Philosophy and Scope of the IUE Final Archive Image Processing

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I. Philosophy of the IUE Final Archive Image Processing

The philosophy that governed the development of the NEWSIPS system was intended to address four fundamental requirements:

1. *Create a uniformly processed and calibrated archive as the final product of the IUE mission*

   IUE data have been processed using the IUESIPS system since launch in 1978. However, the IUESIPS system has undergone a number of modifications and enhancements since that time, rendering the IUESIPS archived data inhomogeneous and not fully intercomparable. A major change to the IUESIPS system occurred in 1981 and this newer version of the software is documented in Version 2.0. A modification to the resampling algorithm used to create the spatially resolved (ELBL) file for low dispersion was implemented in 1985. A new photometric calibration was implemented for the LWP camera data in 1988. Later changes have customarily been documented in *IUE* Newsletters.

2. *Exploit new image processing techniques to improve the photometric accuracy and signal-to-noise ratio of the data*

   A number of new image processing techniques had been identified since the design of IUESIPS that were demonstrated to produce a more accurate photometric correction and increased signal-to-noise ratio of the extracted *IUE* data. Implementation of these techniques significantly improve the quality of the Final Archive.

3. *Verify and correct fundamental information for each image*

   In addition to providing a uniformly processed archive with improved photometric and signal-to-noise properties, the *IUE* Project has expended considerable effort in verifying the information available for each image in the *IUE* Final Catalog of observations.

4. *Base the contents of the Final Archive on requirements from the research community*

   In defining the specifications for the *IUE* Final Archive, and in developing the new processing algorithms and calibrations, the *IUE* Project has been guided for the last five years by the recommendations of the Final Archive Definition Committee, chaired by J. Linsky. This very active committee represents a unique grassroots effort by the astronomical community to assist in defining the scientific content of a NASA space mission, optimizing its utility for future researchers.

It is important to note that the data processed with NEWSIPS differ in fundamental ways from the data processed with IUESIPS. Images processed with these two systems are not directly intercomparable.

1. Uniform Archive

One of the primary assets of the *IUE* archive is the long timeline of observations taken with a remarkably stable photometric instrument. To exploit this asset, observations must be fully intercomparable over the entire lifetime of *IUE*. In order to satisfy the first requirement, that of uniformity, it was essential to develop a fully automated system that allowed no human intervention and was sufficiently robust to process all images acquired by *IUE*. Thus the algorithms developed were designed to yield the best overall result for all types of images. These algorithms may not yield the best result for a particular image or particular class of images because of this design requirement. This represents a change in philosophy from IUESIPS. For example, the data were processed with IUESIPS according to Guest Observer (GO) specifications concerning the width of the extraction slit and the registration of the spectrum with respect to the pseudo extraction slit. In the NEWSIPS system, the width of the extraction slit is automatically determined and registration is always automatic.

2. New Processing Algorithms and Calibrations

The new processing algorithms that have been developed by the NASA *IUE* Project allow several significant improvements in the processed data. The new approach exploits the presence of fixed pattern noise (pixel-to-pixel sensitivity variations in the cameras) as a reliable fiducial to register the raw science image with the raw Intensity Transfer Function (ITF) image. Proper registration of *IUE* images is crucial to accurate photometric correction because the variability of the geometrical distortions introduced by the SEC-Vidicon cameras ensures that raw science images are never perfectly aligned with the ITF. While reseau marks etched on the faceplates of the cameras are intended to be used to geometrically rectify the science images, they cannot be detected at the low exposure levels usually found in the background of *IUE* images. Therefore, the IUESIPS method of processing *IUE* images uses predicted reseau positions to align the science images with the ITF images. Unfortunately, these mean positions are poorly known and the application of a mis-registered ITF (by more than about 0.2 pixel) manifests itself as a source of systematic noise in the photometrically corrected image, and ultimately in the spectrum.

To achieve proper alignment of the ITF images with each science image for the Final Archive reprocessing, the fixed pattern inherent in *IUE* images is used as a fiducial. Small patches of the science image are cross-correlated with similar areas on the appropriate ITF image to determine the spatial displacement between these two images. The displacement of each pixel in the science image from its corresponding pixel in the ITF can thus be determined to sub-pixel accuracy. Such an approach has several advantages: (1) a large number of fiducials can be found anywhere on the image, (2) fixed pattern can be detected even at the lowest exposure levels, and (3) fiducials are available near the edge of the image, where distortion is greatest. In the IUESIPS processing of *IUE* data, the ITF images have been resampled to geometrically correct space, significantly smoothing these calibration data. In the new processing system, the ITF images are retained in raw space, increasing the accuracy of the pixel-to-pixel photometric correction.

Only one resampling of the data is performed in the new processing system, minimizing the smoothing inherent in such an operation. The linearized pixel values are resampled into a geometrically rectified and rotated image, such that the spectral orders are horizontal in the image and the dispersion function of the spectral data within an order is linearized. The resampling algorithm used is a modified Shepard method which preserves not only the flux to 1–3%, depending on the noise level in the image, but also the spectral line shapes.

The low-dispersion spectral data are extracted by a weighted slit extraction method developed by Kinney *et al.* (1991). The advantages of this method over the IUESIPS boxcar extraction are: (1) the signal-to-noise ratio (S/N) of the spectrum is usually improved while flux is conserved, (2) most of the cosmic rays are automatically removed, and (3) the output includes an error estimate for each point in the flux spectrum.

An entirely new data product for the *IUE* Final Archive is a spatially resolved high-dispersion image, geometrically rectified and rotated such that the spectral orders are horizontal. This new data product will allow future investigators to perform customized extractions on the high-dispersion data. One of the most significant problems with the analysis of high-dispersion *IUE* data has been the proper determination of the background in the region where the echelle orders are most closely spaced and begin to overlap. The new processing system includes a background removal algorithm that determines the background level of each high-dispersion image by fitting a two-dimensional surface to the entire image using a Chebyshev interpolation scheme. The extracted high-dispersion spectral data are available order-by-order and as a single concatenated spectrum uniformly sampled in wavelength.

In addition to the new algorithms for processing the *IUE* data for the Final Archive, all absolute flux calibrations have been rederived. The new calibrations use white dwarf models to determine the relative shapes of the instrumental sensitivity functions, while previous UV satellite and rocket observations of η UMa and other standard stars are used to set the overall flux scale. The *IUE* Final Archive extracted spectral data are also corrected for sensitivity degradation of the detectors over time, a calibration not previously available with IUESIPS processing.

These new processing algorithms for the creation of the Final Archive allow a significant improvement in the signal-to-noise ratio of the processed data, resulting largely from a more accurate photometric correction of the fluxes and weighted slit extraction, and greater spectral resolution due to a more accurate resampling of the data. Improvement in signal-to-noise of the extracted spectral data has been shown to range from 10–50% for most images, with factors of 2–4 improvement in some cases.

3. Core Data Item Verifications

The value of the *IUE* Final Archive to future investigators will depend to a large degree on the accuracy and ease of use of the Final Catalog. Significant effort was expended at both *IUE* Observatories to ensure the accuracy of the Final Catalog and the information in the image headers. A set of "core" data items (CDIs) has been identified which were verified from observatory records available at each station. These core items are generally the information necessary to correctly process the image and/or crucial for scientific analysis. While many of the verification procedures are automated, it was necessary in some cases to consult the hand-written scripts or logs to obtain the correct information. The verification of the CDIs is performed before each image is reprocessed for the Final Archive.

4. Community Involvement

The *IUE* Final Archive Definition Committee (FADC), chaired by Jeffrey Linsky, was formed in November, 1987 to provide recommendations and advice to the NASA *IUE* Project on the content of the Final Archive and on the algorithms and methods used to process the data for the Archive. The FADC also provided estimates of resources needed to accomplish the recommended goals. The committee is composed of 24 people, selected for having demonstrated interest in improving the S/N of *IUE* data. The committee met every 3–6 months for 5 years, producing at each meeting a written report of recommendations and near-term goals. These reports are published in the *IUE* Newsletters. The FADC provided user representation by the astronomical community to define the content of the *IUE* Final Archive, optimizing its utility for future investigators.

II. Scope of the IUE Final Archive Image Processing

The primary goal of the *IUE* Final Archive Image Processing is to provide users of the *IUE* archive with data reduced from the raw image data in an accurate and uniform manner so as to be as free of instrumental effects as possible. The NEWSIPS processing system provides two-dimensional photometric calibration of the raw data by means of pixel-by-pixel intensity transfer functions (ITFs) which correct for the SEC vidicon shading and non-linear response. It also provides a two-dimensional, spatially resolved image with wavelength calibration in geometrically rectified space. Wavelength calibration is performed from analytical dispersion relations determined from platinum-neon (Pt-Ne) lamp spectral images.

The low-dispersion data are extracted with a weighted slit extraction method that provides an error estimate for each extracted point. A globally determined background is subtracted from the high-dispersion data prior to extraction. Data are absolutely calibrated and corrected for sensitivity degradation of the detectors. Error conditions are flagged on a pixel-by-pixel basis in the photometrically corrected image, the spatially resolved image, and the extracted spectrum.