01	15.17	13.13
3460	10.89	16.09	8.62	10.22	13.78	10.88	16.89	16.57	9.57	14.03	11.03	15.16	13.14
3550	10.95	16.05	8.69	10.29	13.84	10.95	16.83	16.49	9.63	14.02	11.08	15.15	13.19
3600	10.98	16.01	8.72	10.32	13.86	10.98	16.79	16.43	9.66	14.01	11.10	15.14	13.21
3700	11.07	15.97	8.80	10.40	13.93	11.06	16.73	16.41	9.74	14.02	11.18	15.14	13.26
3777	11.10	15.94	8.82	10.44	13.96	11.08	16.68	16.38	9.80	14.03	11.25	15.17	13.24
3782	11.11	15.93	8.82	10.44	13.96	11.08	16.67	16.38	9.81	14.04	11.26	15.18	13.23
3814	11.12	15.91	8.84	10.43	13.98	11.09	16.63	16.32	9.78	14.00	11.20	15.13	13.17
3822	11.12	15.91	8.84	10.43	13.98	11.09	16.63	16.32	9.77	14.00	11.20	15.12	13.17
3860	11.10	15.89	8.83	10.42	13.96	11.08	16.57	16.29	9.78	13.98	11.18	15.11	13.07
3866	11.10	15.89	8.83	10.42	13.96	11.08	16.57	16.28	9.78	13.98	11.18	15.10	13.07
3905	11.12	15.86	8.85	10.43	13.97	11.09	16.57	16.24	9.81	13.98	11.20	15.08	13.05
3911	11.12	15.86	8.85	10.43	13.97	11.09	16.57	16.23	9.81	13.98	11.20	15.08	13.05
3947	11.13	15.86	8.87	10.45	14.00	11.10	16.52	16.22	9.84	13.98	11.20	15.07	13.05
3953	11.15	15.86	8.87	10.45	14.01	11.10	16.52	16.21	9.85	13.98	11.20	15.07	13.06
3996	11.15	15.84	8.90	10.48	14.04	11.14	16.51	16.20	9.84	13.98	11.23	15.06	13.08
4000	11.15	15.84	8.90	10.48	14.04	11.14	16.51	16.18	9.84	13.98	11.22	15.04	13.07
4050	11.16	15.82	8.92	10.50	14.06	11.16	16.48	16.15	9.85	13.97	11.22	15.05	13.07
4075	11.17	15.81	8.92	10.51	14.06	11.17	16.46	16.14	9.87	13.97	11.24	15.05	13.09
4140	11.22	15.80	8.97	10.56	14.11	11.22	16.43	16.12	9.91	13.98	11.29	15.05	13.12
4220	11.22	15.78	9.00	10.60	14.14	11.25	16.40	16.08	9.94	13.97	11.30	15.05	13.14
4222	11.22	15.78	9.00	10.60	14.14	11.25	16.40	16.08	9.94	13.97	11.30	15.05	13.14
4270	11.25	15.76	9.01	10.62	14.16	11.27	16.38	16.06	9.97	13.97	11.32	15.05	13.15
4390	11.31	15.72	9.08	10.67	14.22	11.33	16.34	16.01	10.03	13.98	11.38	15.05	13.20
4445	11.33	15.72	9.10	10.71	14.25	11.36	16.33	15.99	10.05	13.99	11.40	15.05	13.22
4490	11.36	15.73	9.14	10.73	14.29	11.39	16.33	15.98	10.09	14.01	11.42	15.06	13.25
4500	11.36	15.72	9.15	10.74	14.29	11.40	16.32	15.99	10.10	14.00	11.43	15.07	13.25
4565	11.38	15.70	9.17	10.77	14.32	11.42	16.30	15.96	10.13	14.00	11.45	15.06	13.27
4650	11.41	15.71	9.20	10.81	14.37	11.47	16.28	15.93	10.15	14.00	11.51	15.09	13.31
4760	11.47	15.69	9.25	10.86	14.40	11.53	16.26	15.90	10.17	14.00	11.53	15.08	13.36
4800	11.48	15.68	9.27	10.88	14.42	11.54	16.24	15.88	10.19	14.00	11.54	15.07	13.39
4960	11.54	15.64	9.31	10.94	14.47	11.59	16.17	15.86	10.27	14.01	11.61	15.07	13.42
5150	11.60	15.61	9.39	11.01	14.53	11.66	16.12	15.81	10.34	14.02	11.68	15.07	13.48
5205	11.62	15.60	9.41	11.03	14.55	11.68	16.10	15.80	10.36	14.02	11.69	15.06	13.49
5375	11.68	15.59	9.48	11.10	14.64	11.75	16.08	15.78	10.45	14.05	11.77	15.07	13.55
5460	11.72	15.58	9.52	11.13	14.67	11.78	16.07	15.77	10.47	14.06	11.81	15.08	13.57
5850	11.86	15.56	9.64	11.26	14.79	11.92	16.02	15.72	10.61	14.13	11.94	15.12	13.68
5920	11.87	15.55	9.67	11.28	14.81	11.94	16.02	15.72	10.63	14.15	11.97	15.13	13.70
6200	11.97	15.55	9.75	11.37	14.89	12.03	15.99	15.69	10.73	14.15	12.05	15.14	13.77
6202	11.97	15.55	9.75	11.37	14.89	12.03	15.99	15.69	10.73	14.15	12.05	15.14	13.77
6470	12.06	15.55	9.83	11.45	14.98	12.12	15.98	15.66	10.80	14.18	12.13	15.17	13.85
6750	12.14	15.55	9.92	11.53	15.07	12.21	15.97	15.65	10.89	14.23	12.21	15.20	13.92
6846	12.17	15.55	9.94	11.56	15.09	12.22	15.97	15.64	10.91	14.23	12.24	15.21	13.94
6950	12.19	15.55	9.97	11.58	15.12	12.25	15.97	15.64	10.93	14.25	12.26	15.22	13.94
7040	12.22	15.55	10.01	11.60	15.14	12.28	15.97	15.64	10.97	14.28	12.30	15.22	13.98
7085	12.23	15.55	10.02	11.62	15.16	12.29	15.96	15.63	10.98	14.28	12.31	15.23	13.99
7260	12.28	15.56	10.06	11.65	15.21	12.35	15.97	15.63	11.02	14.31	12.37	15.25	14.05
7300	12.30	15.56	10.08	11.66	15.23	12.36	15.97	15.63	11.02	14.31	12.38	15.26	14.05
7550	12.36	15.57	10.14	11.71	15.28	12.42	15.96	15.63	11.09	14.33	12.42	15.29	14.10
7690	12.40	15.58	10.17	11.75	15.32	12.45	15.96	15.63	11.13	14.35	12.46	15.30	14.13
8100	12.49	15.59	10.26	11.82	15.42	12.55	15.97	15.64	11.23	14.42	12.47	15.37	14.22
8102	12.49	15.59	10.26	11.82	15.42	12.55	15.97	15.64	11.23	14.42	12.57	15.37	14.22
8480	12.59	15.62	10.35	11.90	15.52	12.63	15.98	15.64	11.31	14.47	12.64	15.43	14.29
8560	12.59	15.62	10.37	11.92	15.52	12.65	15.98	15.64	11.33	14.47	12.65	15.44	14.30
8590	12.62	16.62	10.38	11.93	15.53	12.67	15.99	15.65	11.35	14.49	12.66	15.45	14.32
8610	12.62	15.62	10.40	11.93	15.55	12.67	16.00	15.65	11.35	14.49	12.67	15.46	14.32
8650	12.63	15.63	10.41	11.94	15.56	12.68	16.00	15.65	11.36	14.50	12.69	15.47	14.32
8680	12.64	15.63	10.41	11.94	15.56	12.68	16.00	15.66	11.37	14.50	12.70	15.47	14.33
8740	12.66	15.64	10.42	11.97	15.59	12.70	16.02	15.67	11.38	14.52	12.72	15.49	14.35
8760	12.67	15.64	10.43	11.97	15.59	12.71	16.02	15.67	11.38	14.52	12.72	15.51	14.36
8850	12.69	15.66	10.44	11.98	15.62	12.73	16.03	15.68	11.40	14.53	12.74	15.53	14.39
8876	12.69	15.66	10.45	12.00	15.63	12.74	16.03	15.69	11.42	14.55	12.76	15.54	14.40
8960	12.76	15.68	10.49	12.03	15.68	12.79	16.06	15.71	11.46	14.58	12.80	15.57	14.43
9040	12.79	15.72	10.54	12.07	15.71	12.82	16.08	15.73	11.48	14.62	12.84	15.59	14.46
9200	12.80	15.73	10.55	12.06	15.68	12.86	16.10	15.77	11.50	14.67	12.80	15.63	14.48

These were calibrated against α Lyrae using photomultiplier tubes and the Multichannel Spectrometer. The linearity of that system was very carefully checked. It is also hard to understand where there could be nonlinearity in the CCD system. Again, the CCD linearity has been very carefully checked by using a constant light source and varying the exposure time. In fact, the CCD observations were all made by varying the exposure times so the actual signal would always be comparable in size. In the absence of any known problem, the data here are presented as derived. If it is important to have maximum compatibility with other absolute data, then all values of AB in this paper should be made fainter by 0.04 mag.

VI. A TABLE OF ABSOLUTE FLUXES

In order to use the fluxes which have been determined and described above, it is necessary to define values of AB at points where no ambiguity exists for instrument calibration problems due to spectral resolution. This means that values of AB can only be used if they are situated at continuum points or at least flat regions between lines. Such a set of wavelengths has been defined which avoids H I, He I, He II, and the H and K lines of Ca II. The corresponding values of AB are given in Table VII. In this table all wavelengths should be considered in pairs; between each pair a linear interpolation between the pair of wavelengths should represent the values of AB anywhere in the interval. The pairs of wavelengths are often very close where the spectra are complex but quite far apart where the spectra are simple. In a few cases the pairs are so close to spectral lines in some stars that they may not be usable if the resolution is comparable or lower than used for the data in this paper. The data in Table VII have been smoothed mainly in the ultraviolet from 3200 to 3600 Å and in the near infrared above 7000 Å where water-vapor extinction is important. The regions near the A and B band have not been used. Not all the stars are listed in Table VII. In particular, DA white dwarfs are omitted because the hydrogen lines are so broad and stars with rich He I–He II spectra are also omitted. By using observations made in the wavelength intervals defined by the pair of wavelengths in Table VII it should be possible to generate a complete instrumental sensitivity curve from the observations in the same way as was done for the cool subdwarf standards used above.

The digital versions of the spectra shown in Fig. 1 reside at the Space Telescope Science Institute in the Data Management Facility and should be available on line to *HST* Guest Observers and Archival Researchers with computer accounts at the Institute. Others may request the spectra from the Branch Chief, Data Systems Operations Branch, ST ScI, Baltimore, MD 21218.

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