Washburn Extraction and Width of IUE Point Spread Function

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We review the Washburn Extraction Routine for low dispersion IUE spectra. The shape of the point spread function (PSF) in low dispersion spectra is sufficiently well described by a gaussian function. The PSF is in large and small aperture essentially identical and we present values of σ. Several advantages of the extraction routine are mentioned.

Introduction

The Washburn IUE extraction routine (Koornneef and de Boer 1979, henceforth KB) has been used up to now only to extract low dispersion spectra. The routine basically fits an a priori known point spread function (PSF) to the intensity distribution perpendicular to the dispersion. In four iterations the routine finds the intensity I in the spectrum, the background B as the baseline of the input data, and the position x_0 of the spectrum. We find that the PSF can be represented sufficiently close by a gaussian, hence in pixels at positions x, the intensities fit to

$$I(x) = B + \frac{I}{\sqrt{2\pi\sigma^2}} \exp\left\{-\frac{1}{2}\left(\frac{x - x_0}{\sigma}\right)^2\right\} ,$$

where σ is the dispersion of the gaussian function in units of $\sqrt{2}$ x (pixel length). Crivellari and Morossi (1980) also find a gaussian but they suggest that haloing in the camera can be accounted for by adding a 15% effect of a Lorentz profile. Our extraction is performed on a line of pixels diagonally through the image, hence deviating from perfect perpendicular by small angles, 6° for SWP, 8° for LWR (see Fig. 1).

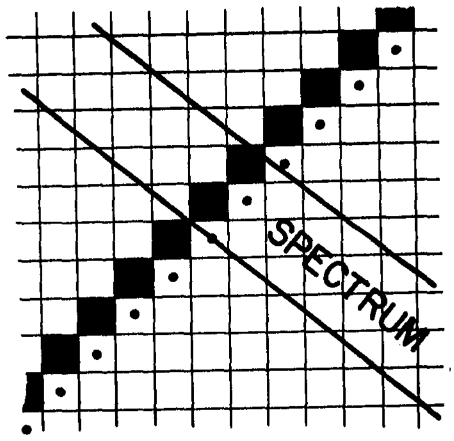

Fig. 1: Schematic view of pixel grid, spectrum and diagonals. Filled squares: set of pixels on one diagonal; dot-pixels: set for next diagonal in Washburn extraction.

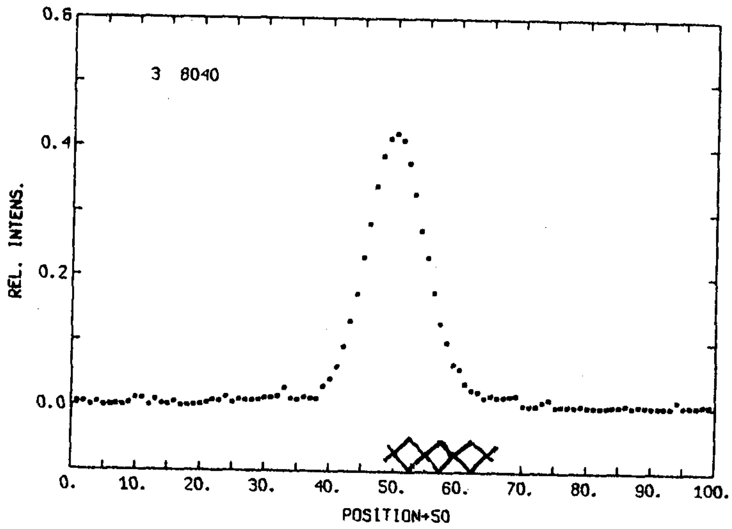

Fig. 2: The actual intensities of the pixels of each fit are coadded, after proper alignment of the centroid of the PSF, and normalization of the fitted PSF to unit area; the PSF is gaussian for point sources. This plot shows the sum of 350 extracted diagonals in SWP between 1580 and 2000Å, of a M_V = 14 BHB star in NGC 6397 (de Boer 1980). The very minor deviation from a gaussian in the lower wings is caused by the change of σ from ≈ 1.1 to ≈ 0.9 respectively (see fig. 4).

Based on a prescribed σ, we have extracted many images since the development of the routine. Coaddition of all the x-adjusted fits provides a check on the actual PSF. In LWR, the PSF is always gaussian. In SWP images reduced in 1979, the PSF turned out to be inexplicably asymmetric. We have reduced the spectra from images of that period which had the flaw in the SWP ITF, by redressing that error at the pixel level based on the data from Table 1 of Holm (1979a). These rereduced spectra now produce also a gaussian PSF in SWP.

Properties of the Point Spread Function (PSF)

In order to find what σ is in the spectra, we have carried out extractions with σ also as a free parameter. In that case, of course, the resulting I is meaningless. From the free-σ extraction we have calculated average σ's in 40Å and 50Å wide bands in SWP and LWR respectively, representing 34 diagonals in SWP and 27 diagonals in LWR. In the calculation of that average, σ's larger than 1.8 and smaller than 0.3 have been excluded, the large σ's because they cannot be real regarding the grand average of σ = 0.98 ± 0.03 ($\sqrt{2}$ x pixel length); the small ones were excluded because they came from an accidentally high central pixel with low wing-pixels on the input diagonal.

Before extracting, extreme-valued pixels get low weight (see KB). In the provided geometric-photometric images all pixels have been offset by 2000 IUE flux numbers. Reseaux then have pixel-values < 1950 f.n.; these get low weight. High pixels (saturated, > 32500 IUE f.n.) also get low weight. There is another set of pixels which gets low weight. KB showed that the ITF's applied to the raw images truncated at a certain value. Hence, in commissioning phase data in LWR no pixel had more than 20000 IUE f.n., resulting in unflagged "semi-saturation" in spectra which had not yet DN near 255. The ITF's employed since May 1978 are better but still have truncation. Holm (1979b) emphasized this more and gave actual DN's. The spectral ranges where this is important are:

λ	max f.n. per pixel (Turnrose 1978)	max trustable standard extracted intensity
≈ 1300	17740	≈ 85000 IUE flux
≈ 2800	25220	≈ 120000 IUE flux

where the maximum trustable intensities are adapted from KB allowing for smaller σ found presently. Such pixels also get low weight resulting in positively improved intensities from the extraction fit (see KB sec 5). Turnrose et al. (1980) described a numerical extrapolation to the ITF.

As reported by KB, the PSF was essentially equal for large and small aperture spectra. For the presently discussed 12 images for each camera, that ratio is close to unity indeed. Figure 3 shows how this ratio behaves with respect to wavelength.

KB reported that the PSF in SWP had σ = 1.05 constant, and in LWR had σ = 1.3 at 2000Å to σ = 0.9 at 3000Å. For later images, Koornneef derived that in SWP σ gradually decreased to shorter wavelengths, and that in LWR the change of σ along the spectrum was less pronounced. Figure 4 shows how, for characteristic images, σ changes along the spectrum. Apparently, the IUE

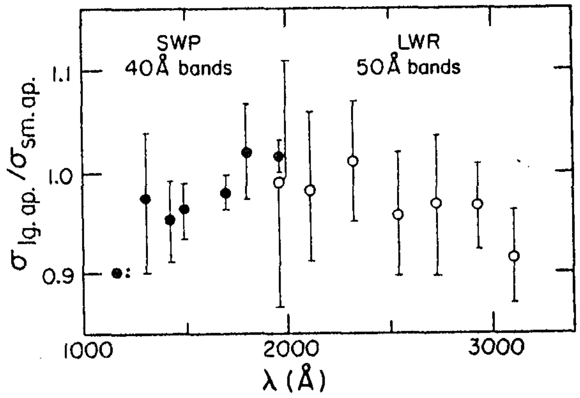

Fig. 3: Ratio $\sigma_{la.ap}/\sigma_{sm.ap.}$ for a gaussian Point Spread Function of IUE low dispersion point-source spectra in its relation to wavelength. Average for 12 images in each camera, with standard deviations given. In several SWP images the signal had vanished at 1180Å leading to a very uncertain ratio in this figure. Images were obtained between Sept. 1978 and Feb. 1980.

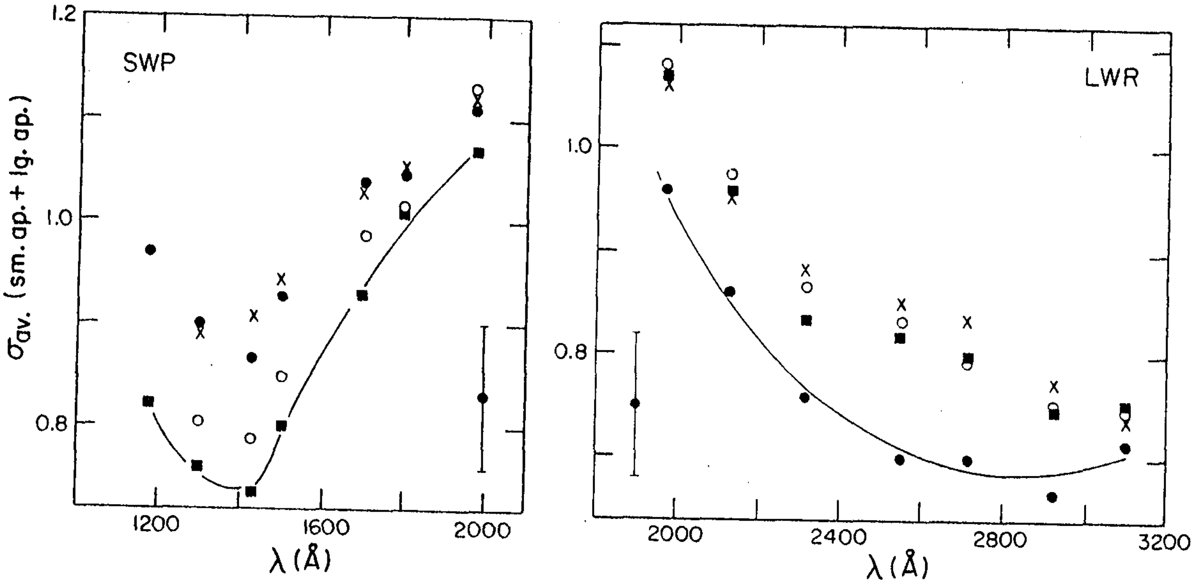

Fig. 4: Width σ of gaussian PSF in relation to wavelength, for 4 images in each camera. The thin lines are only meant to aid the eye. The point with error bar in the corner gives the characteristic size of the dispersion.

optical system has been brought into an optimized condition after a few months of operation. A plot of σ with image number (not shown) indicates large σ for early images, in time levelling off to values of σ as given presently.

Most likely, there is a correlation between σ, i.e. the level of σ, and the temperature in the satellite. Figure 5 shows for each camera the values σ at specified wavelengths in relation with the read head temperature THDA (Bohlin et al. 1980). No clear correlation is apparent.

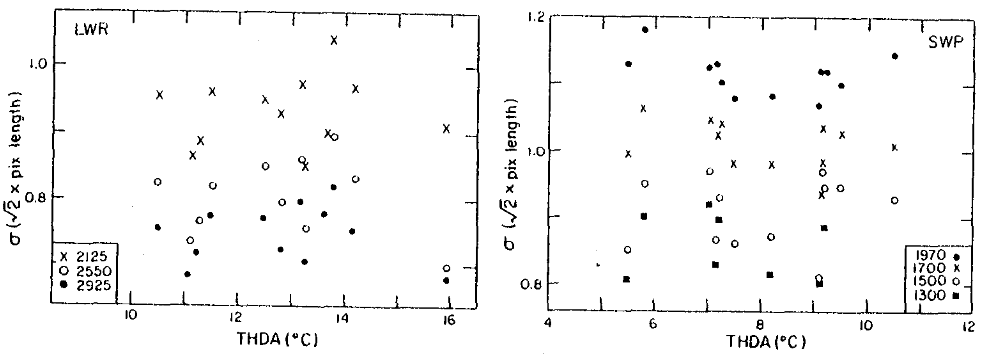

Fig. 5: For all 12 images, in each camera, we show how σ behaves with respect to the temperature THDA available on the scripts. No clear correlation is indicated. The figure can be used to judge the dispersion of the σ's.

Error Estimate

The Washburn routine fits a prescribed PSF to the data points on a line of pixels diagonally through the image. The best fit is found at the minimum of the sum of the deviations of all points. This minimum deviation is used as a quality indicator of the fit. The procedure is set up such that the final error is calculated from all the data points at full weight, hence saturated data points or points from truncated ITF's get "flagged" in proportion to their deviation from the adopted PSF. The error estimate is used as weighting factor in combining data from small with large aperture (if available) and so bad data (reseaux, saturation, etc.) are effectively replaced by good data, in addition to an overall improvement. The propagated errors are most important after calculating the ratio of two different spectra (extinction studies; Koornneef and Code 1980) in order to obtain a fair judgement of the limited spectral overlap between SWP and LWR spectra.

Spectral Resolution

The Washburn IUE extraction routine has a sampling rate twice as large as in the standard IUE extraction. We therefore may expect somewhat better spectral resolution. Often we resolve in low dispersion the strong interstellar Mg II in the direction of the Magellanic Clouds, and the stellar Si IV doublet.

Spatial Resolution

The main advantage of PSF fitting is that one may offer any spatial function to give the best fit. A first step has been made by Koornneef and Mathis (1980) who studied the spatial intensity distribution near 30 Doradus in the LMC. With such procedures also the shape of the UV light distribution of globular clusters in the LMC can be determined (de Boer 1980).

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