An alternative extraction procedure for IUE spectra; preliminary results

We have developed an alternative way of extracting spectra from IUE-images. The adopted algorithm is described and several results are reported. It is shown that knowledge of the intensity distribution perpendicular to the dispersion direction for a point source (point-spread-function = PSF) aids significantly in the interpretation of the data. Unless otherwise noted, all results reported here are based on geometrically and photometrically ("old ITF's") corrected images.

1. Introduction

It has been recognized for some time that the extraction of spectra from high dispersion IUE-images, especially in those parts where the orders are so close together that the PSF's overlap, is very difficult. Intensities are found to be sensitive to the adopted extraction slit heights, the positioning of the "object-" and "background-" slits, and the periodic repositioning of the slit necessary due to the integer slit height combined with the fact that the orders are not quite parallel to an image diagonal.

Far from pretending to offer a ready-made solution to these problems, the foregoing merely serves to illustrate how the extraction approach reported here originated. For the case of high dispersion images we envisaged taking a diagonal through the optical image of $n \leq 426$ pixels approximately perpendicular to the orders (this we call a cross-cut). The intensities for one specific wavelength in each of the (N) orders would then be found by a simultaneous least square fit of the appropriate point-spread-functions.

For the most simple case of N=1 (low dispersion images) we now have an operational procedure which is introduced in the following section.Subsequent sections describe our results, while the last section reports on a preliminary comparison of results obtained from the same images corrected with new ITF's.

2. The extraction of low dispersion spectra by fitting of point-spread-functions (PSF's)

The core of our program generates the best (in a least square sense) fit of an externally supplied function on a set of n data points. For the low dispersion case we sequentially take cross-cut's of length n=15 pixels, in which the spectrum is approximately centered, and fit a Gaussian function:

$$I(x) = I_B + \frac{I_S}{\sqrt{2\pi\sigma^2}} \exp\left\{ -\frac{1}{2}\left(\frac{x - x_o}{\sigma}\right)^2 \right\}$$

where I_B is the background level per pixel, I_S is the extracted intensity, x_o is the distance of the center of the spectrum to the image diagonal almost parallel to the spectrum, and σ is the dispersion of the Gaussian function (FWHM= 2.355 x σ). The parameters in the external function (in this case I_B, I_S, x_o and σ) can be fixed (to a user supplied value) or variable in the iteration procedure. The algorithm converges very fast and after the third iteration no further improvement of the fit is usually seen (as judged from an optional running display of the sum of the squares of the deviations). Total run time for approximately 850 cross-cuts of five iterations each is about 12 minutes on a Mod. Comp. mini computer which includes an appreciable amount of I/O (mainly writing the results on magnetic tape).
Weighting factors can be assigned to individual pixels, a capability we use to automatically set the weight of saturated (see section 5) as well as unusually low DN pixels (reseaux) to zero.

3. Results related to the PSF

By releasing σ as an active parameter in the iteration procedure, we can find the dispersion of the PSF as well as its wavelength dependence. For LWR 1198 (small and large aperture), we find that σ increases linearly towards shorter wavelengths and has a value of 0.9 at $\lambda \approx 3000$A and 1.3 at ≈ 1900A (both σ's expressed in units of diagonal pixels). For SWP 1210 we found no measurable wavelength dependence and adopted an average value $\sigma = 1.05$ (small and large aperture).

In the following we will show that a Gaussian function is a good approximation of the PSF. Knowing the position of the center of the spectrum x_0 for each cross-cut, the total net intensity I_S, and the effective background, we can derive the normalised net intensity distribution perpendicular to the dispersion(PSF) for each cross-cut. As an example we show the combined result for 14 consecutive cross-cuts around λ= 1950A taken from LWR 1198. We have similarly derived the real PSF around 3020A and find again that a Gaussian (now with σ=0.90) gives a very good fit.

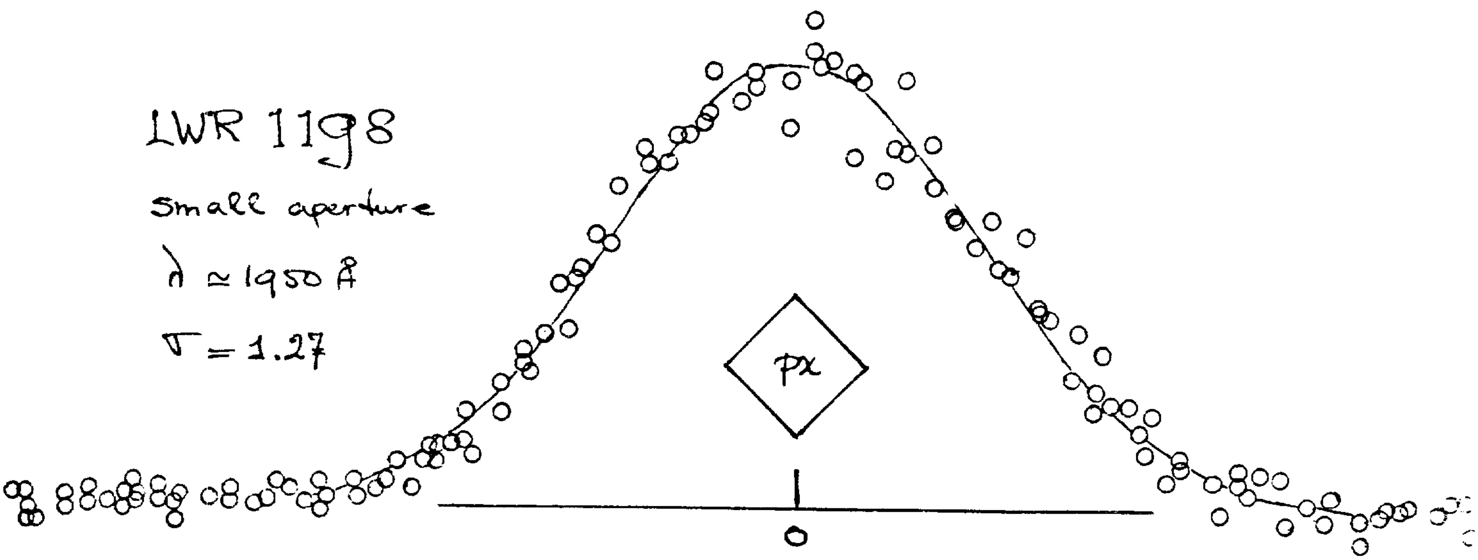

Figure 1. Measured point-spread-function PSF perpendicular to the dispersion for 14 consecutive diagonals around 1950A in a low dispersion image. Obviously, the PSF can be well represented by a Gaussian function.

The option to let σ iterate freely is of little further operational consequence in the data-extraction procedure. Apart from occasional spot-checks to see whether the instrumental profile changes during the satellite lifetime, we would use this option only in cases where a wavelength dependent source size were suspected (globular clusters, H II region knots, etc). In routine extraction we approximate σ by a specific linear function of diagonal number for each camera. Even although we have sofar found no evidence of variations of σ from image to image, it can be noted that serious errors in the intensities due to inappropriate Gaussian dispersion values should not be expected. One can show that errors in σ cause errors in the extracted intensity according to

$$I_{extracted} / I_{real} = \sqrt{\frac{2 r^2}{1 + r^2}}$$

if r is the ratio between the adopted and the real σ's. This function behaves like $\sqrt{r}$ for r close to 1, and the error in the intensity (in %) will therefore be roughly equal to half the error in σ (in %). Errors in the wavelength dependence of the intensity should even be an order of magnitude smaller.

4. Low dispersion data extraction

Having determined appropriate values for σ, we can now proceed to routinely extract spectra from the images. Rather than two numbers per cross-cut (I_B and I_S) we come out of the iteration procedure with four parameters: I_B, I_S, x_o as well as a value for the standard deviation of the fit (called s.d.). In the example given below all those quantities are plotted, a as well as a "saturation level", which is a direct function of σ and I_B and some specified intensity limit (set at a level of 20.000/pix for the example given here, see section 5).
All parameters are plotted (Figure 2) vs. "diagonal number", which starts at 0 in a corner of the image and which relates in a simple linear manner to wavelength. At the top of the box we have plotted the square root of the average (over 15 pixels) square of the differences between the best fit Gaussian and the pixel values. Although not quite the same as the error in the extracted intensities, that parameter serves as a quality indicator. If, for any reason (saturation, reseaux, etc), the observed brightness distribution perpendicular to the dispersion deviates from the PSF, the standard deviation will show a local peak and a spectral feature in the corresponding intensity

will automatically become suspect.
Additional information on the reliability of a specific point in the spectrum can be derived from the plot (also in Fig.2) of the positions of the center of the cross-cut as a function of wavelength. Some large scale curvature remains in the spectrum after the GEOM procedure, and the small scale wiggles in the position line point to pixels disturbed by instrumental effects (reseaux, camera defects, etc). The positional instabi-

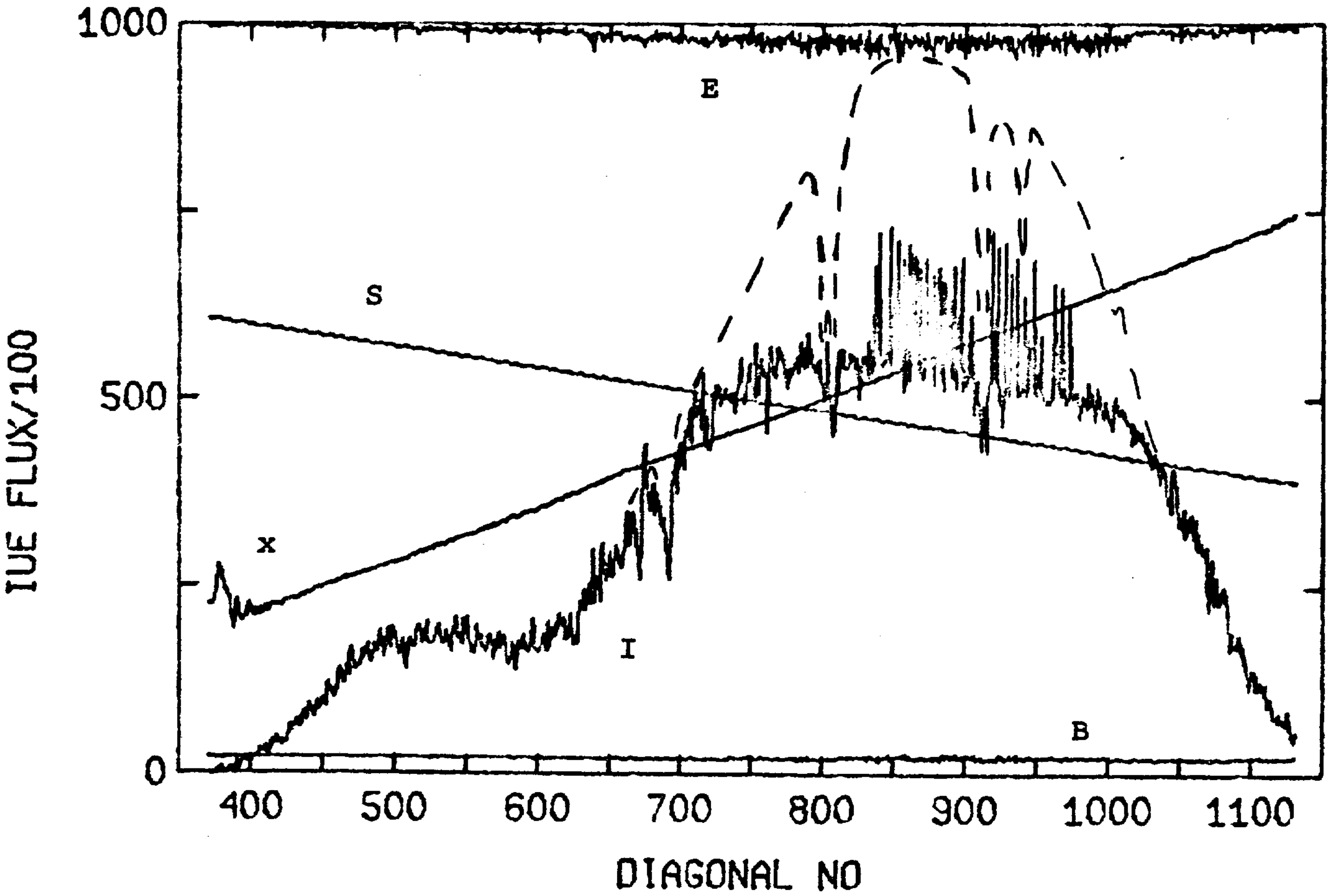

Figure 2. Extracted results of a LWR (1362) image using a gaussian point-spread-function PSF. The curves are labelled: I= stellar extracted spectrum; B= background; x= information on the position of the spectrum (centroid of gaussian fit); E= quality parameter (of fit); S= line above which intensities are unreliable (value of central pixel >20.000, see section 5). In addition the dashed line shows the intensities of the same object, scaled from a shorter exposed image (LWR 1363), to fit the long and short wavelength ends of the given spectrum. In this case the nonlinearity causes errors up to 40%.

lity at the short wavelength end is caused by lack of sufficient information for the iterative procedure.
The background in our extraction is found as the baseline in the 15 pix strip perpendicular to the dispersion. Again, instrumental effects are suppressed by the weight setting procedure. In the Goddard extraction the background used is a running average in the dispersion direction.

5. Saturation effects

With increasing intensity, effects of saturation (non-linearity) will show up first when the central pixel in the PSF is exposed beyond its linear region. To compute the IUE-flux for which this occurs, knowledge of the PSF is required. For the case that the PSF is a Gaussian one can easily show that the maximum safe IUE-flux depends linearly on σ. As σ increases with decreasing wavelength (LWR), the saturation level will be higher at the short wavelength end. In Figure 2, the saturation line satisfies the observed σ-dependence (section 3) and it cuts off that part of the spectrum which, through comparison with a properly scaled shorter exposure, is shown to be saturated. One can show that, for all points on the saturation line, the central pixel value would be about 20.000. Inspection of the actual pixel values in a print-out of the image showed that values in excess of 20.000 did indeed not occur, except for completely saturated (DN=255) pixels to which values in excess of 32500 are assigned.
Comparison of Figure 2 with the corresponding Goddard extracted spectrum reveals that appreciable errors (in this case up to 40%) occur before the Goddard spectrum exhibits peaks caused by 32K pixels.
Our extraction (Figure 2) shows peaks for a different reason. Completely saturated pixels (32K) received zero weight and the Gaussian curve fitting was therefore exclusively based on the wings of the profile. This correctly leads to a higher extracted intensity. We have achieved a real increase in the dynamic

in an additional extraction (not shown) where we gave zero weight to all pixels with values in excess of 19900 (exactly 20.000 was used in the old ITF images for all unsaturated pixels above a certain ITF level). As the central pixel contains 50% of the information, this lower cut-off leads to an increased noise level. Reliable intensities become completely impossible of course, when the image is so overexposed that more than one pixel exceeds the 19900 level.

6. Spectral resolution

As our sampling rate is a factor of two higher than in the Goddard extraction, we are in a good position to study the maximum achievable spectral resolution. Work on this subject is in progress. The preliminary conclusion is that the instrumental resolution (as judged from the structure seen in the 2800 Mg II and 1400 Si IV doublets) is better matched by our, higher, sampling rate. A somewhat puzzling finding is that the PSF in the dispersion direction seems to be significantly narrower than the PSF perpendicular to the dispersion. We anticipate to report on that subject in the near future.

7. New ITF's

We have investigated a very limited number of old images which were reprocessed with the set of ITF's in use since the end of May 1978. We summarize the comparison with our old ITF image extractions as follows.

1. The dynamic range has markedly increased in LWR exactly in the sense we expected from our investigation described in section 5. For SWP we find that the change in dynamic range is (probably) less than 10%. The limiting pixel values (LWR 25220, SWP 17740) as given by Turnrose (IUE newsletter 2) are essentially confirmed. We <u>stress again</u> that with these limits

gross intensities above IUE Flux= 88.000 in SWP and above IUE Flux= 117.000 at 3100A to 137.000 at 2600A in LWR still will be affected by non-linearity effects of the ITF's.

2. The Goddard new ITF spectra show differences in intensity in comparison with old ITF spectra which vary along the spectrum. Our extraction of old ITF spectra had also revealed such a difference, which amounts to ≈15% change along a LWR spectrum. As our extraction on old and new ITF images is identical in non saturated regions, and agrees with the Goddard new ITF spectra, we conclude that consistency is achieved. Probably the replacement of the Goddard COMPARE by EXTLOW, at the end of May 1978 also, removed that wavelength dependent difference.

3. The noise pattern as we obtained in the Washburn extractions are very similar for both old and new ITF spectra. The hope that the new ITF's would lead to a decrease of the noise in the spectra is not effectuated.

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