PHOTOMETRIC CALIBRATION OF THE IUE

X. Fluxes of Stars Used for the SWP and LWR Sensitivities

R. C. Bohlin and A. V. Holm

I. Introduction

The recent promotion of the LWP camera to prime operational status has increased interest in the details of the derivation of the SWP and LWR calibration of Bohlin and Holm (1980) as published in Holm et al. (1982). In deriving those absolute calibrations all the available data was reviewed from the first year of operation between April 1978 and April 1979. The derivation of the Bohlin and Holm calibration was completed in May 1980 and has been used in production data processing since implementation of the present software (Bohlin, Lindler, and Turnrose 1981). The calibration of May 1980 replaced the preliminary version of Bohlin et al. (1980) that was published and widely circulated.

II. Procedure

The derivation of the May 1980 calibration of SWP and LWR followed these steps as resurrected from antiquity:

1. All IUE spectra of the selected calibration stars (Table 1) that were obtained between April 1978 and April 1979 were identified. The number of useful spectra for each camera is given in Table 1. In determining the average IUE spectrum for a star, each spectrum was weighted by the observed flux number (FN). The large-aperture point-source spectra determined the absolute level of the IUE calibration. Trailed and small aperture spectra aided in defining the shape of the calibration curve through normalization to the response to point sources in the large aperture, as described in detail by Wu et al. (1984). More details on the reduction of the IUE spectra are reported in Bohlin and Holm (1980). A more complete description of the precision of the IUE data is given in Wu et al. (1984). The spectra of ζ Aql listed in Table 1 are later in time than the interval reported here and were used only as a final check of the calibration.

2. OAO-2 fluxes (Code and Meade 1979) and TD-1 fluxes (Jamar et al. 1976) were obtained for the bright calibration stars. In addition, Carnochan (1978) provided TD-1 fluxes for the fainter stars HD 60753, HD 93521, BD+75°325, BD+28°4211, and BD+33°2642. These OAO-2 and TD-1 fluxes were corrected to the common IUE scale of Bohlin et al. (1980) using the correction factors given in Table 2. The derivation of these correction factors is based on the flux of η UMa using the technique detailed in Bohlin et al. (1980).

The corrected fluxes are reported in Tables 3 and 4. Note that the OAO-2 flux of η UMa in Table 3 also appears in Bohlin et al. (1980) as the prime UV standard star. The TD-1 fluxes contain a linear interpolation from 2540Å to 2550Å using the 2740Å TD-1 data. Otherwise, no use is made of the broadband 2740Å TD-1 data. Since the corrected OAO and TD-1 fluxes differ by a typical one sigma of just 3 percent, only the OAO-2 fluxes are quoted for those stars which have been observed by both space experiments.

In the course of the derivation of the May 1980 calibration BD+33°2642 was determined to be too faint and to have too much noise in the TD-1 scan to be useful. Therefore, it was omitted from the derivation and is omitted from this report.

3. The inverse IUE sensitivity S^{-1} was derived for each corrected OAO-2 flux distribution in Table 3 and each corrected TD-1 spectrum shown in Table 4 by dividing the known fluxes by the IUE response in FN per second.

4. Because of the larger statistical weight of the IUE data with only TD-1 reference spectra, the 5 stars at the bottom of Table 1 define the IUE sensitivity from 1375 to 2550Å. A smooth curve was drawn through the IUE sensitivity curve for each star and then all 5 smooth curves were considered to determine the final S^{-1}.

5. Spectra of bright stars having OAO-2 reference fluxes were used longward of 2550Å and shortward of 1375Å. Despite some corrections needed to the IUE exposure times for the bright OAO-2 stars, the absolute calibration curves from the OAO-2 stars are continuous with the TD-1 calibration curves.

   Longward of 2550Å, a smoothed curve was drawn through the OAO-defined sensitivity curves in a procedure similar to that followed for the 1375 to 2550Å region. Applying the physical assumption that the final IUE calibration should be smooth, the May 1980 LWR calibration was drawn through all 10 of the results for individual stars.

   The region below 1375Å is complicated by the presence of strong absorption lines, so that a slightly different use was made of the results from the 6 OAO stars. The unsmoothed sensitivity curves (in bins of 25Å) from the 6 OAO stars were plotted along with the 5 smoothed TD-1 curves. Again, continuity between the independent TD-1 and OAO results was evident so that, above 1250Å, a smoothed curve was drawn through all available OAO and TD-1 curves. Below 1250Å the situation was even more complicated and is discussed specifically in Bohlin and Holm (1980).

III. Critique and Error Analysis

Improvements in the transfer of an absolute calibration to IUE could have been obtained by increasing the emphasis on OAO stars, since the full wavelength coverage of OAO-2 is required for a complete IUE calibration. The fainter TD-1 stars are required to set the overall absolute level of the sensitivity, which cannot be done directly for the brighter OAO stars because of the uncertainty in the short IUE exposure times. However, the use of the TD-1 data can be thought of as just setting one overall multiplicative factor for each star, whereas the OAO data is needed to define the detailed shape of the IUE sensitivity over the entire wavelength range. Therefore, the statistical confidence in the shape of the IUE calibration curve could have been as good at other wavelengths as it is from 1375 to 2550Å, if the distribution of the number of observations between TD-1 and OAO-2 stars could be reversed.

Between 1275 and 3100Å none of the calibrations from individual stars differs from the adopted mean by more than 7%; typical deviations are about 3 to 4%. Deviations from the mean exceed 7% at 1250Å and below, and also beyond 3100Å. At 3300Å the calibration from 10 Lac is 14% below the adopted mean, and deviations reach almost 40% near Lα. In both cases of the extreme wavelengths, lack of sufficient IUE response contributed to the observed lack of repeatability. In addition, small errors in wavelength scales and slightly different resolution of the IUE and OAO-2 spectra exacerbated the problem near Lα. In order to better understand the IUE calibration at the long and short wavelength limits, a larger statistical sample of spectra of OAO stars is needed. Some of these added spectra should be overexposures to enhance the signal near the limits of the wavelength coverage.

Since the May 1980 calibration was derived, several subtle effects have been found in IUE data which affect the accuracy of the transfer of the calibration from the other space experiments and the application of that calibration to other IUE observations. These effects include residual deviations from linearity in the intensities derived from both the SWP and the LWR cameras (e.g. Oliversen 1983) and wavelength-dependent differences between trailed and point source fluxes (Panek 1982) and between large aperture and small aperture fluxes (Holm unpublished). For the exposure levels used and over the range of spectral types used, none of these effects is larger than about 5 percent. Thus, the mean IUE spectrum for any star should differ from a pure point source in the large aperture for a theoretical and noise free IUE response by less than 2 to 3 percent, in agreement with the observed scatter. However, these effects may produce larger errors in applying the calibration to spectra that differ substantially from those used for the calibration.

As a final check, the IUE SWP fluxes were compared with ANS results for the subset of stars that had been observed with ANS. The IUE fluxes agree with ANS to within 2.5 percent after application of the correction factors for ANS that appear in Table 2.

TABLE 1

IUE Data Used to Derive the IUE Sensitivity for the First Year of Operations

Star	No. of SWP Spectra			No. of LWR Spectra			OAO-2	TD-1
	P	T	S	P	T	S		
μ Col	2	-	2	2	-	2	Y	Y
ζ Cas	-	1	2	2	1	1	Y	Y
η Aur	1	2	1	1	1	1	Y	Y
λ Lep	2	-	-	-	-	-	Y	Y
10 LAC	-	1	-	-	1	-	Y	Y
η UMa*	-	2	-	-	2	2	Y	Y
ζ Aql	-	-	-	5	-	-	Y	Y
77 Dra	2	2	-	2	6	-	N	Y
HD 60753	6	-	5	5	-	4	N	Y
BD +75° 325	7	-	6	7	-	6	N	Y
HD 93521	15	-	13	13	-	13	N	Y
BD +28° 4211	12	-	12	7	-	7	N	Y

Key to Table: P - Point source in large aperture
T - Trailed source in large aperture
S - Small aperture

* The η UMa spectra constrains the shape of the sensitivity curve but provides no independent measure of the absolute level, since exposure times at the rapid trail rate required for such bright stars are indeterminate.

Table 2

Correction Factors Used to Multiply other Data to Get to the IUE Scale

λ	OAO-2	TD-1	λ	OAO-2	TD-1	λ	OAO-2
1150	.840		1950	.894	.986	2750	1.005
1175	1.231		1975	.921	.978	2775	1.004
1200	1.156		2000	.955	1.000	2800	.986
1225	1.060		2025	.989	1.013	2825	1.005
1250	1.001		2050	1.003	1.020	2850	1.003
1275	.974		2075	1.005	1.025	2875	1.004
1300	.950		2100	.991	1.010	2900	1.001
1325	.930		2125	1.004	1.003	2925	1.006
1350	.913		2150	.996	.997	2950	1.028
1375	.896	1.106	2175	.999	1.010	2975	1.017
1400	.869	1.037	2200	1.002	.994	3000	1.024
1425	.852	1.054	2225	1.000	.989	3025	1.010
1450	.846	1.055	2250	1.000	.983	3050	1.006
1475	.833	1.065	2275	1.001	.968	3075	1.000
1500	.809	1.092	2300	.987	.972	3100	1.000
1525	.776	1.080	2325	.984	1.001	3125	1.000
1550	.777	1.034	2350	.985	1.007	3150	1.000
1575	.787	1.025	2375	.988	1.014	3175	1.000
1600	.800	1.008	2400	.990	1.021	3200	1.000
1625	.825	.942	2425	.992	1.043	3225	1.000
1650	.856	.936	2450	.995	1.080	3250	1.000
1675	.847	.906	2475	.994	1.063	3275	1.000
1700	.842	.917	2500	.994	1.067	3300	1.000
1725	.820	.908	2525	.991	1.064		
1750	.846	1.043	2550	1.004	1.066		
1775	.859	1.038	2575	1.000	1.120		
1800	.860	1.005	2600	1.001	1.114		
1825	.873	.986	2625	1.003	1.119		
1850	.868	.998	2650	.997	1.168		
1875	.868	.998	2675	1.003	1.185		
1900	.868	.980	2700	.995	1.188		
1925	.876	.992	2725	.996	1.188		

λ	ANS
1550	1.083
1800	.995
2200	.909
2500	1.046
3300	1.110

TABLE 3

Corrected Fluxes of OAO-2 Stars (10^{-10} erg s^{-1} cm^{-2} $Å^{-1}$)

λ(Å)	μCol	ζCas	ηAur	λLep	10Lac	ηUMa	ζAql
1175	27.7	47.4	44.2	51.1	20.1	155.	
1200	22.5	35.3	29.8	43.0	17.2	100.	
1225	19.4	28.6	17.3	38.0	14.3	65.7	
1250	24.5	44.3	41.0	48.5	21.0	146.	
1275	25.5	46.0	42.2	51.9	23.2	151.	
1300	25.2	38.3	37.1	49.4	22.9	132.	
1325	23.2	40.4	38.6	47.1	20.7	136.	
1350	21.3	37.9	38.2	44.0	19.6	133.	
1375	20.4	34.6	36.2	40.6	18.8	125.	2.42
1400	16.9	27.3	32.8	32.3	16.1	114.	2.38
1425	16.3	28.7	32.6	33.4	15.6	113.	2.67
1450	16.6	29.6	33.4	32.9	15.5	116.	2.88
1475	16.6	28.8	32.1	32.0	15.4	111.	3.21
1500	15.4	27.3	30.4	30.5	15.1	105.	3.47
1525	14.5	23.8	28.3	27.5	13.9	98.0	3.50
1550	10.3	20.0	27.2	21.2	10.9	95.0	3.46
1575	11.6	21.5	26.2	22.5	11.5	91.0	3.29
1600	11.0	20.7	24.8	22.3	10.8	86.0	3.15
1625	9.52	20.5	23.4	20.2	9.27	81.5	3.00
1650	10.4	21.7	23.8	21.6	10.4	82.5	3.01
1675	10.4	21.5	23.4	21.6	10.4	81.0	3.05
1700	10.5	20.9	22.7	21.2	10.2	78.5	3.06
1725	9.48	18.3	20.3	19.0	9.17	70.0	2.94
1750	9.96	19.2	21.1	19.8	9.86	72.5	3.13
1775	9.96	19.3	20.9	19.4	9.85	71.0	3.25
1800	9.24	19.1	19.9	18.8	9.67	70.6	3.07
1825	8.92	17.2	19.2	18.4	9.27	68.4	3.01
1850	8.42	16.3	18.5	17.2	8.73	64.8	3.02
1875	8.07	15.2	18.0	15.8	8.38	62.2	2.93
1900	7.74	14.3	17.0	14.7	7.86	59.5	2.88
1925	7.12	13.4	16.2	14.2	7.52	56.6	2.79
1950	7.00	13.5	16.1	13.9	7.07	56.0	2.71
1975	6.80	13.5	16.1	13.8	6.91	55.5	2.71
2000	6.92	13.6	16.1	14.0	6.83	55.0	2.74
2025	7.05	13.6	16.0	13.9	6.80	55.0	2.64
2050	6.84	13.0	15.5	13.2	6.34	53.5	2.70
2075	6.45	12.7	15.1	12.7	5.99	51.3	2.65
2100	6.16	12.2	15.0	12.2	5.75	49.3	2.56
2125	6.22	12.3	14.3	12.2	5.54	49.2	2.53
2150	5.94	11.8	13.6	11.7	5.29	47.4	2.48
2175	5.75	11.8	13.3	11.3	5.16	46.0	2.47
2200	5.56	11.3	13.0	11.0	5.02	44.6	2.49
2225	5.44	11.1	12.8	10.1	4.94	43.7	2.48

TABLE 3 (cont.)

λ(Å)	μCol	ζCas	ηAur	λLep	10Lac	ηUMa	ζAql
2250	5.23	10.8	12.2	10.4	4.82	42.2	2.41
2275	5.00	10.6	12.0	9.90	4.61	41.1	2.36
2300	4.61	10.3	11.7	9.40	4.46	40.4	2.45
2325	4.68	10.2	11.5	9.48	4.67	39.3	2.39
2350	4.69	9.92	10.9	9.34	4.61	37.8	2.34
2375	4.30	9.76	10.7	9.03	4.39	37.0	2.28
2400	4.19	9.64	10.5	8.72	4.42	36.3	2.22
2425	4.17	9.46	10.4	8.64	4.39	35.9	2.24
2450	4.13	9.35	10.2	8.48	4.45	35.2	2.27
2475	3.97	9.06	10.0	8.22	4.35	34.5	2.22
2500	3.85	8.79	9.84	7.97	4.14	34.0	2.23
2525	3.69	8.42	9.39	7.61	4.03	32.6	2.17
2550	3.59	8.10	9.18	7.42	4.06	31.8	2.08
2575	3.47	8.18	9.28	7.27	3.88	32.1	2.23
2600	3.34	8.06	9.34	7.06	3.74	31.7	2.22
2625	3.28	7.83	8.95	6.94	3.75	30.9	2.16
2650	3.18	7.54	8.72	6.60	3.54	30.0	2.24
2675	3.10	7.47	8.58	6.38	3.50	29.6	2.28
2700	3.00	7.24	8.40	6.25	3.44	29.0	2.27
2725	2.91	7.15	8.20	6.07	3.32	28.4	2.24
2750	2.81	7.07	7.98	5.96	3.29	27.8	2.22
2775	2.75	6.87	7.85	5.80	3.18	27.3	2.18
2800	2.48	6.46	7.42	5.45	3.02	26.1	2.07
2825	2.59	6.50	7.65	5.51	3.05	26.3	2.17
2850	2.51	6.35	7.44	5.30	2.99	25.5	2.17
2875	2.39	6.22	7.23	5.13	2.92	25.0	2.11
2900	2.31	6.01	7.03	4.96	2.79	24.5	2.11
2925	2.25	5.89	6.92	4.83	2.73	23.9	2.18
2950	2.22	5.78	6.85	4.80	2.66	23.7	2.18
2975	2.11	5.60	6.69	4.61	2.57	23.0	2.13
3000	2.06	5.47	6.65	4.47	2.53	22.8	2.17
3025	1.99	5.32	6.52	4.35	2.42	22.3	2.16
3050	1.93	5.23	6.35	4.28	2.36	21.9	2.16
3075	1.93	5.19	6.25	4.16	2.36	21.5	2.14
3100	1.93	5.06	6.23	4.09	2.32	21.3	2.13
3125	1.89	4.95	6.13	4.00	2.27	21.1	2.12
3150	1.84	4.93	5.99	3.93	2.28	20.7	2.14
3175	1.76	4.82	5.83	3.82	2.20	20.3	2.13
3200	1.71	4.74	5.72	3.76	2.15	20.0	2.12
3225	1.69	4.67	5.74	3.65	2.16	19.7	2.14
3250	1.65	4.59	5.68	3.55	2.04	19.4	2.13
3275	1.64	4.51	5.53	3.50	2.01	19.1	2.14
3300	1.60	4.43	5.48	3.40	2.02	18.9	2.15
3325	1.57	4.31	5.42	3.35	1.92	18.5	2.12
3350	1.53	...	5.32	...	1.86	18.2	2.09

Note to Table 3: The tabulated OAO-2 spectrophotometry is from Code and Meade (1979) after application of the corrections from Table 2. The fluxes in this table were used to determine the sensitivity of the SWP and LWR cameras.

TABLE 4

Corrected Fluxes of TD-1 Stars (10^{-12} erg s^{-1} cm^{-2} $Å^{-1}$)

λ(Å)	77Dra	HD60753	BD+75°325	HD93521	BD+28°4211
1375	...	90.0	55.9	266	36.6
1400	74.0	81.7	50.0	218	31.7
1425	75.9	82.9	49.2	212	31.6
1450	77.2	85.9	47.3	218	30.4
1475	77.6	83.8	46.2	214	30.2
1500	76.4	80.9	45.4	209	29.0
1525	73.4	74.8	43.1	176	25.0
1550	69.7	68.2	39.8	141	22.8
1575	69.0	68.4	38.3	144	20.9
1600	65.0	65.1	34.6	130	19.6
1625	58.9	59.6	28.0	115	16.0
1650	59.2	61.4	30.0	129	16.2
1675	59.4	62.1	31.1	134	15.5
1700	57.8	57.7	29.3	130	15.4
1725	51.5	52.6	27.5	122	15.4
1750	51.2	58.2	29.5	139	13.4
1775	53.6	57.2	28.8	134	15.9*
1800	54.8	54.8	28.5	133	17.0*
1825	52.0	54.8	25.4	134	13.9*
1850	51.1	49.4	23.6	126	12.3
1875	51.0	48.1	22.5	117	12.8
1900	49.8	46.0	22.8	111	11.1
1925	47.6	45.0	21.6	109	11.4
1950	46.9	42.5	20.5	107	9.29
1975	47.4	43.2	18.8	105	8.67
2000	46.6	41.5	19.6	109	9.36
2025	45.6	41.1	20.8	107	8.41
2050	46.0	41.0	18.4	103	8.59
2075	44.9	39.1	17.7	100	8.24
2100	42.1	40.2	16.4	98.2	7.08
2125	40.5	37.6	14.7	98.7	7.95
2150	40.2	35.5	15.0	91.4	7.12
2175	40.7	34.1	15.6	93.3	6.23
2200	38.7	32.8	15.3	88.8	6.39
2225	38.0	31.6	15.2	89.2	5.44
2250	35.9	31.8	13.6	86.5	5.32
2275	35.9	33.3	12.6	83.4	5.83
2300	37.1	31.8	13.5	76.7	5.46
2325	35.5	31.2	13.0	76.3	4.89
2350	33.1	30.8	12.2	73.1	4.94
2375	31.0	31.2	10.8	71.8	4.72
2400	31.6	29.8	10.8	70.6	3.91
2425	32.7	31.8	10.9	71.2	4.30
2450	32.8	31.6	11.5	72.9	6.00*
2475	25.7	30.0	11.7	68.7	3.73
2500	29.6	30.2	12.1	68.1	3.64
2525	29.9	28.5	10.0	62.2	4.59*
2550	29.7	28.4	9.14	57.7	3.73

* Noise spikes.

Note to Table 4: The tabulated TD-1 spectrophotometry is from Jamar et al. (1976) and Carnochan (1978) after application of the corrections from Table 2. The fluxes in this table were used to determine the sensitivity of the SWP and LWR cameras as described in the text.

REFERENCES

Bohlin, R.C., and Holm, A.V. 1980, NASA IUE Newsletter, 10, 37; 1981, ESA IUE Newsletter, 11, 18.

Bohlin, R.C., Holm, A.V., Savage, B.D., Snijders, M.A.J., and Sparks, W.M. 1980, Astron. Astrophys., 85, 1.

Bohlin, R.C., Lindler, D.J., and Turnrose, B.E. 1981, NASA IUE Newsletter, 12, 9.

Carnochan, D. 1978, Private Communication.

Code, A.D., and Meade, M.R. 1979, Ap. J. Suppl., 39, 195.

Holm, A.V., Bohlin, R.C., Cassatella, A., Ponz, D.P., and Schiffer, F.H. 1982, Astron. Astrophys. 112, 341.

Jamar, C., Macau-Hercot, D., Monfils, A., Thompson, G.I., Houziaux, L., and Wilson, R. 1976, UV Bright-Star Spectrophotometric Catalogue, ESA SR-27.

Oliversen, N. A. 1983, NASA IUE Newsletter, 23, 31.

Panek, R. J. 1982, NASA IUE Newsletter, 18, 69.

Wu, C-C., Boggess, A., Bohlin, R.C., Holm, A.V., Schiffer, F.H., and Turnrose, B.E. 1984, IUE Spectral Atlas: Part II-Tables, in preparation.