Recommended Dimensions for Calibration of Trailed Spectra and Spectra of Extended Objects

Discussion at the May 1981 Three-Agency Coordination meeting led to recommendation of new values for the dimensions of the large spectrograph apertures:

	SWP	LWR
trail length (arcsec)	21.4±.4	20.5±1.0
aperture area (sq. arcsec)	200 ±5	203 ±6

These new values are largely based on a report which was presented at this meeting and which is reproduced below so that users may judge for themselves the reliability of the recommended values. These recommendations supplant the earlier estimates provided by Bohlin et al. 1980 Astr. Astrophys. 85, 1.

One should note that the exposure times for trailed spectra have always been based on an assumed 20.0 arcsec trail path length. That is,

Trail exposure = 20.0/(trail rate).

For the sake of consistency and to accommodate possible further revisions of the values, the exposure times for trailed spectra will continue to be reported on the observing scripts assuming a 20.0 arcsec trail path length. The above results indicate that, at the present time, the best estimate is obtained by multiplying the reported exposure time by 1.07 for SWP trails and by 1.03 for LWR trails.

Schiffer is developing techniques for more precise extractions of individual spectra from multiple exposures in the large aperture, and will present more accurate results on these in a future Newsletter.

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Calibration of Trailed Spectra, Spectra of Extended Objects, and Multiple Spectra in the Large Apertures

Calibration of trailed spectra requires knowledge of the path length across the aperture. Calibration of spectra of extended objects requires knowledge of the effective areas of the spectrograph entrance apertures. Use of multiple spectra within the large apertures depends on uniformity of response within the apertures, and requires knowledge of the aperture dimensions for placement to avoid loss of light at the edges.

The fabrication of the aperture plate and preflight measurements were described by Bohlin, Holm, Savage, Snijders, and Sparks (Astr. & Astrophys. 85, 1, 1980). Upper limits to the effective solid angles were also provided. Several different techniques are available for inflight measurements. Here I present aperture dimensions inferred from trailed spectra and from monochromatic images of the apertures. Also, multiple spectra in the large apertures have been used to demonstrate that the detector response is reasonably uniform across the aperture. Penston and Ponz (see ESA IUE Newsletter No. 9, 1981) have already derived some results from analysis of sky Lyman alpha images.

Chords across the large apertures (trailed spectra)

The path length along any chord across the large aperture can be inferred from the exposure obtained when a star is moved through the aperture along this path with the camera exposing. The total exposure is the time spent inside the aperture = path length (")/ known trail rate ("/sec). Trailed low dispersion spectra are routinely obtained by moving the star through the center of the aperture along the X axis in the FES coordinates, which is within 5 degrees of the perpendicular to the dispersion direction and about 11 degrees from the major axis of the large apertures. I have analyzed 23 such trails along the X axis to measure the aperture length and 5 trails along the Y axis to measure the aperture width (see Table 1). In practice each trailed spectrum is ratioed against a standard, aperture-centered point spectrum taken just before or after the trail. All extractions used the extended slits and slit placement appropriate for trailed spectra. A correction has been included for the camera response time

(Schiffer 1980 NASA IUE Newsletter No. 11,3) and for the temperature dependence of the sensitivity (Bohlin et al.).

Figure 1 shows the point by point ratios of trailed/point spectra, expressed as a trail path length, binned into 50 A bins in wavelength. The individual ratios and the average for each camera are shown. The individual ratios show a scatter similar to that among the standard star spectra (Bohlin et al.). However, the SWP length does show a systematic wavelength dependence at the 5 percent level. The mean values are tabulated in Table 2. Average results from ratios binned over 600 A centered at 1550 and over 1000 A centered at 2550 were used to derive the aperture lengths and widths listed in Table 3. Note that the aperture length is assumed 0.8 percent larger than the X axis trail length, and the width 1.8 percent smaller than the Y axis trail length, because of the 11 degree tilt from the major and minor axes of the apertures.

Monochromatic images of the apertures

Monochromatic images of the apertures can be obtained for SWP by exposing to the sky Lyman alpha, and for both cameras by exposing the wavelength calibration lamp in the echelle mode. The aperture mechanism is left open to obtain images of the large and the small aperture simultaneously for a given camera. We assume that the illumination is uniform over the apertures. The observed agreement between the sky Ly α and the SWP lamp results lends some support to the lamp technique.

For each aperture image, a total exposure is obtained by integrating the signal in the geometrically and photometrically corrected image over an elliptical area encompassing the aperture image, with a correction for the background. The exposure level in the center of the large aperture is found by averaging the signal in the 7 central pixels. The effective area of the large aperture in square pixels is then the ratio of the total exposure to the central exposure level. The ratio of the total exposures in the large and small apertures measures the ratio of their effective areas. The center of the apertures is defined as the center of gravity of their exposure. We can compare the measured separation of the apertures in pixels with the separation measured by S/C maneuvers to determine the plate scale. The result is 1".51 per pixel for the SWP and 1.50 for LWR, with an error probably less than 3 percent. With these plate scales, we can transform the effective area of the large apertures from square pixels to square arcseconds as given in Table 3.

Multiple exposures in the large apertures

Three SWP and two LWR spectra of standard stars have been obtained as pairs with various spacings along the perpendicular to the dispersion direction. These spectra were extracted as trails. Figure 2 shows ratios formed from these spectra. For SWP the ratio has a systematic wavelength dependence similar to that of the trailed spectra. It is seen that the increase from 11" to 14" spacing introduced a light loss of no more than a few percent. The pair spaced 14" were nearly completely separated in the spatially extracted spectra. An approximate extraction was done for each spectrum in this pair by summing only the lines which contained the bulk of the signal. The ratio of the resulting spectra, in Figure 3, indicates that there is no gross asymmetry along the aperture length.

Problems

I find that the area of the large aperture from monochromatic images is nearly equal to the product of the length and width determined from trails, whereas I expect area = 0.91 length x width because of the rounded corners. Thus, either the area from monochromatic images is measured 10 percent too large, or the length and width from trailed spectra have 5 to 10 percent errors. These are rather larger than the errors estimated on the basis of internal consistency of each technique so that systematic effects may be present at this level.

One source of systematic errors is the photometric linearity error known to be present in both cameras. This will affect the ratio of the X axis trailed spectra to the point source spectra because most of the pixels in the trailed spectrum are exposed to a level which is near the peak exposure level in the point source spectrum. In the point source spectrum the exposure level decreases perpendicularly to the dispersion by a function which is close to a Gaussian (Koorneef and de Boer 1979 NASA IUE Newsletter No. 5, p.63). So these two types of spectra will respond differently to linearity errors. The nonlinearity will not affect the determination of the width of the apertures from the Y axis trails because there the distribution of exposure perpendicular to the dispersion resembles that of a point source spectrum. However, the photometric nonlinearities do not explain the discrepancy in aperture sizes because the known linearity errors have opposite senses in the two cameras while the area discrepancy is the same. Moreover, the aperture lengths derived here photometrically are in agreement with a geometrical determination by Bohlin (1980, private communication). Using a plate scale of 1.525, Bohlin measured the full width at half maximum of intensity plots perpendicular to the dispersion to be 21.6 arcsec for the short wavelength large aperture and 21.4 arcsec for the long wavelength large aperture. Thus, the photometric and geometrical determinations of aperture length agree to within 1 to 3 percent. While the photometric determination of the aperture width is based on far fewer measurements than the length, we have no reason to suspect that the errors should exceed 5 percent.

The observational techniques utilized here were suggested by A. V. Holm and F. H. Schiffer, both of whom also contributed to the interpretation of the results.

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Table 1 Images used for aperture geometry analysis

X axis trails and comparison spectra

star	trailed	untrailed	star	trailed	untrailed
HD60753	SWP 1757	SWP 1752	HD60753	LWR 1648	LWR 1642
	SWP 3904	SWP 3901		LWR 2822	LWR 2829
BD+75 325	SWP 6242	SWP 6240	BD+75 325	LWR 3038	LWR 3035
	SWP 9583	SWP 9582		LWR 5414	LWR 5412
	SWP 9588	SWP 9582		LWR 8876	LWR 8874
HD93521	SWP 6960	SWP 6958	HD93521	LWR 1591	LWR 1589
	SWP 7979	SWP 7978		LWR 5914	LWR 5912
				LWR 6951	LWR 6950
BD+28 4211	SWP 2060	SWP 2059	BD+28 4211	LWR 1858	LWR 1857
	SWP 5742	SWP 5741		LWR 4965	LWR 4964
	SWP 7809	SWP 7808		LWR 5644	LWR 5643
	SWP10962	SWP10961		LWR 6822	LWR 6821

Y axis trails and comparison spectra

BD+75 325	SWP 9581	SWP 9582	BD+75 325	LWR 8873	LWR 8874
	SWP 9589	SWP 9582		LWR 8875	LWR 8874
HD93521	SWP10940	SWP10939			

Lyman alpha sky images

SWP 6205, SWP 6427, SWP 8872, SWP 8873

Wavelength calibration images

SWP 7205 1 sec aperture open
SWP10427 2 sec aperture open + 3.5 sec aperture closed
SWP10722 2 sec aperture open + 4 sec aperture closed
LWR 5411 1 sec aperture open
LWR 9416 1 sec aperture open + 2 sec aperture closed

Pairs with various spacings

BD+33 2642	SWP10516	3"8 spacing	BD+28 4211	LWR 9350	3"8 spacing
	SWP10517	11"3 spacing		LWR 9051	11"3 spacing
	SWP10518	13"9 spacing			

Table 2 Average SWP Length

wavelength	length	wavelength	length
1250 A	20.7	1600 A	22.0
1300	20.6	1650	21.8
1350	20.9	1700	21.7
1400	20.9	1750	21.5
1450	21.2	1800	----
1500	21.6	1850	21.5
1550	21.9	1900	21.5
		1950	21.3

Table 3 Summary of Results

SWP	LWR	technique
length of large apertures (arcsec)[1]		
21.6+-0.4 (11)	20.7+-1.0 (12)	total exposure of trails
< 23.0	<23.8	Bohlin et al
width of the apertures (arcsec)		
8.9+-0.3 (3)	9.3+-0.1 (2)	total exposure of trails
< 10.3	<10.2	Bohlin et al
area of the large apertures (sq arcsec)		
175 +- 9	175 +- 10	0.91 x length x width
205 +- 6 (22)	203 +- 6 (14)	CALWL images
196 +- 5 (4)	----------	sky images
< 214	<221	Bohlin et al
ratios of aperture areas (large/small)		
27.2+-2.5 (17)	29.5+-1.5 (7)	CALWL images
29.2+-0.7 (4)	----------	sky images
31.4	----------	Penston, Ponz
26.5	17.8	Bohlin et al

aperture separation (pixels)

SWP			LWR			
line	sample	distance	line	sample	distance	
20.4+-0.3	17.5+-0.3	26.9+-0.2	20.2+-0.2	18.8+-0.2	27.6+-0.2	CALWL images
20.1 0.2	16.9 0.2	26.3 0.2	----------	----------	----------	sky images
		26.3				Penston, Ponz
		26.3+-0.2			26.9+-0.2	Image Processing Information

[1]Errors quoted are the standard deviation of the mean, with the number of individual measures in parenthesis.

Figure Captions

Fig 1a: Deduced aperture length, for 11 SWP spectra.

Fig 1b: Deduced aperture length, for 10 LWR spectra.

Fig 1c: Mean aperture length for SWP spectra.

Fig 1d: Mean aperture length for LWR spectra.

Fig 1e: Deduced aperture width for 3 SWP spectra.

Fig 1f: Deduced aperture width for 2 LWR spectra.

Fig 2a: Rates of total flux for paired SWP spectra. One expects unity ratio since the total exposure was identical for all pairs.

Fig 2b: Ratio for LWR spectra.

Fig 3: Ratio of the individual spectra within the pair with 13.″9 separation, extracted simply from the line by line (spatially resolved) spectral file. Unity ratios is expected, since the exposures were equal.