Chapter 1

Introduction

1.1 Purpose of Document

This document provides the researcher who plans to analyze images acquired with the *International Ultraviolet Explorer* (*IUE*) with the information necessary to understand the raw data characteristics and image processing operations, and to interpret the processed output products for data processed with the New Spectral Image Processing System (NEWSIPS). The document also provides detailed descriptions of each procedure and algorithm in the image processing system, the techniques used to calibrate the data in wavelength and absolute flux, and a complete specification of output file formats.

Data acquired with the *IUE* satellite were originally processed with the *IUE* Spectral Image Processing System (IUESIPS) from the time of satellite launch. Over the years, IUESIPS underwent a number of enhancements and modifications, which were documented in the IUE Image Processing Information Manual Versions 1.0 (Turnrose and Harvel 1980), 1.1 (Turnrose et al. 1981), and 2.0 (Turnrose and Thompson 1984). These manuals are still the standard reference to be used with Guest Observer (GO) format data processed with IUESIPS. The NEWSIPS system described in this document is fundamentally different in algorithm and technique from the previous IUESIPS. For FITS format data processed with NEWSIPS, this document supersedes and replaces all previous versions of the IUE Image Processing Information Manual, as well as the IUE NEWSIPS Manual Version 1.0 (Nichols et al. 1993).

1.2 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. The original IUESIPS system was documented in the IUE Image Processing Information Manual Versions 1.0 and 1.1. A major change to the IUESIPS system occurred in 1981 and this newer version of the software is documented in the IUE Image Processing Information Manual 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 improves 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.

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 was guided by the recommendations of the Final Archive Definition Committee, chaired by Dr. Jeffrey Linsky. This very active committee represented 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.

1.2.1 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 low-dispersion system, the width of the extraction slit is automatically determined and registration is always automatic. The NEWSIPS high-dispersion system uses a boxcar extraction where the width of the extraction slit is set according to an automated source type determination (i.e., point or extended). As is the case in low-dispersion, the high-dispersion registration is also always automatic.

1.2.2 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 were intended to be used to rectify geometrically 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 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 against corresponding 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. The high-dispersion spectral data are extracted using an IUESIPS style boxcar extraction method. As a result the S/N improvements may not be as good as those seen in low-dispersion data.

An entirely new data product for the *IUE* Final Archive is a geometrically rectified and rotated high-dispersion image, with horizontal spectral orders. This new data product will allow future investigators to perform customized extractions and background determinations 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, in succession, one-dimensional Chebyshev polynomials, first in the spatial and then the wavelength direction. The extracted high-dispersion spectral data are available order-by-order with wavelengths uniformly sampled within an order.

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 and temperature, 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 the signal-to-noise ratio of the extracted low-dispersion spectral data has been shown to range from 10–50% for most images, with factors of 2–4 improvement in cases of high-background and underexposed data (Nichols-Bohlin 1990).

1.2.3 Core Data Item Verifications

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 process correctly the image and/or are crucial for scientific analysis. While many of the verification procedures are automated, it is necessary in some cases to consult the handwritten scripts or logs to obtain the correct information. The verification of the CDIs is performed before each image is reprocessed for the Final Archive.

1.2.4 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 was composed of 24 people, selected for having demonstrated interest in improving the S/N of *IUE* data for their own research. 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 Nos. 34, 36, 38, and 48. The FADC provided user representation by the astronomical community to define the content of the *IUE* Final Archive, optimizing its utility for future investigators.