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REPORT OF THE MAY 17-18, 1988 MEETING OF THE IUE SIGNAL-TO-NOISE COMMITTEE

This lengthy and very detailed report was written to answer three questions:

(1) What requirements should govern the creation of the final archive? These are described in detail in Part I.

(2) What specific tasks should be done in the near term in order to learn how to reprocess the data properly and efficiently before the final archive is created? These tasks are described in detail in Part II.

(3) What is a sensible implementation plan in terms of numbers of people and time in order to accomplish the tasks described in Part II? This implementation plan is described in Part III.

The agenda of the meeting and participants are attached as appendices.

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PART I. REQUIREMENTS FOR THE FINAL IUE ARCHIVES.

The main guideline in establishing the final IUE archives is to provide the best possible dataset in a form that is readily accessible and usable by the general astronomical community. Future users should not be expected to process the data themselves if they only require reliable time-averaged fluxes, wavelengths, etc. from the IUE database. Future users who may wish special data products or more refined processing, however, must be prepared to read the User Manuals (see below) in detail and to perform the custom processing themselves, although in many cases they should be able to use well-documented existing software. The IUE final archives should meet the following requirements:

Completeness:

All data, including images obtained by both NASA and ESA, should be included in the final IUE archive dataset. Since most users do not need to know where the images were obtained, and since not including all of the images could greatly hinder future studies utililizing these data, anything less than a complete dataset would seriously compromise the usefulness of the archives.

Documentation:

After the last IUE image has been obtained, the IUE expertise will begin to disappear. Most IUE archival users will then have had little direct experience with IUE data. Thus, it will be very important to provide these users with the most complete documentation describing the processing and use of IUE data. This documentation should include the following five components.

(1) Manuals containing a complete and detailed description of how the IUE images were processed.

(2) A comprehensive "Users Guide to the IUE". This should contain a very complete description of the accuracy and uncertainties of fluxes, wavelengths, spacecraft pointing, etc.

(3) Various reference materials. These should include special IUE data that are relevant to catalogues, calibration standards for fluxes and wavelengths. In addition, catalogues of IUE data should also be available to potential archival users.

(4) Special efforts should be made to provide documentation of timely software written by archival users to other interested astronomers. This would be an important role for the IUE Newsletter, which should be continued as an important source of knowledge for IUE data for archival users. Microfiche copies of the Newsletters should be available as part of the general IUE archival documentation.

(5) The current on-line access to the merged IUE log should be continued. As is presently true, the archival user should be able to quickly find all relevant IUE images for a particular object, or class of objects, or for several other selection criteria.

Accuracy:

Preserving and improving the accuracy of the IUE database is a very important goal. An important concern is not to "over-correct" the data base by destroying the original GO comments or by making other changes that are not warranted. Several suggested changes or improvements to the database are presented below.

(1) Whatever changes are made, the original GO comments must be preserved.

(2) Errors presently in the headers should be corrected. This effort should be started now, since many present users of archival IUE data rely heavy upon this information.

(3) Observations obtained by blind-offsets should be flagged. Obvious pointing errors are in the present datasets, especially for serendipity exposures where coordinates are entered for the other camera.

(4) Warning flags for possible problems in coordinates, etc. as well as other changes in the database should be flagged to alert the user.

(5) Microfiche of all the scripts for both images obtained at GSFC and VILSPA should be available to the user. Often the scripts are the final and ultimate source for answering questions about exposure time and intent of the GO.

(6) The database should have extended comments to fully describe the reasons for any other than the most obvious changes in the database.

Signal-to-Noise Improvement:

The images should be processed with an explicit geometric correction in order to have the highest feasible signal-to-noise.

Uniformity:

A single photometric and geometric scheme should be applicable to all of the data. The format selected for the final IUE archival data should be one that is best suited to maintain the integrity of the IUE data. Furthermore, to the extent feasible it should be compatible with the Astrophysics Data System. Although FITS tape format is extensively used in the astronomical community, this format is inappropriate because it can not preserve IUE data integrity. Possibly, an extended FITS format might suffice.

Modern Media:

The support and use of networking should be continued. This has proven to be a very important tool especially to small institutions which have limited computing facilities and support staff to handle IUE data.

It is still premature to choose a specific modern medium such as optical disc for achival users. The utilization of the latest technology should be fully explored as a means to distribute large amounts of IUE data in a compact and easily accessible form. However, the capability for distributing data in older formats (ie. magnetic tape and floppy disks) should be retained to distribute data to astronomers in remote parts of the world.

Photometric Precision and Accuracy:

In the final IUE dataset the most recent and accurate ITFs and absolute flux calibrations should be used consistently. This will also include the application of best appropriate signal-to-noise optimization and the best available IUE wavelength scale.

Content of Data Files:

The suggested contents of the archival data files are as follows:

(1) The raw image.

(2) A photometrically and (explicitly) geometrically corrected image. (This could be an image that is rotated such that the file will be equivalent to a line-by-line data file , the current ELBL file, except it would be available not only for low dispersion, but also for high dispersion images as well. Whether the creation of such a rotated image can be accomplished without degrading the IUE data remains to be determined.)

(3) An extended line-by-line file (for low dispersion only). (If a rotated photometrically and geometrically corrected image can be used, then this file would not be necessary.)

(4) One or two extracted spectral files. (Generally, two extracted spectral files should be provided. One should be generated using the current rectangular extraction slit (with no weighting). The other should be a GEX or optimal type extraction with its own calibration. Even though the GEX-type extraction should have higher S/N, the rectangular slit extraction should be included to maintain continuity with the current database and with what has been previously published in the literature.

(5) These extraction procedures should be applied to both high and low dispersion data. In the case of extended sources, only a rectangular extraction shall be applied. In very special cases, such as planetary nebulae and their central stars, it might be necessary to provide three extracted spectra; an extended source extraction as currently done, and two point source extractions, one with a rectangular slit and one with a GEX-type slit.

(6) In the case of high dispersion images, a ripple-corrected (untrimmed) absolutely-calibrated spectrum. To indicate splice points between the spectral orders, wavelength flags should be used. If the data remain untrimmed, the user can decide whether to use all the data in the overlap region.

(7) A file containing estimates of errors. This file should include a data quality index with some estimate of the r.m.s error of the data as well as bad data flags.

PART II. HOW TO REPROCESS IUE DATA FOR THE ARCHIVES: RECOMMENDATIONS FOR NEAR-TERM STUDY

At the May 17-18, 1988 IUE Signal-to-Noise Improvement Committee Meeting, it became apparent that fundamentally important questions remainunanswered concerning the IUE instruments, data, and data-processing. Before decisions can be made about the proper way to reprocess and archive the IUE data, we must better understand the behavior of the IUE cameras and spectrographs, in particular the origin of the fixed pattern (FP) that is not removed by the application of the ITFs in the present version of IUESIPS.

A subcommittee (consisting of Meg Urry, Ralph Bohlin, and Nancy Evans) convened to discuss and to set priorities for the necessary studies. These were amended and elaborated by the full workshop during the final session. A summary of the most important considerations follows; <u>its order reflects our priorities</u>, but we stress that most of these projects can be carried out in parallel. Given the short amount of time available for this work, we strongly recommend that all available expertise be concentrated on as many of these tasks as possible in the next six months.

I. <u>Study cross-correlation techniques for explicit geometric correction</u>. (This can be done using flat fields only.)

A. Determine parameters of the fixed pattern (FP)
   (1) Is the FP constant with time?
   (2) Is the FP a function of intensity level, temperature, or previous lamp exposures, or background radiation?

B. Determine quantitatively the improvement achievable with proper alignment of ITF with the image using explicit geometric correction with found reseaux.
   (1) Quantify the S/N ratio improvement in flat-fields.
   (2) Quantify the residual noise after the explicit geometric correction is applied.
   (3) Compare cross-correlation results using the FP to results for an explicit geometric correction using found reseau positions.

C. Assess the feasibility of using the FP cross-correlation technique in production processing of the final archive by implementing prototype software.
   (1) How many patches per image are needed for cross-correlation in low dispersion and how many in high dispersion?
   (2) How can patches be identified in high dispersion? Are they fixed? How is the interorder region defined?
   (3) How accurate (in fractions of a pixel) must the geometric correction be in order to remove substantially all of the misalignment noise?

(4) Test the prototype software on a wide variety of images (high background, low background, optimal exposure levels, underexposed spectrum, etc.).

II. Implement and test the best feasible geometric correction technique that treats the data image and ITF images identically.

A. Use a finer sampling and higher-order interpolation scheme.

B. Perform an explicit geometric correction and an approximately 50 degree rotation simultaneously to reduce to one the number of times the data are resampled.

C. Obtain constant wavelength scale in (B) above.

D. Rotate the ITF as well to reduce processing time and to restrict to one resampling each of the ITF images and the spectral images.

III. Study the effects of smoothing the individual-pixel ITFs using splines.

Does the signal-to-noise improve using smoothed ITFs for each pixel (as is done by the Lund Observatory group)? (There may be additional existing work on this subject by groups besides the Lund group.)

IV. Study the physical origin of the fixed pattern.

Whether the fixed pattern (FP) arises as pure electronic noise, or as slight quantum efficiency differences in the photocathode material, or as a pattern in the fluffy KCl target is not presently known. It may be impossible to determine the origin, but an attempt is worthwhile because of the insight it may give into the proper reduction technique to be applied to raw images. Understanding the origin allows one to employ correct algorithms and potentially, to reduce costs of re-reduction. The following specific questions are aimed at defining the physical origin of the FP.

(1) Is the FP noise additive or multiplicative?

(2) Is the pattern electronic, caused perhaps by the energy in the electron read beam generating variable capacitance in the target-mesh part of the SEC tube?

(3) Is the pattern associated with interference fringes in the tube face plate? (As with CCD's, if the flat fields (equivalent to ITF's) are obtained at one wavelength but the spectra cover other wavelengths, then fringing will not be properly accounted for.)

(4) Is the pattern related to electronic noise associated with interaction of the beam with the charged target (associated with beam pulling)?

(5) Does the pattern shift with the reseaux? (The reseaux are at the front of the tube, but all the effects noted above, except interference, are at the back of the tube.)

(6) Is the pattern in the raw images related to the pattern in the reduced images?

(7) Does the fixed pattern occur in the reduced images?

Note: Don York is proposing to the IUE Project to do a number of specific tests on SWP, LWP, and LWR images to attempt to answer these questions.

V. <u>Develop sophisticated spectral extraction routines</u> (weighted according to the point spread function).

A. For low-dispersion spectra, two promising methods (Gaussian-weighted extraction (GEX) and the Optimal Method of Keith Horne) have already been developed. Both require a few additional refinements and further testing.

(1) Improvements to the GEX program.
   a. Finding the appropriate noise model with which to weight the data. (This is currently under study, but will have to be repeated after the processing procedure is changed.)
   b. Automation of the binning procedure.
   c. Application of pre-filter and epsilon vector to reject bad data points prior to spectral extraction.
   d. Review of other studies of the point spread function, notably work by Cassatella. Is implementation of an asymmetric Gaussian useful or necessary?

(2) Improvements to the Optimal Extraction program. (See paper by Kinney and Rivolo in IUE NASA Newsletter #34, p.41)

(3) Select a variety of spectra on which to test both the GEX and Optimal Extraction methods. Identify cases for which these methods will not work (e.g. extended sources with surface brightness profiles that vary with wavelength).

	Type of Spectrum	Typical Object with this Spectrum
a.	well-exposed, low background, with strong emission lines	RS CVn stars
b.	well-exposed, low background, continuum sources	calibration stars
c.	weak exposure, low background	specific calibration stars,
d.	weak exposure, high background continuum sources	BL Lac objects
e.	good exposure, high background continuum sources	BL Lac objects
f.	weak exposure, high background	quasars and Seyfert galaxies, emission line objects
g.	good exposure, high background	quasars and Seyfert galaxies, emission line objects

h.	strong emission-line, weak continuum objects	planetary nebulae, symbiotic stars
i.	absorption line objects	OB-type stars
j.	objects with steep spectral slope	A-type stars in SWP camera
k.	trailed spectra	flare stars
l.	two exposures in large aperture	flare stars
m.	extended sources (especially with different extent of continuum and emission lines).	nebulae, galaxies

(4) Run and evaluate both GEX and Optimal programs, in batch mode, on spectra of the type listed above.
   a. Calculate the signal-to-noise and make plots:
      i. R as defined by Kinney in IUE Newsletter No. 34, p.41
      ii. Standard deviation of spectrum about a spline fit to the continuum (in line-free regions)
      iii. ratio of spectrum to IUESIPS-extracted spectrum
      iv. offset plots of spectra from the three methods (GEX, Optimal, and IUESIPS)

(5) Quantify the noise model. (After reprocessing with new geometric correction and new ITFs.)

(6) Apply GEX and Optimal methods to derive new calibrations. (Also after reprocessing.)

B. For high dispersion spectra, develop weighted-slit methods for spectral extraction.

(1) Study the background (smoothed to eliminate the effects of high-frequency noise) - can it be modelled adequately?
   a. Identify inter-order regions at long wavelengths (lambda>1400) and short wavelengths (lambda<1150), where order overlap is not a problem.
   b. Study variation in these clear-background regions as a function of position, background level, etc.
   c. Compare to nulls and serendipitous blank fields to see if these can be used as background templates.
   d. What are the physical causes of the background? Halation? Scattered light? Obtain test images of a bright source (to see if halation is important, to study order overlap, etc.)

(2) Study the point spread function (PSF). (This has been done to some degree.)
   a. Characterize the PSF perpendicular to the dispersion, as a function of wavelength and of order.
   b. Characterize the PSF along the dispersion (using Pt lines).
   c. How does the PSF vary with time, with camera temperature, with background level, and perhaps other parameters?

(3) If the above two steps indicate the methods will be feasible, write and test some prototype code (generalize GEX and/or Optimal Method).

VI. Identify and characterize uncorrectable problems that will be flagged in the archives.

A. Effects of overexposure: loss of sensitivity? phosphorescence? How long do these effects last?

B. Catalog the overexposures - from scripts? from existing archive?

C. Catalog other problems such as microphonics and data dropout.

D. Flag the bad points (reseaux, hits, hot spots, etc.); ignore these points during spectral extraction; add these points to the output error vector.

VII. Study the accuracy of the wavelength scale. [Note: Tom Ayres plans to study this problem in the SWP camera. A similar study should be carried out for the LW cameras.]

A. Description of the Problem

There exist systematic deviations of wavecal emission spots from their laboratory wavelengths, as revealed by co-adding series of standard (120 s) and non-standard (18 s) calibration spectra in the SWP camera at high dispersion.

Ayres has conducted a study to determine whether the systematic deviations are due to uncertainties in the laboratory wavelengths: those in the IUE line library date back to the 1930s. A new line list for a prototype Pt-Ne hollow-cathode similar to the flight lamps on IUE, was obtained from a group at the NBS. The new wavelengths show a small (~1 km/s) systematic difference with respect to the old wave-lengths, but no individual errors are large enough to explain the empirical deviations in co-added wavecals.

Other possible explanations include: (1) distortions introduced by the implicit geometric correction currently used in production processing (also believed to be responsible for the FP noise in photometrically-corrected images); and (2) the comparatively low order of the polynomial representation of the dispersion relations used to map from line and sample coordinates into wavelengths and echelle orders. The latter problem prevents the dispersion relation from compensating correctly for small-scale structure in the true wavelength transformation. (Such small-scale structure may result from shearing distortions in the fiber-optic bundles in the SEC Vidicon cameras.)

B. Possible Tests to be Performed

Ayres is planning to acquire a large sample of wavecal spectra from the archives of program PHCAL for the SWP camera. (His approach can be applied equally well to the long-wavelength cameras.)

He will have these images geometrically corrected using the explicit approach (this may already have been done since the wavcal spectra must be measured in geometrically-corrected space). He will extract the spectra using a fixed set of dispersion relations (i.e., with no time and temperature corrections), and will then measure approximately 500 clean PtII-NeII lines in each of the ~100 wavecal images using an automated numerical procedure. He will examine the data base to determine how systematic the wavelength-scale distortions truly are, and also explore the relationship between the gross thermal shifts of the spectra and the orientation plus (solar) insolation of the satellite (as parameterized by the beta angle and the time of year). The thermal shifts currently are corrected according to a spacecraft temperature (THDA) that might be less well correlated with the spectrograph/camera conditions than is the beta angle and the day-of-year. He will also examine a subset of about 10 images processed with the present implicit geometric correction and compare these with images processed with the explicit geometric correction to establish whether or not the explicit approach can improve the wavelength scales. He will also compare a subset of about 10 LWP and LWR wavecals to explore differences associated with the specific cameras, and will investigate whether more complex dispersion-relation-mapping functions - beyond the bi-quadratic polynomials currently used - might be used to improve the assigned wavelength scales.

C. For the Project to Investigate:

At the very least, the correct NBS wavelengths should be implemented in the standard IUE line library to remove the small systematic errors that currently exist.

VIII. <u>Modify current activities of the project</u>?

There was some discussion at the Workshop concerning whether the tasks currently underway by the Project (by the most talented, most expert IUE people), such as the development of new ITFs and new absolute calibrations, should be postponed so that these talented people can work on the pressing problems of items I-VII above (particularly items I and II). In addition, the immediate recommendations of the S/N Workshop will likely result in radically different processing procedures, in which case all of the ITFs and absolute calibrations must be re-derived. This is very labor-intensive, and we question whether it is sensible to do this work twice.

PART III. PROPOSED IMPLEMENTATION PLAN FOR THE IMPROVEMENT OF THE SIGNAL-TO-NOISE IN THE IUE DATA

The following plan is to implement the tasks described in Part II in order to learn how to reprocess the data properly and efficiently prior to the creation of the final IUE archives. This plan does not include such other tasks as corrections of the errors in the headers, rewriting of IUESIPS to change data formats or to change computers, or the details of the actual reprocessing. The emphasis in this plan is to increase the quality of the IUE data itself.

This implementation plan assumes that

(1) 1/2 FTE will be supplied for supervising this effort,
(2) very knowledgeable people in the IUE Project will be assigned to these tasks,
(3) some of the effort can and should be assigned to astronomers at universities who are highly competent and propose to do specific tasks, and
(4) sufficient computing resources will be provided for this task. In particular, it is highly desirable that access be provided for a CPU separate from the IUE machine that is now processing the IUE data stream if the current CPU cannot handle both tasks efficiently.

PHASE A - PROOF OF CONCEPT FOR MINIMIZING MISALIGNMENT NOISE

Objectives

(1) To study cross-correlation techniques for the explicit geometric correction of the IUE images.
(2) To implement and test the best feasible geometric correction technique that treats the data image and ITF images identically.
(3) To study the effects of smoothing the individual-pixal ITFs.

Time to Completion

This phase should be completed in six months (June-November 1988), but considerable effort should be done early to prepare for important presentations at the September 20-23, 1988 Three Agency meeting in Paris and the October 21, 1988 meeting of the IUE Users' Committee.

Effort Required

Two (2) people working full time for six months are required to present a final proof of concept and detailed description of how to best do the explicit geometric correction and application of the ITFs. This effort does not include developing the necessary software. It does include:

(a) demonstrating the degree of S/N improvement,
(b) proof of applicability to the entire archives,
(c) development of a good algorithm for the technique,
(d) estimate of time needed to complete the reprocessing using this technique.

PHASE A PRIME - A PARALLEL STUDY EFFORT THAT DOES NOT INTERFERE WITH PHASE A

Objectives

(1) To study the physical origin of the fixed patterns.
(2) To develope sophisticated spectral extraction routines,
(3) To study the accuracy of the wavelength scale.

Time to Completion

Six to nine months of effort with completion in November 1988-March 1989.

Effort Required

These tasks will require about 1 1/2 people working full time for 6-9 months. Most or all of this effort can be accomplished by astronomers outside of the IUE Project.

PHASE B - DEVELOPMENT TESTING OF PRODUCTION SOFTWARE

Objectives

(1) To develop and test production software for the new explicit geometric correction technique and other changes to the current IUESIPS.
(2) To verify and/or create appropriate ITFs for the new geometric correction.
(3) To determine absolute calibrations for all cameras with the explicit geometric corrections.
(4) To improve the wavelength scales,
(5) To determine absolute calibrations for the optimized extraction procedures.

Time of Completion

Twelve months December 1988-December 1989.

Effort Required

Two (2) people working full time for 12 months.

PHASE B PRIME - A PARALLEL STUDY TO DEVELOPE AN OPTIMIZED EXTRACTION SCHEME FOR HIGH DISPERSION SPECTRA

Objective

(1) To develope a GEX or Optimal extraction scheme for high dispersion spectra

Time to Completion

Six (6) months December 1988-May 1989.

Effort Required

This task will require one (1) person working full time for six months just to evaluate the degree of effort necessary to develop an optimized or Gaussion extraction technique which is applicable to all types of data in the archives. (Things to consider include scattered light, halation, order overlap, variations with spectral type etc.) This task could be accomplished by an astronomer outside of the IUE Project.