An Algorithm for Analyzing Pseudotrailed Spectra for Time Variability

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Pseudotrailing is a technique in which the pointing direction of the IUE is changed slightly one or more times during the exposure so that the position of the object in the large aperture takes two or more positions along a line perpendicular to the dispersion direction. One advantage lies in allowing an adequate exposure of a faint source continuum while not overexposing bright emission lines. While this can also be achieved by coadding separate spectra, coadding tends to compound background-subtraction errors. Spectra obtained by pseudotrailing are customarily combined to produce a net extracted spectrum, thus losing potential information on time variability of the object's emission. In this paper, we describe a numerical method for extracting and comparing individual spectra from pseudotrailed images.

The method is designed for line-by-line (LBL) data files, which are discussed in detail in the *IUE Image Processing Information Manual.* Briefly, LBL files represent a stage in the generation of the usual net extracted spectrum from a low-dispersion image. The LBL files are generated after images are corrected for geometric distortions and photometric response. LBL files are routinely generated in the processing of each image. They consist of 55 or 110 individual "pseudo-orders", with each pseudo-order containing over 1000 pairs of numbers, each pair being a net flux with a corresponding wavelength. (Pseudo-orders occur in all LBL files, whether or not pseudotrailing was used; the similarity of terms is coincidental.) The net flux values are extracted along lines parallel to the dispersion direction, so that the pseudo-orders represent a set of scan lines which taken together cover the image diagonally across the physical pixels and parallel to the spectra. Since late 1985, extended line-by-line spectra have been generated, which contain 110 pseudo-orders rather than the 55 pseudo-orders in LBL spectra (Gass, 1985; Peiro, 1985).

The spectrum made by each placement of a pointlike source in the large aperture is spread over several pseudo-orders by various instrumental effects. In a pseudotrailed image, there are typically two or three such spectra which overlap across about a dozen pseudo-orders. These overlapping spectra are superimposed on a background which is approximately uniform across the image, so that the pseudo-orders far from the spectra record only the background.

The goal is to obtain a flux at each wavelength for each of the two or three pseudo-trailed spectra. Because the spectra partially overlap, especially around bright emission lines, these fluxes are derived as the amplitudes of two or three partially ovelapping Gaussian functions of order number. (Pseudo-orders are numbered 1 through 55 or 1 through 110.) The Gaussians describe the spread of the spectra across the orders, that is, perpendicular to the dispersion direction. Cassatella, Barbero, and Benvenuti (1983) and Urry and Reichert (1988) have shown that a Gaussian is an accurate representation of the "spread function" of a point source in an IUE image.

To determine the centers and widths of the Gaussian profiles, we consider the pseudo-order number to be a continuous variable. We use numerical non-linear least-squares fitting to determine the optimum values of these parameters, with the pseudo-order number as the independent variable.

For the first stage of this numerical extraction, we have modified a version of the algorithm SIMPLEX (Caceci and Cacheris, 1984). Our SIMPLEX algorithm is applied to a set of 55 or 110 mean flux values (one per pseudo-order). Each mean flux value is an average taken over the length of a pseudo-order over all wavelengths longward of the geocoronal Lyman alpha emission. The Lyman alpha fluxes are excluded from the analysis because the geocoronal emission essentially fills the large aperture, and would introduce spurious results. Since each mean is taken over about 600 fluxes, spurious fluxes due to occasional cosmic ray hits do not produce a significant error. It should be possible to interpolate across hits, but we did not find that to be necessary.

When coded in FORTAN, SIMPLEX proved effective and efficient in finding optimum values of the width and centers. SIMPLEX was chosen for this task because it is a simple and reliable algorithm able to find optimum parameter values in an analytical function having any number of parameters and variables. Its goodness-of-fit criterion is the sum of the squared residuals, which is treated as a function of the adjustable parameters. SIMPLEX seeks the values of the centers and width which minimize the sum of the squared residuals.

Because SIMPLEX is somewhat slow, the best-fit centers and width found by SIMPLEX are input to an International Mathematical and Statistical Library routine called IFLSQ. IFLSQ determines for each wavelength the amplitudes of the Gaussians and the background value. At each wavelength, IFLSQ fits 55 or 110 data points of flux vs. pseudo-order number by varying four parameters: three Gaussian amplitudes and a constant background level.

The version of SIMPLEX which we developed calculated uncertainties in the output values due to stochastic variations in the data. The effect of these uncertainties on the IFLSQ output was found by examining changes in the output produced by altering the input. It was found that the range of IFLSQ output values caused by the range of SIMPLEX uncertainties was smaller than the standard deviation of the mean of the IFLSQ output.

The effect of the implicit assumption that the Gaussian widths do not depend on wavelength was also investigated. Cassatella *et al.* (1983) showed that there is some dependence of width upon wavelength. SIMPLEX was able to detect this wavelength dependence. However, the flux differences between spectra at the same wavelengths, which are the essential results being sought, are unaffected to within the stochastic uncertainties represented by the standard deviations of the means (typically 10% to 15% in the spectra analyzed). Variation of the Gaussian width with wavelength would, at worst, introduce a relatively small error that would be independent of pseudo-order and only slowly dependent on wavelength. Such an effect would not introduce artificial differences between Gaussian amplitudes at a common wavelength.

The assumption that the spectra were exactly parallel was checked by comparing SIMPLEX values for the centers at wavelength intervals at either end of the spectrum. Within SIMPLEX uncertainties, there was no deviation from parallelism.

We found some evidence that determining the background level during the fitting process, as described above, can introduce small systematic errors if the background has a gradient across the dispersion direction. This effect was eliminated by using the more usual artificial slit method for background subtraction before applying the Gaussian fit technique to the LBL data.

This technique was applied to several archived pseudotrailed images of Seyfert galaxies to search for differences between spectra of the same image which would indicate time variability (McCollum, Stoner, and Ptak 1987). In these images, the continua were relatively faint with respect to the background noise. Even so, the uncertainties in the relative fluxes at each wavelength were only around 10%. More precise results could be expected for better exposures of brighter objects. The fact that, even in these relatively noisy spectra, SIMPLEX detected the dependence of width upon wavelength, which had been found by Cassatella *et al.* under ideal test conditions, enhances confidence that this SIMPLEX technique gives reliable results.

Interested observers are invited to contact either of the authors to learn more details or to obtain a copy of the program.

References

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