PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, **111**:1426–1433, 1999 November

Spectrophotometry: Revised Standards and Techniques

MICHAEL S. BESSELL

Research School of Astronomy and Astrophysics, Institute of Advanced Studies, The Australian National University, Private Bag, Weston Creek P.O., ACT 2611, Australia; bessell@mso.anu.edu.au

Received 1999 July 28; accepted 1999 July 29

ABSTRACT. The telluric features redward of 6700 Å have been removed from the accurate spectrophotometric standards of Hamuy et al. to permit more reliable relative and absolute spectrophotometry to be obtained from CCD spectra. Smooth fluxes from 3300 to 10500 Å are best determined by dividing the raw spectra of all objects taken in a night by the raw spectrum of a "smooth" spectrum star before deriving the instrumental response function using the revised standard star fluxes. In this way the telluric features and any large instrumental variation with wavelength are removed from the raw data, leaving smooth spectra that need only small corrections to place them on an absolute flux scale. These small corrections with wavelength are well described by a low-order polynomial and result in very smooth flux-calibrated spectra.

1. INTRODUCTION

High-quality CCD spectra are now routinely obtained for stars and galaxies at most observatories. However, flux calibration of these spectra has not been universal, nor has it been very accurate when done, because of the paucity of suitable accurate spectrophotometric standards. Another problem with CCD spectroscopy has been the reluctance of many observers to remove the effects of atmospheric (telluric) absorption from their red spectra, as can often be seen in published data. This makes the identification of weak stellar features difficult and the computation of synthetic colors and magnitudes imprecise. The recent publication of precise standards by Hamuy et al. (1994) is a major contribution to precise spectrophotometry; however, they have also neglected to remove the telluric absorption in their standard fluxes, which unnecessarily degrades the precision of flux calibration. The problem is that the atmospheric absorption is not constant. Some of the bands, particularly the O_2 bands, are almost saturated, but the H_2O bands are only partially saturated and vary with humidity and with some power of the air mass. It is much better to remove the atmospheric absorption from the raw spectra and use the telluric-free absolute fluxes for calibration.

2. CORRECTED FLUXES FOR THE HAMUY ET AL. STARS

The list of Hamuy et al. (1994) spectrophotometric standards comprised a set of 10 bright A-type stars at 16 Å spacing and a set of 19 fainter white dwarf and subdwarf stars at 50 Å spacing. I have removed the telluric absorption separately from the two sets.

For some of these stars I had low-dispersion spectra in which the telluric bands had been removed using the techniques described in § 6. These showed that Feige 110 and some other stars have completely smooth spectra beyond Hα. Consequently, a third-order polynomial was fitted to the highest points in the Hamuy et al. spectrum of Feige 110 redward of 6700 Å, and this continuum was taken to be the "true" spectrum. These magnitudes were then subtracted from the original spectrum and provided the first estimate of a set of magnitude corrections. This correction was applied to several other of the smooth stars and the continuum similarly fitted. In the G subdwarfs the absorption lines due to the Ca II triplet were reinstated below the smooth continuum. Finally, an average correction derived from the subdwarfs and the continuous white dwarfs was applied to those hotter stars showing Paschen lines and a Paschen jump, and a polynomial was fitted between 6700 and 8400 Å. Above the Paschen jump the continuum between the Paschen lines was made smooth. In Figure 1 are plotted all the differences between the originally published spectra and the "telluric-free" spectra. The variations in the H_2O absorption bands from spectrum to spectrum can be seen. One star, LTT 3218, had significantly larger residuals than the average, indicating that it may have been observed at larger air mass. The 19 telluric-free spectra are available together with the set of average magnitude corrections by anonymous ftp.[1] For a first-order correction to the bright A-star spectra, the average telluric spectrum at 50 Å spacing was interpolated at 16 Å spacing and subtracted from the spectra of the hotter stars HR 3454

---

[1] Available from mso.anu.edu.au at /pub/bessell/ or from http://www.mso.anu.edu.au/~bessell/FTP/.

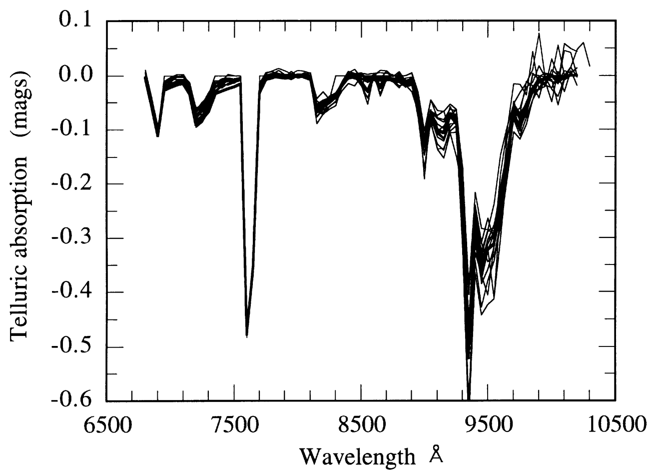

FIG. 1.—Plot of telluric absorption (revised minus original magnitudes) for the faint standards of Hamuy et al. (1994). Data are in 50 Å bins.

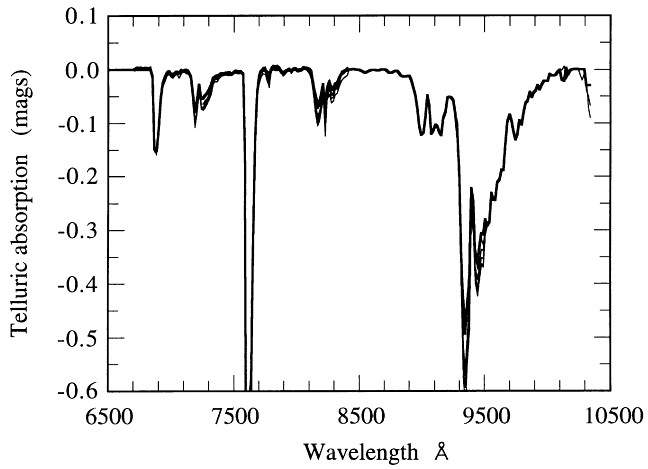

FIG. 2.—Same as Fig. 1 but for the bright A-star standards of Hamuy et al. (1994). Data are in 14 Å bins.

and HR 9087. The resultant spectra had a polynomial fitted to the continua between 6800 Å and the Paschen jump at 8400 Å, and a smooth gradation was ensured for the continuum between the Paschen lines by hand correction. These corrected spectra were then subtracted from the two original spectra directly, producing a 16 Å spaced set of corrections. This average correction was then subtracted from all the other stars. For some of the stars the correction was nearly perfect, but in several the correction was insufficient, requiring additional correction between 9300 and 9500 Å. Polynomial fits were used for all stars between 6800 and 8400 Å. In Figure 2 are plotted the individual differences for all the bright stars. There is some scatter in the H_2O features, but it is less than for the faint group of standards. The telluric-free spectra of the 10 HR stars are also available together with the set of average magnitude corrections by anonymous ftp.

There are also some very weak atmospheric H_2O bands between about 5900 Å and Hα, but these have been removed from only four of the DA white dwarfs where it is certain that there are no stellar features.

3. SPECTROPHOTOMETRIC STANDARDS

In Table 1 are listed the coordinates and *UBVRI* colors in the Cape-SAAO *UBVRI* system for the bright standards.

In Table 2 the colors and coordinates for the 19 fainter Hamuy et al. standards are given along with several other stars useful for spectrophotometry. The Hamuy et al. stars were selected from the tertiary standard lists of Baldwin & Stone (1984), Stone (1977), and Massey et al. (1988) and from the secondary standard list of bright stars by Taylor (1984); see Hamuy et al. (1992) for details. Other lists of spectrophotometric stars have been given by Oke (1974; white dwarfs), Oke & Gunn (1983; subdwarfs), Bartkevicius & Sviderskiene (1981; metal-poor dwarfs and giants), Massey et al. (1988; white dwarfs and sdO stars), and

TABLE 1

BRIGHT A-STAR SPECTROPHOTOMETRIC STANDARDS

HR	Name	HD	Spectral Type	*V*	*B−V*	*U−B*	*V−R*	*V−I*	R.A. (J2000)	Decl. (J2000)
718.......	ξ^2 Cet	15318	B9 III	4.279	−0.056	−0.107	−0.023	−0.063	02 28 09.9	08 27 36
1544......	π Ori	30739	A1 Vn	4.355	0.02	−0.03	0.014	0.039	04 50 36.7	08 54 01
3454......	η Hya	74280	B3 V	4.295	−0.200	−0.743	−0.083	−0.200	08 43 13.4	03 23 55
4468......	θ Crt	100889	B9.5 Vn	4.70	−0.08	−0.18	−0.023	−0.063	11 36 40.8	−09 48 08
4963......	θ Vir	114330	A1I V	4.375	−0.01	−0.01	0.003	0.010	13 09 56.9	−05 32 20
5501......	108 Vir	129956	B9.5 V	5.681	−0.023	−0.080	...	...	14 45 30.1	00 43 02
7596......	58 Aql	188350	A0 III	5.62	0.10	−0.02	...	...	19 54 44.7	00 16 25
7950......	ϵ Aqr	198001	A1 V	3.778	−0.001	0.029	−0.005	−0.010	20 47 40.5	−09 29 45
8634......	ζ Peg	214923	B8 V	3.40	−0.09	−0.27	...	...	22 41 27.6	10 49 53
9087......	29 Psc	224926	B9 III	5.120	−0.136	−0.501	−0.052	−0.122	00 01 49.3	−03 01 39

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

TABLE 2

Faint Spectrophotometric Standards

Star	WD	Other	Spectral Type	V	$B-V$	$U-B$	$V-R$	$V-I$	R.A. (J2000)	Decl. (J2000)	μ_α yr^{-1} (arcsec)	μ_δ yr^{-1} (arcsec)	Reference
LTT 377		−34°239	sdG	11.225	0.488	−0.058	0.295	0.587	00 41 47	−33 39.2	−0.030	−0.245	H
VMa 2	0046+051	LHS 7	DZ7	12.382	0.550	0.006	0.255	0.499	00 49 10	+05 23.4	0.0812	−2.722	O
LTT 1020		−28°595	sdG	11.511	0.570	−0.193	0.356	0.715	01 54 48	−27 28.7	0.0225	−0.201	H
EG 21	0310−688		DA3	11.380	0.036	−0.671	−0.087	−0.180	03 10 30	−68 36.1	0.0090	−0.075	H
LTT 1788		L995-86	sdG	13.153	0.485	−0.273	0.304	0.635	03 48 24	−39 08.6	0.0176	−0.191	H
LTT 2415		L894-1	sdG	12.210	0.413	−0.201	0.270	0.559	05 56 25	−27 51.5	0.0194	−0.173	H
H600			B1 V	10.42	…	…	…	…	06 45 14	+02 08.3	…	…	H
L745-46A	0738−172	LHS 235	DZQ6	13.03	0.245	−0.58	0.154	0.310	07 40 21	−17 24.9	0.0785	−0.548	O, H
LTT 3218	0839−327	LHS 253	DA	11.846	0.229	−0.531	0.088	0.203	08 41 31	−32 56.4	−0.0836	1.347	H
LTT 3864		L465-10	sdG	12.164	0.506	−0.157	0.322	0.662	10 32 15	−35 37.5	−0.0229	0.015	H
LTT 4364	1142−645	LHS 43	DQ6	11.512	0.190	−0.674	0.161	0.295	11 45 43	−64 50.4	0.4154	−0.325	H
Feige 56			B5p	11.11	…	…	…	…	12 06 40	+11 40.3	…	…	H
LTT 4816	1236−495	LHS 2594	DA6	13.782	0.177	−0.646	−0.013	0.007	12 38 46	−49 49.1	−0.0574	−0.128	H
CD −32°9927			A0	10.441	0.339	0.118	0.166	0.329	14 11 46	−33 03.2	0.0005	−0.019	H
LTT 6248		L916-15	a	11.812	0.488	−0.203	0.319	0.659	15 38 59	−28 35.5	−0.0173	−0.179	H
HD 140283		LHS 405	sdG	7.212	0.499	−0.203	0.331	0.688	15 43 03	−10 56.0	−0.0776	−0.317	O, B
EG 274	1620−391		DA2	11.012	−0.132	−0.949	−0.125	−0.267	16 23 34	−39 13.9	0.0068	−0.008	H
LTT 7379		−44°12736	sdG	10.227	0.616	−0.016	0.354	0.707	18 36 26	−44 18.7	−0.0145	−0.156	H
EG 131	1917−077	LDS 678A	DBQ5	12.28	0.04	0.04	0.08	…	19 20 35	−07 40.1	−0.0042	−0.190	G, M
LTT 7987	2007−303		DA4	12.217	0.060	−0.632	−0.096	−0.178	20 10 56	−30 13.1	−0.0285	−0.240	H
LTT 9239		L877-23	sdG	12.062	0.629	−0.118	0.384	0.780	22 52 41	−20 35.4	0.0059	−0.309	H
LTT 9491	2316−173	L822-50	DB3	14.104	0.029	−0.831	0.023	0.071	23 19 35	−17 05.4	0.0174	0.022	H, O
Feige 110	2317−054		sdO	11.846	−0.304	−1.153	−0.133	−0.325	23 19 58	−05 09.9	…	…	H, O

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees and arcminutes. Spectrophotometric data from H: Hamuy et al. (1994); O: Oke (1974), Oke & Gunn (1983), Oke (1990); B: Bartkevicius & Sviderskiene (1981); G: Greenstein (1984); M: this paper

TABLE 3

STARS WITH NEAR-BLACKBODY FLUXES

Star	WD	Spectral Type	T_{BB}	$\mathrm{mag}_{AB(5550\ Å)}$	Absorption Features
VMa 2.........	0046+051	DZ7	6650	12.36	Shortward of 4100 Å
L745-46A......	0738−688	DZQ6	8600	13.03	HK Ca II 3850–4050 Å
HZ43	1314+293	DA1	35000	12.99	Weak H lines
EG 131	1917−077	DBQ5	11800	12.27	None
L1363-3........	2140+207	DQ6	9500	13.22	Weak C_2 4600–5300 Å
F110	2317−054	sdO	55000	11.85	Weak H and He lines

Greenstein (1984; white dwarfs); the additional stars in Table 2 are taken from these papers. The magnitudes given by Oke & Gunn (1983) for the wavelength points longward of 9000 Å in HD 140283 are incorrect. They should be 9300 Å: 6.80; 9700 Å: 6.79; 9900 Å: 6.78; 10200 Å: 6.78 (Bartkevicius & Sviderskiene 1981). *UBVRI* photometry for Table 2 has been taken from Kilkenny & Menzies (1989) with some additional stars measured by the author; Landolt (1992) has also measured many of the stars. *UBVRI* photometry for Table 1 is from Cousins (1971, 1984; *UBV*) and Cousins (1980; *VRI*). The WD identification in Table 2 is from McCook & Sion (1999). The LHS identification, coordinate, and proper motions are from Luyten (1979a); the L and LTT identifications, coordinates, and proper motions are from Luyten (1979c). Finding charts are discussed in a later section. The published spectrophotometric data for the white dwarfs L745-46A and VMa 2 have lower precision than for the Hamuy et al. (1994) stars. Until better data are available, it may be better to use blackbody fits to their continua. The fluxes for EG 131 have been derived by the author.

Table 3 lists blackbody temperatures, AB magnitudes at 5500 Å, and comments on any weak features for stars with near-blackbody fluxes. The fitted blackbody fluxes are also available by anonymous ftp. Spectrophotometric standard fluxes have also been presented by Oke (1990) for 25 white dwarfs and subdwarfs for the *Hubble Space Telescope*. Filippenko & Greenstein (1984) also published fluxes for four of these stars.

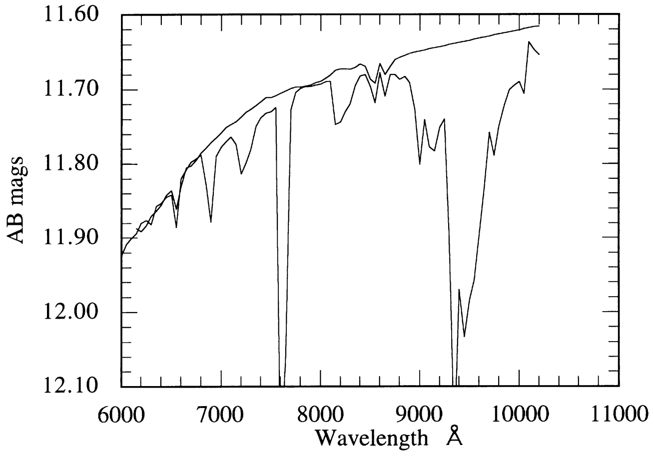

FIG. 3.—Original and revised magnitudes for LTT 9239

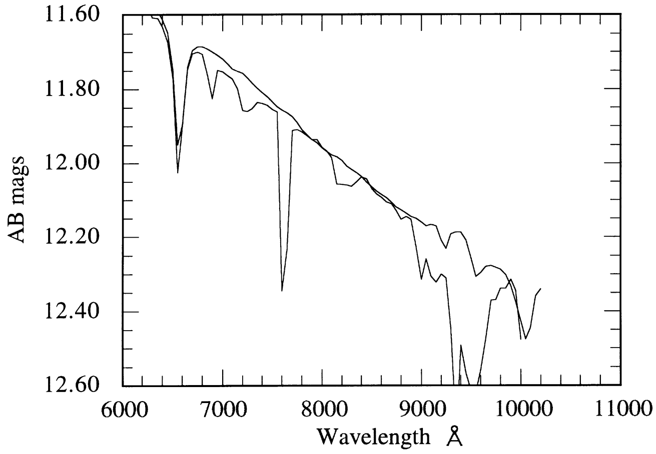

FIG. 4.—Original and revised magnitudes for EG 21

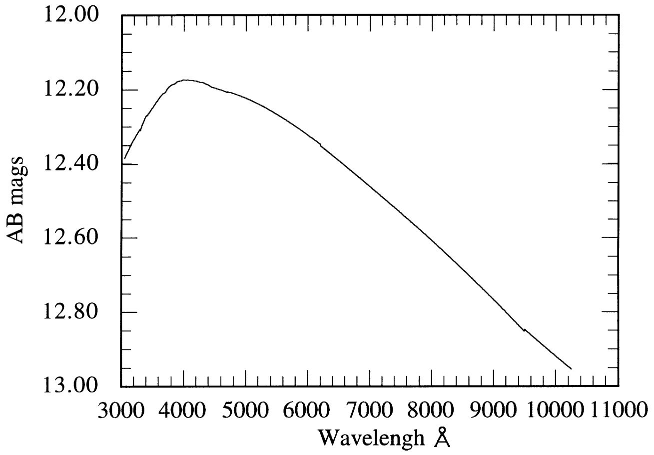

FIG. 5.—Magnitudes for the new standard EG 131

Figures 3 and 4 shows two sample spectra of standard stars with and without telluric correction. Figure 5 shows the spectrum of the new standard EG 131.

4. SMOOTH SPECTRUM STARS FOR TELLURIC LINE REMOVAL

As will be described below, extremely metal-poor G dwarfs and red giants make good smooth templates for low-resolution spectrophotometry for wavelengths redward of ≈5500 Å. The best stars are those with metallicities below −2 dex and with temperatures between 5000 and 6000 K. They have essentially smooth spectra at low resolution (≈10 Å) apart from weak Hα and weak Na D or Ca II lines. A list of suitable stars for telluric line elimination is given in Table 4. These have been selected from the photometry of Norris, Bessell, & Pickles (1985) and the papers of Oke & Gunn (1983) and Bartkevicius & Sviderskiene (1981). Many of the extreme metal deficients stars were identified by Bond (1980). The bright He-rich white dwarfs L745-46A and VMa 2 are especially useful in the red as they have no bands or lines redward of 4100 Å and are smooth blackbodies. Other suitable subdwarfs are given in Table 2. At very high resolution (0.1 Å), many sharp lines can be seen in the spectra of these metal-poor stars, so for removal of telluric lines in high-resolution spectra it is best to use fast-rotating B stars.

5. BLUE STARS FOR INSTRUMENTAL RESPONSE NORMALIZATION AND *UBVRI* SYNTHETIC PHOTOMETRY

Although there are no telluric lines between 3400 and 5500 Å, it is still useful to have smooth template stars that can be used between these wavelengths to remove the instrumental response, which is often changing rapidly with wavelength below 4000 Å. The Huggins ozone bands below 3400 Å can also best be removed using stars that are bright and smooth in the UV; hot DA white dwarfs are ideal for ozone removal (Schachter 1991) but are not as useful for

TABLE 4

SUITABLE LOW-RESOLUTION SMOOTH SPECTRUM STARS

Star	Spectral Type	V	R.A. (J2000)	Decl. (J2000)	μ_α yr^{-1} (arcsec)	μ_δ yr^{-1} (arcsec)	Reference
HD 2665	Giant	7.7	00 30 45.4	+57 03 53.7	0.0051	−0.064	B
HD 2796	Giant	8.5	00 31 16.9	−16 47 40.8	−0.0003	−0.051	
HD 4306	Giant	9.0	00 45 27.1	−09 32 40.0	0.0037	0.016	
VMa 2	DG	12.4	00 49 10	+05 23 24.0	0.0812	−2.722	O
HD 19445	Dwarf	8.0	03 08 25.6	+26 19 54.9	−0.0149	−0.795	O, B
HD 26169	Giant	8.9	04 00 52.5	−75 36 11.4	0.0374	0.077	
HD 33771	Giant	9.5	05 10 49.4	−37 49 06.9	...	...	
L745-46a	DF	13.0	07 40 21	−17 24 54.0	0.0785	−0.548	O, H
HD 64090	Giant	8.3	07 53 33.1	+30 36 17.9	0.0561	−1.834	B
HD 84903	Giant	8.0	09 47 19.2	−41 27 04.5	−0.0007	−0.007	
HD 84937	Dwarf	8.1	09 48 56.1	+13 44 39.3	0.0255	−0.775	O, B
HD 85773	Giant	9.4	09 53 39.2	−22 50 08.4	−0.0010	−0.018	
HD 88609	Giant	9.2	10 14 29.0	+53 33 59.2	0.0005	−0.031	
HD 94028	Dwarf	8.2	10 51 28.1	+20 16 39.0	−0.0188	−0.453	B
HD 104893	Giant	9.2	12 04 43.1	−29 11 05.6	−0.0025	−0.013	
CD −37°7677	Giant	9.9	12 07 53.1	−38 40 25.3	−0.0009	−0.032	
HD 122563	Giant	6.2	14 02 31.8	+09 41 09.6	−0.0131	−0.075	B
HD 126587	Giant	9.1	14 27 00.4	−22 14 39.1	−0.0009	−0.049	
BD +26°2606	Dwarf	10.1	14 49 02.4	+25 42 08.8	−0.0002	−0.351	O
HD 140283	Dwarf	7.3	15 43 03.1	−10 56 00.7	−0.0759	−0.302	O, B
HD 165195	Giant	7.4	18 04 40.0	+03 46 44.8	−0.0016	−0.075	B
EG 131	DC	12.3	19 20 35.0	−07 40 06.0	−0.0042	−0.190	
HD 184711	Giant	8.0	19 37 11.9	−39 44 37.5	0.0002	−0.061	
HD 188510	Giant	8.8	19 55 09.7	+10 44 27.3	−0.0025	0.289	B
BD −18°5550	Giant	9.3	19 58 49.7	−18 12 11.3	0.0005	−0.091	
CD −20°6008	Giant	9.8	20 42 48.8	−20 00 39.4	−0.0011	−0.007	
CD −37°14010	Giant	9.7	20 57 27.4	−36 32 53.3	0.0024	−0.044	
BD +17°4708	Dwarf	9.4	22 11 31.4	+18 05 33.6	0.0359	0.049	O, B
HD 219617	Dwarf	8.2	23 17 05.0	−13 51 03.9	−0.0340	−1.192	B
HD 221170	Giant	7.7	23 29 28.8	+30 25 57.7	−0.0015	−0.055	B

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Spectrophotometric data from O: Oke (1974), Oke & Gunn (1983); B: Bartkevicius & Sviderskiene (1981); G: Greenstein (1984).

response normalization redward of the Balmer jump. In Table 5 are listed some hot stars that are excellent for this purpose. The best star is EG 131, a bright DC He-rich white dwarf which has unfortunately been overlooked by all those setting up standards because it was erroneously classified as DAwk. This 12th magnitude star has no lines in its spectrum between 3000 and 11000 Å and has a blackbody spectrum. It can also obviously be used in the red. Subdwarf O stars such as Feige 110 that have virtually no Balmer discontinuities are the next best stars with which to remove the often rapid changes with wavelength in the UV-blue sensitivity function. Some of the sdO stars are from a list of spectrophotometric standards by Massey et al. (1988). The extremely blue stars are also very important for standardizing the far-blue end of the *UBVRI* system when making synthetic photometry. The *UBVRI* colors are from Menzies, Marang, & Westerhuys (1990). The bright A stars in Table 1 should be used for *UBVRI* standardization in the important region $(U-B,\ B-V) = (0,\ 0)$ where stars have large Balmer jumps.

6. OBSERVING AND REDUCTION STRATEGIES

The observing technique that is recommended is to observe a series of "smooth" spectrum stars during the night at air masses encompassing those for the program stars. Some of these smooth stars may also be spectrophotometric standards. One of these spectra or the average of several spectra is then used as the template for division through all objects observed in the night at the same grating setting. Such a division serves two purposes. First, it removes most of the telluric absorption, and second, it removes any large variations along the spectrum due to detector sensitivity, grating efficiency, and spectrograph vignetting.

Before division, the template spectrum should have any stellar lines removed. In the red, the cool metal-poor dwarfs and giants may show Hα, Na D (5889, 5896 Å) and the Ca II (8498, 8542, 8662 Å) triplet. The spectrum can also be smoothed in regions with no telluric lines. After division by the template spectrum, the spectra of other smooth spectrum stars taken at larger air mass or at a different time will likely show residual H_2O absorption at a few places. These spectra should then be normalized and flattened so that their continua have a level of about 1.0, and in the regions where the telluric absorption was successfully removed the continua should be replaced by 1.0 exactly. The resultant normalized spectra or some power of the normalized spectra can then be divided into any other spectra that show evidence of insufficient H_2O correction without

TABLE 5

BLUE STARS FOR UV RESPONSE NORMALIZATION

Name	Spectral Type	V	$B-V$	$U-B$	$V-R$	$V-I$	R.A. (2000)	Decl. (J2000)	Reference
BD −12°134	sdO	11.772	−0.316	−1.246	−0.084	−0.178	00 47 03	−11 52 37	
BD −11°162	sdO	11.169	−0.072	−1.043	0.048	0.131	00 52 15	−10 39 57	
UV 0141−24	sdOB	11.774	−0.303	−1.131	−0.138	−0.345	01 43 51	−24 02 57	
PG 0216+032	sdO	14.6	...	...	...	...	02 19 19	+03 26 54	M
CD −26°1339	sdO	11.305	−0.354	−1.229	−0.182	−0.343	03 33 14	−25 51 47	
UV 0512−08	sdOB	11.317	−0.268	−1.108	−0.127	−0.266	05 15 00	−08 48 39	
HD 49798	sdO	8.297	−0.291	−1.173	−0.113	−0.260	06 48 05	−44 18 59	
CD −31°4800	sdO	10.550	−0.306	−1.207	−0.131	−0.293	07 36 30	−32 12 57	
BD −03°2179	sdB	10.347	−0.299	−1.140	...	...	08 02 15	−03 58 16	
UV 0832−01	sdOp	11.466	−0.299	−1.207	−0.131	−0.316	08 35 20	−01 55 48	
PG 0823+546	sdO	14.3	...	...	...	...	08 26 50	+54 28 05	M
UV 0904−02	sdOp	11.991	−0.324	−1.219	−0.141	−0.319	09 07 07	−03 06 07	
CD −28°7246SW	sdO	11.223	−0.221	−1.098	−0.072	−0.188	09 25 36	−28 38 41	
PG 0934+554	sdO	12.2	...	...	...	...	09 38 20	+55 05 53	M
Feige 34	sdO	11.2	...	...	...	...	10 39 37	+43 06 11	M, O
BD −22°3230	...	11.749	−0.255	−1.160	0.006	0.039	11 50 51	−23 21 52	
Feige 67	sdO	11.8	...	...	...	...	12 41 49	+17 30 57	M, O
HZ 44	sdO	11.7	...	...	...	...	13 23 35	+36 08 01	M, O
HD 127493	sdO	10.039	−0.260	−1.184	−0.115	−0.276	14 32 21	−22 39 26	
HD 149382	sdB	8.962	−0.289	−1.108	−0.125	−0.264	16 34 23	−04 00 52	
PG 1708+602	sdO	13.7	...	...	...	...	17 09 16	+60 10 10	M
EG 131	DC	12.28	0.04	0.04	0.08	...	19 20 35	−07 40 06	
BD +28°4211	sdO	10.5	...	...	...	...	21 51 11	+28 51 53	M
NGC 7293	...	13.51	...	...	...	...	22 59 38	−20 50 13	O
UV 2309+10	...	13.101	−0.324	−1.166	...	...	21 12 19	+10 47 20	

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Spectrophotometric data from M: Massey et al. (1988); O: Oke (1990).

changing the overall flux scale. See below for Wade & Horne's (1988) appropriate sec *z* scaling.

The extinction table to be used with the telluric-corrected spectra should correct only for the continuous absorption and scattering and not for the H_2O bands. The extinction table of Hayes & Latham (1975) is suitable for such interpolation.

Shortward of about 5000 Å it is best not to use the metal-poor cool stars as templates as they have many blended features. The main purpose of division in this spectral region is to remove the instrumental response, which often changes very rapidly between 3300 and 4300 Å. The flat-field lamp useful in the red for this purpose is of little use here because most lamps provide insufficient UV light. As noted above, the DC white dwarf EG 131 is the best choice; L745-46a and VMa 2 can be used redward of about 4100 Å. Subdwarf O stars can be used quite effectively. Obvious hydrogen and helium lines are first removed; then the resultant spectrum is heavily smoothed before division to increase the effective signal-to-noise ratio. It is important to use spectra of stars without Balmer jumps so that the effect of the division is to produce a smooth transition through the region of the confluence of the Balmer lines.

The results of red and blue divisions should be telluric line-free spectra showing only slowly varying changes of continuum intensity with wavelength. A comparison between these spectra and the standard fluxes will yield small magnitude differences that vary only slowly with wavelength. Such differences can be readily fitted with a low-order polynomial which permits confident interpolation across fairly large wavelength intervals. This is necessary when the values derived from strong-lined standards at the confluence of the Balmer and Paschen lines are poorly determined or when data points are absent, such as in the many flux calibrations tabulated at the minimal "Oke standard" wavelengths. Low-order polynomials produce much better results than spline fits.

Others have paid careful attention to the removal of telluric lines and instrumental response function. The author's first experience was in using the image dissector scanner (Robinson & Wampler 1972) on the Anglo-Australian Telescope in the early 1970s under the tutelage of J. Wampler. A blackbody spectra or a bright smooth star's spectrum was stored on-line and divided through one's observations with a remarkable enhancement of the visibility of very weak features that had not been seen previously on photographic or image tube spectra of the objects. It was then natural to seek to emulate these excellent results when CCDs later came into regular use.

Wade & Horne (1988) also discuss the importance of telluric absorption removal. They have found that the mean telluric magnitude differences obtained near the zenith (such as in Figs. 1 and 2) can be scaled with increasing air mass as $(\sec z)^{0.6}$ and that this corrects both the O_2 and H_2O bands, although the H_2O band are susceptible to variation with time.

In addition, Schachter, Filippenko, & Kahn (1989, 1990) have emphasized the importance of not degrading the signal-to-noise ratio of the program stars observations by division by a template star. Rather than use the stellar spectrum directly, they approximate the featureless continuum with a cubic spline, thus interpolating over intrinsic and telluric absorption lines. They then set the spline continuum to unity in all regions away from the telluric features to produce a template.

Reducing data in the way described above enables one in the blue to confidently identify weak broad features such as emission in QSOs, interstellar absorption bands, cyclotron absorption in cataclysmic variables, Zeeman broadened hydrogen lines in magnetic white dwarfs, and carbon bands in cool He-rich white dwarfs. In the red, one can easily identify weak bands of CN, TiO, and ZrO bands in cool giant stars and the important bands of FeH in cool dwarfs. Most importantly, it enables one to rule out the presence of such features in spectra and thus avoid erroneous classifications.

7. IDENTIFICATION CHARTS

Charts for all the Hamuy et al. stars can be found in Stone & Baldwin (1983). Luyten (1979b) has excellent charts for almost all the LHS stars, and Luyten (1949) provided charts for many of the brightest white dwarfs, but note that the high proper motion stars have moved significantly from their positions in these charts and in the LHS charts which were made from plates taken in the 1950s.

Probably the best way to make (unmarked) charts is to use the Canadian Astronomy Data Centre Web site[2] and provide a file containing the name, right ascension, declination, epoch, and chart size for each star, one per line. A gif file for each star is generated with the scale attached. These gif files of the fields for each of the faint spectrophotometric standards (Table 2) and the blue stars (Table 5) are also available (faint.gif.tar and blue.gif.tar) from the author's anonymous ftp site.[3]

I would like to thank the referee Alex Filippenko for his helpful comments and Heath Jones for his advice on making finding charts.

---

[2] See the CADC Interface to the Digitized Sky Survey at http://cadcwww.dao.nrc.ca/cadcbin/getdss.

[3] See mso.anu.edu.au at /pub/bessell/ or http://www.mso.anu.edu.au/~bessell/FTP/.

REFERENCES

Baldwin, J. A., & Stone, R. P. S. 1984, MNRAS, 206, 241
Bartkevicius, A., & Sviderskiene, Z. 1981, Vilnius Astron. Obs. Bull., 57, 60
Bond, H. E. 1980, ApJS, 44, 517
Cousins, A. W. J. 1971, R. Obs. Ann., 7
———. 1980, South African Astron. Obs. Circ., 1, 166
———. 1984, South African Astron. Obs. Circ., 8, 69
Filippenko, A. V., & Greenstein, J. L. 1984, PASP, 96, 530
Greenstein, J. L. 1984, ApJ, 276, 602
Hamuy, M., Suntzeff, N. B., Heathcote, S. R., Walker, A. R., Gigoux, P., & Phillips, M. M. 1994, PASP, 106, 566
Hamuy, M., Walker, A. R., Gigoux, P., Heathcote, S. R., & Suntzeff, N. B. 1992, PASP, 104, 533
Hayes, D. S., & Latham, D. W. 1975, ApJ, 197, 593
Kilkenny, D., & Menzies, J. W. 1989, South African Astron. Obs. Circ., 13, 25
Landolt, A. U. 1992, AJ, 104, 372
Luyten, W. J. 1949, ApJ, 109, 528
———. 1979a, LHS Catalogue (Minneapolis: Univ. Minnesota)
———. 1979b, LHS Atlas (Minneapolis: Univ. Minnesota)
———. 1979c, NLTT Catalogue (Minneapolis: Univ. Minnesota)
Massey, P., Strobel, K., Barnes, J. V., & Anderson, E. 1988, ApJ, 328, 315
McCook, G. P., & Sion, E. M. 1999, ApJS, 121, 1
Menzies, J. W., Marang, F., & Westerhuys, J. E. 1990, South African Astron. Obs. Circ., 14, 33
Norris, J. E., Bessell, M. S., & Pickles, A. J. 1985, ApJS, 58, 463
Oke, J. B. 1974, ApJS, 27, 21
———. 1990, AJ, 99, 1621
Oke, J. B., & Gunn, J. E. 1983, ApJ, 266, 713
Robinson, L. B., & Wampler, E. J. 1972, ApJ, 171, 83
Schachter, J. 1991, PASP, 103, 457
Schachter, J., Filippenko, A. V., & Kahn, S. M. 1989, ApJ, 340, 1049
———. 1990, ApJ, 362, 74
Stone, R. P. S. 1977, ApJ, 218, 767
Stone, R. P. S., & Baldwin, J. A. 1983, MNRAS, 204, 347
Taylor, B. J. 1984, ApJS, 54, 167
Wade, R. A., & Horne, K. 1988, ApJ, 341, 974