

**THE OPTIMAL EXTRACTION
OF
LOW RESOLUTION IUE SPECTRA**

A. L. Kinney

Space Telescope Science Institute

A.R. Rivolo

University of Pennsylvania

November 1987

ABSTRACT

The optimal extraction technique of Keith Horne is applied to IUE spectra. There are three areas of improvement over IUESIPS extraction: 1) A reduction in noise of about 20% (which is equivalent to an increase in effective exposure time of 40%). 2) An elimination of spurious emission lines. 3) An elimination of spikes from cosmic rays adjacent to the spectrum. Several examples are given.

I. INTRODUCTION

The IUESIPS extraction was primarily designed for the reduction of spectra of strong sources with relatively high signal to noise ratios. When reducing the much fainter spectra typical of quasars, BL Lac objects, and Seyfert galaxies, it becomes very important to treat noise in an appropriate way. To illustrate this point, Figure 1 shows a cross cut of SWP10117, a 5 hour exposure of the 15th magnitude quasar, 2201+315. There are only 5 points that are distinguishable from the background, yet the IUESIPS adds with equal weights the data from all 18 points centered on line 55. IUESIPS thus adds considerable **unnecessary** noise to the spectral flux.

Programs that are primarily interested in high signal-to-noise ratio as opposed to absolute flux add only the central few lines of data (Dultzin-Hacyan *et al.* 1982). But considerable flux is thrown away by this method as can be seen in Figure 2, where many samples of data have been summed to show the spectral profile. The profile extends over 9 lines of data and is Gaussian in shape (Figure 3, deBoer *et al.* 1980, Cassatella *et al.* 1984). People that work with quasar data must resort to writing their own reduction routines that weight the data in some appropriate way (Kinney *et al.* 1985). Shouldn't the final archives include an extraction that produces the best possible signal-to-noise ratio for the available data?

The goal is this: **to weight the data points in a way that takes advantage of our knowledge of the spectral profile so that we increase the signal-to-noise ratio while preserving the total flux.** The optimal extraction algorithm used here (Horne 1986) does just that. It solves for the line profile as a function of wavelength imperically, thereby allowing for asymmetry of the profile, for deviation of the profile center, and for defocusing at end of the spectrum (as is the case for the SWP). The algorithm weights data points according to that profile.

II. RESULTS

Three cases are considered; S2394, a 6.3 hour exposure of a 14th magnitude BL Lac object with no features in the spectrum; S10117, a 5 hour exposure of a 15th magnitude quasar with strong emission lines; and S24010, a 7.3 hour exposure of a 16.5 magnitude BL Lac object that is only marginally detected.

Spectra of the IUESIPS and of the optimally extracted spectra are shown in Figures 4 and 5 for S2394 and S10117. The three areas of improvement of the optimally extracted spectra are: 1) The overall SNR is improved. 2) Spurious emission lines no longer appear. 3) Spikes are removed.

To quantify the improvement in SNR in the optimal extraction routine the point to point deviation has been measured and is expressed as a ratio for optimal extraction over IUESIPS extraction.

$$R = \frac{\sqrt{\sum (F_i - F_{i+1})^2_{Opt Ext}}}{\sqrt{\sum (F_i - F_{i+1})^2_{IUESIPS}}}$$

This is a better measure of the noise properties than the standard deviation because it does not increase with the presence of continuum features (like a steep slope) as standard deviation does. However this ratio will increase with the presence of emission lines, so it should be used in regions absent of features.

Table 1 summarizes this ratio for S2394, S10117, and S24010. For S10117, it is relevant to look at the ratio for the first hundred data points, where there are no emission lines or spikes. In that region the point-to-point deviation has gone down by 83% in the optimally extracted spectrum. In S2394 the point-to-point deviation has gone down by 75%. **The decrease in noise is equivalent to an increase in effective exposure time of approximately 40%.**

The spurious emission lines are caused by various forms of noise. In S2394, the feature seen at 1360 Å is caused by a comet like cosmic ray hit (Figure 6), while in S10117 it is caused by an area of warm pixels. Although that may not be clear in Figure 6, it can be clearly demonstrated by taking a cut in line 55 down the middle of the spectrum (Figure 7). The crosscut shows a very strong broad Lyman α line at 1570 Å, but no broad feature at 1665 Å. In other words, the feature seen at 1665 Å in the IUESIPS version is present in the direction perpendicular to the spectrum, but is not apparent in the direction of the spectrum. In addition, the feature falls on an area of warm pixels that is well known.

The spikes seen in the IUESIPS extraction are cosmic ray hits that fall within the IUE extraction slit but do not fall in the central pixels of the spectrum. (Although the optimal extraction algorithm has an option to remove cosmic rays that fall on the spectrum, that option has not been exercised in these examples.) The cosmic ray hits can in some cases be easily identified on a two dimensional picture of the line-by-line file (Figure 6).

The optimal extraction algorithm does depend on imperically determining the profile of the spectrum. In the limit of extremely low flux, the algorithm does not have the information to solve for the profile and should perhaps be modified to allow the spectral profile as a function of wavelength to be set. An example can be seen in Figure 8. In S24010, 0323+022 is just barely detected, and the optimal extraction (Figure 8B) is very noisy. In contrast, the GEX algorithm (the Gaussian Extraction program developed by Gail Reichert and Meg Urry and available at the RDAF) produces a spectrum with less noise. For low level exposures the GEX algorithm is definitely preferable.

III. CONCLUSION

The three benefits of optimal extraction are: 1) An increase in the effective exposure time of 40%. 2) The elimination of spurious features. 3) The removal of spikes due to

cosmic ray hits adjacent to the spectrum. The spike removal may improve even more when the cosmic ray rejection for hits on the spectrum is enabled. The optimal extraction routine as it stands is not the best possible option for extremely low level exposures, where GEX is the superior algorithm. One of the best features of the optimal extraction is the imperical solution for the spectral profile, which automatically takes into account asymmetry in profile, deviation of profile center from line 55, and change in focus as a function of wavelength.

TABLE 1
Ratio of Deviation of Optimal Extraction to IUESIPS

Camera	Entire Spectrum	First 100 Samples
SWP2394	0.7	
SWP10117	0.5 ^a	0.8
SWP24010	1.0	

(a) This is overly optimistic because of the strong spikes that are removed in the optimal extraction routine. The ratio quoted for the first 100 samples, where there are no emission lines and no spikes, is a more realistic measure of the improvement in reduction of noise.

References

Cassatella, A., Barbero, J., and Benvenuti, P. 1980, in *IUE Newsletter*, No. 24, p. 84.

de Boer, J.S., Koornneef, J., and Meade, M.R. 1980, in *The Universe at UV Wavelengths. The First Two Years of International Ultraviolet Explorer*, ed. R.D. Chapman (Greenbelt: Goddard Space Flight Center), p. 771.

Dultzin-Hacyan, D., Salas, L., and Daltabuit, E. 1982, *A.A.*, **111**, 43.

Horne, K. 1986, *P.A.S.P.*, **98**, 609.

Kinney, A.L., Huggins, P.J., Bregman, J.N., and Glassgold, A.E. 1985, *Ap. J.*, **291**, 128.

FIGURE CAPTIONS

Figure 1. A crosscut of SWP10117 at sample number 200 (approximately corresponding to 1260 Å). IUESIPS adds with equal weights 18 data points centered on line 55, represented here by filled in diamonds. IUESIPS forms the background by skipping 9 data points on either side of the central 18 and median filtering and smoothing data in the next 5 lines. These two strips are then averaged for the background.

Figure 2. A cross cut of SWP10117 summed over 150 samples, demonstrating the spectral profile of IUE. Only the central 30 lines are shown.

Figure 3. The same sum as above, with a Gaussian profile overlaid. The spectral profile is practically indistinguishable from the Gaussian profile.

Figure 4. A: The IUESIPS extraction of S2394 using a boxcar slit 18 data points wide. B: The optimal extraction of the same camera. Note the absence in B of the spurious emission line at 1370 Å.

Figure 5. A: The IUESIPS extraction of S10117. Tick marks show the positions of the nearby emission features of Lyman α at 1215.6 Å and OI at 1302 Å. B: The optimal extraction of the same camera. Note the absence in B of the spurious emission line at 1665 Å.

Figure 6. The first 512 samples of the line-by-line file for S10117 and S2394. Note the comet like cosmic ray hit in S2394 which results in the spurious emission line seen in Figure 5A at 1370 Å. Note the strong cosmic ray hit adjacent to the left side of the spectrum in S10117 that appears in the IUESIPS extraction at about 1460 Å.

Figure 7. Line 55 of S10117.

Figure 8. A: The GEX extraction of S24010. B: The optimal extraction of the same spectrum.

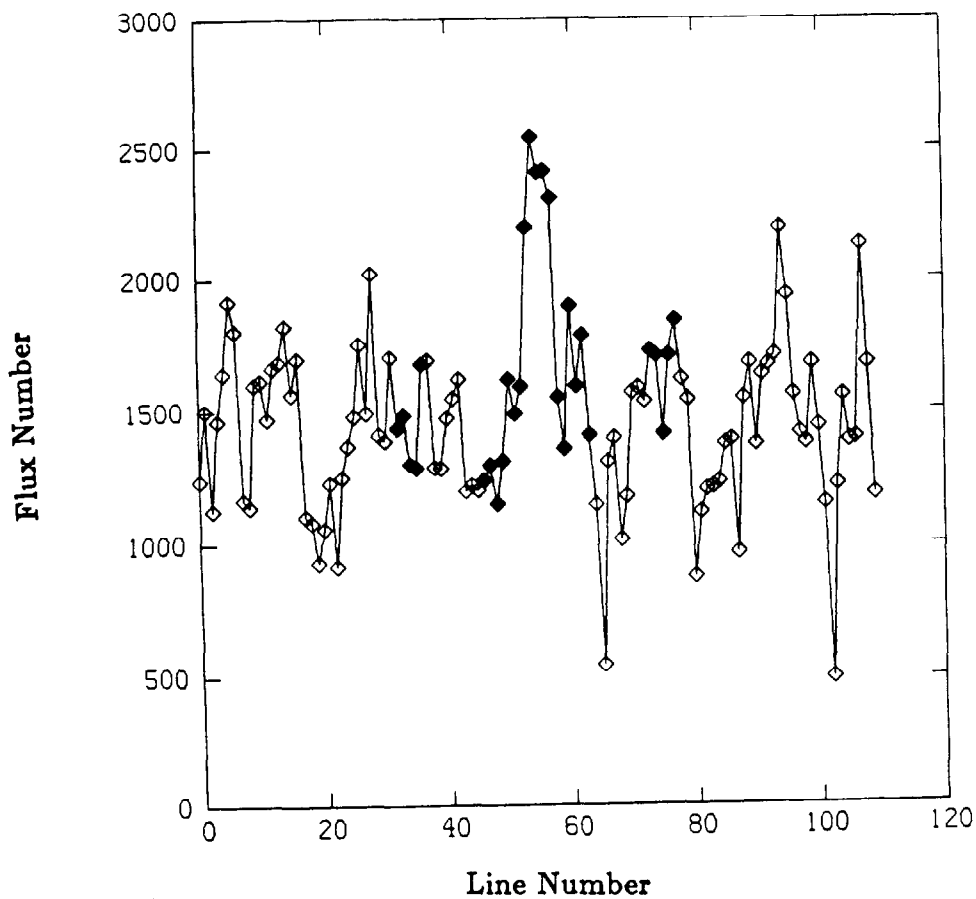


Figure 1. S10117. Crosscut at sample 200.

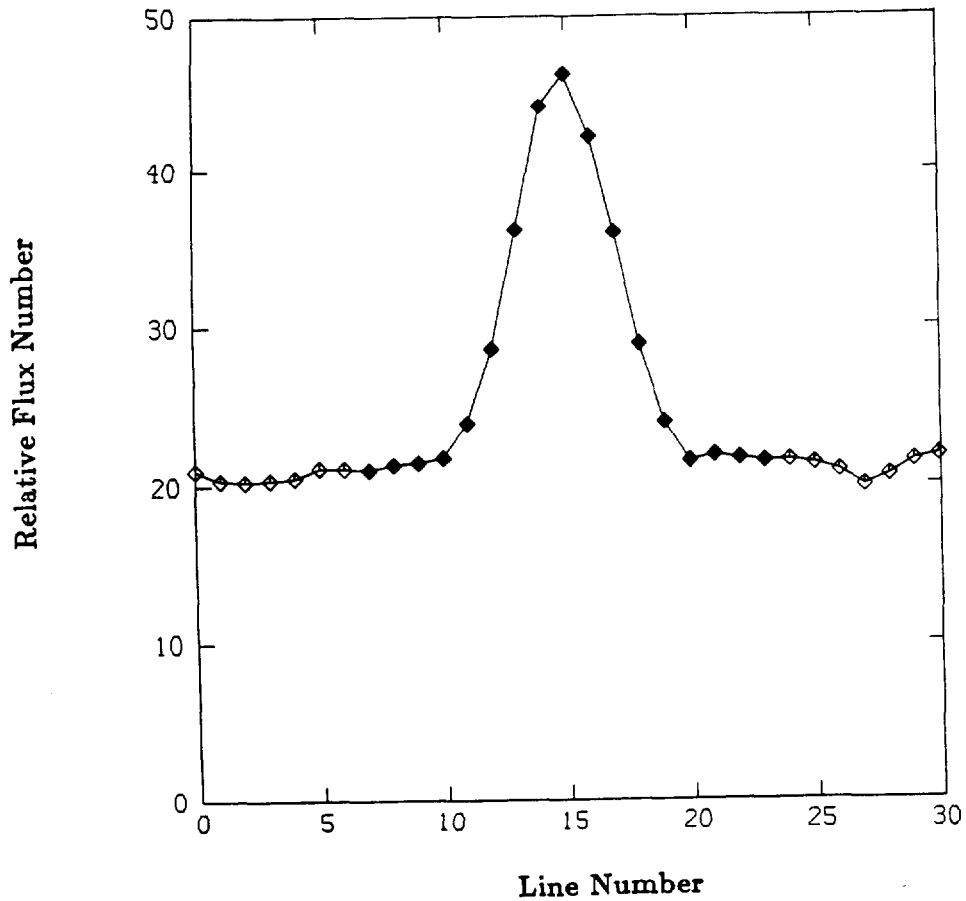


Figure 2. S10117. Crosscut summed from sample 200 to 350.

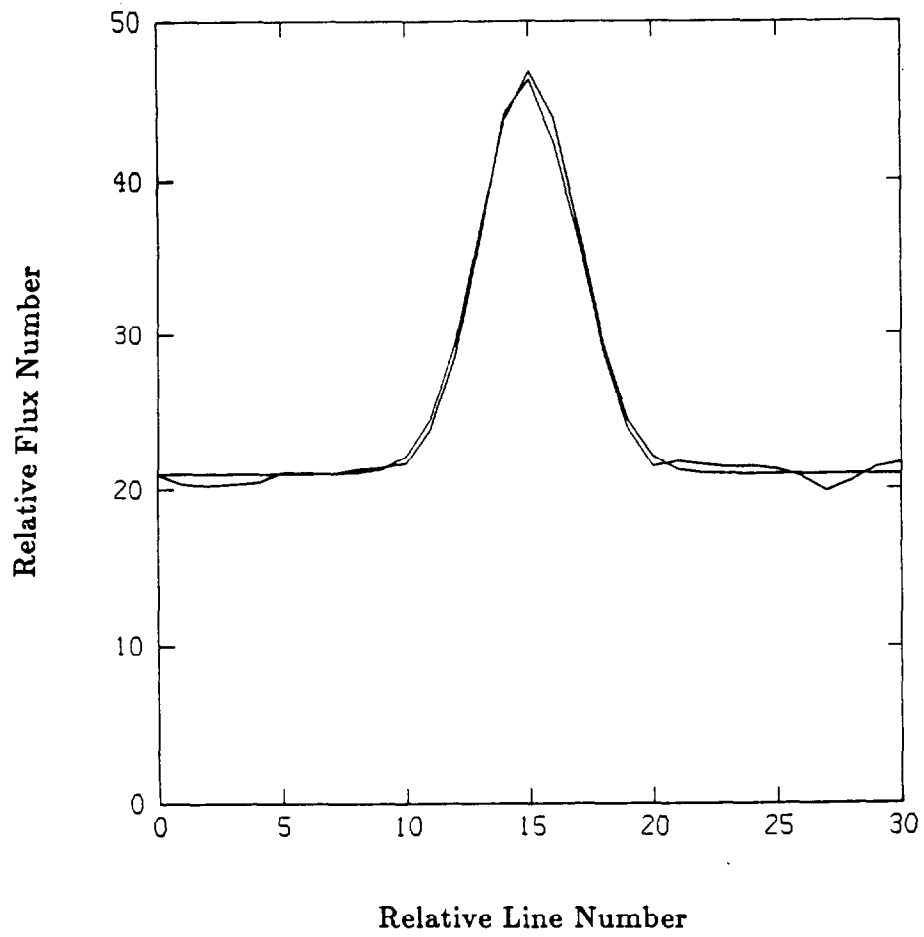


Figure 3. S10117. Summed crosscut with Gaussian overlay.

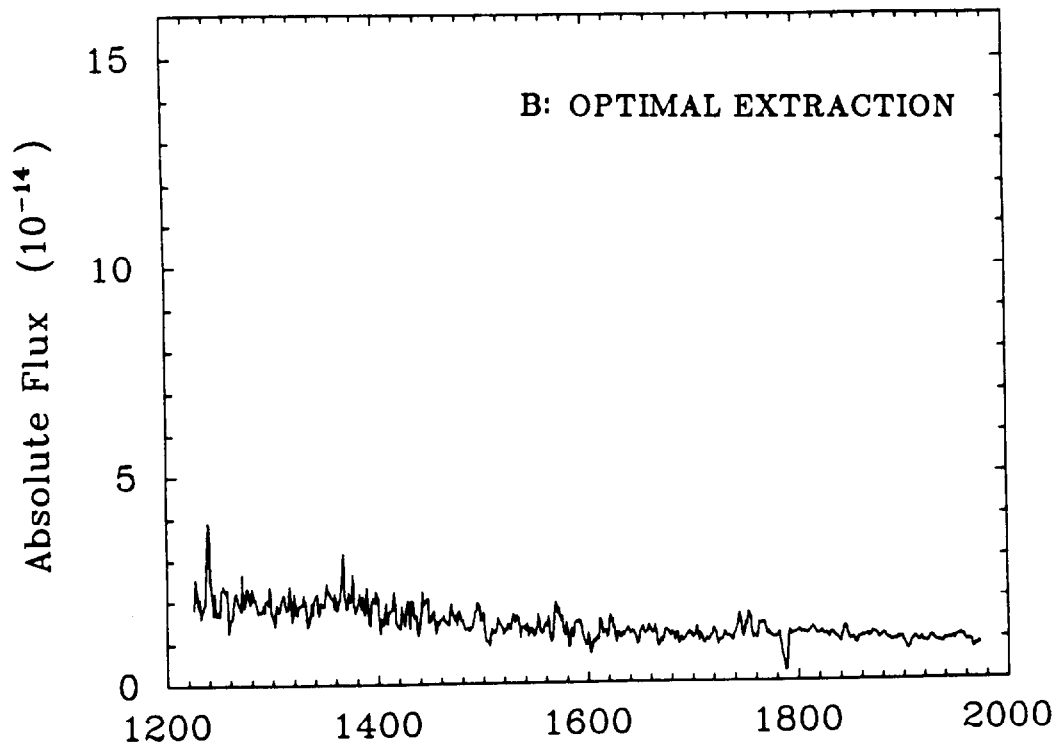
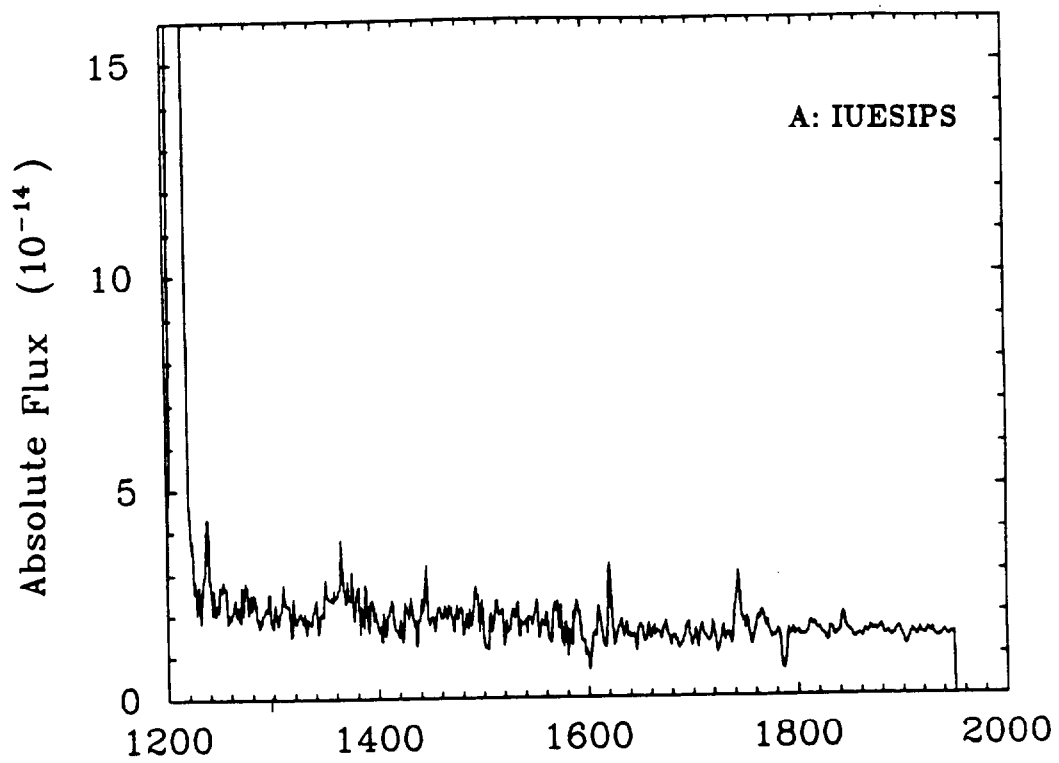


Figure 4. A: IUESIPS extraction for S2394. B: Optimal extraction for S2394

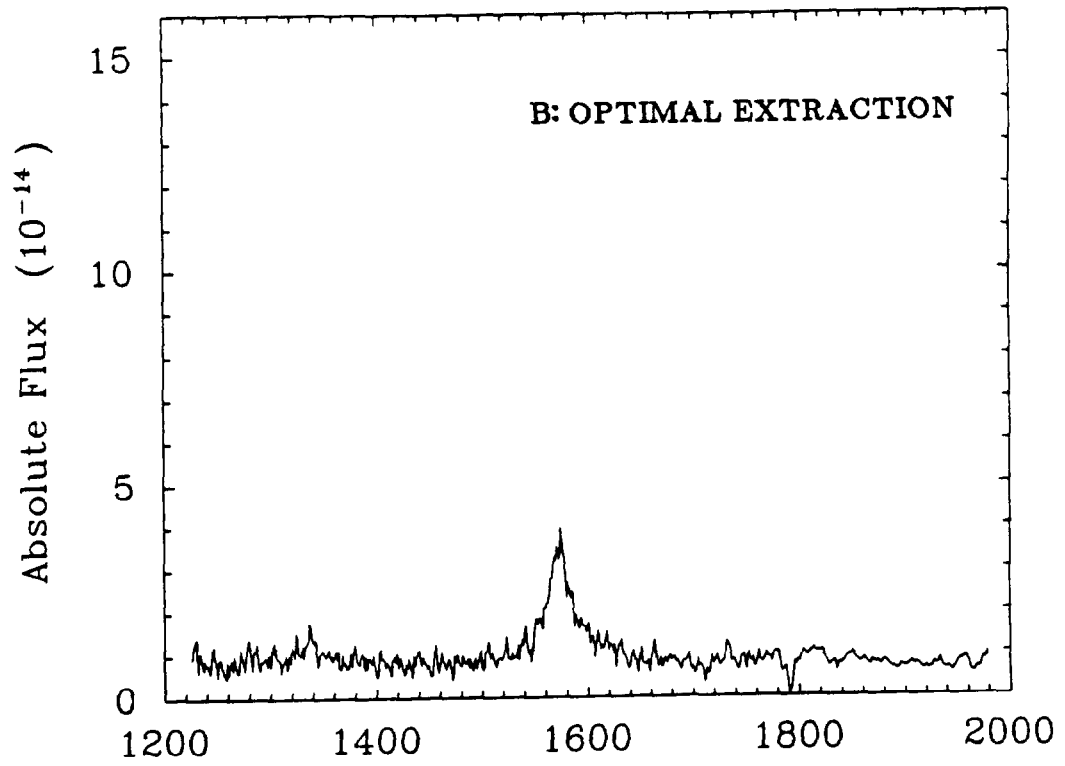
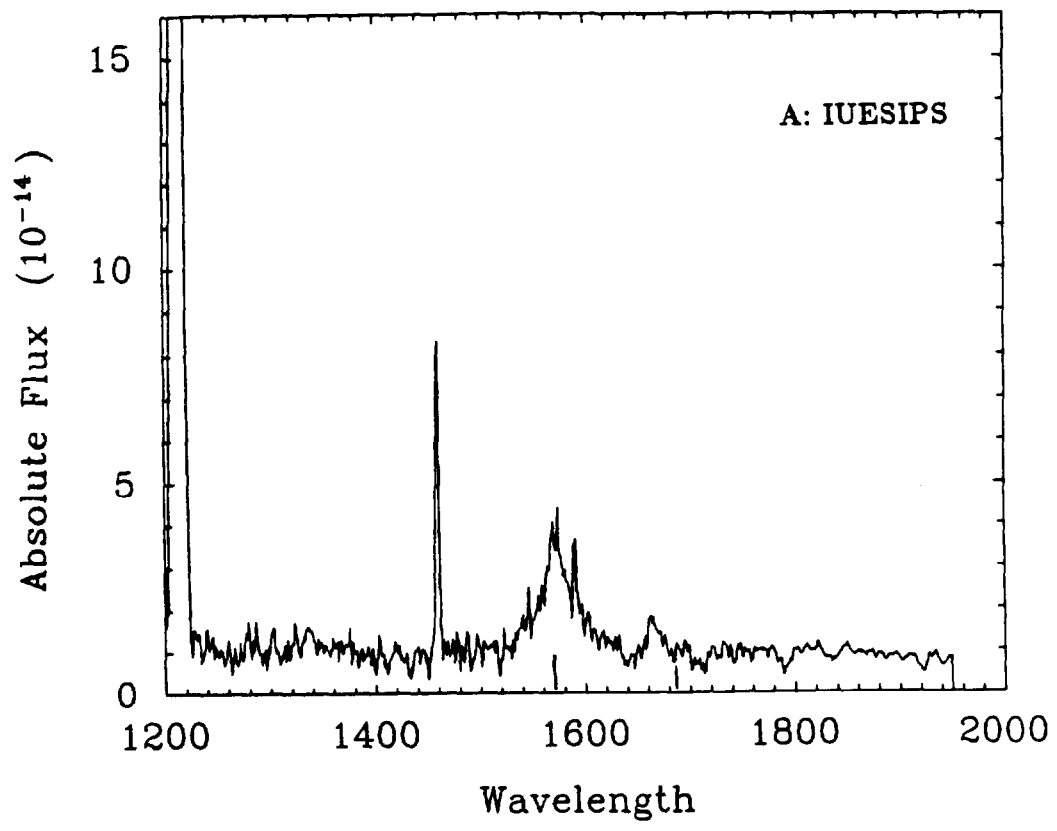
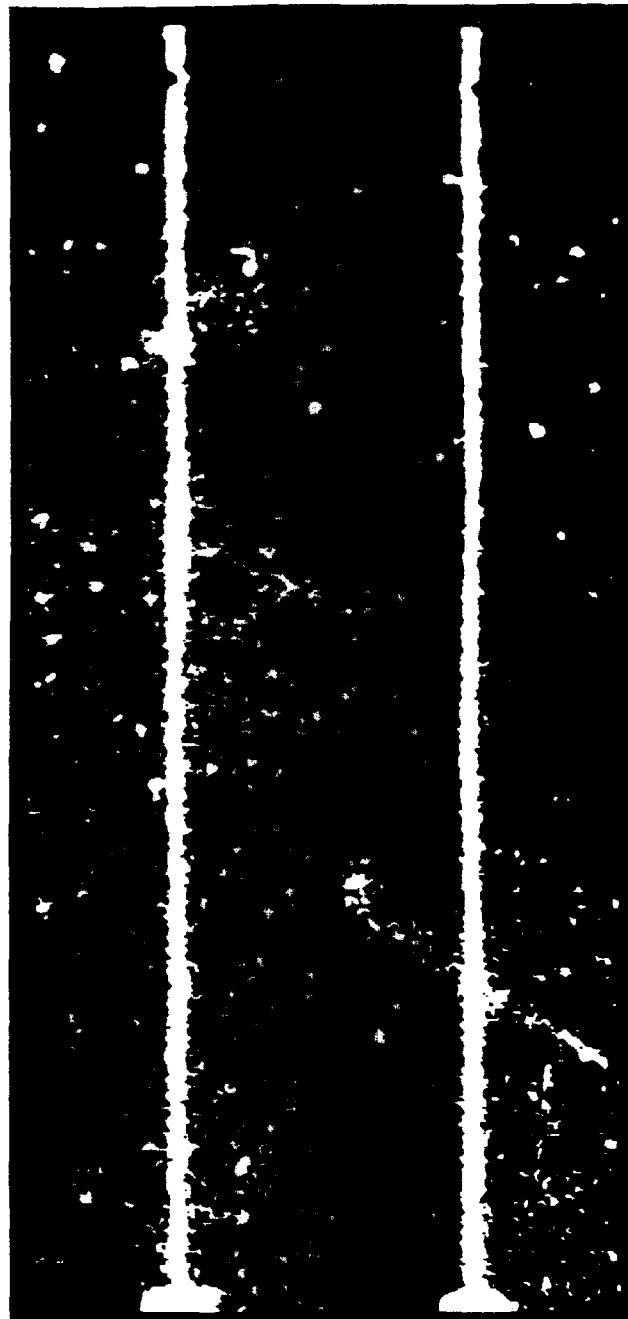


Figure 5. A: IUESIPS extraction for S10117. B: Optimal extraction for S10117.



S10117

S2394

Figure 6. Line-by-line file for S10117 and S2394.

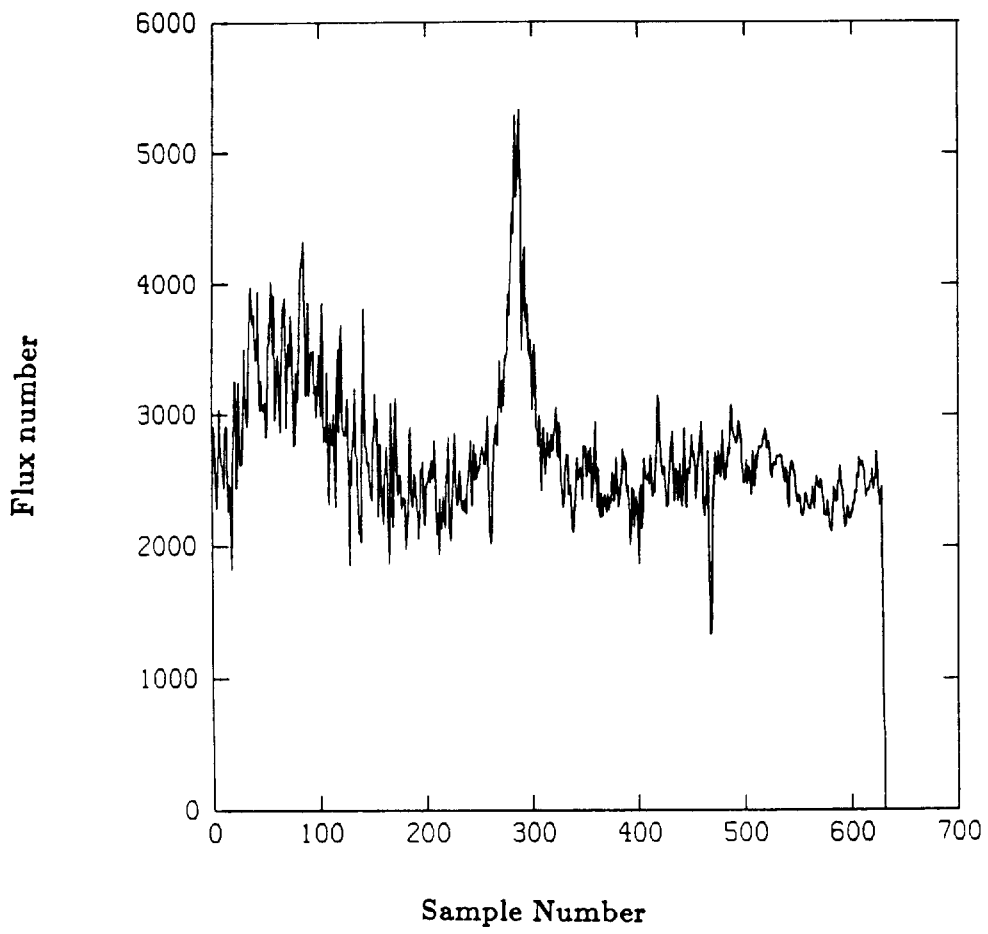


Figure 7. S10117. Cut along line 55 of spectrum.

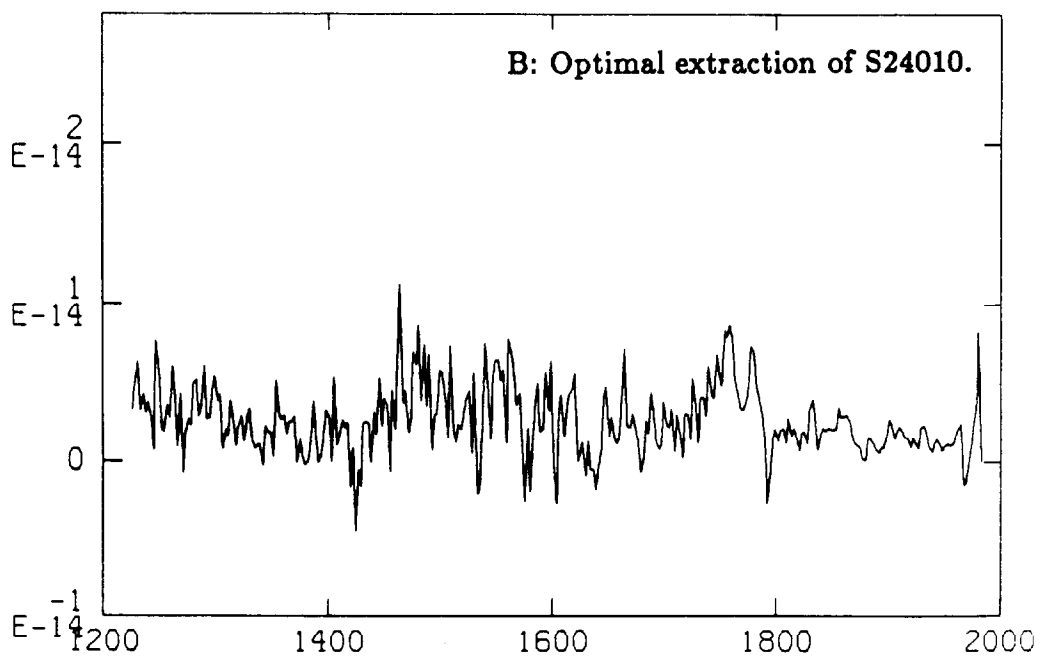
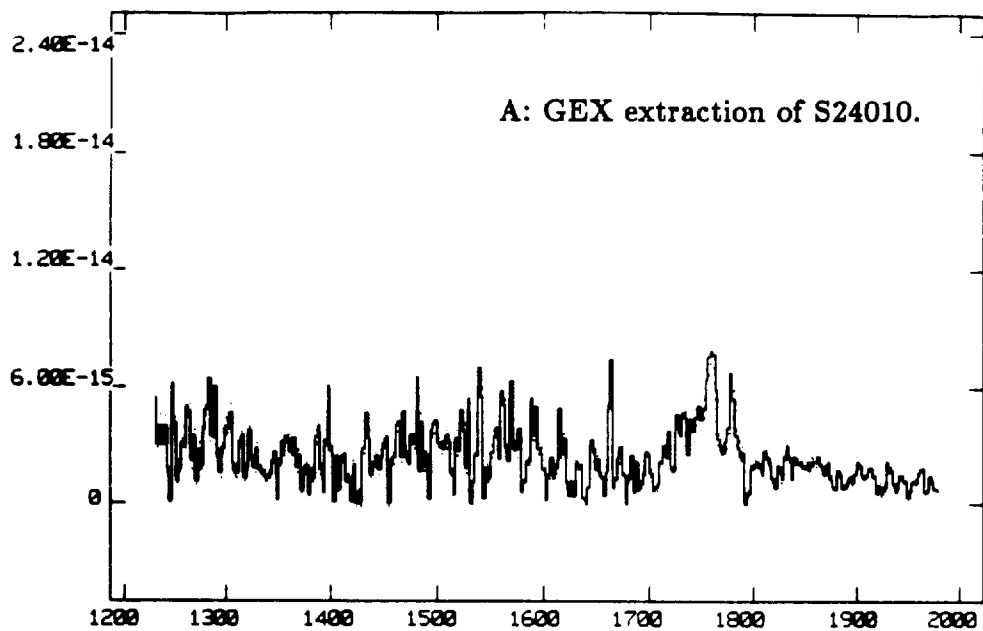


Figure 8. A: GEX extraction of S24010. B: Optimal extraction of S24010.