EXTRACTION OF LOW DISPERSION SPECTRA FOR INES

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Abstract

In this paper we outline the modifications introduced to the optimal extraction algorithms for *IUE* Low-Dispersion data under *INES*. A major modification has been the creation of new noise models for the three cameras, in order to improve the handling of very high and very low FN values. Other changes affect the background estimate, the extraction profile determination and the treatment of flagged pixels. Altogether, the changes do not affect significantly to the vast majority of *IUE* Low-Dispersion data, but definitely improve the quality for those cases where *SWET* was known to produce unsatisfactory results.

Key words: IUE; Optimal Extraction

1 INTRODUCTION

A revision of the optimal extraction algorithms used in NEWSIPS (**S**_ignal_ **W**_eighted_ **E**_xtraction_ **T**_echnique_, *SWET*) has been motivated by the unsatisfactory results provided under some conditions. The aim has been to modify the algorithms in order to improve the treatment of such cases, but preserving the good performance of *SWET* for the vast majority of *IUE* LORES spectra.

The basic equation for any optimal extraction is (Horne (1986)):

$$FN(\lambda) = \frac{\sum_x \left[FN(x,\lambda) - B(x,\lambda)\right] \frac{p(x,\lambda)}{\sigma(x,\lambda)^2}}{\sum_x \frac{p(x,\lambda)^2}{\sigma(x,\lambda)^2}} \quad (1)$$

where

- x is the spatial coordinate in the SILO file

- λ is the spectral coordinate in the SILO file
- $FN(x, \lambda)$ is the FN value at pixel (x, λ) in the spatially resolved (SILO) file
- $B(x, \lambda)$ is the background at pixel (x, λ).
- $\sigma(x, \lambda)$ is the noise at pixel (x, λ).
- $p(x, \lambda)$ is the extraction profile at pixel (x, λ).
- $FN(\lambda)$ is the total flux number (FN) at λ

From Eq. 1, the extraction error ($\Delta FN(\lambda)$) associated to $FN(\lambda)$ is given by

$$\frac{1}{\Delta FN(\lambda)^2} = \sum_x \frac{p(x, \lambda)^2}{\sigma(x, \lambda)^2} \tag{2}$$

The power of *any* optimal extraction procedure is driven by the accuracy with which the background ($B(x, \lambda)$), the extraction profile ($p(x, \lambda)$) and the errors ($\sigma(x, \lambda)$) can be determined. These determinations are model dependent and the best results are obtained after the fine-tuning of many parameters. The election of the parameters determine at the same time the type of data for which the performance will be optimal *and* the type of data for which the technique may be unsatisfactory. It is also worthy to remark that these equations were obtained and are directly applicable to CCD's, but the *IUE* detectors are TV cameras which behave quite differently from CCD's.

If the processing of the data is done interactively, the best set of parameters can be used for each case, but for an automatic processing of a large data set with fixed extraction parameters, these should be chosen so as to cover the largest number of possible cases. It is obvious that if the parameters are chosen so as to comply with many different data types, the performance for each particular type will be degraded.

It is worth to recall that the purpose of any optical extraction technique is to obtain the best representation of the actual data. And by best it is meant that representation of the *real* data with the minimum realistic error. It may well happen, and actually it happens, that if the extraction parameters are the best suited for a particular case, these same parameters will provide meaningless results for a different case.

According to this and Eq 1, the application of the Eq 1 to *IUE* data requires a careful determination of the noise model (Sect. 2), the background estimate (Sect. 3), the extraction profile (Sect. 4) and the treatment of "bad" quality "pixels" (Sect. 5).

2 Noise models

The noise models used by *SWET* are based on polynomial fits to a set of available data. These polynomials represent well the noise behaviour of the detectors within the dynamic range defined by the data from which the coefficients were obtained. However, outside this range (very high and very low FN values) the extrapolation given by the polynomials is not satisfactory.

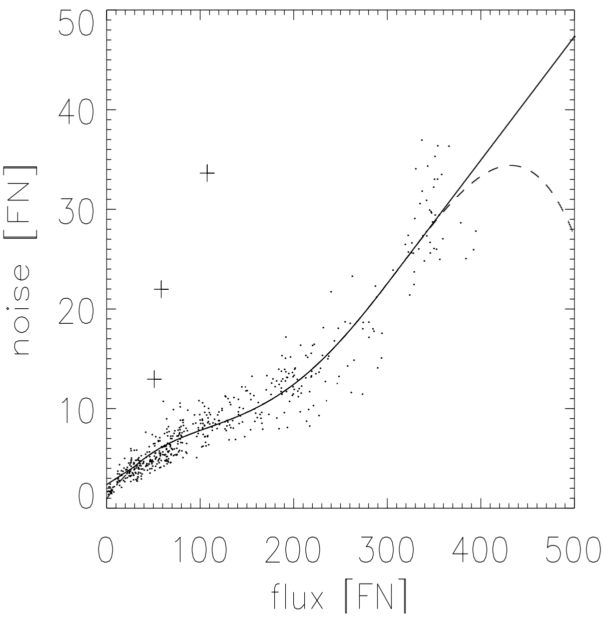

Figure 1: *The dots represent the derived standard deviation, $\sigma\,(FN)$ over the corresponding median flux numbers $< FN >$ for a wavelength of 1652Å. The crosses indicate data values which were not considered for the modeling of the data. The continuously drawn line shows the finally accepted polynomials and the corresponding extrapolation. For comparison, the broken line shows the extrapolated polynomial used in SWET.*

Analogue to *SWET* (Garhart et al. (1997, Chapter 9), compare also Kinney, Bohlin and Neill (1991)) the *INES* noise models are derived empirically from some hundreds of flat-field images. The process to obtain the models can be structured in three steps:

1. The mean FN values and corresponding standard deviations are determined for every image and wavelength. From these calculations flagged pixels were excluded.
2. The standard deviation as function of the flux number were described by polynomials for every wavelength. A fifth order polynomial was necessary to describe the noise measured for the SWP whereas a fourth order polynomial was sufficient for the LWP. In order to avoid "boundary effects" the noise of flux numbers below 30 was described by a linear function. Similarly, for high FN values where measurments are not available the functions were extrapolated linearly (see Fig. 1)
3. The values resulting from the functions determined in the previous step were smoothed in wavelength direction by fitting polynomials. In order to conserve the inherent structure of the noise as function of wavelength and flux number it was again necessary to split in several wavelength ranges and to use different order polynomials to describe them.

The obtained noise models are provided as fits-files which contain the expected noise for every possible flux number and wavelength. The models and a detailed description of their generation, Schartel & Rodríguez Pascual (1997), will be attached to the INES CD-Roms. Especially the used images, the ranges and the corresponding order of polynomials will be provided.

3 Background determination

In *SWET* the background is basically a 6th degree Chebyshev polynomial, where the coefficients of the polynomial are obtained by fitting the average FN values in swathes outside the aperture region. This background is assumed to be constant across the aperture region. These two assumptions are more than acceptable for many cases, but there are spectra where a 6th degree polynomial is not able to track the actual variations of the background in the wavelength direction. The assumption of constant background in the spatial direction across the aperture also fails occasionally and results in incorrect extraction profile determinations.

For these reasons the background estimate has been changed to account for smaller scales variations in the dispersion direction and variations in the cross-dispersion direction. (Fig. 2)

The new method uses the same swathes above and below the aperture region. The first step is to compute the average background above and below the aperture. This is done by taken the weighted spatial average in each swath. Since the FN values in the background region may occasionally be well into the extrapolated part of the noise models, we take as error for individual pixels the largest value between the noise model value and the weighted r.m.s. in the spatial direction for each wavelength.

Next step is to smooth the background estimates above and below the spectrum. This is done by taking the weighted average in windows 31 wavelength steps wide. This process is iterated until outlying values (3σ) are completely rejected. Finally, the background in the aperture region is taken as a linear interpolation in the cross-dispersion direction between the two estimates above and below.

4 Extraction profile determination

Without going into details, the extraction profile determination method in *SWET* is based on spline fits along the spatial direction of the actual data. Since the number of spline nodes is limited to 15, the smallest scale variations in the spectral direction of the extraction profile is effectively of the order of 30-40 wavelength steps.

This scale is definitely too large to account for the “beam-pulling” effect in regions with large flux variations. This effect is due to deflections of the read beam near regions of high charge on the SEC target and results in shifts in the image registration of up 1.5 pixels. The general shift is to the top of the standard view of the RAW images, i.e., towards lower order lines. The effect is then more serious in spectra with very large differences in the exposure level at small wavelength scales, that is, spectra with strong narrow emission lines on top of a weak continuum.

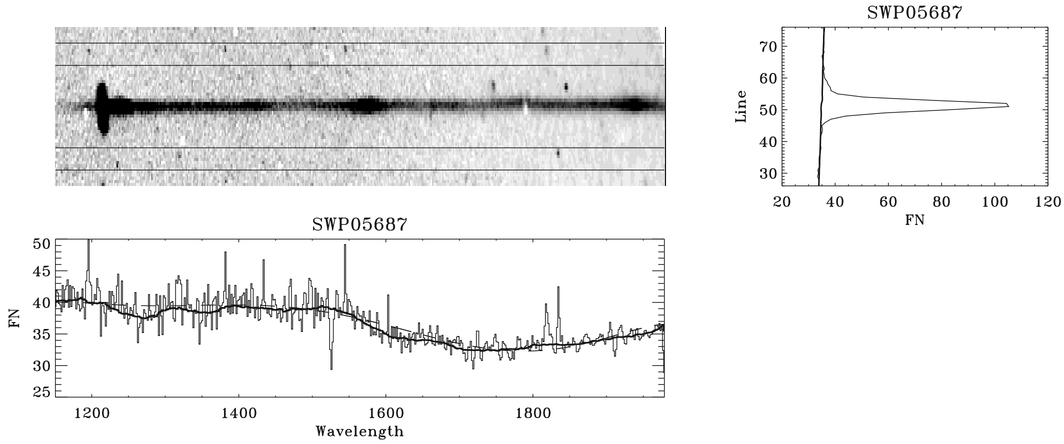

Figure 2: *SWP05687 has been chosen as an example because it is the most popular image of IUE, according to the ULDA statistics. The lines above and below the spectral region indicate the limits of swathes chosen to estimate the background. The average background along the spatial direction is shown in the bottom panel together with the SWET estimate (dashed line), and along the spectral direction in the upper right panel.*

The problem is even exaggerated by *SWET* since it identifies the true emission line as a bright spot because it deviates largely from the profile estimate based mostly on the continuum. All this results in a extraction profile that is shifted near strong emission lines, that in addition are flagged as "bad" pixels. As shown by Skillen & Schartel elsewhere in these proceedings, the output line spectrum in these cases is meaningless.

To overcome this problem the modified method does not fit splines but simply takes the average spatial profile in chunks of constant total S/N and then linearly interpolates between them. As in *SWET*, an iterative process is allowed to reject outlying pixels.

Another source of potential problems already identified is the treatment of weak spectra. *SWET* uses the default point-source extraction profile for those images where the total signal-to-noise ratio (S/N) is below a given threshold *and* the "IUECLASS" keyword correspond to a point-like source. In addition, the default profile is located at the center of the aperture. This approach results in a higher S/N spectrum whenever (a) there is a spectrum, (b) the target is point-like and (c) it was properly centered in the aperture. If any of these conditions fails, the extracted spectrum is meaningless, since either there is no signal or the part of the flux is missing because either the actual profile is not point-source or the extraction profile is misscentered. Considering that most of these images of extremely low exposure level are weak objects, poorly known and with not very accurate coordinates at the time of the exposure, the conditions above are definitely too strong.

For low exposure level images, the modified method simply adds up all the flux within the whole aperture. This results in poorer S/N spectra, when the targets are point-like and well centered, but on the other side no flux is lost during the extraction procedure.

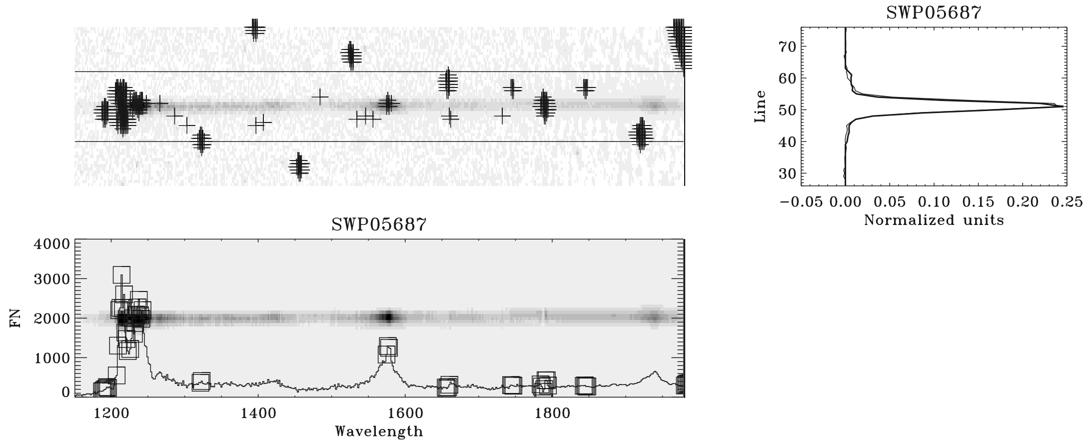

Figure 3: *The SILO file of the same image as in Figure 2, but after background subtraction. Now the horizontal lines mark the spectrum extraction region and crosses are flagged pixels. In the upper right panel, the average spatial profile is compared to the average extraction profile. The extracted spectrum together with its associated extraction errors and the flagged pixels are shown in the lower panel. Also shown in this panel is the reconstruction of the 2D spectrum from the 1D extracted spectrum and the extraction profile.*

5 Quality flags management

5.1 Quality flags handling in extraction procedure

Quality flags (ν's) mark those pixels whose quality is not optimal. There are different effects that degrade the quality of a pixel and there is also a gradation in the reliability of the value. The importance of a proper handling of ν's is two-fold: first, they are taken into consideration by the extraction procedure and second, they flag in the final 1-D spectrum those wavelength steps where the user should be warned about the realibility of the flux provided.

SWET directly sets as non-usable pixels all already flagged in previous steps, except those marked as "Negatively extrapolated ITF - far below ITF level 1". Among the pixels directly rejected, it is clear that those not photometrically corrected, not containing real data because of minor frames were missing during the downlink, reseaux marks and permanent ITF artifacts are indeed not valid. However, that is not so clear for pixels whose FN values have been obtained after extrapolation of the lowest and highest ITF levels. Even the rejection of saturated pixels may cause missalignments of the extraction profile with respect to the actual profile, especially in cases of strong emission lines on top of weak continuum, as discussed in previous section.

The aim of discarding all flagged pixels in the extraction procedure was to take advantage of the capabilities of optimal extraction algorithms to recover the flux at flagged pixels, in particular recover the true line profiles of core saturated lines. However, this capability relies on the ability of the technique to use the correct extraction profile on bad pixels. The problems mentioned in previous section about the ability of *SWET* to track the correct extraction profile in some cases, leads to serious doubts that this is case for *IUE* data. In view of these problems, the extraction procedure has been modified so as to use also pixels flagged as extrapolated FN value and even saturated pixels.

5.2 Quality flags propagation

The way the information about bad quality pixels is passed onto the final 1-D output spectrum is also linked to the role these pixels play in the extraction procedure. The approach followed in *SWET* is to flagg only those wavelength steps where the flagged pixels account for more than 55% to total extraction profile. And in these cases, only flags that contribute more than 15% the total extraction profile are passed into the 1-D flag spectrum. This approach is aimed to reduce the total number of flagged pixels in the final 1-D spectrum whose quality is, at the end, not that bad. However, it has been identified that this play with percentages may lead to non desirable results. Namely, wavelength steps to which some bad pixels contributed to the flux are not flagged in the 1-D flag spectrum. For the new extraction a more conservative approach has been followed and the flag of any pixel in the 2-D SILO file where the extraction profile is non-zero is passed into the 1-D flag spectrum.

6 Conclusion

The modifications to the extraction procedures for Low-Dispersion *IUE* spectra mean a more conservative approach than in *SWET*. Both methods give essentially the same results from well exposed images. It is for underexposed images and the particular case of strong emission line spectra where the differences become significative. In general, the compromise between minimizing the extraction errors and the need of collecting all the flux has been balanced towards the second option. The modifications introduced intend to assure that no flux is missing in the extraction procedure although this may mean higher extraction errors in some cases, which do however give a more accurate description of the real noise in the spectra.

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