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Extraction of Point Source Spectra from STIS Long Slit Data

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Abstract. STIS provides a unique opportunity to obtain spectra of point sources from very crowded fields and complex scenes, such as galactic nuclei, utilising high spatial resolution. A small suite of programs is described for simple and optimal extraction of point source spectra, targeted specifically at STIS data. A multi-channel (spatial) restoration is also under development using the method employed by Lucy and Hook for imaging data. The algorithms are briefly described and applications to STIS SMOV data illustrates the potential.

1. Introduction

STIS long slit spectra can be obtained both with the MAMA and CCD detectors with slit lengths of 24″.6 and 51″.2 respectively. The Line Spread Function (LSF) of the spectrometer in the spectral direction is excellent (2.0 pixels FWHM for the CCD and about 3.0 for the MAMAs); the Point Spread Function (PSF) of the telescope and instrument is 4.3 pixels (0″.10) for the FUV-MAMA at 1430Å and 3.2 pixels (0″.08) for the NUV-MAMA at 2400Å; at 7750Å the FWHM is 2.3 pixels for the CCD (0″.12). The MAMA detectors suffer from a halo of radius about 20 pixels (worse for the NUV MAMA—Fig. 7.3 in Baum et al. 1996) and the CCD shows a halo at wavelengths beyond 7000Å increasing in strength to longer wavelengths; these haloes add a pedestal to the otherwise narrow PSF. In comparison with ground-based long slit spectrographs, STIS offers a very stable PSF—one which is suited to well defined extraction methods and also to image restoration.

With excellent spatial resolution and a stable PSF, STIS is thus ideally suited to obtaining spectra of point sources in crowded fields—such as stellar spectra of stars in globular clusters, spectra of single stars in nearby galaxies (e.g., supergiants, supernovae), resolution of the spectra of close visual binaries and faint companions in multiple star systems, compact emission line knots in nearby nebulae (e.g., Herbig-Haro objects), the spectrum and hence velocity dispersion in stellar cusps in galaxy cores and the emission from AGN resolved from the surrounding narrow line region or circumnuclear starburst. Indeed many of the STIS GO and GTO programmes reflect these advantages and this is one of the areas in which STIS will have the greatest scientific impact, since FOS already offered large continuous wavelength coverage and GHRS a high spectral resolution UV capability.

There are excellent tools available for the extraction of spectra from long-slit data such as in the IRAF TWODSPEC.APEXTRACT package. Whilst they are not designed for STIS data, the STIS pipeline data can be easily adapted to their use. However, the fixed PSF of STIS suggests that the extraction of point source spectra from complex scenes could be optimized for this instrument. In response to these differences a package of routines is in preparation, to be run under IRAF, to specifically handle STIS long slit data. This contribution provides a brief description of the elements of the package so far built and the plans for implementing (spatial) restoration tools aimed at exploiting to the full the 2-D spectral data from STIS.

2. Software Package

The baseline was to provide a tool for optimal extraction of point source spectra from STIS long slit spectra. This can be done with the IRAF interactive task APALL. However, since pipeline calibrated STIS data come with carefully produced data quality and propagated statistical error images in the association, these should be fully incorporated in the extraction software. The usual implementations of the optimal extraction algorithm, such as that due to Horne (1986) and Robertson (1986), and later improvements such as for distorted spectra by Marsh (1989) and for cross dispersed spectra by Mukai (1990), determine the spatial PSF from the data itself, fitting it in the spectral direction to form the extraction weights ($W_{x\lambda}$, see Horne 1986). However, given the fixed PSF for STIS, the extraction weights could be a priori assigned using a model PSF. The TIM (`http://www.stsci.edu/ftp/software/tim/`) and TinyTim (`http://scivax.stsci.edu/~krist/tinytim.html`) packages allow PSFs to be constructed for HST instruments, such as WFPC2 and NICMOS for example; as yet no implementation in TinyTim for STIS is available, although one is planned (Hook, private communication) and would be very useful for enhancement of both imaging and long slit spectral data.

A number of routines have been written in FORTRAN 77, using F77VOS for the data I/O, for spectral PSF image manufacture, simple extraction, profile fitting and optimal extraction. Under development are a 2-channel restoration tool and enhancements for multiple object spectral extraction. The input data are the reduced STIS associations (bias corrected, flat fielded, hot pixel cleaned, cosmic ray rejected and wavelength and flux calibrated) and the output point source spectrum is written as an STSDAS table with columns of wavelength, flux, propagated statistical error and data quality.

Spectral PSF image

A number of images of model PSFs at different wavelengths are read and a long slit “PSF spectrum” is formed. The pixel size and slit width can be adjusted and the slit can be offset from the centre of the source in the wavelength direction. The integrated spatial profile of the PSF at the different wavelengths are formed and interpolated onto the wavelength grid of the data frame to be analysed. This is used for subsequent processing.

Simple extraction

Simple extraction of the spectrum is achieved by fitting the background column-by-column (where the slit length is in the column direction and the dispersion in the row direction) and summing the point source over some selected extent (e.g., to 1% of the peak). Various forms of fit to the background are possible such as low order polynomial (for isolated point sources) or interpolation (e.g., cubic spline). Fitting the PSF image to the data can also be performed and the point source flux can be summed over the PSF rather than the data—this allows imperfections and cosmic rays to be distinguished and rejected from the spectrum. The extracted spectrum is output as a table and the background image, without the point source, can be saved.

Optimal extraction

Optimal extraction is performed using the Horne (1986) algorithm and a polynomial is fitted to the wavelength variation of the PSF with iterative rejection of points a selected distance from the fit. The background is subtracted from the image prior to optimal extraction and the errors are fully propagated. The point source spectrum is again an STSDAS table. Instead of using the input spectrum to produce the weights, another spectrum such as that produced from model PSFs or from an archival, high signal-to-noise, isolated point source spectrum (with the same slit, grating and central wavelength) can be applied. This would be advantagous when the signal-to-noise ratio is very low, when there are regions of the spectrum without data (such as saturated absorption lines) or for emission line spectra.

Numerical experiments are required to determine the advantages to be had for extracting very low signal-to-noise spectra with a prior PSF. Optimal extraction cannot be readily applied to blended spectra without first decomposing the two point source profiles through fitting.

Two-channel restoration

The constancy of the PSF implies that restoration techniques (in the spatial dimension) should be applicable. The two-channel restoration algorithm (Lucy 1994, Hook & Lucy 1994) could be used here. The position of the point source is given and the (smooth) background is fitted by the second channel using the Richardson-Lucy technique. Initial experiments have shown that this technique may be promising. However, the current implementation of the code (`plucy` in the STSDAS.CONTRIB package) only allows the point sorces to be specified by integer pixel values—a refined code is under development by Lucy and Hook whereby the point sources are specified by non-integral pixel coodinates. Each spatial column is then separately restored with the 2-channel restoration and the point source flux written to the output table and background to a separate file. There could be some smoothing applied before restoration, such as summing several columns (although this will degrade the spectral resolution). Since the position of the point source may shift slightly with wavelength, the position of the point source for input to the 2-channel restoration may have to be redetermined across the spectrum. The advantage of this method is that a number of point source spectra can be extracted simultaneously, whereas for the optimal extraction the background fitting and point source extraction are independent.

3. Initial Results

Currently there are no public STIS data on which to comprehensively test these routines. Tests of the point source extraction software were performed using STIS CCD (grating G750L) spectra (e.g., for standard stars GD153 and Feige 110). However, to simulate point sources on an extended background, simulated data was produced by adding existing STIS point source spectra to model images. In addition, no model PSFs at different wavelengths were available, so 2-D Gaussians were used.

Figure 1 shows an extracted spectrum (not flux calibrated) of the spectrophometric standard star GD 153 (DA white dwarf) taken from a G705L spectrum (data set O3TT20040). Here the data were fitted by the PSF spectrum and the flux of the best fitting PSF at each wavelength increment was output to the extraction table. Bad pixels have been excluded and the error bars have been propagated from the pipeline calibrated data and are plotted in Fig. 1. The wavelength scale was produced from the image header.

Figure 2 shows the cross-section, in the spatial direction, through a simulated image of a point source on an extended background. The dotted line shows the restored background resulting from a two-channel restoration (using the code `plucy`). The "ringing" around the restored point source is due to the position of the point source being specified only to the nearest pixel. The upper line shows the estimated errors on the two-channel restoration. The errors were computed by restoring 25 separate spectra each with the statistical errors given by the spectrum counts together with the STIS read-out noise (4 e^-). The computed error was added to each spectrum using a different random number seed. The mean error from the 25 trials is plotted. These errors were found to be about half of the statistical errors on the data (an entropy term was applied to the background which forces it to be smooth).

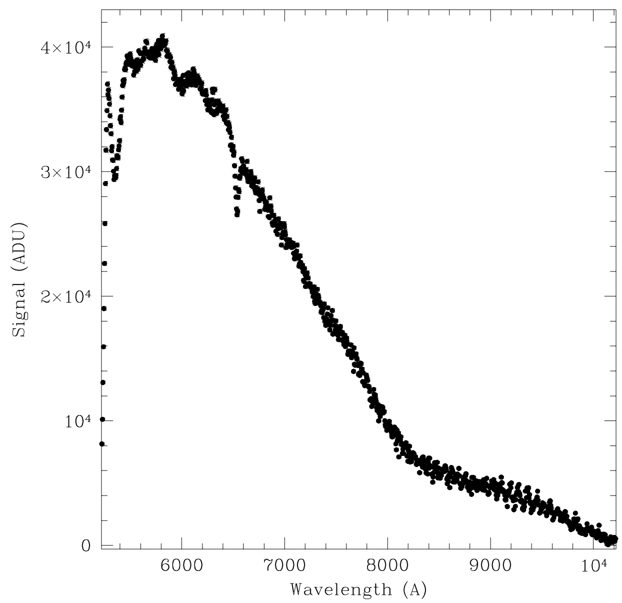

Figure 1. Unweighted extracted spectrum of GD 153 taken from a STIS G750L CCD longslit image.

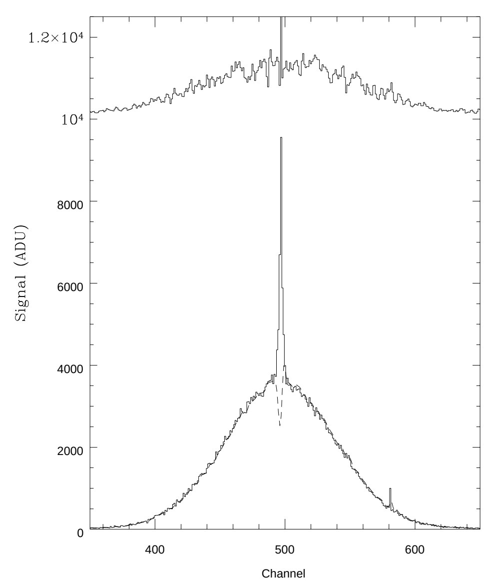

Figure 2. Spatial cross section through a model STIS longslit spectrum showing a point source on an extended background. The dotted line shows the resulting background from a two-channel restoration. The upper line shows the mean error ($\times 20$) on the restoration from Monte Carlo trials.

4. Conclusions

A package of programs to extract point source spectra from longslit data, tailored to STIS MAMA and CCD data, is under development. Extensive testing of the package of progams on realistic data will taken place when the GTO data are released in October 1997. The package, including the two-channel restoration code, will be made public.

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