Chapter 11

Calibration of the Net Flux

11.1 Low-Dispersion Absolute Flux Calibration

11.1.1 1985-Epoch Point Source Calibrations

Absolute flux calibrations have been derived for the low-dispersion modes of the *IUE* cameras through observations of ultraviolet photometric standard stars, as well as observations and models of the white dwarf star, G191-B2B. The wavelength-dependence of the inverse sensitivity function (S_λ^{-1}) for each camera has been determined by comparison of *IUE* observations of the white dwarf star with model atmosphere calculations that were provided to the *IUE* project by D. Finley. The overall zeropoint of the calibration curves has been set by applying the white dwarf derived S_λ^{-1} values to *IUE* observations of ultraviolet photometric standard stars and comparing these results with OAO-2 measurements in the 2100–2300Å band (see González-Riestra, Cassatella, and de la Fuente 1992 for details regarding the calibration procedures).

The final S_λ^{-1} curves for the LWP, LWR (ITFs A and B), and SWP, defined in 15Å bins for the long-wavelength cameras and 10Å bins for the SWP and fit with spline curves, are listed in Tables 11.1–11.4. The absolute flux at a given wavelength, F_λ (ergs sec^{-1} cm^{-2} Å^{-1}), is computed as follows:

$$F_\lambda = FN_\lambda \times S_\lambda^{-1}/t_{eff}$$

where FN_λ is the extracted net flux in FN units, S_λ^{-1} is the inverse sensitivity value at that wavelength, and t_{eff} is the effective exposure time in seconds. The inverse sensitivity value at a particular wavelength is determined by quadratic interpolation of the tabulated values for a given camera.

The effective exposure time for non-trailed (e.g., point, extended, flat-field) sources is derived from the original commanded exposure time, t_{com}, and takes into account the effects of On-Board Computer (OBC) tick rounding and the camera rise time, t_{rise}, as follows:

$$t_{eff} = 0.4096 \times INT(t_{com}/0.4096) - t_{rise}$$

where the values of t_{rise} for each camera are taken from González-Riestra (1991) and are 0.123, 0.126, and 0.130 for the LWP, LWR, and SWP cameras, respectively. Tick rounding results from the integer arithmetic used by the OBC in commanding exposures. Effective exposure times for large-aperture trailed observations are determined according to:

$$t_{TR} = Trail\ length/Trail\ rate \times Passes$$

where *Trail length* is the trail path length of the aperture in arcsec, *Trail rate* is the effective trail rate in arcsec/sec, and *Passes* is the number of passes across the aperture. Because the OBC uses integer arithmetic in calculating fixed rate slews, there is a truncation in the commanded trail rate. This "rounding off" is similar to the OBC quantitization of non-trailed exposure times. The effective trail rate is calculated using the following equation:

$$TR = \sqrt{(LSB \times INT(0.4695 \times TR_{com}/LSB))^2 + (LSB \times INT(0.8829 \times TR_{com}/LSB))^2}$$

where LSB is the least significant bit (0.03001548/32 arcsec/sec) and TR_{com} is the commanded trail rate.

11.1.2 Aperture Response Corrections

The S_λ^{-1} functions described above apply only to point source observations acquired through the large aperture. The small-aperture and trailed observing modes are known to have different relative responses as compared to large-aperture point spectra (e.g., Harris and Cassatella 1985, Bohlin 1986, Crenshaw and Park 1989). This effect has been ascribed to several sources, including vignetting effects of the entrance apertures in trailed and small-aperture spectra and spatial inhomogeneities in the UVC efficiency (Cassatella 1990). Application of the large-aperture point source calibration to spectra obtained either in trail mode or through the small aperture will introduce photometric errors of at least 5–7% in the regions near the detector edge and of 1–2% in regions where the camera response is flatter.

Calibration corrections for small-aperture observations and for large-aperture trailed observations have been derived and are applied by the processing system when necessary. *IUE* standard-star observations from the 1984–1985 epoch have been used to calculate the wavelength-dependent flux ratios of small- and large-aperture point sources, and of large-aperture point source and trail mode observations. Observations from the 1984–1985 epoch were chosen so as to match the large-aperture point source calibration epoch. Also, by limiting the range of time over which the observations were obtained, effects due to sensitivity degradation in the cameras are minimized.

Optimal exposure level observations of the four TD1 standard stars BD+28° 4211, HD 93521, HD 60753, and BD+75° 325 were used to compute the small-to-large aperture (S/L) ratios and the large-aperture trailed-to-point source (T/L) ratios. The effective exposure times of the trailed observations were determined using a value of 21.48 arcseconds for the SWP major-axis trail path length (Garhart 1992b), 22.55 arcseconds for the LWR major-axis trail path length, and 21.84 arcseconds for the LWP major-axis trail path length. The ratios of pairs of observations of the same object obtained through the small and large apertures, or in point and trail modes were averaged together to determine the mean S/L and T/L spectral ratios. Approximately 20 pairs of spectra were used to determine each of the two response ratios. The mean spectral ratios were resampled into the bin size of the appropriate inverse sensitivity function and a spline fit to the binned ratios was calculated. Tabulated values of the spline fits for each camera are listed in Tables 11.5–11.8.

Because centering errors in the small aperture can lead to large variations in the overall observed flux level for individual spectra, it is impossible to determine an absolute S/L ratio. Therefore, the average of S/L over all wavelengths is normalized to unity. *As a result, the small-aperture fluxes are known in a relative sense but not in an absolute one.* The relative small- and absolute large-aperture inverse sensitivities are related by

$$S_\lambda^{-1}(S) = S_\lambda^{-1}(L)/(S/L).$$

Investigators should be aware that absolute fluxes for small-aperture data are significantly less reliable than those of large-aperture data. For the ratio of trailed response to point sources in the large aperture, the absolute calibrations are related by

$$S_\lambda^{-1}(T) = S_\lambda^{-1}(L)/(T/L).$$

Only trailed large-aperture spectra are calibrated with the T/L ratio applied. Images processed as extended sources are calibrated as point source observations.

11.1.3 Gain Factors

The S_λ^{-1} function for the LWR camera was derived from observations obtained at a UVC voltage setting of −5.0 kV. Therefore all LWR observations that have been obtained at the reduced voltage setting of −4.5 kV have an absolute calibration gain correction factor of 1.37 applied by the processing system (Harris 1985) to compensate. A message to this effect is included in the processing history log. In the event that an observation for any camera has been obtained at non-standard settings of either the exposure gain (normally MAXIMUM) or the camera read gain (normally LOW), an additional absolute flux scaling factor is multiplicatively applied as follows (cf. Coleman et al. 1977):

- Exposure Gain Corrections

  Maximum: Correction = 1.0

  Medium: Correction = 3.0

  Minimum: Correction = 10.0

- Read Gain Corrections

  High: Correction = 0.33

  Low: Correction = 1.0

Table 11.1: LWP Absolute Calibration

λ	S^{-1}[a]	λ	S^{-1}	λ	S^{-1}
1850	93.736	2360	6.108	2870	2.823
1865	62.950	2375	5.855	2885	2.877
1880	45.372	2390	5.560	2900	2.925
1895	35.791	2405	5.221	2915	2.998
1910	30.233	2420	4.918	2930	3.135
1925	25.704	2435	4.699	2945	3.314
1940	21.886	2450	4.498	2960	3.414
1955	18.946	2465	4.221	2975	3.686
1970	16.467	2480	3.902	2990	3.911
1985	14.460	2495	3.892	3005	4.132
2000	13.095	2510	3.892	3020	4.465
2015	12.447	2525	3.650	3035	4.868
2030	12.234	2540	3.460	3050	5.326
2045	12.084	2555	3.222	3065	5.972
2060	11.730	2570	3.173	3080	6.614
2075	11.326	2585	3.162	3095	7.318
2090	11.123	2600	3.010	3110	8.075
2105	11.227	2615	2.904	3125	9.101
2120	11.355	2630	2.853	3140	10.060
2135	11.266	2645	2.801	3155	11.577
2150	11.174	2660	2.739	3170	13.041
2165	11.127	2675	2.673	3185	14.704
2180	11.095	2690	2.635	3200	16.832
2195	11.050	2705	2.666	3215	19.605
2210	10.963	2720	2.726	3230	23.110
2225	10.806	2735	2.633	3245	27.069
2240	10.533	2750	2.636	3260	31.107
2255	10.026	2765	2.618	3275	35.122
2270	9.261	2780	2.648	3290	40.094
2285	8.657	2795	2.759	3305	47.271
2300	8.456	2810	2.702	3320	57.623
2315	7.974	2825	2.705	3335	71.007
2330	7.225	2840	2.729	3350	87.001
2345	6.560	2855	2.769		

[a] Inverse sensitivity in units of 10^{-13} ergs cm^{-2} Å^{-1} FN^{-1}.

Table 11.2: LWR ITFA Absolute Calibration

λ	S^{-1}[a]	λ	S^{-1}	λ	S^{-1}
1850	150.815	2360	7.404	2870	2.962
1865	100.432	2375	7.082	2885	2.981
1880	67.875	2390	6.768	2900	3.059
1895	51.682	2405	6.422	2915	3.214
1910	43.664	2420	6.021	2930	3.408
1925	36.055	2435	5.564	2945	3.489
1940	29.671	2450	5.123	2960	3.571
1955	26.087	2465	4.791	2975	3.803
1970	21.773	2480	4.624	2990	4.141
1985	19.958	2495	4.545	3005	4.426
2000	18.914	2510	4.442	3020	4.668
2015	17.786	2525	4.236	3035	5.194
2030	16.714	2540	3.981	3050	5.378
2045	15.910	2555	3.765	3065	5.873
2060	15.509	2570	3.647	3080	6.553
2075	15.350	2585	3.569	3095	7.337
2090	15.195	2600	3.443	3110	8.238
2105	14.868	2615	3.227	3125	9.269
2120	14.438	2630	3.055	3140	10.442
2135	14.090	2645	3.045	3155	11.772
2150	14.099	2660	3.061	3170	13.527
2165	14.235	2675	2.951	3185	16.124
2180	14.129	2690	2.814	3200	18.375
2195	13.629	2705	2.907	3215	22.451
2210	13.475	2720	2.813	3230	25.421
2225	13.725	2735	2.654	3245	30.192
2240	12.470	2750	2.754	3260	38.728
2255	12.053	2765	2.812	3275	46.958
2270	11.348	2780	2.826	3290	51.385
2285	10.490	2795	2.871	3305	60.704
2300	10.036	2810	2.859	3320	70.023
2315	9.535	2825	2.857	3335	110.890
2330	8.595	2840	2.926	3350	151.761
2345	7.860	2855	2.959		

[a] Inverse sensitivity in units of 10^{-13} ergs cm^{-2} $Å^{-1}$ FN^{-1}.

Table 11.3: LWR ITFB Absolute Calibration

λ	S^{-1}[a]	λ	S^{-1}	λ	S^{-1}
1850	149.533	2360	7.407	2870	2.929
1865	108.895	2375	7.025	2885	2.962
1880	71.052	2390	6.697	2900	3.014
1895	53.992	2405	6.369	2915	3.159
1910	45.698	2420	5.983	2930	3.390
1925	37.905	2435	5.513	2945	3.461
1940	31.051	2450	5.052	2960	3.573
1955	26.426	2465	4.723	2975	3.906
1970	22.927	2480	4.598	2990	4.149
1985	20.562	2495	4.540	3005	4.336
2000	19.567	2510	4.364	3020	4.620
2015	18.827	2525	4.085	3035	5.047
2030	16.966	2540	4.075	3050	5.382
2045	16.849	2555	3.633	3065	5.867
2060	16.174	2570	3.514	3080	6.509
2075	15.269	2585	3.543	3095	7.279
2090	15.296	2600	3.342	3110	8.172
2105	15.661	2615	3.133	3125	9.178
2120	14.869	2630	3.013	3140	10.290
2135	14.905	2645	2.987	3155	11.499
2150	14.822	2660	2.989	3170	12.880
2165	14.503	2675	2.917	3185	14.826
2180	14.337	2690	2.746	3200	17.627
2195	14.176	2705	2.794	3215	20.836
2210	13.233	2720	2.748	3230	23.865
2225	13.843	2735	2.653	3245	27.121
2240	12.606	2750	2.646	3260	33.308
2255	11.817	2765	2.672	3275	39.515
2270	11.317	2780	2.706	3290	43.614
2285	10.375	2795	2.745	3305	53.328
2300	10.228	2810	2.787	3320	63.042
2315	9.434	2825	2.829	3335	78.023
2330	8.562	2840	2.867	3350	93.004
2345	7.901	2855	2.899		

[a] Inverse sensitivity in units of 10^{-13} ergs cm^{-2} Å^{-1} FN^{-1}.

Table 11.4: SWP Absolute Calibration

λ	S^{-1}[a]	λ	S^{-1}	λ	S^{-1}
1150	10.60	1440	1.491	1730	1.269
1160	7.032	1450	1.535	1740	1.226
1170	4.666	1460	1.568	1750	1.185
1180	3.204	1470	1.593	1760	1.149
1190	2.377	1480	1.616	1770	1.117
1200	1.921	1490	1.642	1780	1.089
1210	1.614	1500	1.677	1790	1.067
1220	1.396	1510	1.721	1800	1.049
1230	1.249	1520	1.766	1810	1.035
1240	1.153	1530	1.798	1820	1.025
1250	1.090	1540	1.808	1830	1.019
1260	1.045	1550	1.805	1840	1.017
1270	1.012	1560	1.798	1850	1.019
1280	0.991	1570	1.789	1860	1.025
1290	0.980	1580	1.778	1870	1.034
1300	0.977	1590	1.764	1880	1.046
1310	0.981	1600	1.745	1890	1.059
1320	0.992	1610	1.729	1900	1.071
1330	1.008	1620	1.706	1910	1.081
1340	1.030	1630	1.681	1920	1.086
1350	1.057	1640	1.652	1930	1.084
1360	1.089	1650	1.620	1940	1.073
1370	1.125	1660	1.584	1950	1.054
1380	1.166	1670	1.544	1960	1.038
1390	1.213	1680	1.501	1970	1.040
1400	1.265	1690	1.456	1980	1.075
1410	1.322	1700	1.409		
1420	1.381	1710	1.362		
1430	1.439	1720	1.315		

[a] Inverse sensitivity in units of 10^{-12} ergs cm^{-2} Å^{-1} FN^{-1}.

Table 11.5: LWP S/L and T/L Relative Sensitivities[*]

λ	S/L	T/L	λ	S/L	T/L	λ	S/L	T/L
1850	1.048	0.989	2360	1.024	1.003	2870	0.998	0.995
1865	1.026	0.989	2375	1.021	1.000	2885	0.997	0.995
1880	1.005	0.989	2390	1.017	0.996	2900	0.996	0.994
1895	0.989	0.989	2405	1.013	0.993	2915	0.994	0.994
1910	0.978	0.989	2420	1.009	0.990	2930	0.990	0.994
1925	0.973	0.988	2435	1.006	0.988	2945	0.987	0.994
1940	0.972	0.987	2450	1.004	0.987	2960	0.983	0.994
1955	0.974	0.986	2465	1.003	0.985	2975	0.979	0.995
1970	0.978	0.986	2480	1.002	0.985	2990	0.976	0.996
1985	0.983	0.985	2495	1.003	0.984	3005	0.973	0.997
2000	0.986	0.984	2510	1.004	0.984	3020	0.971	0.999
2015	0.988	0.984	2525	1.005	0.984	3035	0.970	1.001
2030	0.989	0.984	2540	1.007	0.985	3050	0.971	1.004
2045	0.987	0.984	2555	1.008	0.985	3065	0.973	1.007
2060	0.985	0.985	2570	1.009	0.986	3080	0.977	1.011
2075	0.983	0.987	2585	1.010	0.987	3095	0.982	1.016
2090	0.980	0.988	2600	1.010	0.989	3110	0.988	1.022
2105	0.978	0.991	2615	1.009	0.990	3125	0.995	1.029
2120	0.977	0.994	2630	1.008	0.991	3140	1.002	1.036
2135	0.976	0.998	2645	1.006	0.993	3155	1.008	1.045
2150	0.977	1.002	2660	1.004	0.994	3170	1.015	1.054
2165	0.980	1.006	2675	1.001	0.995	3185	1.021	1.064
2180	0.984	1.010	2690	0.999	0.996	3200	1.027	1.073
2195	0.990	1.013	2705	0.997	0.997	3215	1.031	1.080
2210	0.996	1.016	2720	0.995	0.998	3230	1.034	1.084
2225	1.003	1.019	2735	0.993	0.998	3245	1.037	1.085
2240	1.009	1.020	2750	0.992	0.998	3260	1.038	1.082
2255	1.016	1.021	2765	0.992	0.998	3275	1.040	1.074
2270	1.021	1.020	2780	0.992	0.998	3290	1.040	1.060
2285	1.025	1.019	2795	0.993	0.998	3305	1.040	1.039
2300	1.028	1.017	2810	0.995	0.997	3320	1.040	1.012
2315	1.029	1.014	2825	0.996	0.997	3335	1.039	0.980
2330	1.029	1.010	2840	0.997	0.996	3350	1.039	0.946
2345	1.027	1.007	2855	0.997	0.996			

[*] Normalized to an average value of unity over all wavelengths.

Table 11.6: LWR ITFA S/L and T/L Relative Sensitivities*

λ	S/L	T/L	λ	S/L	T/L	λ	S/L	T/L
1850	1.014	0.986	2360	0.997	0.986	2870	1.023	0.954
1865	1.014	0.998	2375	0.995	0.982	2885	1.027	0.956
1880	1.014	1.008	2390	0.994	0.977	2900	1.030	0.958
1895	1.014	1.012	2405	0.992	0.973	2915	1.032	0.961
1910	1.014	1.006	2420	0.991	0.968	2930	1.032	0.963
1925	0.980	0.992	2435	0.990	0.963	2945	1.032	0.966
1940	0.960	0.977	2450	0.991	0.959	2960	1.031	0.968
1955	0.951	0.970	2465	0.992	0.955	2975	1.029	0.971
1970	0.951	0.972	2480	0.995	0.952	2990	1.026	0.974
1985	0.955	0.979	2495	0.997	0.949	3005	1.023	0.976
2000	0.960	0.988	2510	1.001	0.947	3020	1.019	0.975
2015	0.963	0.993	2525	1.004	0.945	3035	1.014	0.969
2030	0.964	0.995	2540	1.008	0.943	3050	1.010	0.960
2045	0.963	0.995	2555	1.011	0.942	3065	1.005	0.950
2060	0.962	0.994	2570	1.013	0.941	3080	0.999	0.942
2075	0.959	0.992	2585	1.014	0.940	3095	0.993	0.949
2090	0.956	0.990	2600	1.014	0.939	3110	0.985	0.964
2105	0.953	0.988	2615	1.013	0.938	3125	0.975	0.975
2120	0.951	0.988	2630	1.011	0.938	3140	0.963	0.981
2135	0.949	0.989	2645	1.008	0.938	3155	0.949	0.984
2150	0.949	0.990	2660	1.004	0.938	3170	1.000	0.992
2165	0.951	0.992	2675	1.001	0.938	3185	1.000	0.998
2180	0.955	0.994	2690	0.997	0.938	3200	1.000	1.012
2195	0.959	0.996	2705	0.994	0.939	3215	1.000	1.044
2210	0.964	0.998	2720	0.991	0.939	3230	1.000	1.053
2225	0.970	1.000	2735	0.990	0.940	3245	1.000	1.022
2240	0.976	1.001	2750	0.990	0.941	3260	1.000	1.000
2255	0.982	1.002	2765	0.991	0.942	3275	1.000	1.000
2270	0.988	1.002	2780	0.994	0.943	3290	1.000	1.000
2285	0.992	1.001	2795	0.998	0.945	3305	1.000	1.000
2300	0.995	0.999	2810	1.002	0.946	3320	1.000	1.000
2315	0.997	0.997	2825	1.007	0.948	3335	1.000	1.000
2330	0.998	0.993	2840	1.013	0.950	3350	1.000	1.000
2345	0.998	0.990	2855	1.018	0.952			

*Normalized to an average value of unity over all wavelengths.

Table 11.7: LWR ITFB S/L and T/L Relative Sensitivities*

λ	S/L	T/L	λ	S/L	T/L	λ	S/L	T/L
1850	1.015	1.008	2360	0.997	0.978	2870	1.047	0.956
1865	1.015	1.015	2375	0.997	0.975	2885	1.052	0.957
1880	1.015	1.020	2390	0.997	0.972	2900	1.054	0.959
1895	1.015	1.019	2405	0.996	0.969	2915	1.053	0.961
1910	1.015	1.010	2420	0.996	0.966	2930	1.050	0.963
1925	0.971	0.995	2435	0.996	0.962	2945	1.044	0.965
1940	0.946	0.981	2450	0.997	0.958	2960	1.036	0.967
1955	0.935	0.974	2465	0.999	0.954	2975	1.026	0.979
1970	0.935	0.977	2480	1.002	0.951	2990	1.016	0.991
1985	0.941	0.985	2495	1.005	0.949	3005	1.004	1.000
2000	0.948	0.994	2510	1.008	0.948	3020	0.992	1.000
2015	0.952	0.999	2525	1.011	0.947	3035	0.981	1.000
2030	0.953	1.000	2540	1.014	0.946	3050	0.969	1.000
2045	0.953	0.999	2555	1.017	0.946	3065	0.959	1.000
2060	0.950	0.996	2570	1.018	0.946	3080	1.000	1.000
2075	0.947	0.992	2585	1.019	0.945	3095	1.000	1.000
2090	0.943	0.988	2600	1.018	0.945	3110	1.000	1.000
2105	0.939	0.985	2615	1.015	0.945	3125	1.000	1.000
2120	0.935	0.982	2630	1.011	0.945	3140	1.000	1.000
2135	0.933	0.981	2645	1.006	0.945	3155	1.000	1.000
2150	0.933	0.980	2660	1.001	0.945	3170	1.000	1.000
2165	0.934	0.980	2675	0.996	0.945	3185	1.000	1.000
2180	0.938	0.981	2690	0.991	0.945	3200	1.000	1.000
2195	0.943	0.981	2705	0.987	0.946	3215	1.000	1.000
2210	0.950	0.982	2720	0.985	0.946	3230	1.000	1.000
2225	0.957	0.983	2735	0.985	0.947	3245	1.000	1.000
2240	0.964	0.984	2750	0.986	0.947	3260	1.000	1.000
2255	0.972	0.985	2765	0.991	0.948	3275	1.000	1.000
2270	0.979	0.985	2780	0.997	0.949	3290	1.000	1.000
2285	0.985	0.985	2795	1.005	0.950	3305	1.000	1.000
2300	0.990	0.984	2810	1.014	0.951	3320	1.000	1.000
2315	0.994	0.983	2825	1.023	0.952	3335	1.000	1.000
2330	0.996	0.982	2840	1.032	0.953	3350	1.000	1.000
2345	0.997	0.980	2855	1.040	0.954			

*Normalized to an average value of unity over all wavelengths.

Table 11.8: SWP S/L and T/L Relative Sensitivities*

λ	S/L	T/L	λ	S/L	T/L	λ	S/L	T/L
1150	0.970	1.000	1440	1.020	0.981	1730	0.997	0.994
1160	0.974	0.995	1450	1.020	0.984	1740	0.996	0.995
1170	0.977	0.991	1460	1.020	0.986	1750	0.995	0.995
1180	0.981	0.986	1470	1.020	0.988	1760	0.993	0.995
1190	0.984	0.982	1480	1.020	0.990	1770	0.992	0.995
1200	0.987	0.977	1490	1.019	0.991	1780	0.991	0.996
1210	0.990	0.973	1500	1.019	0.992	1790	0.990	0.996
1220	0.992	0.969	1510	1.019	0.992	1800	0.988	0.996
1230	0.995	0.965	1520	1.018	0.992	1810	0.987	0.996
1240	0.997	0.962	1530	1.018	0.992	1820	0.986	0.997
1250	1.000	0.959	1540	1.017	0.993	1830	0.984	0.997
1260	1.002	0.956	1550	1.016	0.992	1840	0.983	0.997
1270	1.004	0.953	1560	1.016	0.992	1850	0.982	0.998
1280	1.006	0.951	1570	1.015	0.993	1860	0.981	0.998
1290	1.007	0.949	1580	1.014	0.993	1870	0.980	0.998
1300	1.009	0.947	1590	1.013	0.993	1880	0.979	0.998
1310	1.010	0.947	1600	1.012	0.993	1890	0.977	0.999
1320	1.012	0.946	1610	1.011	0.993	1900	0.976	0.999
1330	1.013	0.947	1620	1.010	0.993	1910	0.975	0.999
1340	1.014	0.948	1630	1.009	0.993	1920	0.974	1.000
1350	1.015	0.949	1640	1.008	0.993	1930	0.973	1.000
1360	1.016	0.952	1650	1.007	0.993	1940	0.972	1.000
1370	1.017	0.955	1660	1.006	0.993	1950	0.971	1.001
1380	1.018	0.958	1670	1.005	0.993	1960	0.971	1.001
1390	1.018	0.962	1680	1.004	0.993	1970	0.970	1.001
1400	1.019	0.965	1690	1.003	0.994	1980	0.969	1.002
1410	1.019	0.970	1700	1.001	0.994			
1420	1.020	0.973	1710	1.000	0.994			
1430	1.020	0.977	1720	0.999	0.994			

*Normalized to an average value of unity over all wavelengths.

Corrections are also applied to the absolute flux spectrum to take into account changes in camera sensitivity as a function of time (observation date) and camera temperature (THDA). The derivation and application of these corrections are detailed in the following sections.

11.1.4 Time-Dependent Degradation Correction

The sensitivity of the SEC Vidicon camera is known to degrade with time, hence the need for a method to correct for this loss. One of the fundamental requirements of the *IUE* Final Archive is that the dataset be fully intercomparable. The sensitivity degradation correction is essential in satisfying this requirement and allowing full utilization of the remarkably long timeline of *IUE* observations. The broad-band sensitivity analysis (Garhart 1992a) that monitors the degradation effects on the optical coatings of the camera caused by exposure to radiation is of insufficient resolution to provide a proper correction algorithm. The analysis described herein was motivated as a result of this concern.

11.1.4.1 Database

The database employed in the analysis contains the same images used for quick-look sensitivity monitoring and consists of several hundred low-dispersion point source and trailed observations distributed amongst the sensitivity monitoring standard stars. Each image was carefully examined for defects such as data dropouts, cosmic ray hits, etc. and any corrupted spectra were discarded. All of the data were uniformly reprocessed using the prototype final archive processing software (Nichols-Bohlin 1990) and the updated line library and wavelength calibration (Bushouse 1991a). The original databases include images taken through early 1992 for the SWP, mid-1993 for the LWP, and late 1994 for the LWR.

11.1.4.2 Analysis

The analysis was done on the extracted net spectra, before application of the absolute calibration (i.e., in flux numbers), and the data sets for each standard star were treated separately. The spectra were corrected for camera head amplifier temperature (THDA) induced sensitivity variations (Garhart 1991) and sections of the spectra affected by camera reseaux were interpolated across using adjacent good data points. Several absorption features (e.g., Si IV, C IV, and geocoronal Ly α,) were also interpolated across by applying the same technique. Each spectrum was then normalized by dividing by an average of several spectra taken in a six-month time period centered on 1985. The normalized data were then binned in 5Å intervals and a set of degradation ratios was produced by performing a final binning of the data at six-month intervals. The ratios derived from each standard star were compared and found to be in good agreement, so the last step of the process was repeated using all the data and a combined set of degradation ratios was derived. The same analysis was performed on low-dispersion trailed data and a separate set of degradation ratios was produced. Subsequent testing of the trailed corrections showed that only the SWP solutions provided any improvement over use of point source corrections when applied to trailed data.

Therefore, the LWP and LWR cameras apply point source degradation corrections to the trailed data.

11.1.4.3 Initial Fits to the Ratios

LWP - The LWP camera appears to have two behavioral trends in sensitivity degradation (Teays and Garhart 1990). The division occurs at approximately 1984.5, which corresponds to the time this camera became the default camera. Post-1984.5 data are corrected using a linear fit (Bevington 1969) to the ratios in that time period, while images taken prior to 1984.5 are corrected using a linear interpolation between each pre-1984.5 degradation ratio. The fluxes of corrected pre-1984.5 data will be less accurate than the fluxes of corrected post-1984.5 data due to the higher uncertainty in the degradation ratios for the early data. Fortunately little science data (except for calibration images) were taken using this camera during the pre-1984.5 time period, so the impact on the entire archive is minimal.

LWR - As is the case with the LWP camera, the LWR exhibits two trends with the dividing point occurring at approximately the same time. However, since the LWR is a closed data set, the binned degradation ratios were fit with a fourth-order polynomial covering the entire time period.

SWP - The SWP sensitivity degradation for the post-1979.5 epoch is represented by a linear relationship. The 1978.5 to 1979.5 epoch degradation ratios, which exhibit a behavior unlike the post-1979.5 epoch, were fit using a linear interpolation between each discrete point (Garhart 1992c).

11.1.4.4 Calibration Updates

1995 Update - In early 1995, concerns were raised about the accuracy of the extrapolations of the sensitivity corrections to times beyond the original database of observations. While no errors due to the extrapolated corrections were seen in NEWSIPS data, the *IUE* Project felt that updating the old sensitivity degradation analysis would result in more accurate fluxes for post-1992 and 1993 images. As a result of these concerns, the LWP and SWP sensitivity degradation analysis was updated in 1995 using data taken though the beginning of 1995. These new corrections were applied to post-01 January 1990 images while the old corrections were used for pre-1990 images. This 1995 update represents the first sensitivity degradation calibration update. No calibration update was required for the LWR camera, as it comprised a closed data set.

1996 Update - Towards the end of 1996, a changing trend in the late-epoch sensitivity degradation of the SWP camera was seen. Absolutely calibrated fluxes of post-1994 data showed systematic errors of approximately −3% (i.e., lower fluxes) when compared with images taken prior to 1994. This indicated that the 1995 updated calibration was under-correcting the post-1994 data and could occur if the rate of SWP camera degradation were increasing. In the case of the LWP camera, there was marginal evidence for a possible opposite effect, namely a slight overcorrection of post-1995 data, which could occur if the rate of camera degradation were tapering off. As a result, the SWP low-dispersion point source sensitivity degradation correction analysis was updated to include data taken through August of 1996 (Garhart 1997). In order to join the new late-epoch correction smoothly to the existing linear fit, a new linear fit was computed, joined to the old linear fit at a specific time (1993.0) and extended through a point defined by the average of the last three time-binned fluxes (i.e., an average of 1995.5, 1996.0, and 1996.5 bins). This resulted in a set of segmented linear fits (one for each wavelength bin) which are splicings of the previous linear fits and the late-epoch linear fit. A similar approach was tried with both SWP trailed and LWP point source data. However, in both cases the use of a segmented correction was no better than using an extrapolation of the old sensitivity degradation correction. Therefore the *IUE* Project decided to continue to use an extrapolation of the 1995 sensitivity degradation correction update for these two cases.

11.1.4.5 Application of Degradation Correction

The degradation ratio at 1985.0, which corresponds to the mean time of the ITFs, was calculated for each wavelength bin using the linear fits. A zeropoint correction was then applied to the y-intercepts in order to force the degradation ratios to be one. This ensures that no degradation correction will be applied to data near the 1985.0 fiducial date.

The ratios are applied to the net flux spectra using a nearest neighbor wavelength interpolation scheme along with the inverse sensitivity function so as to provide absolutely calibrated and degradation-corrected flux data. Extended source images are corrected using the point source ratios. The correction is performed in the following manner:

- The appropriate coefficients which correspond to the calibration epoch of the observation in question are identified. In the case of the LWR camera, there is only one calibration epoch.

- A correction ratio for each wavelength is calculated in the following manner:

  $$R_t = R_0 + R_1 D + R_2 D^2 + R_3 D^3 + R_4 D^4$$

  where D is the observation date expressed as either decimal years (e.g., 1984.3) for the LWP and SWP or decimal years minus 1978.0 (e.g., 6.3 for an observation date of 1984.3) for the LWR. In addition, the coefficients R_2, R_3, and R_4 are zero for the LWP and SWP.

- The correction ratio is applied as follows:

  $$Time\ Dependent\ Corrected\ Flux_\lambda = FN_\lambda / R_t(\lambda)$$

  where λ refers to the closest 5Å bin and $R_t(\lambda)$ is the R_t value for that bin.

11.1.5 Temperature-Dependent Degradation Correction

IUE flux values are corrected for variations in camera sensitivity as a function of THDA using the temperature-dependent coefficients as derived from the sensitivity monitoring analysis (Garhart 1991). This correction is applied to the net flux along with the absolute calibration and sensitivity degradation corrections according to:

$$R_T = \frac{1}{(1 + C(THDA - ref.\, THDA))}$$

and

$$Temperature\ Dependent\ Corrected\ Flux = FN_\lambda \times R_T$$

where $Flux$ is the net flux, C is the temperature coefficient and $ref.\, THDA$ is the reference THDA. The reference THDA was calculated by taking an average of the THDAs for the sensitivity monitoring data which were used to derive the temperature coefficients. Table 11.9 contains the correction values, as used in the above equation.

Table 11.9: Temperature Coefficients and Reference THDAs

	LWP	LWR	SWP
Temp. Coef. C	-0.0019 ± 0.0003	-0.0088 ± 0.0004	-0.0046 ± 0.0003
Ref. THDA (°C)	9.5	14.0	9.4

11.1.6 Application of Calibrations and Corrections

It is important to note that, as implemented in the image processing software, the interpolated inverse sensitivity values, time- and temperature-dependent sensitivity corrections, effective exposure time normalization, and any overall gain correction factor (for non-standard exposure or read gain or LWR UVC voltage settings) are computed as independent correction factors and then all applied simultaneously to the net flux and sigma spectra to result in fully calibrated and corrected spectra in absolute flux units. The net flux spectrum (in FN units), as determined by *SWET*, that is retained in the low-dispersion extracted spectrum does not have any of these correction factors applied to it. The calibrations and corrections are applied as follows:

$$F_{calib} = FN_\lambda \times S_\lambda^{-1} \times gain \times R_T/R_t/t_{eff}$$

$$\sigma_{calib} = \sigma_{FN_\lambda} \times S_\lambda^{-1} \times gain \times R_T/R_t/t_{eff}$$

where S_λ^{-1} is the inverse sensitivity (including any necessary S/L or T/L response corrections), $gain$ is the cumulative UVC voltage and gain correction factor (if necessary), R_t and

R_T are the time- and temperature-dependent sensitivity correction factors, respectively, and t_{eff} is the effective exposure time. The values for S_λ^{-1} and R_t are evaluated at the wavelength of each pixel through quadratic and nearest neighbor interpolation, respectively, of their tabulated values. The resulting absolutely calibrated units are ergs/cm^2/Å/sec.

11.2 High-Dispersion Absolute Flux Calibration

11.2.1 Ripple Correction

A distinctive feature of echelle gratings is the variation in sensitivity as a function of wavelength within a spectral order, commonly known as the blaze function. The adjustment applied to eliminate this characteristic is referred to as a ripple correction. The use of the term "ripple" becomes apparent when the net fluxes in successive orders are plotted as a function of wavelength. A series of scalloped or ripple patterns appear which must be corrected for prior to the application of the absolute calibration.

The ripple correction and all associated equations are defined in Cassatella (1996, 1997a, 1997b). The basic form of the ripple correction as a function of order number and wavelength is:

$$R_m = \sin^2 x/x^2$$

where x is expressed as:

$$x = \pi m\alpha(1-\lambda_c)/\lambda,$$

the α parameter is given as a function of order number:

$$\alpha = A_0 + A_1 m + A_2 m^2,$$

and the central wavelength corresponding to the peak of the blaze is:

$$\lambda_c = W_0/m + W_1 T + W_2 D + W_3.$$

Note that unlike the SWP camera, the LWP and LWR ripple corrections do not exhibit a dependence of central wavelength on THDA; instead the observed central wavelengths vary linearly with time. In addition, the LWR α parameter evinces a bimodal behavior which has been fit with two separate functions (i.e., a linear and a quadratic polynomial). Here, m is order number, λ is wavelength in Ångstroms, T is the THDA, and D is the observation date in decimal years. The ripple correction is applied to the net flux prior to the application of the heliocentric velocity correction to the wavelengths. The various ripple coefficients used in the above equations are given in Table 11.10 for each camera.

11.2.2 Absolute Flux Calibration Function

The high-dispersion inverse sensitivity curve is defined to be the product of the low-dispersion inverse sensitivity curve and a wavelength-dependent high-to-low absolute calibration function (Cassatella 1994, 1996, 1997a, 1997b):

$$C = n/N$$

Table 11.10: High-Dispersion Ripple Coefficients

Coefficients	LWP	LWR		SWP
		$m < 101$	$m \geq 101$	
A_0	0.406835	3.757863	1.360633	0.926208
A_1	0.01077191	−0.0640201	−4.252626e−3	0.0007890132
A_2	−5.945406e−5	3.5664390e−4	0.0	0.0
W_0	230868.177	230538.518		137508.316
W_1	0.0	0.0		0.0321729
W_2	−0.0263910	−0.0425003		0.0
W_3	56.433405	90.768579		2.111841

where C is the calibration function, n is the low-dispersion net flux normalized to the exposure time, and N is the high-dispersion ripple-corrected net flux also normalized to the exposure time. The calibration function represents the efficiency of high-dispersion spectra relative to low-dispersion and was determined empirically using pairs of high- and low-dispersion spectra obtained close in time so as to minimize the effects of the time-dependent sensitivity degradation. C is represented functionally as a polynomial in the following form:

$$C_\lambda = C_0 + C_1\lambda + C_2\lambda^2 + C_3\lambda^3$$

where λ is wavelength in Ångstroms. The coefficients used in the calibration function are given in Table 11.11.

Table 11.11: High-Dispersion Calibration Function Coefficients

Coefficients	LWP	LWR	SWP
C_0	251.383956	251.383956	1349.8538
C_1	−0.053935103	−0.053935103	−2.0078566
C_2	0.0	0.0	1.10252585e−3
C_3	0.0	0.0	−2.0939327e−7

11.2.3 Application of Calibrations and Corrections

High-dispersion absolutely-calibrated fluxes are obtained using a combination of the high-dispersion net fluxes, the ripple correction, the high-dispersion calibration function, the low-dispersion inverse sensitivity function, time- and temperature-dependent sensitivity corrections, effective exposure time normalization, and any overall gain correction factor (for non-standard exposure or read gain or LWR UVC voltage settings). The calibrations and corrections are applied as follows:

$$F_{calib} = FN_\lambda \times S_\lambda^{-1} \times gain \times R_T \times C_\lambda / R_m / R_t / t_{eff}$$

where S_λ^{-1} is the low-dispersion inverse sensitivity including any necessary S/L response correction, *gain* is the cumulative UVC voltage and gain correction factor (if necessary), R_t and R_T are the time- and temperature-dependent sensitivity correction factors, respectively, C_λ is the high-dispersion calibration function, R_m is the ripple correction, and t_{eff} is the effective exposure time. Except for R_m and C_λ, all corrections are defined in the previous section concerning low-dispersion calibrations. No T/L response correction is used for high-dispersion trails, as they are obtained by slewing across the minor-axis (versus the major-axis for low-dispersion trails) of the aperture and therefore the low-dispersion T/L ratio is not applicable. The values for S_λ^{-1} and R_t are evaluated at the wavelength of each pixel through quadratic and nearest neighbor interpolation, respectively, of their tabulated values. The resulting absolutely calibrated units are ergs/cm^2/Å/sec.

Note: an error in the application of the time-dependent sensitivity degradation correction for LWP and LWR high-dispersion images was detected after the majority of these images were processed by GSFC. The error is such that it applies an incorrect solution to fluxes longward of approximately 2712Å and is on the order of several percent shortward of 3000Å, but can increase to 20% or more beyond 3200Å. LWP and LWR images affected by this error can be identified by a NEWSIPS version number of 3.3.1 or 3.3.2 in the processing history portion of the FITS header. It is the project's intent to correct this error by re-archiving corrected high-dispersion merged extracted image FITS files (MXHIs). Such corrected files will be identifiable by notations in the NEWSIPS processing history. Corrected LWP and LWR MXHIs will carry NEWSIPS version numbers of 3.3.1_A_C and 3.3.2_A_C, respectively. Additionally, the version numbers in these corrected files will be appended with the following text: "(CORRECTED SENS. DEGRAD.)". Data processed with the corrected NEWSIPS high-dispersion image processing pipeline system will be identifiable by a NEWSIPS version number of 3.3.3.