OVERVIEW OF OPERATIONAL IUE SPECTRAL EXTRACTION ROUTINES

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Abstract

A comparison is made of operational extraction software for IUE spectra. This includes the standard IUESIPS, the Washburn Extraction Routine, and programs developed by Giddings (UCL), by Gondhalekar (UCL), by Laurent (Verrieres le Buisson) and by Snijders (UCL). Basic advantages of the non-standard methods are : proper recognition of bad pixels and removal of their effects, better photometric accuracy, improved spectral resolution and spatial information.

1. Introduction

Several extraction techniques have been developed by individuals to retrieve photometric and spectral information from images obtained with the IUE. In most cases, the desire to enlarge the amount of information from an image (compared to the standard methods in use at the IUE observatory) was the driving force behind the efforts made in several institutes. In the hope of benefitting from knowing the advantages of the various methods developed, we describe here briefly the principal characteristics as well as advantages and drawbacks of the methods known to us. This overview also may help in judging aspects of data as presented currently in the literature.

We have concentrated on those programs which use the actual images (raw of GPHOT) to extract the spectra. Some groups derive additional, mostly spatial information, from the rotated (hence resampled) image given in the "the strips"; those will not be discussed (fourth file methods).

Little of the basic information on IUE images is publicly available. Apart from a large number of internal notes at UCL, NASA-GSFC and ESA the essentials of IUE, its images, and basic data handling have been described in a number of papers (Refs.1-10). Table 1 gives a short resume of the principal characteristics of the various spectral extraction methods discussed in the overview below.

2. Description of the Operational Software Packages

(1) Laurent (Verrieres-le-Buisson)

Input is the raw image. The extraction method was developed for interstellar line studies which do not require an intensity calibration, only that the instrumental response is linear. These requirements are fulfilled provided the gross intensity is on the linear part of the ITF. Wavelengths are determined from the values assigned with the standard extraction method to recognizable features in the spectra.

Data from the image are stored in an array which follows the diagonals more or less parallel to the spectrum. The actual background (better than the inter-order level) is found by fitting a gauss to two adjacent orders. This background is then used with the intensity for the order of interest. Extraction per diagonal yields the well known improvement of spectral resolution. (Ref. 11).

(2) Standard IUESIPS

Input is the geometric and photometric corrected image (2nd file). The location of the spectrum is assumed to be known from λ-calibration images. On approximately every 2nd diagonal through the image, the pixel closest to the centre of the spectrum is found and the relevant wavelength is determined. Then all the intensities found in a "slit" of sketched shape are added. This is the gross. The sum of pixels on each side of the spectrum, on the same diagonal, are incorporated as the background which is smoothed using a triangular filter, charged particle events or fiducials are not removed from the background. The difference (with the background area normalized to the "slit" area) is the net spectrum. Each next intensity is found in a "slit" along side the previous one. Due to the deviation of the direction of the spectrum from 45^{o} for diagonals (SWP 6^{o} off, LWR 8^{o} off), and the arrangement of the software, in low dispersion for the SWP spectra a width of half a slit is not sampled every 4-5 data points or 10% of the information is lost. Various "improvements" of the basic extracted data have been implemented (Ref. 4, 10).

(3) Washburn Extraction Routine

Input is the geometric and photometric image (2nd file). The approximate position of the spectrum is known from the photowrite. 51 pixels on an image diagonal are selected which contain the information for both large and small aperture. A limited set of pixels containing one spectrum is compared with the point spread function (found to be Gaussian, Refs 12, 13). In four iterations a best fit is determined, giving net intensity (area under PSF), the background (as baseline to the PSF) and the position of the centre of the PSF. The process is repeated for the other aperture spectrum and both results are combined in one output array.

No special attention is given to pixels affected by particle events. However, before the fit, all pixels below IUE flux number 1800 (the reseaux) and pixels with intensities above 27000 in LWR and 18000 in SWP (the limits of reliable ITF's) are given low weight. The fit then effectively ignores these pixels, giving a correct final intensity. The final error ($\sqrt{\frac{\Sigma \text{ dev}}{n}}$) is calculated from all pixels at full weight, providing a "flag" in the error for trouble fits. The high intensity limit also implies ignoring saturated pixels and the intensity is found from a fit to the wings of the PSF. That allowed in one case to retrieve the continuum in a 3x over exposed spectrum to within 10% of the intensities found from a well exposed image.

Intensities are found at the tru centre of the spectrum, hence the data are equidistant in λ (1.2 Å in SWP, 1.9 Å in LWR). A disadvantage is that with low intensity levels above background, the iterative fit may select a higher noise pixel as the "centre". That can be recognized afterwards by the scatter in the central position array. In these cases a re-extraction is needed, in which the running average of the position found previously, is imposed. The final errors are used to weight individual input intensities before spectra (of both apertures or of two images) are combined.

The width of the PSF is found to vary with wavelength but does not deviate significantly from a Gaussian. The PSF is narrowest near 1400 Å in SWP and near 2800 in LWR (Ref. 13).

TABLE 1

	METHOD	INPUT	SAMPLING	DISPERSION	INTERACTIVE	INTENSITIES FROM
1.	Laurent	raw image	each diag.	high	yes	fit Gaussian PSF to the data
2.	IUESIPS	GPHOT image	1 per 2 diag.	high & low	no	Σ Sp. – Σ background
3.	Washburn	" "	each diag	low	no	fit Gaussian PSF to the data
4.	Giddings	" "	variable	high & low	yes	Σ Sp. – Σ background
5.	Gordhalekar	" "	each diag.	low	no	"
6.	Snijders	" "	1 per diag. or 1 per 2 diag.	"	yes	"

Notes : Raw images (file 1) do not suffer from the resampling done in the construction of the geometric and photometric corrected image (GPHOT image, file 2). The sample rate in Giddings program is variable.

(4) Giddings (UCL).

Input is the geometric and photometric corrected image (2nd file). The image is reorganized without resampling so that only information of interest is retained (such as the region of the low dispersion spectra only, or a few orders of the high dispersion spectra) in a manner which is close to parallel to the dispersion direction. Fiducial marks and saturated pixels are marked and the affected wavelengths bins are deleted. Pixels influenced by the ITF truncation error are flagged and the wavelength points concerned can be removed. Wavelengths are assigned from the known IUESIPS dispersion relations. Faulty pixels in the background are removed by applying a mean filter once, with a 3 sigma cut-off criterion, and smoothing the resulting background with a triangular filter. Wavelength points are equidistant with a variable bin width, which is usually set equal to 2.67 Å for the short and 4.44 A for the long wavelength camera in the low resolution mode. The program can track the orders and hence in high resolution always determine the background exactly between the orders. Intensities are found from adding and subtracting the relevant pixel intensities (Ref. 14)

The program is implemented on the STARLINK system.

(5) Gondhalekar (UCL)

The input is the geometric and photometric corrected image (2nd file). The location of the spectrum is assumed to be known from the wavelength calibration. On each diagonal through the image, pixels near the centrum of the spectrum are read and stored in an array. In order to get a perfectly straight spectrum the data are resampled into a new array. The sum of the total spectrum (addition of all position adjusted resampled array elements) shows a nearly Gaussian profile. Adding a second Gaussian profile at the 15% level gives a reasonable fit to the observed profile. The background is filtered once using a mean filter with a 3 sigma cut-off criterion, the true background is then determined by fitting a straight line to the filtered background points. The wavelength points are equidistant and the stepsize is 1.3Å for the short and 2.2 Å for the long wavelength camera. Fluxes are determined by adding up and subtracting the relevant pixel intensities . The resampling of the pixels must lower the resolution a bit but the small wavelength stepsize more than compensates and the resolution is actually better than that obtained with the software packages of Giddings or Snijders when those are run with stepsizes of 2.7 Å and 4.4 Å.

(6) Snijders (UCL)

Input is the geometrically and photometrically corrected image (2nd file). For each pixel on each diagonal near the spectrum the actual wavelength is determined. Because the direction of the spectrum in the image differs from 45^{o} (by 6^{o} in the SWP and by 8^{o} in the LWR camera) the wavelength along the diagonals assigned to the pixels varies. The pixels, labelled by wavelength, are reorganised in an array with one axis perpendicular and one axis parallel to the dispersion direction without resampling the pixels. Pixels affected by fiducials, the telemitry limit, ITF truncation errors or charged particule events are directly visible in this array. If a symmetric PSF is adopted only half the profile perpendicular to the dispersion direction is required in order to be able to correct individual faulty pixels (Ref. 17). Particular emphasis is placed on the exclusion of faulty pixels from the background by applying a mean filter up to 3 times and excluding all pixels which deviate more than 2 sigma from the final mean. The PSF is found to be wavelength dependant and variable in width and shape. Wavelength points are equidistant, at present the binsize is either 2.7 Å for the short and 4.4. Å for the long or 1.3Å for the short and 2.2 Å for the long wavelength spectra. Fluxes are determined by adding up the pixel intensities in each wavelength bin for a gross spectrum and subtracting the relevant background flux which is obtained by smoothing the filtered background signal with the usual triangular filter (Refs. 15-17).

The program is implemented on the STARLINK system.

(7) <u>The new IUESIPS low resolution method</u>

A new standard reduction for low dispersion spectra was implemented at Goddard November 1980 (Ref.21). Principal differences with IUESIPS are:

a) no geometric correction is applied.

b) slit width is reduced by a factor 2.

c) the sampling rate is doubled, and consequently spectral resolution is now comparable to the non standard methods described above.

d) extensive resampling to keep the slit perpendicular to the dispersion direction.

No experience with this method is available yet so no comparison of merits can be made at the present time.

3. Discussion

The programs were compared by extracting fluxes using the different programs available to us on a few test images. From the results and a study of the program descriptions some quite general conclusions could be drawn:

1. All alternative programs do indeed better than current IUESIPS. However each program is best in the field of interest of the author(s), perhaps not surprising.

2. Profile fitting is essential, especially for noisy spectra or images affected by permanent camera blemishes at "inconvenient" points. A major problem here is disagreement over the true shape of the PSF (see below).

3. Adapted high resolution programs usually are not as good for the analysis of low resolution data as custom built low resolution programs are. For instance, future versions of IUESIPS use the same program for high and low resolution data extraction and as curve fitting techniques are too expensive for IUESIPS for high resolution data they will not be used for low resolution spectra either.

4. For both cameras the ITF tables still contain errors and these while smaller than the well known error discovered in 1979 (Ref. 18) in the SWP ITF, should be removed. Especially for the LWR ITF, where the remaining errors are now the largest, this matter is under active study (Refs. 19, 20).

5. Filtering the background before smoothing is essential and available alternative programs either use a mean filter before smoothing or Gaussian profile fitting to obtain an improved background. The peak background errors found on long exposures

in the SWP camera for low resolution spectra with current IUESIPS (which does not filter) are at least a factor 20 larger than peak background errors found after applying a mean filter to the background (Ref. 15). For both the Gaussion fit and the mean filter programs r.m.s. errors in the background after 7^h exposures in the SWP camera are typically 2 to 5 x 10^{-16} erg $cm^{-2}s^{-1}A^{-1}$.

6. Better resolution is obtained by decreasing the wavelength bins to about 1.3 Å and 2.2 Å for respectivily the SWP and LWR low resolution spectra, but a price is paid in a 40% decrease in S/N.

7. Based on the various extraction methods, conflicting statements have been made on the shape of the PSF perpendicular to the low resolution dispersion direction. Snijders finds that the response is variable - about 30% of the images have approximately a Gaussian PSF with weak extended wings. The remainder is asymmetric, the asymmetry varies from day to day but images obtained during the same shift usually have the same PSF. Gondhalekar stated (private communication) that it is Gaussian with wings. From the Washburn Routine it is found that the PSF is Gaussian. People working with fourth file methods find wings. It is hard to make a final judgement, also in view of the fact that these results are based on different sets of data, such as single diagonals only, or the whole spectrum added. (see also Ref. 6). With both the Washburn and the Snijders software packages it is found that the width of the PSF varies along the spectrum with minima ground 1400 and 2800 Å (e.g. Ref. 13). Cassatella and Ponz (Note

November 1979) find a constant width, but they worked with the fourth file which involves an additional smearing step compared to the second file. Gondhalekar (who resamples) and Clavel (private communication) find constant widths. Settle, who used the GPHOT image, analyzed a small set of images and obtained an asymmetric PSF comparable to some of the results obtained by Snijders (UCL internal memo, 1979).

However the good agreement between the results obtained with the (completely different) methods of Snijders and the Washburn group, concerning both the FWHM and its variation with wavelength establish the reality of the wavelength dependance of the width of the PSF in the low resolution mode. In addition it is well known (Refs. 1, 5) that the IUE cameras are better focussed at the center of the images than at the edges and the increase in the width of the instrumental profile for the SWP camera at the long wavelength end is at least partly due to this effect.

From a comparison of the use astronomers make of different software packages at institutes where more than one method is available it appears that programs which give spatial information are by far the most popular. Even for point source spectra (where there is no direct need for this) observers apparently highly value the extra information, for instance for the exact location of image defects in the spectrum. All methods in

Table 1 (except IUESIPS), and the (re-sampled data of the) 4th file, provide that information.

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