FAINT SECONDARY STANDARDS FOR SPECTROPHOTOMETRY AND THE ENERGY DISTRIBUTIONS OF HORIZONTAL-BRANCH A-STARS

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The energy distributions of 16 horizontal-branch A-stars and 11 horizontal-branch stars in globular clusters have been measured using the Harvard Scanners at KPNO and CTIO and the Oke multichannel spectrophotometer on the 5-m telescope at Mt. Palomar (Philip and Hayes 1983, Hayes and Philip 1983). Wavelengths between 3400 and 6800 Å were measured and reduced to absolute energy distributions on the system of Hayes and Latham (1975). The internal measuring errors were ± 0.034 mag. per observation for the 15th mag. globular cluster stars and ±0.025 mag. per observation for the 7th to 11th mag. field stars, averaged over all wavelengths. Eleven of the field stars have been observed over nine times each and have low internal measurement errors; these stars plus four globular cluster stars with low internal measurement errors are recommended as secondary standard stars. (See Table I.)

Three secondary standard stars recommended by Breger (1976) ξ^2Cet (HR 718), η Hya, (HR 3454) and 109 Vir (HR 5511) have been used as the standards in the observations of the field stars. BD +17°4708, the primary standard of the four faint secondary standards proposed by Oke and Gunn (1983) has been used as a standard for the observations of the globular cluster stars. We have discussed the internal consistency of our observations of the Breger standards in a general way (Philip and Hayes 1983). Oke and Gunn's energy distribution for BD +17° 4708 is on the system of Hayes and Latham (1975) and we have used observations of five stars observed both at Palomar and at KPNO and CTIO to show the excellent consistency of their calibration with that of the Breger standards over this wavelength range (Hayes and

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Philip 1983).

A new discussion of the secondary standards for spectrophotometry has been published recently by Taylor (1984). Taylor includes the Breger standards plus some new ones. The result of this work is a set of energy distributions for a compete set of secondary standards on the system of Hayes and Latham, and this catalog of secondary standards is being proposed to be a replacement for Breger's. Taylor's discussion appears to be quite convincing but we thought that a detailed comparison of our own observations of five of these stars with Taylor's new energy distributions would be of value.

Our own observations include θ Crt (HR 4468) and 29 Psc (HR 9087) in addition to the three stars mentioned previously. In order by HR number 718, 3454, 4468, 5511 and 9087 we have 23, 53, 34, 37 and 22 scans of each star, with the observations being made at both KPNO and CTIO over the years 1978, 79 and 80. The observations were described in detail elsewhere (Philip and Hayes 1983). We should emphasize that all five standard stars were observed in various combinations depending on the season and the observatory. We attempted to observe at least three standards each night. In order to give the final reduction the greatest possible coherence, we used the minimum number of standards to reduce the data and we chose the three stars listed above. We used Breger's energy distributions for 3400 - 6056 Å and those of Taylor (1979) for 5840 - 6790 Å. We made some minor modifications to Breger's energy distributions (described in Philip and Hayes 1983). We included the wavelength 3704 Å, which is not in Taylor's tables (thus this wavelength is not included in the present comparison).

For the present comparison we have fitted each of our energy distributions to those of Taylor by normalizing them to minimum deviations. Then the residuals were used to calculate an "external" standard deviation per observation, using all wavelengths. This is our measure of the agreement between our values and those of Taylor (or Breger). We have also calculated an "internal" standard deviation which is based on the internal agreement of the scans for each star; it has been averaged over all wavelengths. In order of HR number, the internal standard deviations are ±0.009, 0.016, 0.015, 0.006 and 0.010 mag. The "external" standard deviations are ±0.006, 0.010, 0.007, 0.011 and 0.008 against Taylor's values and ±0.007, 0.016, 0.007, 0.007 and 0.012 against Breger's values. The agreement with Taylor and Breger is excellent. Except for 109 Vir (HR 5511) the agreement is actually better with Taylor than with Breger. This comparison is slightly circular since Taylor used our observations of 29 Psc (HR 9087) as one of the four contributors to his energy distribution for this star. Comparing the agreement with Taylor and Breger is somewhat redundant, since Taylor used much of the same source material as Breger. Yet, Taylor uses new material and his treatment is different. We show the comparison for each star in

Fig. 1. It is clear that the systematic agreement is excellent, except at a few wavelengths, such as 4464 Å, as noted by Taylor. In this regard we should note that the corrections for He and Mg lines have been applied to his values for the points at 4036 and 4464 Å in η Hya (HR 3454) and 29 Psc (HR 9087). Note that the Balmer discontinuity of 29 Psc agrees very well, whereas the Balmer jump measured by Breger was 0.008 mag. smaller than ours.

Our conclusion is that our measurements for these stars are in agreement with the new system of secondary standards proposed by Taylor (1984) over the wavelength range covered. Further, we can extend this conclusion to include our examination of the agreement of Oke and Gunn's (1983) energy distribution of BD +17° 4708 with that of Breger's standards. The energy distribution for BD +17° 4708 is in excellent agreement with the system of Taylor's standards as well. These conclusions then imply that the secondary standards that we recommend from our data are in agreement with the system of Taylor's standards.

Finally, we note that one of the stars used, 109 Vir (HR 5511) is one that has been classified by Taylor as "archival" since he (Taylor 1982) has found possible evidence of episodes of variability. We have examined our own data, including both the scanner data discussed here and extensive Strömgren four-color photometry, plus some other data from the literature (Philip and Hayes 1983, 1984) and found no evidence for variability. Taylor recommends replacing 109 Vir with 108 Vir, in this part of the sky. We have concluded that our use of 109 Vir does not compromise our investigation of HB stars. We note that the observational history of 109 Vir as a spectrophotometric standard is extensive (Philip and Hayes 1984) whereas that of 108 Vir is limited. We recommend that observers who use 109 Vir as a standard do so with caution, and that monitoring it for variability is important. (We are planning such monitoring, ourselves.) We also recommend that those who prefer to use 108 Vir contribute observations of this star which will strengthen its position as a secondary standard.

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Table I.

The Secondary Standards

Star	BD	Type	HD	V mag	b-y mag	c mag	Source	n	Errors UV	Blue	Red
HD 2857	-06 86	FHB	A2	9.98	0.132	1.216	P&H	21	0.026	0.025	0.027
57336	-79 243	FHB?	A0	7.4	0.126	1.210	P&H	17	0.023	0.022	0.020
74721	+13 1981	FHB	B9	8.72	0.028	1.255	P&H	22	0.026	0.033	0.027
83041	-28 7417	FHB?	A0	8.78	0.221	0.733	P&H	11	0.021	0.019	0.024
86986	+15 2156	FHB	A0	7.99	0.088	1.265	P&H	15	0.020	0.020	0.021
107369	-31 9638	Hi Lum	A0	9.58	0.143	1.614	P&H	17	0.029	0.028	0.027
109995	+40 2558	FHB	A0	9.07	0.045	1.285	P&H	9	0.010	0.029	0.008
117880	-17 3883	FHB	A0	8.13	0.055	1.205	P&H	16	0.023	0.018	0.026
130095	-26 10505	FHB	B8	8.13	0.060	1.244	P&H	9	0.025	0.017	0.018
161817	+25 3344	FHB	A0	6.96	0.125	1.207	P&H	10	0.011	0.009	0.013
12 17 24		FHB?		11.99	0.121	1.103	H&P	15	0.019	0.014	0.013
M5 III 17		BHB		15.0	0.11	1.22	H&P	4	0.028	0.022	0.017
M13 SA531		BHB		14.9	0.10	1.17	H&P	4	0.036	0.018	0.019
M13 SA 16		BHB		15.0	0.06	1.34	H&P	4	0.031	0.030	0.026
M92 XII 6		BHB		15.9			H&P	4	0.057	0.065	0.062

P & H: Philip and Hayes, 1983
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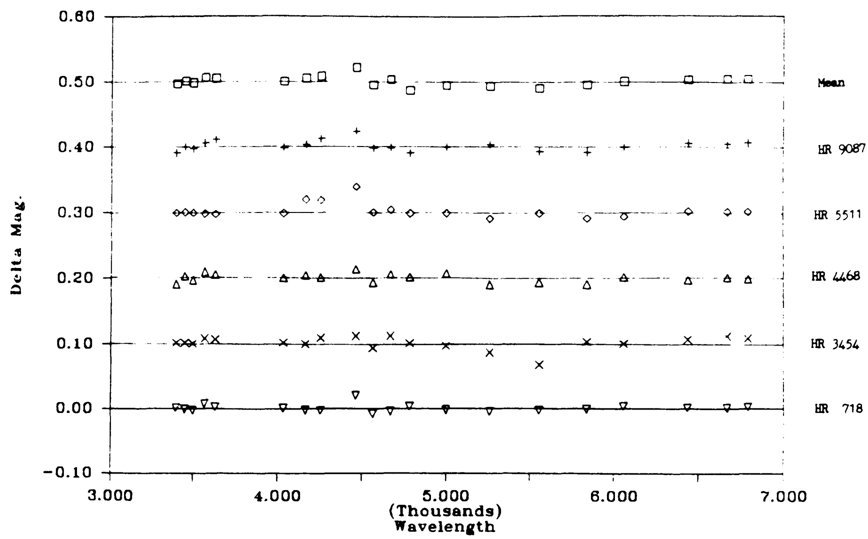

Fig. 1. Comparisons of scans made by Taylor (1984) and by Philip and Hayes (1983).

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