RECALIBRATION FOR THE FINAL ARCHIVE OF THE
INTERNATIONAL ULTRAVIOLET EXPLORER (IUE)
SATELLITE

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1. RATIONALE

Since its launch in 1978, the International Ultraviolet Explorer (IUE) satellite has obtained more
than 80,000 ultraviolet spectra of astronomical sources in the 1170-3200 Å spectral region and con-
tinues to operate with no major loss of capability. IUE obtains both low dispersion (6 Å resolution)
and high dispersion ($\lambda/\Delta\lambda \approx 10,000$) spectra with the short wavelength SWP and long wavelength
LWP and LWR cameras. The scientific accomplishments of IUE have been summarized by Kondo
et al. (1989) and by Kondo, Boggess, and Maran (1989).

For the past several years the IUE Project has been developing the software needed to reprocess
the entire data set into a form suitable for its Final Archive. The objective of the Final Archive
Project is to produce a uniform archive of all spectra, including enhanced signal-to-noise and
corrections for fixed pattern noise and scattered light, and new algorithms for sensitivity changes
with time and spectrograph temperature. The Final Archive will use the new Signal Weighted
Extraction Technique (Kinney, Bohlin, and Neill 1991) to extract spectra with the highest feasible
signal/noise and will use the best available absolute flux calibration. The present brief report
will summarize the absolute flux calibration approach used in preparing the Final Archive; more
complete descriptions are now being written by González-Riestra, Cassatella, and de la Fuente

2. PREVIOUS RADIOMETRIC CALIBRATIONS OF THE IUE SECTRO-
GRAPHS

The approaches used in creating the previous photometric calibrations of the IUE satellite are
described briefly here and summarized in Table 1. The photometric calibration involves first the
construction of an Intensity Transfer Function that removes the nonlinearities in converting raw
data numbers (DN) from each SEC Vidicon detectors to flux numbers (FN) for each pixel. Then
for low-dispersion large-aperture untrailed spectra, the relative instrumental sensitivity with wave-
length scale is determined by reference to broadband observations of a small number of standard
stars that are calibrated by instruments on the OAO-2, TD-1, and ANS satellites and several rocket
experiments. The absolute flux scale is set by reference to the star $\eta$ UMa which was observed by
the same space experiments.

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The various calibrations mentioned here differ in the epochs for which data were obtained to construct the ITFs and the time intervals during which the standard stars were observed. Close attention was paid to the variation in sensitivity of the cameras with time and spectrograph temperature. The resulting calibration is generally stated as tables of the inverse sensitivity, $S^{-1}$, in units of $10^{-14}$ ergs cm$^{-2}$ Å$^{-1}$ FNU$^{-1}$ ($10^{-17}$ J m$^{-2}$ Å$^{-1}$ FNU$^{-1}$), vs. wavelength. The photometric calibration for high dispersion spectra involves additional steps and is not yet fully understood.

- The first photometric calibration of the SWP and LWR cameras, described by Bohlin et al. (1980), was based on observations of four photometric standard stars observed between March 1978 and February 1979. These stars were HD 60753 (B3 IV), HD 93521 (O9 Vp), BD+28°4211 (O$^p$), and BD+33°2642 (B2 IV). The authors state that for spectral bands wider than 25 Å the reproducibility for repeated observations of the same star is $2\sigma = 6\%$. They believed that their absolute flux scale was probably accurate to $\pm 10\%$ for wavelength bands longward of 1200 Å, but they were concerned about nonlinearities in the derived fluxes.

- The so-called May 1980 recalibration described by Bohlin and Holm (1980) increased the SWP absolute flux scale by the factor $1.093 \pm 0.016$ and the LWR absolute flux scale by the factor $0.937 \pm 0.022$, thereby eliminating a discrepancy between the SWP and LWR fluxes for the same stars near 2000 Å where the two cameras overlap. These recalibrations resulted primarily from the use of additional TD-1 and OAO-2 photometric standards and correction of an error in the reduction of trailed spectra. This recalibration and a correction algorithm to be applied to the previously calibrated data are also described by Holm et al. (1982), who point out that the nonlinearity in the SWP fluxes described by Bohlin et al. (1980) was due to an error in the ITF used at that time. Bohlin and Holm (1984) describe how $\eta$ UMa was used to place the OAO-2 and TD-1 photometric standard stars on a common absolute flux scale.

- After the LWP camera was brought into use in 1982, it was calibrated using four photometric standard stars and four absolute flux standard stars (see Cassatella and Harris 1983).

- In their program to use IUE spectra of 37 stars as calibration standards for HST, Bohlin et al. (1990) derived new calibrations for the SWP, LWR, and LWP cameras using the new ITF for the LWP camera but the original 1978 ITFs for the SWP and LWR cameras. They also used $\eta$ UMa as the absolute flux standard and five other stars as relative photometric standards. Bohlin et al. called attention to a possible systematic error in the absolute flux scale defined by $\eta$ UMa; the ratio of the observed flux of the hot white dwarf G191-B2B to that predicted by model atmosphere calculations is systematically 10-15\% low between 1300 and 1900 Å (see Fig. 1).

<table>
<thead>
<tr>
<th>Cameras</th>
<th>Data obtained</th>
<th>Calibration stars</th>
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<tr>
<td>SWP, LWR</td>
<td>1978-1979</td>
<td>4 standard stars</td>
<td>Bohlin et al. (1980)</td>
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<tr>
<td>SWP, LWR</td>
<td>1978-1979</td>
<td>correction algorithm to previous calib.</td>
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<td>SWP, LWR, LWP</td>
<td>1984-1985</td>
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<td>Nichols-Bohlin &amp; Garhart (1993)</td>
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Fig. 1. Ratio of the IUE flux for the white dwarf star G191-B2B to the predicted flux from a model atmosphere (see Bohlin et al. 1990).

3. THE 1993 RECALIBRATION FOR THE FINAL ARCHIVE

As described in more detail by González-Riestra, Cassatella, and de la Fuente (1993) and by Nichols-Bohlin and Garhart (1993), the Final Archive will include a number of changes in the photometric calibration chain to incorporate what has been learned from 15 years experience in analyzing IUE spectra. The Final Archive will use the 1985 epoch ITF for the SWP camera and the 1992 ITF for the LWP camera. Also, new values have been derived for the effective exposure times. ratios of fluxes when stars are observed either through the small aperture or as trailed spectra compared to untrailed observations through the large aperture, and for the temporal and temperature changes in the sensitivities of each camera.

The relative flux calibration is no longer based on the observed spectra of O-type and B-type stars, which contain many absorption lines and are difficult to model, but rather on the observed spectra of the white dwarf stars G199-B2B and PG1620-391. The model atmosphere spectrum for the hot DA-type white dwarf G199-B2B computed by D. Finley with parameters \(T_{eff} = 58,000\) K and \(\log g = 7.5\) shows a very smooth nearly power-law spectrum with only a weak Lyman \(\alpha\) absorption feature (see Fig. 2). The computed spectrum of the cooler white dwarf PG1620-391 is very similar. A good test of the new relative flux calibration is the shape of the observed flux of the nucleus of the hot planetary nebula NGC 246. Theoretical models predict a simple power-law spectrum, which is confirmed in Figure 3.
The new absolute flux calibration is tied to previous rocket and satellite measurements of several standard stars, in particular η UMa, in the 2100-2300 Å band where the previous absolute flux calibrations by OAO-2 and TD1 are in excellent agreement. This absolute flux calibration point agrees to within 4% with that obtained from observations of G199-B2B using the radius inferred from its visual magnitude and effective temperature. Figure 4 shows the new inverse sensitivity curves for the SWP and LWP cameras. The ratio of the new to the old absolute sensitivity curves is about +4% in the 2000-2400 Å range and +10% in the 1200-1900 Å range, although the ratio exhibits some spectral variations (see Fig. 5). The absolute flux calibration of the high resolution spectra is not complete at this point but will take into account echelle ripple and interorder scattered light.

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4. REFERENCES

Bohlin, R.C., and Holm, A.V. 1984, NASA IUE Newsletter 24, 74.
Figure 2: Model atmosphere flux for the white dwarf star G191-B2B computed by D. Finley.
Fig. 3. Mean of eight spectra of the hot planetary nebula nucleus in NGC 246 calibrated using the white dwarf derived inverse sensitivity function. The straight line is a least-squares fit.
Figure 4: Inverse sensitivity curves for the SWP and LWP cameras.
Figure 5: Ratio of the new inverse sensitivity curves derived from the white dwarf models to the previous inverse sensitivity curves derived from rocket and satellite measurements of the UV flux from standard stars.