FOC *f*/48 Spectrograph Rectification

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ABSTRACT

The f/48 wavelength calibration procedure (ISR OSG-FOC-096) accurately corrects geometric distortion in the dispersion direction of an FOC long-slit spectrographic image. This report describes how we correct the distortion of spectrographic images in the spatial direction, using data from the f/48 spectrophotometric calibration program. We find that applying a shear transformation to the wavelength-calibrated data shifts the spectra so that they run parallel to the dispersion direction to within ~0.1 degrees. The shear distortion turns out to be time-dependent on suborbital timescales, making it difficult to align the spectra more closely. Residual displacements of the spectrum centroids from a linear fit are < 0.3 pixels and are probably an artifact of the geometric correction procedure. Because of the distortion's time dependence, observers are advised to calibrate and rectify spectrographic images using an INTFLAT taken within the same orbit. We describe a new procedure that rectifies and calibrates the wavelength scale of FOC f/48 spectrographic images in a single step. We also call attention to a revision in the standard wavelength scale.

1. Introduction

The wavelength correction procedure for the *f*/48 spectrograph, described in ISR OSG-FOC-096, ensures that spectral lines in calibrated images run directly along the *x*-axis of the FOC pixel grid, but it does not correct for optical distortions in the spatial dimension. Proposal 6198, intended primarily for spectrophotometric calibration, provides enough spatial information to correct for low-order spatial distortions. This program observed the white-dwarf standard star LDS 749B at the fiducial slit location and at a second location offset from the fiducial point by 3 arcsec. At each location we stepped the target perpendicular to the slit so that at least one observation would be optimal, with the center of the target falling directly into the slit. Table 1 lists the relevant observations, along with the associated INTFLATs.

Table 1. Relevant Spectrophotometric Calibration Observations

Dataset	Target	Exposure Time (sec)	POS TARG (arcsec)	Offset from Slit (arcsec)	Date
x3l80105t	LDS 749B	357.250	-0.12 , 0.0	-0.04	25 Dec 1996
x3l80106t	LDS 749B	357.250	-0.08 , 0.0	0.00	25 Dec 1996
x3l80107t	LDS 749B	357.250	-0.04 , 0.0	0.04	25 Dec 1996
x3l80109t	INTFLAT	800.000			25 Dec 1996
x3l8010at	LDS 749B	357.250	0.00 , 0.0	0.08	25 Dec 1996
x3l80205t	LDS 749B	357.250	-0.06 , -3.0	0.00	26 Dec 1996
x3l80206t	LDS 749B	357.250	-0.02 ,- 3.0	0.04	26 Dec 1996
x3l8020at	INTFLAT	800.000			26 Dec 1996

These observations provide us with well-exposed continuum spectra of a point source, separated by 3 arcseconds along the slit, that can be used to correct for spatial distortions up to second order in the FOC spectrograph. Section 2 shows that a second-order correction is unnecessary. A simple shear transformation rectifies the continuum spectra adequately, aligning them parallel with the dispersion direction. This shear is time-dependent, so observers who wish to rectify f/48 spectra accurately should create their own geometric correction files, based on INTFLATs taken during the same orbit, if possible. Section 3 describes a simple procedure for creating these files. Section 4 points out a revision in the standard wavelength scale.

2. Shearing Correction

Analysis of the spectra in Table 1, following wavelength calibration according to the procedure described in ISR OSG-FOC-096, showed that the stellar continuua were tilted with respect to the dispersion direction. The best-fit line to the flux centroid at each wavelength ran at an angle ~1° with respect to the y-direction of the pixel grid. (Note that the x-axis is the spatial direction and the y-axis is the dispersion direction.) Linear fits to the best exposures at each slit position, x3l80106t at the fiducial point and x3l80205t three arcseconds along the slit, had slopes $dx/dy = 0.01407$ and $dx/dy = 0.01427$, respectively. A second-order fit was no more accurate.

Because the previously applied wavelength calibration had forced the spectral lines to run along the x-axis, a shear transformation, rather than a rotation, was necessary to align the continuum spectra along the y-axis without tilting the spectral lines. Applying the shear transformation

$$(x,y) \rightarrow (x - 0.01417y, y)$$

rectified the spectra quite well at both positions along the slit.

Figure 1 illustrates the positions of the spectrum centroids in the rectified version of exposure x3l80106t. The downward tilt arises because the shear correction (dx/dy = -0.01417) slightly overcompensates for the shear in this image (dx/dy = 0.01407). The residual deviations of the spectrum from the best-fitting line are ~0.2 pixels, but they vary systematically. We suspect that these deviations are artifacts of the geometric correction procedure itself. This procedure employed fifth-order polynomials to compensate for the geometric distortion of the FOC camera, and the residuals appear to vary across the spectrum as a fifth-order polynomial would. That is, the residuals have four to five nodes. Nevertheless, the small amplitude of these residuals is quite acceptable and well within expectations for FOC geometric corrections.
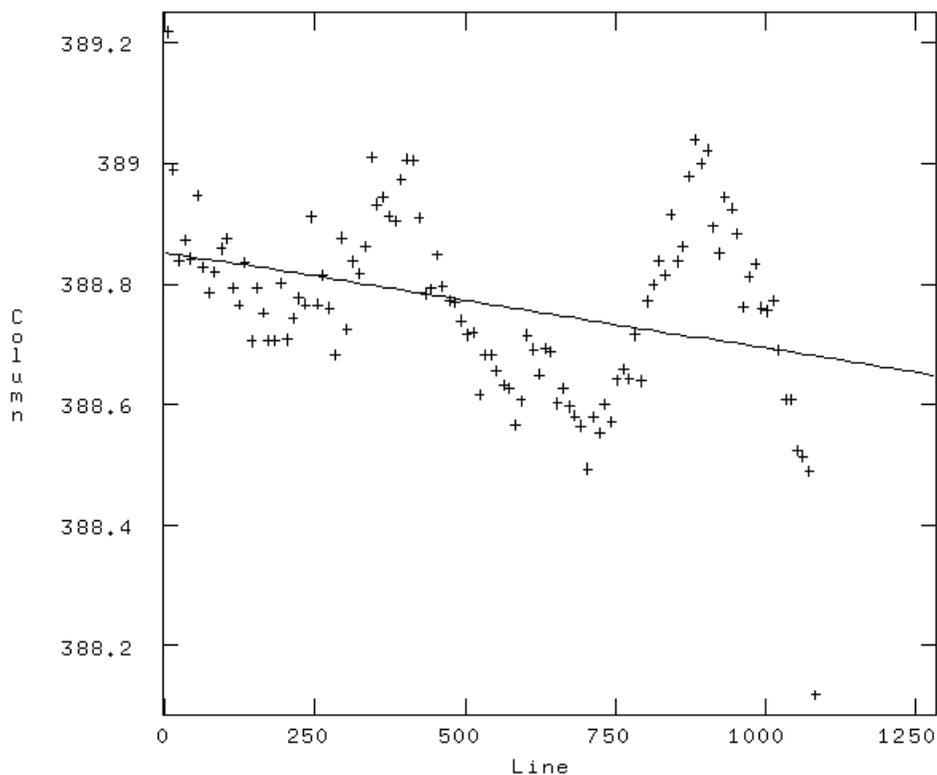

Figure 1: Spectrum centroid as a function of position in rectified spectral image x3l80106t. Column numbers represent the spatial dimension (x), and line numbers run along the dispersion dimension (y).

Applying the same shear transformation to the other spectral images demonstrates that the shear distortion is time dependent, with the best-fit slope dx/dy varying by ~0.001 within a single orbit. Figure 2 shows the rectified version of exposure x3l80107t, which followed immediately after x3l80106t in the same orbit. The same geometric correction, relying upon the same INTFLAT (x3l80109t), was applied to both images, yet the centroid

lines of the two spectra have different slopes. Apparently the inherent shear distortion of the *f*/48 camera itself can change by ~0.1% in less than an hour. Note also that the systematic deviations of the centroids from the best-fit line follow the same pattern as in x3l80106t (Figure 1), as one would expect if the deviation were inherent in the geometric correction itself.
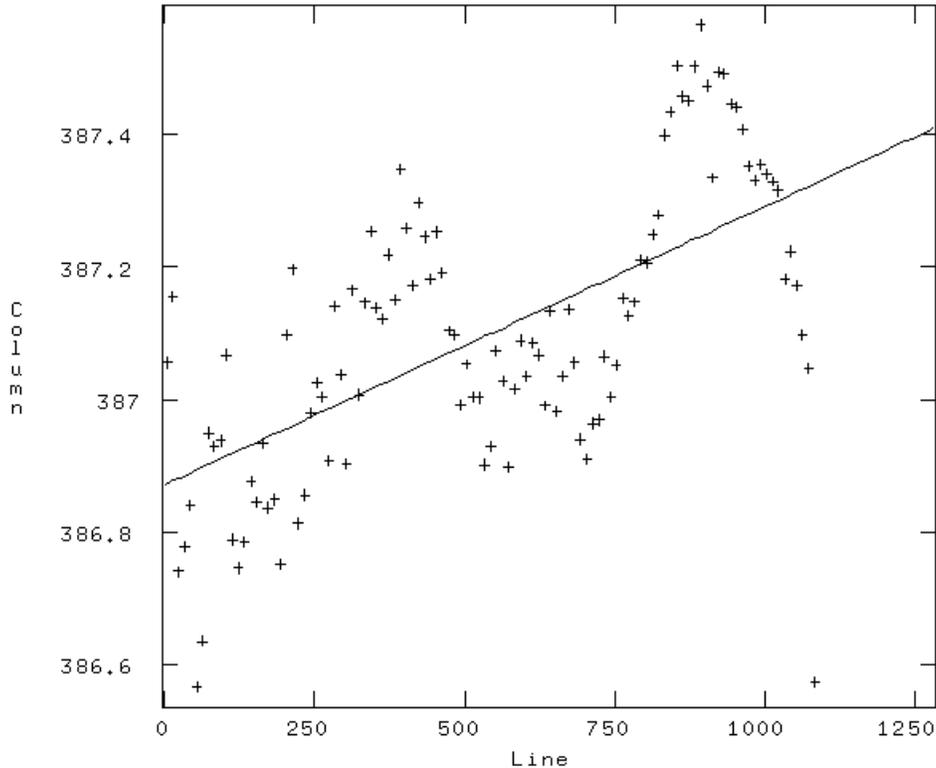

Figure 2: Spectrum centroid as a function of position in rectified spectral image x3l80107t.

3. One-Step Geometric Correction

The FOC geometric correction, wavelength calibration, and spectral rectification procedures map the counts in an uncorrected image onto a corrected pixel grid, while conserving total counts. These three procedures necessarily smooth an image on roughly the scale of a pixel. Ideally, we would like to smooth an image only once. One way to achieve this goal is to construct a transformation that simultaneously accomplishes all three goals. In other words, we want to find a transformation that maps the reseau positions in a raw FOC image to a set of reseau positions defining an undistorted, wavelength-calibrated space in which continuum spectra run directly along the dispersion direction.

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Reseau marks are generally not visible in FOC spectral images, so we need to base our correction for a particular image on the INTFLAT taken most recently before or after the image. In Section 2 we described how the correction obtained by mapping raw reseau positions to wavelength-calibrated reference positions produces slightly skewed spectra. Applying the shear transformation from Section 2 to these reference reseau positions yields a superior set of reference reseau positions suitable for implementing the one-step transformation we desire. However, such corrections will frequently be imperfect at the 0.1% level because of the time-dependence of the FOC camera distortion.

To apply one-step correction to f/48 spectral images, one needs to obtain from an FOC instrument scientist a table of reference reseau positions for the format of interest. Using `rfindx` in the `focgeom` package of STSDAS, locate the reseau positions in the appropriate INTFLAT. Then run `rfitx` to find the polynomial transformation taking the raw reseau positions to the positions in the reference table. A fifth-order transformation is usually necessary to achieve < 0.2 pixel rms residuals. The routine `p2geo` constructs a geometric correction file from this polynomial transformation, and `newgeom` applies this transformation to the spectral image. The resulting spectral image will be geometrically corrected to < 0.5 pixels, wavelength calibrated to 0.5 Å, and rectified to ~0.1%.

4. Revision of *f*/48 Wavelength Scale

The original wavelength calibration of the *f*/48 spectrograph (ISR OSG-FOC-096) mapped 5300 Å to *y*-pixel 100. This choice of y-offset placed the reddest wavelengths in the spectrum off the bottom of a calibrated image. The truncated portion of the spectrum was considered expendable because its wavelength calibration is likely to be very poor. We have no information on the actual wavelength scale beyond 5007 Å. However, in the interests of making the entire spectrum visible in a calibrated image, we have revised the standard wavelength scale so that 5300 Å now maps to *y*-pixel 200. The standard dispersion remains unchanged at -1.7 Å / pixel.