Low-Dispersion Wavelength Calibration for the IUE Final Archive

HOWARD BUSHOUSE

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I. Introduction

Changes in IUE image formats and processing techniques that will result from implementation of the new software system that is under development for production of the IUE Final Archive will make it necessary to change the way in which dispersion solutions are determined. This report is an introduction to some of the major differences between the two systems. First, a note on terminology: hereafter the current production version of the IUESIPS will be refered to as "IUESIPS", while the system under development for the final archive will be refered to as "NEWSIPS".

II. Background

Small-aperture spectra of the on-board platinum-neon calibration lamp are used to determine wavelength as a function of position in IUE images. These wavelength calibration (WAVECAL) exposures are obtained once a month for each of the operational cameras. Each set of calibration images is processed to determine analytic relations between wavelength and pixel position. The derivation of these dispersion relations as currently implemented in IUESIPS is a multi-step process which I will describe briefly below. Further details are contained in section six of the IUE Image Processing Information Manual - Version 2.0. First, the pixel locations of the Pt-Ne emission lines are measured on a geometrically corrected WAVECAL image by a cross-correlation search algorithm. The measured Pt-Ne line positions are then combined with laboratory values for the wavelength of each emission line (stored in a "line library") and used in a regression analysis to determine a set of dispersion constants relating wavelength and line and sample pixel positions. For low dispersion the spectral format is represented by a linear relation. The dispersion relationships are then used to guide the extraction of spectral data from two-dimensional photometrically-corrected (PI) science images to produce line-by-line (ELBL) files.

NEWSIPS will produce a low dispersion resampled image (known as "SILO") which is photometrically- and geometrically-corrected, and has the spectral data rotated so that the dispersion direction is parallel to one image axis. Thus the format of this type of image will be similar in appearance to the ELBL files produced by IUESIPS. Dispersion solutions for NEWSIPS will be determined from the SILO files of WAVECAL images and therefore the new dispersion solutions will be a function of only one image coordinate instead of two as in IUESIPS. The SILO images will also differ from the current ELBL files in that they will contain spectral data for both the large and small entrance apertures (if data is present for both apertures), and will have the offset between the two apertures in the dispersion direction removed so that a single dispersion solution applies to the entire image.

III. Updated Line Libraries

Before the process of determining dispersion solutions for the SILO images was begun, new comparison lamp line libraries were constructed, based on the Pt-Ne line positions measured recently by Reader *et al.* (1990) at the National Institute of Standards and Technology (NIST). The existing IUE line libraries were based on the results of Shenstone (1939) and are known to be less accurate than the NIST measurements (see also Ayres, Jensen, and Engvold 1988).

After examining the low-dispersion line libraries used by IUESIPS some important deficiencies were discovered. First, some of the lines used in the dispersion solutions were either heavily blended or severely saturated by the exposure times typically used for the wavelength-calibration images, and thus it was difficult to accurately measure a centroid position for these lines. As many of these lines were removed as possible without leading to undersampling of the spectral range. Second, several well-exposed lines near either end of the spectral ranges of the short- and long-wavelength cameras were not being used. These lines are now included in the new low-dispersion line libraries and extend significantly the wavelength coverage used in calculating the dispersion solutions. For example, the reddest line in the current LW library is at 3065Å, while the new library includes lines out to 3350Å. Similarly, the bluest line in the current SW library is at 1380Å, while the new library goes down to 1248Å. Figure 1 shows low-dispersion wavelength calibration (WAVECAL) spectra for the LWP and SWP cameras and indicates which blended or saturated lines have been removed from the line libraries and which new lines have been added. Table 1 contains listings of the old and new low-dispersion line libraries. Please note that testing of the new line libraries is still underway and therefore it is possible that this list may yet change before being implemented in NEWSIPS.

IV. New WAVECAL Processing and Analysis Procedures

While the current processing procedure for WAVECAL images is highly automatic and allows little user intervention, the techniques under development for NEWSIPS are more interactive and therefore allow for real-time inspection of image and/or dispersion solution anomalies, should they arise.

Briefly, routines within the IRAF package "APEXTRACT" are used to locate, trace, and extract the WAVECAL spectra from the two-dimensional SILO files. Then the IRAF routine "IDENTIFY" is used to locate the spectral features included in the new line libraries and to compute a dispersion solution. The resulting dispersion solution information for a given WAVECAL image is then appended to a master dispersion constants file for each IUE camera. The application of these solutions to science images will be discussed in §VI.

In the following section I will show comparisons of dispersion solutions calculated from WAVECAL images processed through both NEWSIPS and IUESIPS. The dispersion solutions for WAVECALs processed with IUESIPS have been calculated using the same IRAF routines as with the NEWSIPS processing, but the spectra have been extracted from the line-by-line (ELBL) files produced by IUESIPS. Users familiar with the ELBL files will note that these files already have a wavelength solution applied to them by IUESIPS, but for our purposes here the IUESIPS wavelength assignments have been ignored and new dispersion solutions have been calculated based on the measured positions of the Pt-Ne lines in the extracted spectrum.

V. The New Dispersion Solutions

IUESIPS assumes that the relationship between pixel and wavelength space in low-dispersion mode is linear. After analyzing WAVECAL spectra processed through both IUESIPS and NEWSIPS it has been discovered that this is not exactly true. Residuals from a linear fit to the emission-line positions in WAVECAL spectra show significant second- and third-order terms. Figures 2 and 3 show the residuals to a linear fit of a WAVECAL spectrum for each of the LWP and SWP cameras, respectively. The top panel of each figure is for an image produced by NEWSIPS, while the bottom panel is for the same image processed by IUESIPS. Notice that both show systematic second- and third-order departures from the mean fit over the entire spectral range, although the effects are most severe at the long-wavelength ends of both cameras. Had the wavelength coverage of the line libraries not been extended the worst effects might have gone unnoticed. The cause of these high-order terms is not yet completely understood, although residual geometric distortions may play a role.

Solving for and implementing a third-order dispersion solution is feasible, however this would leave the NEWSIPS output data products non-linear in wavelength space and therefore the wavelength increment per pixel would not be constant along a spectrum. After analyzing third-order dispersion solutions for many WAVECAL spectra, it has been determined that the first, second, and third-order terms are quite uniform over time and camera head amplifier temperature (THDA). Figures 4 and 5 show the first, second, and third-order terms of a Chebyshev polynomial dispersion solution for approximately 40 WAVECALs for each of the LWP and SWP cameras, respectively, sampling a large range in time and THDA. The error bars plotted in each panel of the figures show the typical uncertainty in the value of each term for an individual solution.

Since these high-order terms appear to be quite stable, it is possible to incorporate a "linearization correction" into the geometric-correction phase of NEWSIPS which removes the second- and third-order wavelength dependencies, thus producing a SILO file that is linear in wavelength space. The form of the correction is based on the average of the high-order terms for the sampling of WAVECALs processed so far. Since this correction is done at the same time as the rest of the geometric corrections, we are resampling the raw image only once. The middle panels of figures 2 and 3 show the residuals to a linear dispersion solution for WAVECAL spectra that have undergone this correction. Notice that not only is the RMS of the residuals somewhat smaller than that achieved by IUESIPS, but the residuals also now show a random scatter about the fit, as opposed to the systematic offsets due to the neglected second- and third-order terms in the linear solution used by IUESIPS.

VI. Application To Science Images

The derived dispersion solutions for individual WAVECALs are not directly used in the current production processing, nor will they be in NEWSIPS. Instead, the wavelength calibration is applied using mean dispersion relations. The direct application of dispersion relations calculated from the monthly WAVECAL images would produce a discontinuity in the wavelengths assigned to science images due to the small uncertainties (and hence slight differences) in the dispersion constants derived from individual calibration images. Furthermore, shifts in the location of the spectral format within individual images are known to occur as a function of time and THDA (see e.g. Thompson 1988). These shifts occur both along and perpendicular to the dispersion and therefore result in changes to the wavelength zero-point as well as the spatial location of spectra within NEWSIPS SILO images. Mean dispersion constants and their correlation with time and THDA are determined via a regression analysis of the individual solutions stored in the master dispersion constants file for each camera. The dispersion solutions applied to science images are then derived by adding corrections to the mean dispersion constants appropriate to the time and THDA of the science observations.

References

Ayres, T. R., Jensen, E. and Engvold, O., 1988, *Ap.J.Suppl.*, **66**, 51.

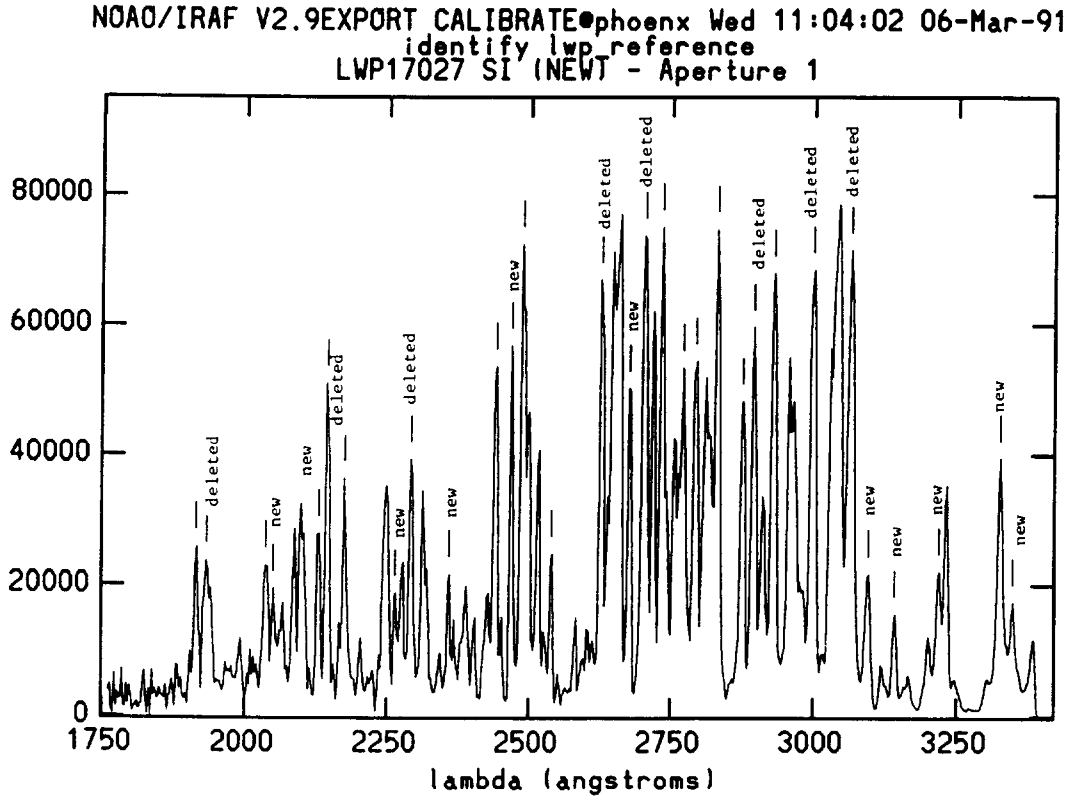
Reader, J., Acquista, N., Sansonetti, C. and Sansonetti, J. E., 1990, *Ap.J.Suppl.*, **72**, 831.

Shenstone, A. G., 1939, *Phil. Trans. Royal Soc. London, Ser. A*, **237**, 453.

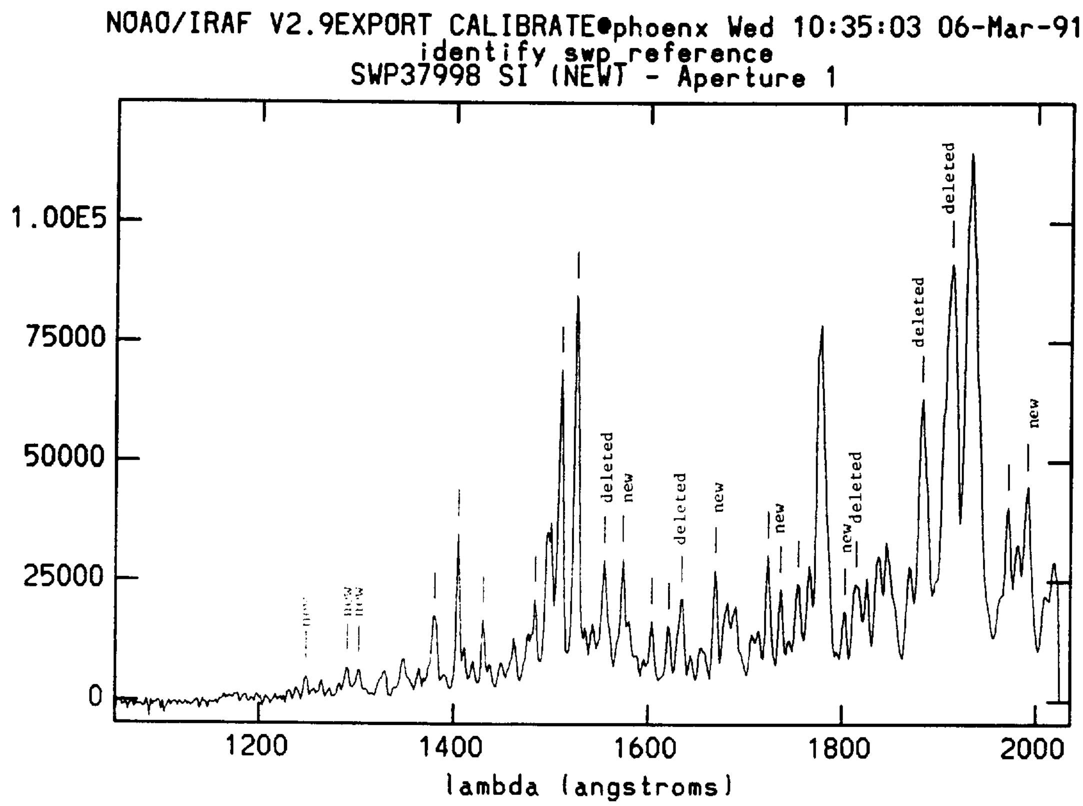
Thompson, R. W., 1988, *IUE NASA Newsletter No. 35*, 108.

TABLE 1
Line Libraries

Short Wave Cameras		Long Wave Cameras	
Old	New	Old	New
	1248.61	1913.23	1913.23
	1289.95	1937.84	removed
	1302.79	2037.12	2037.12
1380.49	1380.49		2050.05
1403.90	1403.90		2129.31
1429.23	1429.52	2144.92	2144.92
1482.83	1482.83	2175.36	removed
1509.29	1509.29		2263.42
1524.73	1524.73	2290.71	removed
1554.90	removed		2357.83
	1574.31	2440.80	2440.80
1604.01	1604.01		2468.15
1621.66	1621.65	2489.16	2487.92
1635.21	removed	2539.97	2539.97
	1669.23	2628.82	removed
1723.13	1723.13		2677.94
	1736.52	2703.87	removed
1753.82	1753.83	2734.77	2734.77
	1802.94	2772.49	2772.48
1812.94	removed	2793.97	2792.84
1883.05	removed	2830.13	2831.13
1913.23	removed	2876.43	2876.48
1971.52	1971.54	2896.47	removed
	1990.58	2930.65	2930.65
		3000.79	removed
		3065.61	removed
			3094.90
			3140.30
			3219.12
			3324.69
			3346.42



NOAO/IRAF V2.9EXPORT CALIBRATE@phoenx Wed 11:04:02 06-Mar-91
identify lwp reference
LWP17027 SI (NEWT - Aperture 1
lambda (angstroms)



NOAO/IRAF V2.9EXPORT CALIBRATE@phoenx Wed 10:35:03 06-Mar-91
identify swp reference
SWP37998 SI (NEWT - Aperture 1
lambda (angstroms)

FIGURE 1

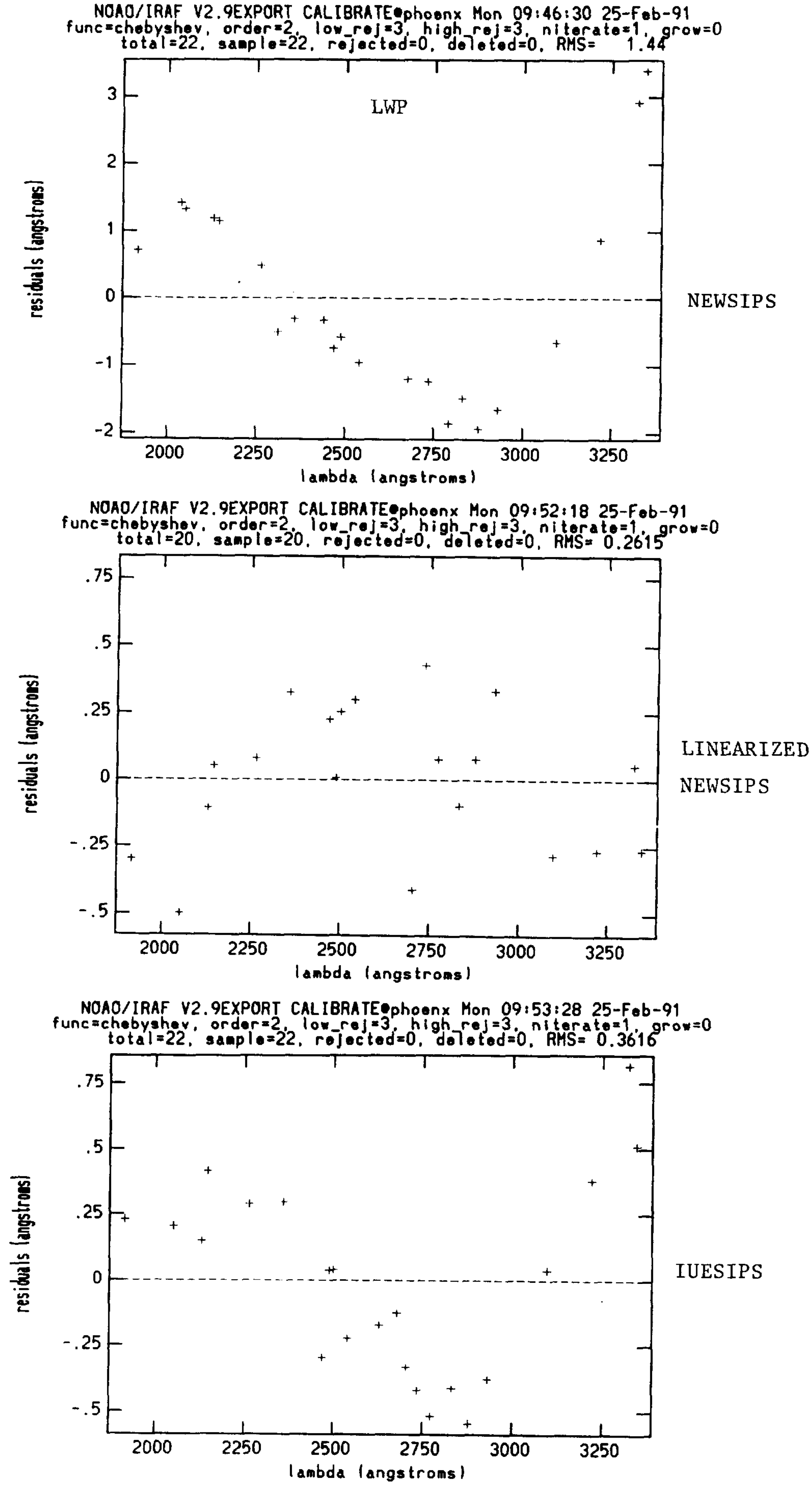

NOAO/IRAF V2.9EXPORT CALIBRATE@phoenx Mon 09:46:30 25-Feb-91
func=chebyshev, order=2, low_rej=3, high_rej=3, niterate=1, grow=0
total=22, sample=22, rejected=0, deleted=0, RMS= 1.44
LWP
residuals (angstroms)
lambda (angstroms)
NEWSIPS
NOAO/IRAF V2.9EXPORT CALIBRATE@phoenx Mon 09:52:18 25-Feb-91
func=chebyshev, order=2, low_rej=3, high_rej=3, niterate=1, grow=0
total=20, sample=20, rejected=0, deleted=0, RMS= 0.2615
residuals (angstroms)
lambda (angstroms)
LINEARIZED
NEWSIPS
NOAO/IRAF V2.9EXPORT CALIBRATE@phoenx Mon 09:53:28 25-Feb-91
func=chebyshev, order=2, low_rej=3, high_rej=3, niterate=1, grow=0
total=22, sample=22, rejected=0, deleted=0, RMS= 0.3616
residuals (angstroms)
lambda (angstroms)
IUESIPS

FIGURE 2

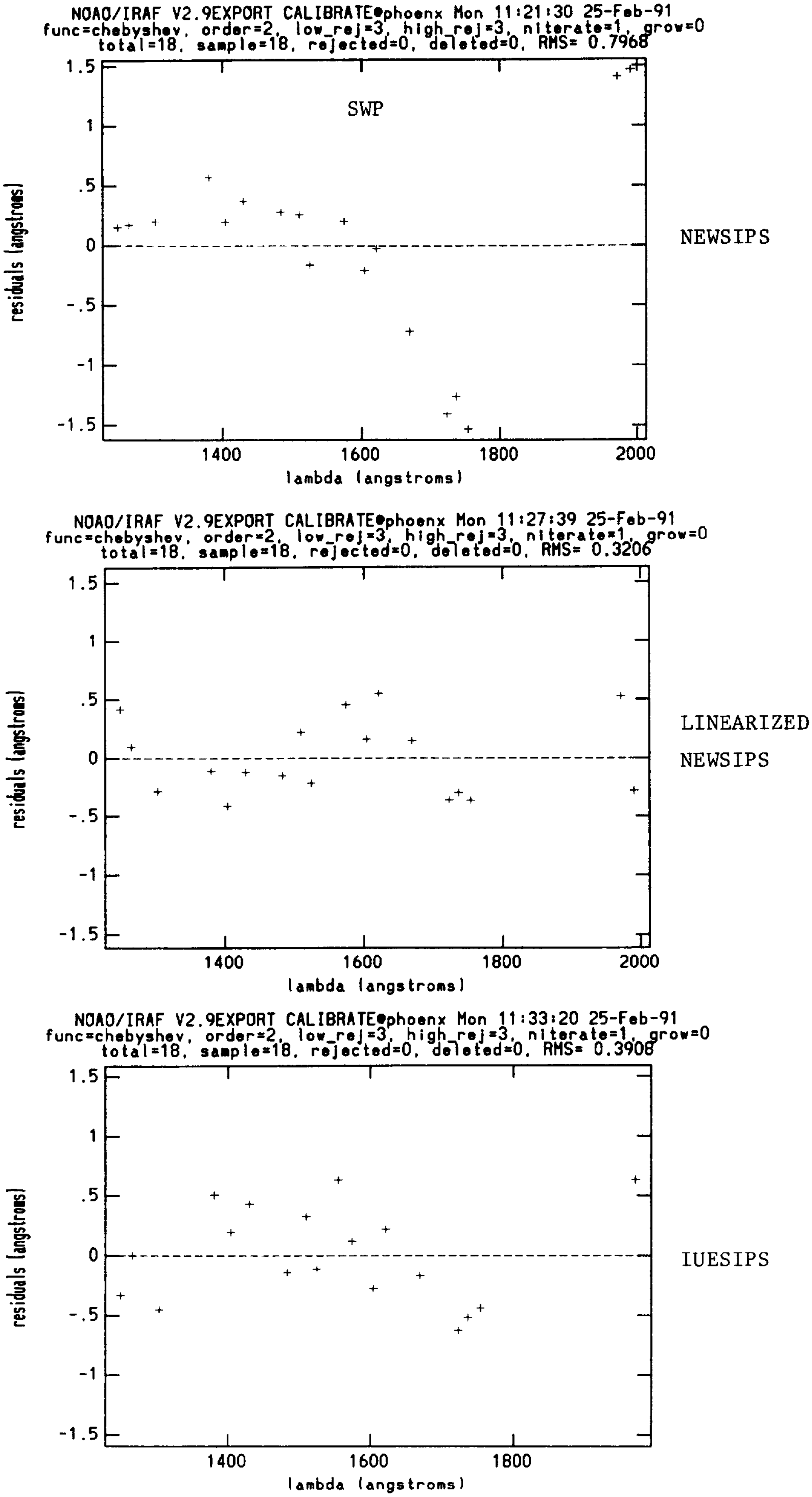

NOAO/IRAF V2.9EXPORT CALIBRATE@phoenx Mon 11:21:30 25-Feb-91
func=chebyshev, order=2, low_rej=3, high_rej=3, niterate=1, grow=0
total=18, sample=18, rejected=0, deleted=0, RMS= 0.7968
SWP
NEWSIPS
residuals (angstroms)
lambda (angstroms)
NOAO/IRAF V2.9EXPORT CALIBRATE@phoenx Mon 11:27:39 25-Feb-91
func=chebyshev, order=2, low_rej=3, high_rej=3, niterate=1, grow=0
total=18, sample=18, rejected=0, deleted=0, RMS= 0.3206
LINEARIZED
NEWSIPS
residuals (angstroms)
lambda (angstroms)
NOAO/IRAF V2.9EXPORT CALIBRATE@phoenx Mon 11:33:20 25-Feb-91
func=chebyshev, order=2, low_rej=3, high_rej=3, niterate=1, grow=0
total=18, sample=18, rejected=0, deleted=0, RMS= 0.3908
IUESIPS
residuals (angstroms)
lambda (angstroms)

FIGURE 3

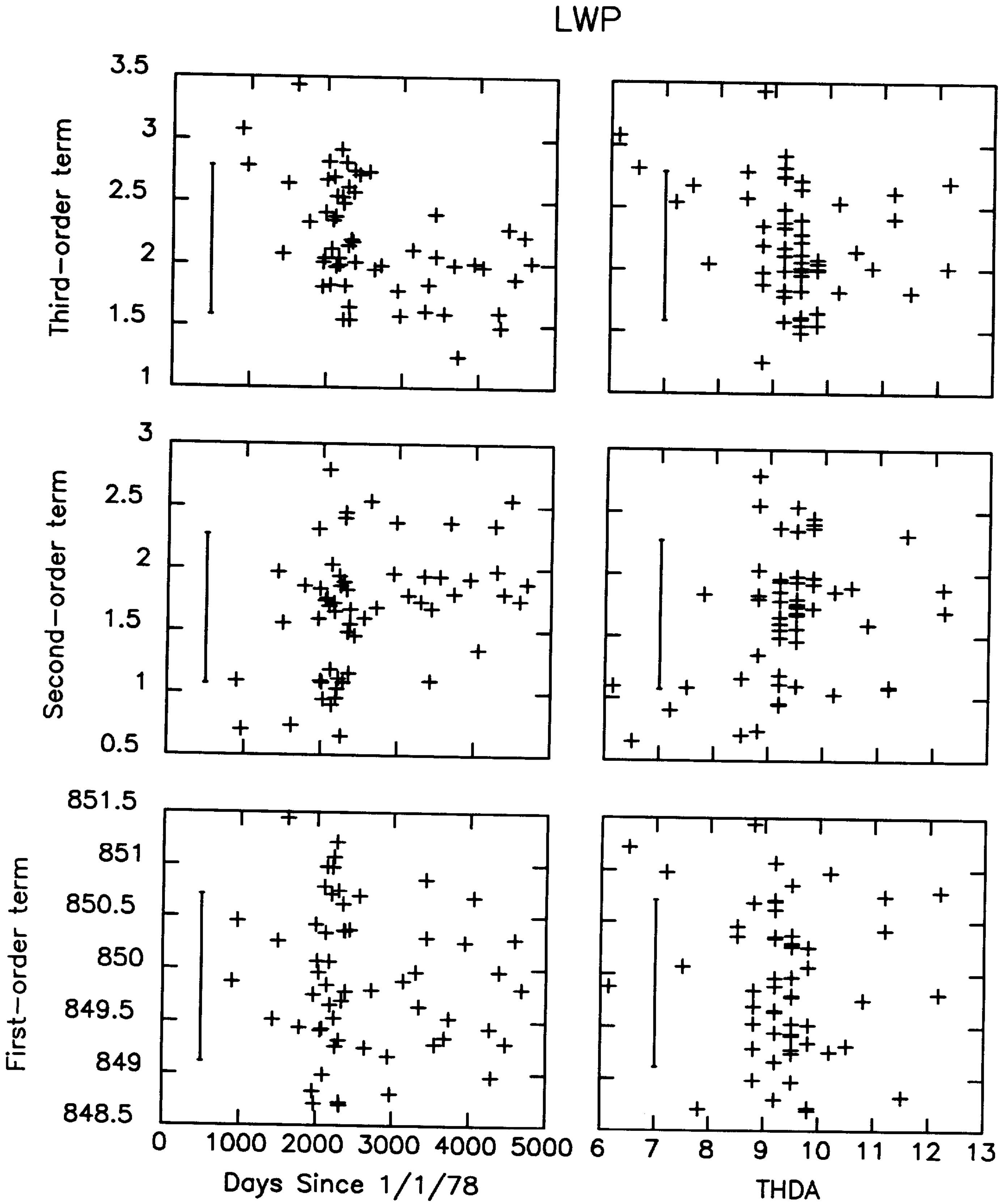

LWP
Third-order term
Second-order term
First-order term
3.5
3
2.5
2
1.5
1
0.5
851.5
851
850.5
850
849.5
849
848.5
0
1000
2000
3000
4000
5000
6
7
8
9
10
11
12
13
Days Since 1/1/78
THDA

FIGURE 4

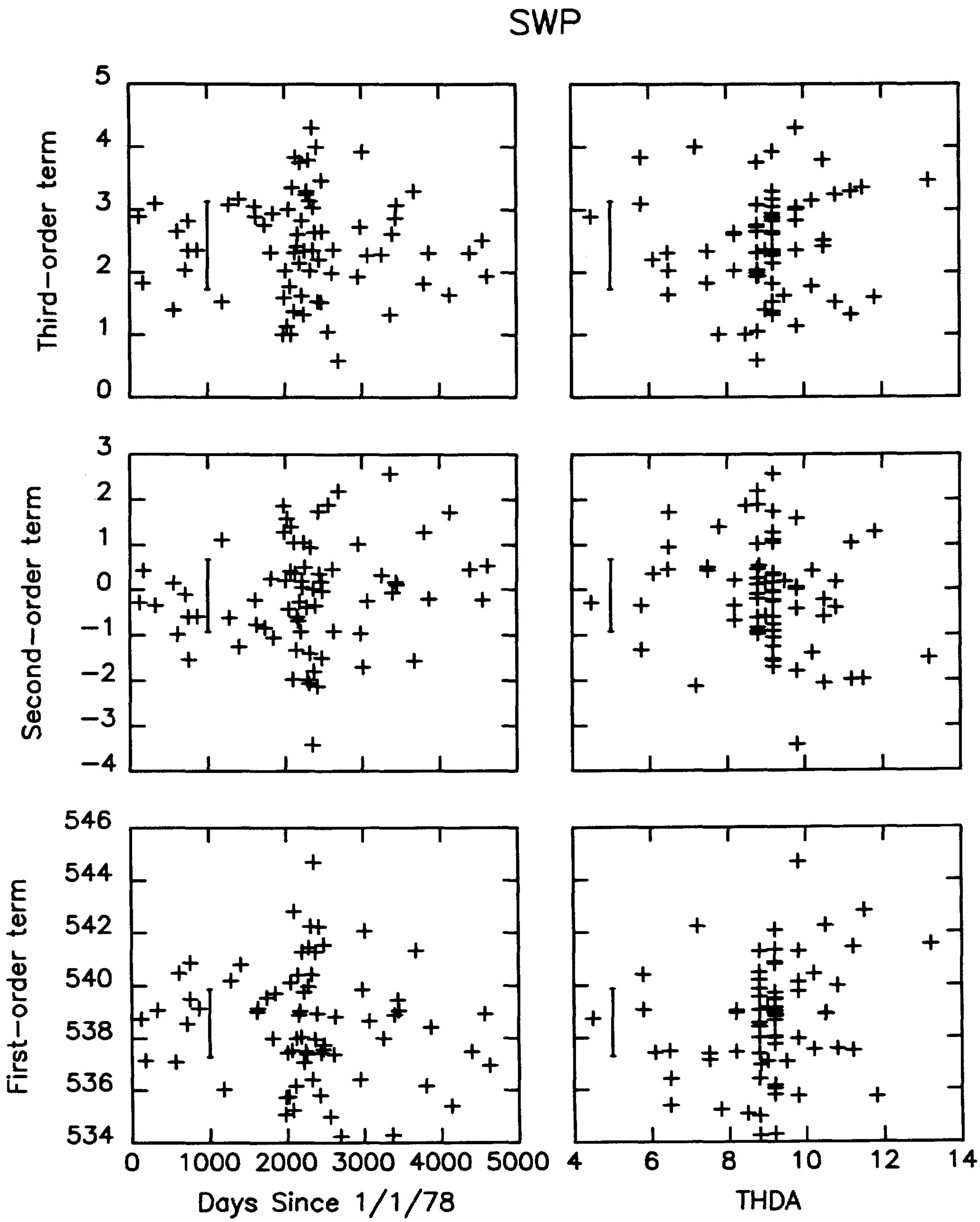

SWP
Third-order term
Second-order term
First-order term
Days Since 1/1/78
THDA
0
1000
2000
3000
4000
5000
4
6
8
10
12
14
0
1
2
3
4
5
-4
-3
-2
-1
0
1
2
3
534
536
538
540
542
544
546

FIGURE 5