GENERATION OF THE NEW EXTENDED LINE-BY-LINE SPECTRUM (ELBL)

ABSTRACT

The IUE Spectral Image Processing System (IUESIPS) will be upgraded in order to enhance the spatial resolution of the Line-By-Line (LBL) Low Dispersion Spectral File.

This document presents the corresponding software modifications and its impact on the G.O. Tape file format.

The implementation date of the new Extended Line-By-Line (ELBL) in the standard IUESIPS process will be : 1-October-1985 for both VILSPA and GSFC.

However, before the above date, the G.O.'s can have the ELBL just filling the appropiate option in the IUE Image Processing Request.

IGCS / VILSPA
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April 1985

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1. INTRODUCTION

In its Low Resolution mode, IUE provides an opportunity to study the spatial distribution of light from an extended source across the Large Aperture of its spectrographs.

This information is written in the form of the so-called Line-By-Line (LBL) spectrum on the Guest-Observer (G.O.) tape. This file consists of 55 different narrow spectra, extracted in a direction parallel to the dispersion line. Each of these scan lines or "pseudo-orders" is (√2) 1.414 pixels high (i.e., a diagonal of a Raw Image pixel) and contiguous to the adjacent ones.

On the other hand, a detailed study by A. Cassatella, J. Barbero and P. Benvenuti (1985) has shown that the full width at half maximum (FWHM) of the IUE point spread function (PSF), perpendicular to the dispersion direction is about 3 pixels wide; its actual value is a function of wavelength and can be as low as 2.47 ± 0.07 pixels at 2900 A for the LWP camera (i.e., 3.8 arcsec) or as high as 4.5 pixels at 1900 A for the SWP Camera.

Therefore, the present sampling rate for the LBL Spectrum does not exploit the full resolving capability of the IUE instrument, since a proper sampling of the PSF requires a step of the order of ~ 1/3rd of its FWHM. Such was the driving motivation which lead to the replacement of the LBL file by an " Extended Line-By-Line " (ELBL) Spectrum, where the "pseudo orders" have their slit-heigth reduced to half a diagonal pixel, i.e., √2/2 (0.707) pixels.

The terms 'present' or 'current' software will be used to indicate the IUESISPS software as after the installation of the ' New Low Resolution Software ' (GSFC, 3 November 1980 and VILSPA, 10 March 1981) Refer to ESA Newsletter #14 or NASA Newsletter #25.(Configuration #60).

2. EXTRACTION METHOD OF THE NORMAL LINE-BY-LINE SPECTRUM

(Present Software)

IUE images are arrays of 768 lines each of 768 samples (ie. 768 * 768 pixels). Low Resolution Data lie along a strip inclined by approx. 45° with respect to the line/sample direction.

The present software extracts the fluxes from the Photometrically Corrected Image. It relates wavelengths and positions via the following dispersion formulae:

$$Lc = B(1) + B(2) * \lambda$$
$$Sc = A(1) + A(2) * \lambda \qquad [1]$$

where (Lc,Sc) represent the (Line,Sample) coordinates of the central point of the spectrum for a given wavelength λ. The locus of these central points defines the dispersion line. Note that Lc and Sc need not be integer, as a result of [1] for any real wavelength.

The values of the dispersion coefficients A and B can be found in the Image Header or in the Scale Factor Record (Record Zero) in the Tape files, or on the plots. They define the exact angle Θ between the dispersion direction and the Line (L) direction (Figs. 1 & 2), since :

$$\Theta = \text{Arc tan} (A(2) / B(2))$$

Along the dispersion line, wavelengths are sampled at a constant wavelength step, corresponding to half a diagonal pixel:

$$\Delta\lambda = \sqrt{2} / (2*\sqrt{(A(2)^2 + B(2)^2)}) \qquad A$$

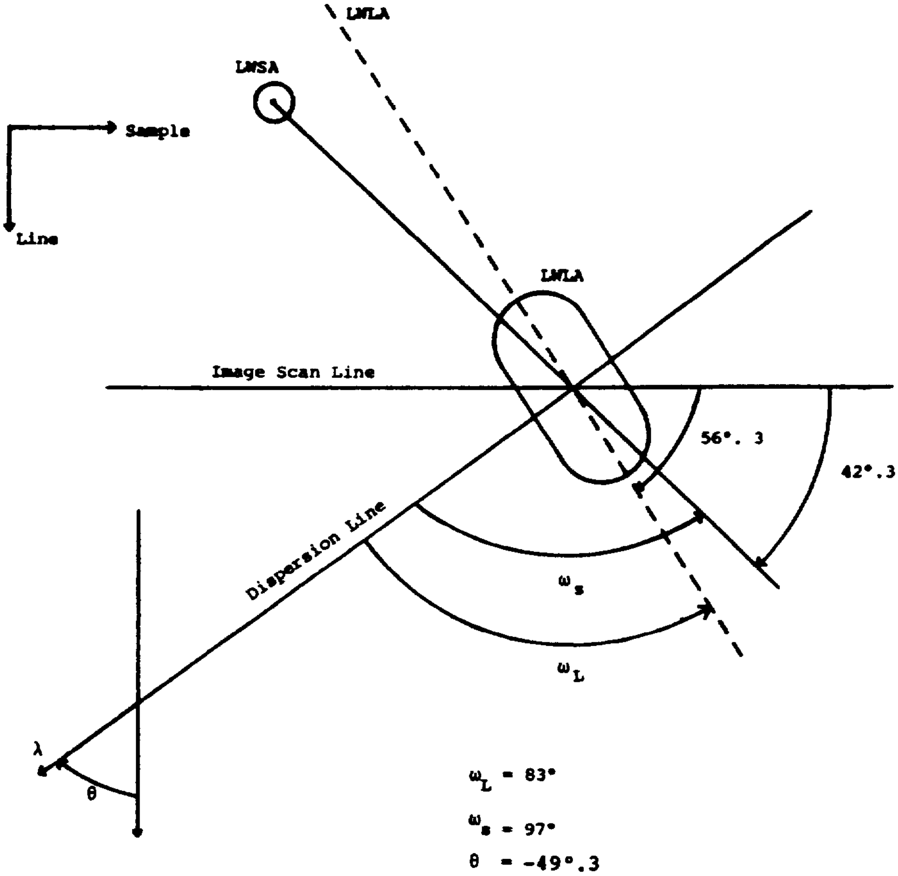


Fig. 1.a. LWP Geometry

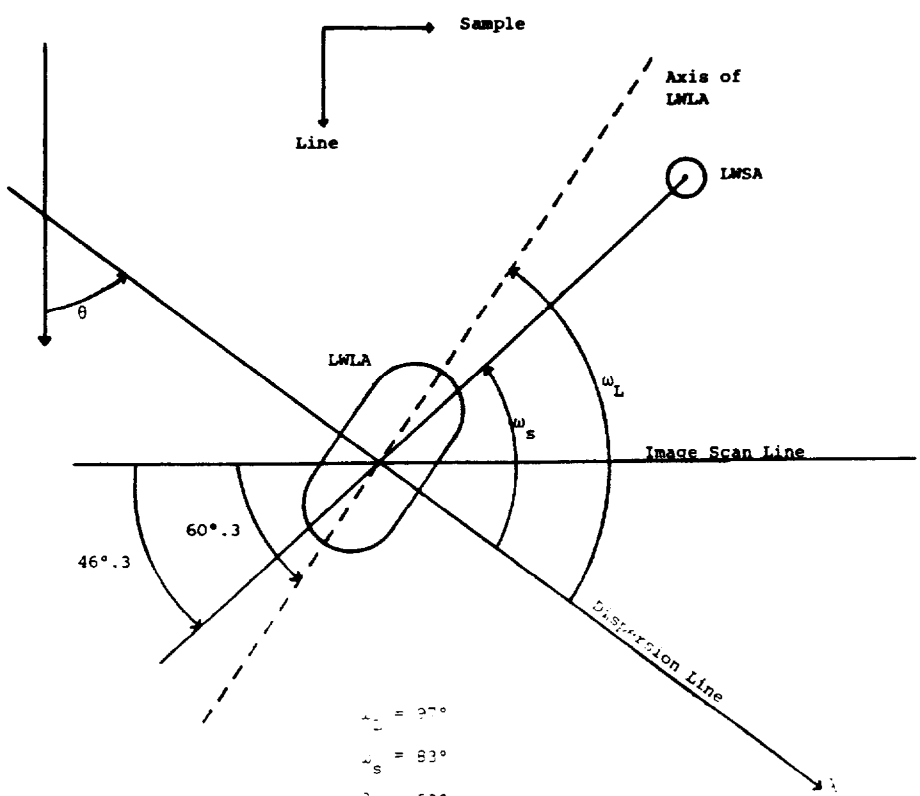
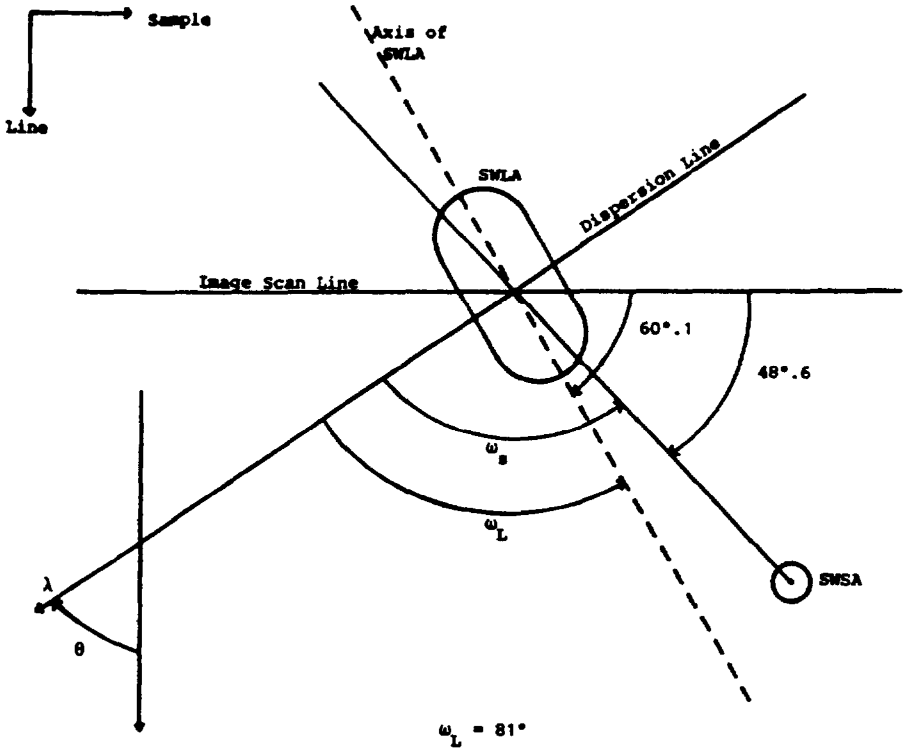


Fig. 1.b. LWR Geometry



ω_L = 81°

ω_s = 92°.5

θ = -51°

Fig. 1.c. SWP Geometry

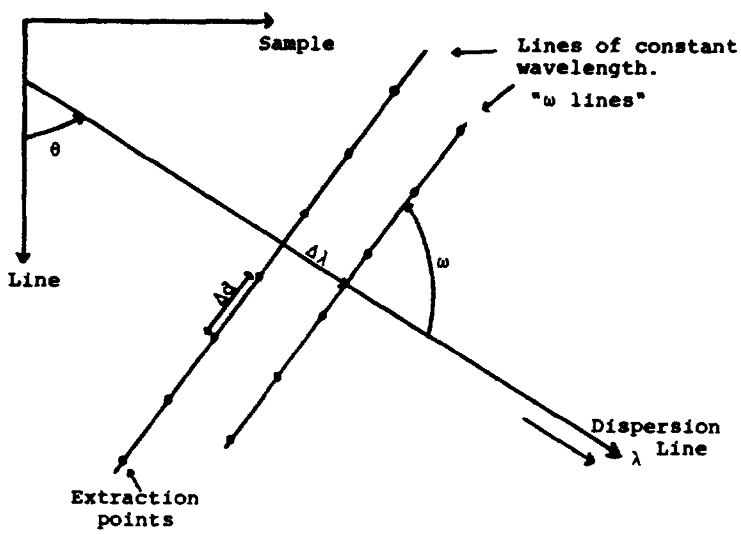


Fig. 2

Line-By-Line Extraction Procedure

$|\Delta d| = \sqrt{2}/2 = |\Delta l, \Delta s|$

$\theta = \mathrm{Arctan}\ (A(2) / B(2))$

$\Delta\lambda = \sqrt{2}/2 * \sqrt{A(2)^2 + B(2)^2}$

A(2) and B(2) = Linear coefficients of dispersion constants (see text).

Because of the spectrograph geometry, lines of constant wavelength are not exactly normal to the dispersion line. The angle between the two directions (dispersion and constant wavelength) is called ω .

For Large Aperture data, it is the angle $\omega = \omega(L)$ defined by the direction of the Aperture Major Axis; for Small Aperture data $\omega = \omega(S)$, and it is defined by the line which joins the centers of the Large and Small Apertures (Fig.1); for trailed or multiple exposures , $\omega = 90°$.

Flux values are extracted from the Photometrically Corrected Image (P.I.) every $\sqrt{2}/2$ pixels (relative to the Geometrically Corrected coordinates) along these lines of constant wavelength. There are 110 extraction points for each ω line. Therefore, the nth position of the extracting slit is defined by the following algorithm (Fig. 2) :

$$[L1,S1] = [Lc,Sc] + 54.5 * [\Delta l,\Delta s]$$

where

$$\Delta l = (\sqrt{2}/2) * \sin\alpha \qquad \alpha = \omega + \theta - \pi/2$$

$$\Delta s = - (\sqrt{2}/2) * \cos\alpha$$

and,

$$[Ln,Sn] = [L1,S1] - \sum_{i=2}^{i=n} [\Delta l,\Delta s] \qquad [2]$$

$$n = 2,3,4,....,110$$

At each location (Ln,Sn), all the flux which falls into an area corresponding to the surface of 1 pixel (from the Geometrically Corrected Space) is summed. Bilinear interpolation between adjacent pixels from the Phot. Image is used to weight their contribution to the total flux at that point (Fig. 3a). At this stage, for historical reasons (compatibility with the original software at Launch Time), the flux values are then multiplied by 2.

Note that, first, although the ω line is tilted with respect to the line/sample direction, the extraction slit remains untilted, i.e. : with the normal orientation of the Raw Image pixel. Second, since the spatial increment ($\sqrt{2}/2$) is smaller than the dimension of a pixel along the ω line ($\sqrt{2}$), this implies that the flux is actually oversampled since two adjacent extracting slits overlap by ~ 1/4th of a pixel area (Fig. 3b); with this sampling procedure no loss of data occurs but the extracted fluxes are not totally independent from their neighbours.

Once they have been extracted, adjacent points are added in the spatial direction, resulting in a set of 55 spatially resolved gross flux points, each one distant from the next one by $\sqrt{2}$ pixels in the Geometrically Corrected Space. This process is repeated for each sampled wavelength (Fig. 4).

The final result of this extraction is a two dimensional image, called the Line-By-Line Spectrum. Within this image, each row is treated as a separate spectral ' pseudo-order'. The 28th or central row is centered on the Dispersion Line and assigned an arbitrary order number of 100.

As can be derived from algorithm [2] and Figs. 1a, 1b & 1c, the order numbers increase in the direction from the Large Aperture toward the Small Aperture for the LWR and SWP cameras; for the LWP camera, the order numbers increase in the opposite direction (Fig. 5).

The resulting data file is output to the Guest Observer Tape and it is defined as the 'Line-By-Line Spectrum' (LBLS) file.

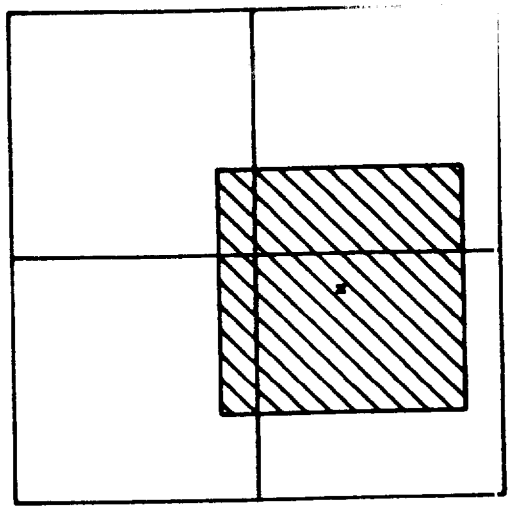


Fig. 3a

ux value at x is equivalent to a weighted average of the surrounding our pixels in the Photometrically Corrected Image, with weights pro - ortional to the area of each pixel within the hatched region.

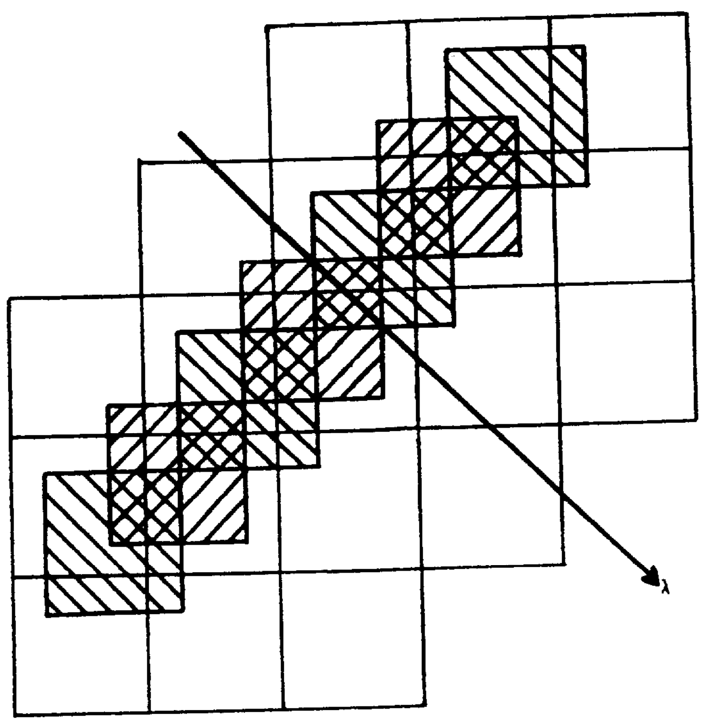


Fig. 3 b

Extraction slits at a given wavelength. As can be seen, the flux is oversampled along the ω line, since the spatial increment is $\sqrt{2}/2$ pixels. The locations of the extraction points are the centers of the hatched squares. In this example, ω = 90°, for clarity.

("New" Software)

The generation of the Extended Line-By-Line (ELBL) Spectrum uses the same concepts as that of the LBL : dispersion line, ω line, bilinear interpolation,etc.

The differences can be summarized as follows:

(A) The algorithm used for finding the extraction points is slightly different.

(B) Adjacent lines are not added, i.e. all 110 "pseudo-orders" are retained.

(C) The order numbers increase in the same direction for all three cameras (LWP,LWR and SWP), that is, from Large to Small Aperture.

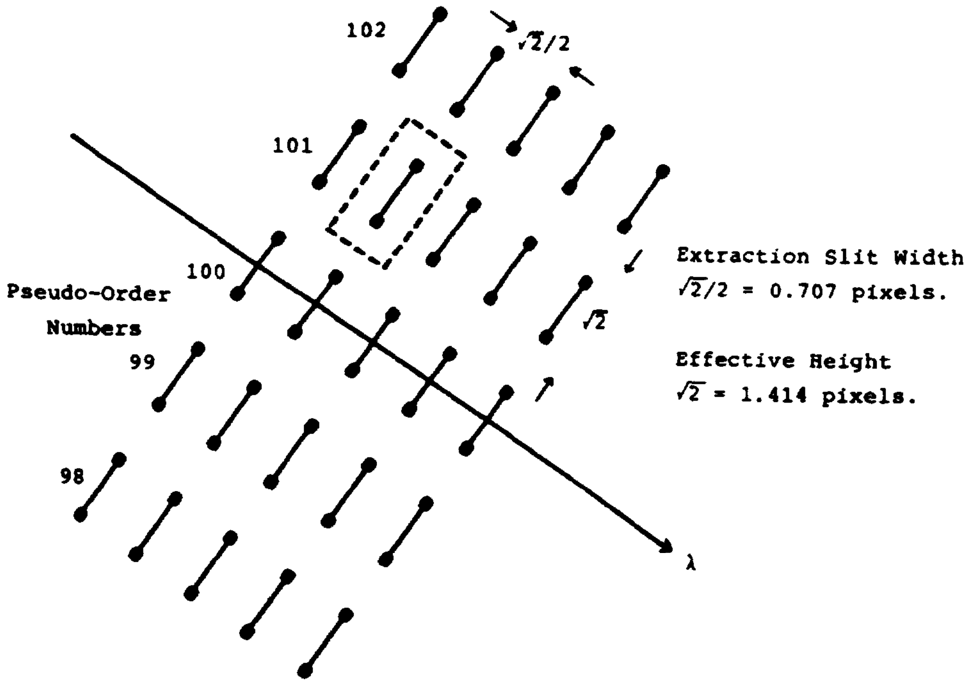
(D) As a consequence of (B), the format of the LBL Tape File has been modified.

A detailed description of these modifications is given in the next sections :

(A) NEW ALGORITHM

The algorithm described in the previous section (present software) yields a systematic error in the coordinates of the extracted points. This error arises from the computation of the value of √2 . This contains an implicit truncation error which, according to algorithm [2] is propagated and accumulated when computing the coordinates of the different extraction points.

LINE-BY-LINE



EXTENDED LINE-BY-LINE

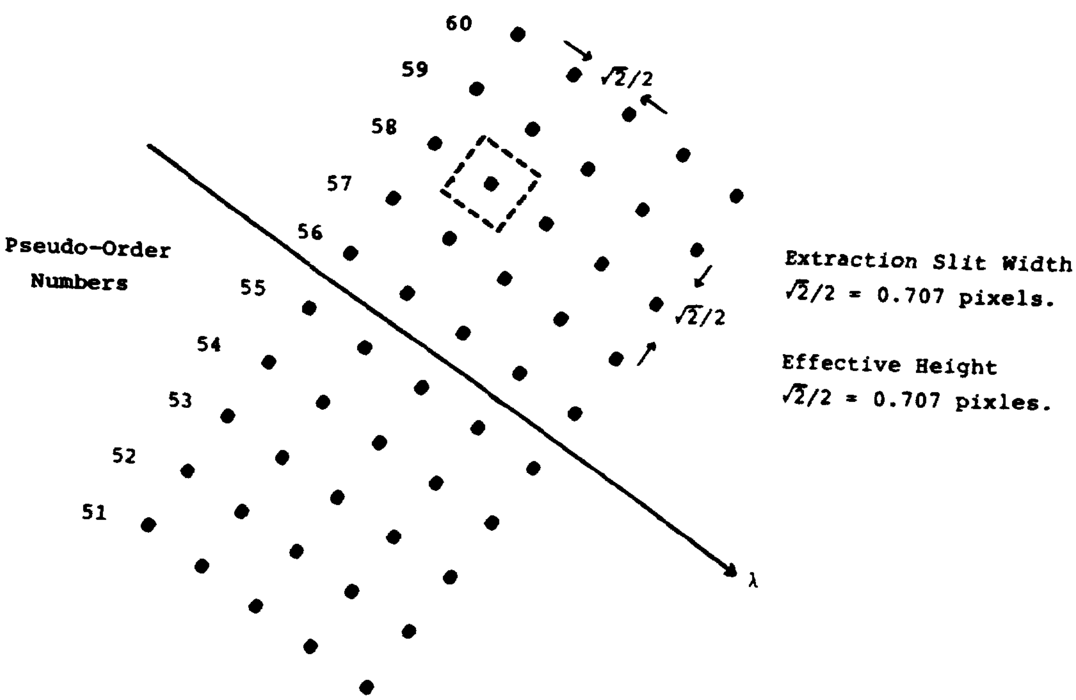


Fig. 4. Extraction of Flux Numbers and Pseudo-Order Numbering in the Normal LBL and in the Extended LBL.

The new algorithm is as follows :

[Lc,Sc] and [L1,S1] are unchanged, but subsequent positions are computed as :

$$[Ln,Sn] = [L1,S1] - (n-1) * [\Delta l,\Delta s] \qquad n=2,3,4,...,110 \qquad [3]$$

With algorithm [3], the truncation error is not accumulated, and the computed coordinates are symmetrical with respect to the dispersion line.

The new algorithm defined by [3] being more accurate, the extracted spectral flux values (MELO) will be slightly different than with the present software. On the average, this difference is always < 1 %.

(B) GENERATION OF 110 "ORDERS"

As described earlier, in the current software, adjacent points were added in the spatial direction.

In the New Extended Line-By-Line (ELBL), adjacent points are not added.

The ELBL Spectrum, therefore, contains 110 spectral 'pseudo-orders', (Fig. 4), each one distant from the preceeding and following ones by $\sqrt{2}/2$ pixels. Since 1 Raw Image pixel corresponds to 1".525 ± 0".010 on the sky (Panek, 1982; Bohlin et al., 1980), the heigth of the ELBL slit is 1".078 = 1".525 * $\sqrt{2}/2$.

Taking advantage of the software modification, this plate scale factor will be, from now on, written into the Record Zero of the ELBL file (item #37; see Table I and section 3.D).

The change in the number of pseudo-orders has no impact on the format of the Merged Extracted Low Dispersion File (MELO) (Fig. 6).

Flux values in the ELBL file remain in the same unit as before.

However, they correspond to a spatial area which is a factor of 2 smaller than with the LBL Spectrum and should be, therefore, half as large on the average.

For example, many G.O.'s are accustomed to re-extract the Gross flux directly from the LBL file. For a point source, they usually sum the flux in the 9 most central orders. For them, the only change will consist in summming the 18 central rows instead of 9, i.e., co-adding scan lines 47 to 64 of the ELBL. The rest of the extraction procedure, and in particular the absolute calibration, remains unchanged.

(C) ORDER NUMBERING AND "INVERSION" OF THE ELBL FOR THE LWP CAMERA

As a result of the extension of the LBL, the "pseudo-order" numbers had to be redefined to run from 1 to 110 and are no longer written in items #203-302 of Record Zero (see discussion of Record Zero structure in the following section).

As previously indicated, in the current software, the "pseudo-order" numbers could either increase or decrease, when going from the Large Aperture (LAP) to the Small Aperture (SAP), depending on the Camera. (Fig. 5)

Taking advantage of the ELBL implementation, a more uniform numbering was introduced :

From now on, the "pseudo-order" numbers will always increase along the Large to Small Aperture direction, whatever camera is used.

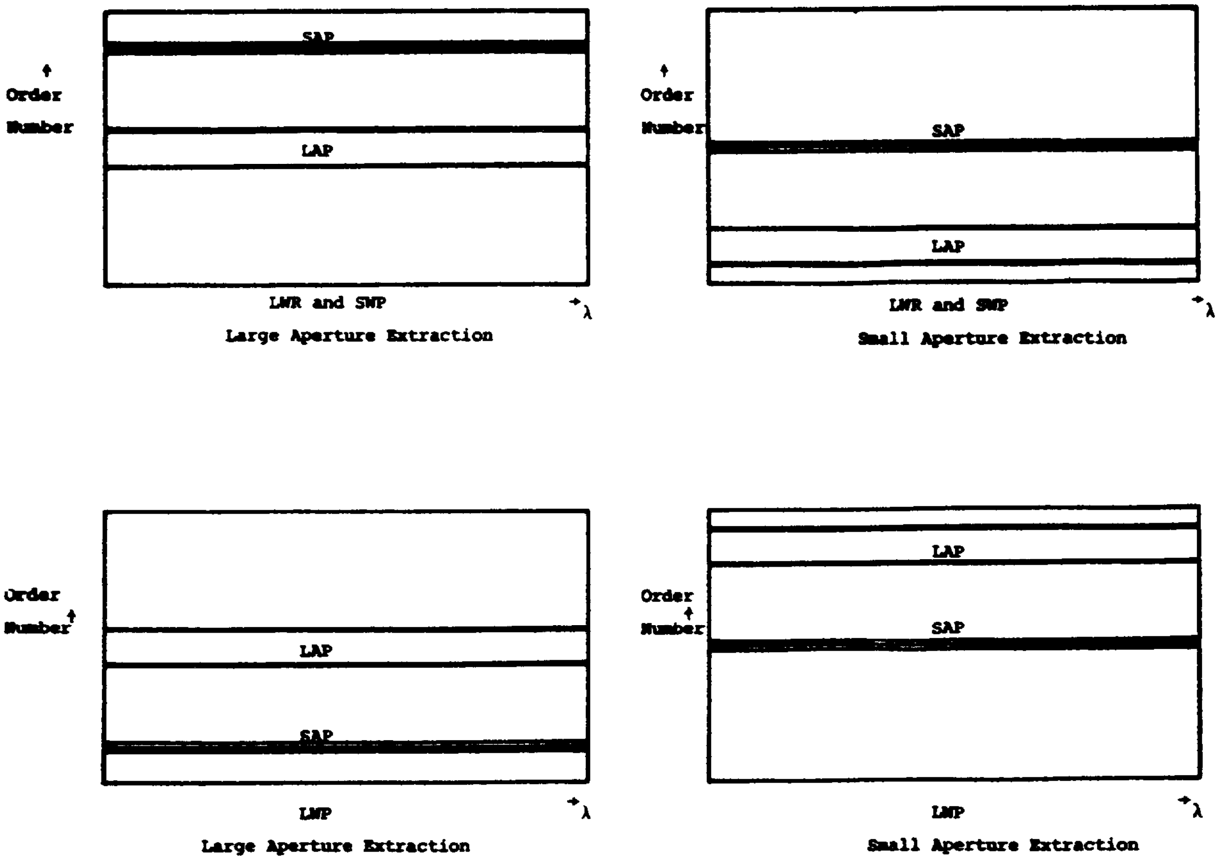


Figure 5. Order Numbering in the Present Software

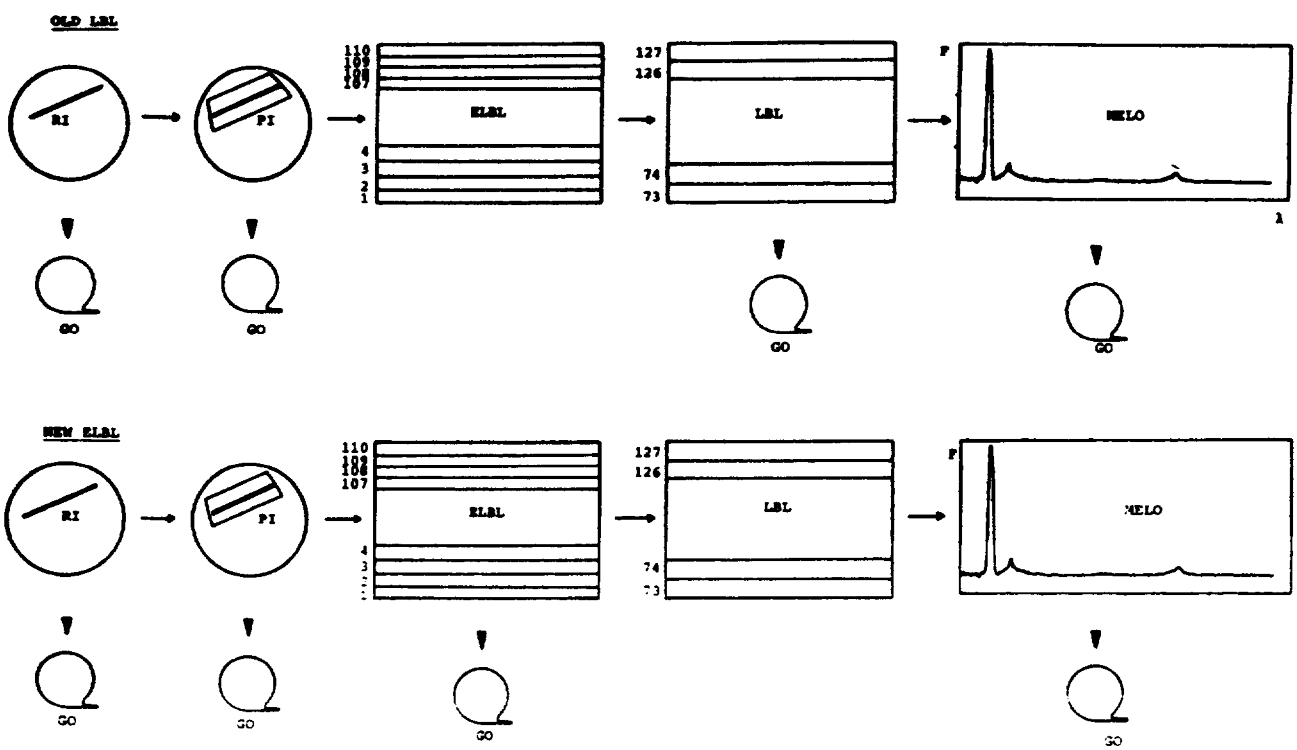


Fig. 6. Output Files from the Old LBL Software and New Extended LBL Software.

The "inversion" of LWP's ELBL is done merely by changing the sign of the [$\Delta l, \Delta s$] displacements along the ω line, that is:

$$\Delta l = -(\sqrt{2}/2) * \sin \alpha$$
$$\Delta s = (\sqrt{2}/2) * \cos \alpha$$

(D) MODIFICATION OF THE GUEST OBSERVER TAPE FORMAT

(LOW Dispersion only)

The sequence of files written to tape remains unchanged, e.g. for a single aperture exposure (Fig.6):

1. Raw Image (RI)
2. Photometrically Corrected Image (PI)
3. Extended Line-By-Line Spectrum (ELBLS)
4. Merged Extracted Spectrum (MELO)

and for double aperture exposures :

1. Raw Image (RI)
2. Photometrically Corrected Image (PI)
3. ELBLS (Large Aperture)
4. MELO (Large Aperture)
5. ELBLS (Small Aperture)
6. MELO (Small Aperture)

Among these files, only the structure of the ELBLS file (3rd or 3rd & 5th) is modified. The new format is as follows :

- The label records remain the same, except the number of lines field (bytes 33 to 36 of first label line), which is changed from 166 to 331.

- Since the name of the application program which generates the New Extended LBL has changed, the image processing history section of Label and the Plot Label will be different: 'SPECLO' changed to 'ESPECLO', and the old message 'LINE-BY-LINE SPECTRUM, SPATIALLY RESOLVED' is changed to 'EXTENDED LBL SPECTRUM, SPATIALLY RESOLVED'

- The data records are 2048 bytes long. Each entry is a two-byte or 16-bit halfword integer (range is 32767, with negatives in two's complement form), i.e., there are 1024 entries per record (Fig. 7).

  The first entry of each record is a data-record sequence number which begins with 0 for the first physical record.

  This first record (record sequence number 0) is a scale-factor record containing data pertinent to all following records. The changes in the so called Record Zero will be described below.

  The remaining records contain the actual extracted spectral data in scaled form, and arrenged in groups of logically associated records.

  For the ELBL Spectrum, there is only one scaled flux record per group, representing the Gross Line-By-Line flux for one "pseudo-order. Hence, there are three records per group :

  1) scaled wavelengths
  2) quality flags (epsilons)
  3) scaled fluxes.

  The total number of groups is 110.

** E L B L Format **

← 2048 BYTES →

		HALFWORD 1	HALFWORD 2	HALFWORD 3	HALFWORD 4	HALFWORD 5	HALFWORD 6	etc.....	HALFWORD 1024	
	RECORD# 1	0	1022	λ min	λ max	Camera	Image#	etc.	0	SCALE RECORD Record "Zero"
ORDER 1	RECORD# 2	1	# points	λ 1	λ 2	λ 3	λ 4	etc.	0	SCALED λ's
ORDER 1	RECORD# 3	2	# points	ε 1	ε 2	ε 3	ε 4	etc.	0	ε's
ORDER 1	RECORD# 4	3	# points	F 1	F 2	F 3	F 4	etc.	0	SCALED FLUXES
ORDER 2	RECORD# 5	4	# points	λ 1	λ 2	λ 3	λ 4	etc.	0	SCALED λ's
ORDER 2	RECORD# 6	5	# points	ε 1	ε 2	ε 3	ε 4	etc.	0	ε's
ORDER 2	RECORD# 7	6	# points	F 1	F 2	F 3	F 4	etc.	0	SCALED FLUXES
	.	.			.				.	
	.	.			.				.	
	.	.			.				.	
	.	.			.				.	
ORDER 110	RECORD#329	328	# points	λ 1	λ 2	λ 3	λ 4	etc.	0	SCALED λ's
ORDER 110	RECORD#330	329	# points	ε 1	ε 2	ε 3	ε 4	etc.	0	ε's
ORDER 110	RECORD#331	330	# points	F 1	F 2	F 3	F 4	etc.	0	SCALED FLUXES

NOTE : The 110 pseudo-orders are "orders" 1 - 110, each one is one scan.
Within each "order", the λi, εi, Fi and # points refer to data for that "order".
For any point i, the λi values are the same for all orders
Within each "order", the corresponding λi, εi & Fi values are found in the same halfword of successive records.

Fig. 7

Record Zero Structure

The general structure of the Scale-Factor record (Record Zero) for all the extracted files, both resolutions (ELBL, MELO and MEHI) is shown in Table I.

In particular, for the old LBL Spectrum, the following items had the shown values :

Item	Value in LBL
5	55 (# of orders present)
8	3 (# of records per order)
21-24	Scale factors for flux
37-39	Spares
103-202	λo , wavelength offset for each order All values are 0 .
203-302	Order number; first 55 items are numbers 73 to 127; remaining are 0 .
303-402	Number of points per order; first 55 items have the same value, remaining ones are set to 0 .
403-502	Slit heigth * 100 = 141 . Only Item #403 . Remaining items are set to 0 .

For the ELBL Spectrum, some of these fields have been redefined :

Item	Value in ELBL
5	110 (new number of orders)
8	3 (unchanged)
21-24	Unchanged
37	"Plate" Scale factor for ELBL file (Arcsec * 1000 = 1078).
38	(Julian Date - 2440000) for midpoint of observation.
39	Fraction of Julian Date (* 10000) at midpoint of observation.
103-202	Unchanged. They remain set to 0 .
203-302	All items are set to 0 .
303-402	Number of points per order; it is the same for every scan and, therefore, it is written only once, in item #303 ; remaining entries are set to 0.
403-502	Slit height * 1000 = 707 . Only item #403. Remaining items are set to 0.

Table I . Format of Scale Factor Record
(Record Sequence Number Zero)

Item (16-bit halfword)		Quantity
1		Zero (for record 0)
2		1022 (Maximum number of halfword entries in remainder of record 0)
3		Minimum wavelength (truncated to nearest A)
4		Maximum wavelength (rounded to nearest A)
5		Number of orders present
6		Camera number
7		Image number
8		Number of records per group (i.e. per order)
9		Year
10		Day Number of midpoint of
11		Hour observation (GMT)
12		Min
13-16		As 9-12 for time of image processing (GMT)
17		Target aperture (1=large, 2=small)
18		Total line shift (pixels * 1000)
19		Total sample shift (pixels * 1000)
20	***	THDA * 10 (C) used for reseau correction (normally at the time of read)
21		Scaled minimum flux for Gross
22		Scaled maximum flux for Gross
23		J for Gross where actual FN = data on
24		K for Gross tape * J * 2**(-K)
25-28		as in 21-24 for Background
29-32		as in 21-24 for Net
33-36		as in 21-24 for Absolute Net (Low) or Ripple Corrected Net (High)
37		"Plate" scale factor for ELBL file (=1078) (Arcsec*1000).
38		(Julian Date - 2440000) at midpoint of observation
39		Fraction of Julian Date (*10000) at midpoint of observation
40-41		Spares
42-44	NI	Minutes, seconds and miliseconds of exposure in target aperture.
45		Hours
46		Minutes Right Ascension of target
47		Seconds * 10
48		Degrees
49		Arc minutes Declination of target
50		Arc seconds

51-53	**	(Vx , Vy , Vz) Velocity of Earth in celestial coordinates (km/sec * 10).
54-56	**	(Vx , Vy , Vz) Same as 51-53 for IUE with respect to Earth, at midpoint of exposure.
57	**	Net velocity correction applied (km/sec * 10)
58		Omega angle (degrees * 10) (Zero in High)
59		Wavelength scaling factor (5=Low , 500=High, where actual λ = (λ on tape)/(scal. factor) + λo
60		Background slit height - Low
61		Background distance - Dispersion from dispersion line - Only (pixels * 100)
62		Dispersion constant shift mode (0=no shift, 1=auto shift, 2=manual shift)
63	NI	Bright Spot removal threshold DN
64		THDA * 10 for dispersion constant correction (normally at the end of the exposure)
65-70		Spares
71-102		For use of IUE Regional Data Analysis Facility.
103-202		λo , offset wavelengths for each order
203-302		m, order number for each order
303-402		Number of extracted data points for each order
403-502		Slit height for each extracted order (pixels*100) In the ELBL, only item #403 is used (pixels*1000)
503		Sign and first 4 digits after decimal of dispersion constant A1
504		Sign and second set of 4 digits after decimal of dispersion constant A1
505		Sign and third 4 digits after decimal of dispersion constant A1
506		Exponent (including sign) of dispersion constant A1 where: A1=[item(503)*10**(-4) + item(504)*10**(-8) + item(505)*10**(-12)] * 10**(item(506))
507-538		As above, for dispersion constants A2 through A9
539-574		As above, for dispersion constants B1 through B9
575-1024		Spares

** High Dispersion only

*** Currently not used to correct reseau positions for the LWR and LWP cameras

NI Not implemented yet.

4. REFERENCES

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APPENDIX

THE ORIENTATION OF THE CELESTIAL COORDINATES IN THE ELBL

With the new ordering, the ELBL Image files have the same appearence for the 3 cameras (LWP,LWR and SWP), (see section 3.C.

However, their orientation with respect to the Celestial Sphere is not uniform. Therefore, we illustrate below, by a simple example, the orientation of the IUE slits as they can be derived directly from the Spacecraft Roll Angle (R); (ESA IUE Newsletter #10, p.7).

The Large Aperture Position Angle (P.A.) is measured with respect to the Celestial North with normal astronomical conventions.
It defines the direction of its Major Axis which, by definition, is oriented positively from the Small to the Large Aperture. (Fig. 8).

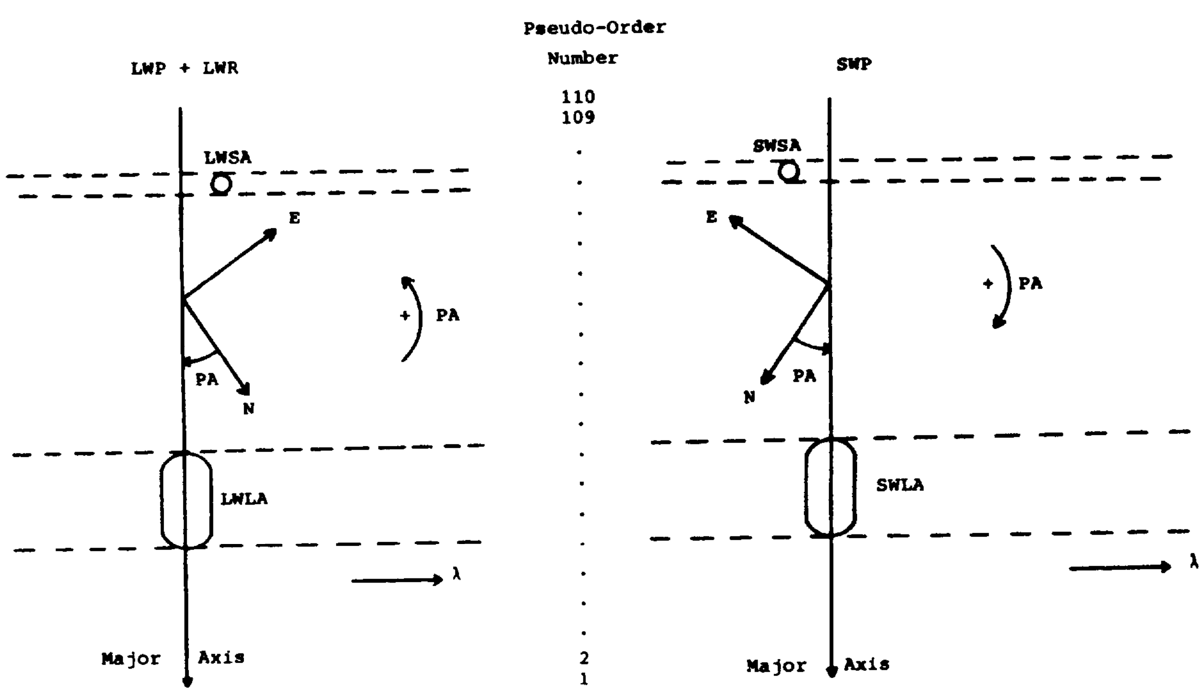
The P.A. of the Large Aperture is defined by:

$$PA = 73^o - R$$

Then, the Celestial Axes can be easily found on the ELBL as shown in the following figure.

For example, for an observation made at R = 118°, then,

$$PA = 73^o - 118^o = - 45^o$$



P.A. = - 45°   P.A. = - 45°

The relative position ($\Delta\alpha$, $\Delta\delta$) in Arcsec, for any Aperture with respect to any other, can be found through :

$$\begin{pmatrix} \Delta\alpha \\ \Delta\delta \end{pmatrix} = \begin{pmatrix} -0.2680 \cos(R+28^\circ.31) & , & 0.2617 \sin(R+28^\circ.31) \\ -0.2680 \sin(R+28^\circ.31) & , & -0.2617 \sin(R+28^\circ.31) \end{pmatrix} \begin{pmatrix} \Delta X \\ \Delta Y \end{pmatrix}$$

The quantities ΔX and ΔY, which are the distance between any two apertures in FES units can be obtained from Fig. 8.

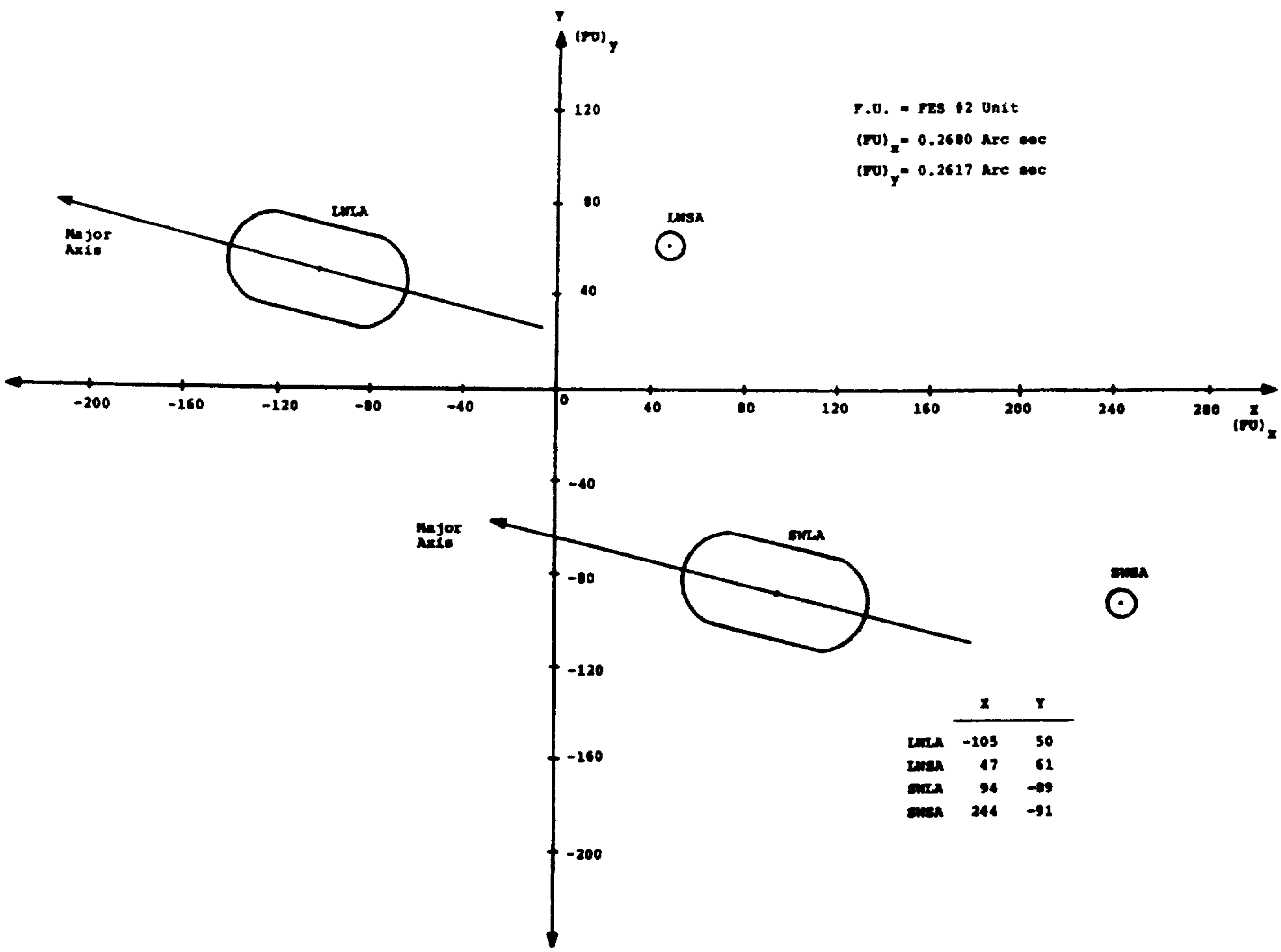


Fig. 8. Lay-out of the IUE focal plane in the FES #2 System of Coordinates. The four spectrograph apertures are shown and their (X, Y) positions are listed in FES units (FU). Note that the plate scale is slightly different along the 2 axis, $(FU)x \neq (FU)y$.