3 November 1987

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Dear Yoji:

I would like to report to you on the results of the Workshop on IUE Signal-to-Noise Improvement held at Goddard on October 19-20, 1987. The Workshop invited participants (see attached list) welcomed the challenge of helping the IUE Project plan for the final IUE archives, which should contain the full IUE data set reprocessed with the highest feasible signal-to-noise and the most accurate flux calibration.

Before listing our recommendations, we re-emphasize the enormously valuable role that the IUE data archives will play in astronomical research for the next several decades. IUE has already obtained more than 70,000 spectra. This unique data set, which will likely not be duplicated in our lifetime, comprises an irreplaceable record of the temporal evolution of a great many objects as well as their ultraviolet spectra covering the full 1200-3200 Angstrom range. While the HST will certainly observe with higher spectral resolution and signal-to-noise a few of the objects that IUE has already studied, the HST will devote most of its observing time to fainter and more distant objects. The IUE data set will definitely provide invaluable guidance for these future HST observations. We therefore urge that the NASA IUE Project continue to work closely with ESA and SERC in planning for the final reprocessing of the IUE data now scheduled to begin by December 1989.

The reprocessing of the full IUE data set (including both the Goddard and the Villspa data) will be a major undertaking for the Project, and realistically we anticipate that it will only be done once. Thus we must endeavor to do it right the first time. It is essential, therefore, that the Agencies greatly expand their efforts over the next 13 months to understand the nature of fixed pattern noise and how it can be minimized in the final reprocessing. We urge that the NASA IUE Project devote 2 man-years of effort during the next year and that ESA and the SERC devote a commensurate effort so that by December 1988 the three Agencies will be able to begin writing and testing code for the final reprocessing scheduled to begin in December 1989.

The Workshop participants would be pleased to assist the NASA IUE Project by meeting periodically to assess and advise these ongoing efforts. We are prepared to meet again in March 1988 to assess the first 6 months of effort and then perhaps every 4 months for as long as our advice is deemed valuable.

We now list our recommendations in order of priority:

A. Understanding the Fixed Pattern Noise.

It is essential that the IUE Project place in the final archives reduced

two-dimensional images with all known instrumental effects removed or appropriately flagged. These geometrically and photometrically corrected images are the essence of the archives, but the fixed pattern noise (FPN) must be understood before this task can be implemented. Also, the signal-to-noise enhancement procedures should not reduce the photometric or wavelength accuracy of the final data product.

(a) Objectives for the Next Six Months Study.

Current studies of the fixed pattern noise show that the signal-to-noise of IUE spectra can be improved by more than a factor of the square root of two by correct removal of the FPN. We recommend as a prerequisite for a high quality archive that the IUE Project now make a systematic study of the characteristics of the FPN. The first step in this critical task is to assess images after processing with the new ITFs, both as currently applied and with geometrical shifts using the fixed pattern (FP) as fiducials to see whether the FPN is decreased. This study should start with the SWP camera, because it is the most heavily used camera.

The images should then be analyzed to determine the characteristics of the remaining FPN with time, camera temperature, DN level, background level, and aperture or location in the aperture. Also, is the noise additive or multiplicative? The images of many types of objects should be examined as processed with the new ITFs. Two-dimensional Fourier transform analysis should be performed on a significant sample of raw and geometrically corrected images to determine whether some elements of noise (e.g. pixel electronic noise) can be removed in production processing. If this noise is important, then it should be removed.

If necessary, additional calibration time should be allocated for analysis of the FPN. We request a report on the FPN in the SWP camera with the new ITF at our next meeting in March 1988, as a basis for assessing whether further major computation effort should be considered for the reprocessing effort.

The current IUESIPS procedure for applying the ITF is based upon predicted reseaux positions. Alternative approaches should be investigated, including (1) cross-correlation of measured reseaux positions for each image with the ITF reseaux, and (2) cross-correlation of the object image FP with the ITF FP. The study should ascertain the degree of signal-to-noise improvement for each of these alternatives by intercomparing results from IUESIPS with results using the actual reseaux positions and FP cross-correlation.

(b) Implementation of New ITFs.

We urge that the three Agencies immediately implement the new LWP, SWP, and LWR ITFs in the standard IUESIPS software, even though the absolute flux calibrations that go with these ITFs are not yet available.

Immediate implementation of the new LWP ITF is of highest priority by far, since the new LWP ITF is based on four images per level rather than one, and consequently the noise level in the new ITFs could be as much as a factor of 2 lower than the previous LWP ITFs. Once these new ITFs are implemented, the Project should seriously consider reprocessing the LWP images in the archives that were processed with the old and quite inferior ITFs. Implementation of the new SWP and LWR ITFs have lower priority, because the existing SWP ITFs are

based on 4 images per level and because the LWR camera is now rarely used.

Observers should have the option (to be specified on the observing scripts) of requesting special processing with the old ITFs. All new observations placed in the archives should be processed with the new ITFs. IUE users should be allowed to request reprocessing of old data with the new ITFs for special studies, with priority given to studies in preparation for the archives.

We recommend that new observations be obtained for the purpose of deriving new ITFs. Should the UV flood lamp deterioration pose a serious problem for a new LWP ITF calibration, the IUE staff should consider using the tungsten flood lamp for such calibration purposes.

Because of the age of the IUE and the increasing risk of spacecraft failure, any new observations that might be needed to calibrate IUE should be given high priority, especially those flat-field lamp data that might be used to reduce the fixed pattern noise. This is particularly important, since the new ITFs are required for the absolute flux calibration and for the reprocessing of the IUE archival data.

(c) Reconstruction of Old ITFs.

The null and UV flood exposures made to generate the old ITFs should be reprocessed using new geometrical correction procedures. With these reprocessed ITFs (beginning with the SWP) one can properly intercompare old and new ITFs to determine any time dependency. One can then decide which ITFs should be applied when reprocessing the old observations for the final archives.

B. Optimizing the Spectral Extraction.

The final IUE archive should also include 1-dimensional spectra for point sources extracted by an algorithm that optimizes the signal-to-noise ratio. Realistically, most users of the archive will use these data rather than extract spectra from the photometrically corrected 2-d images. This extraction algorithm should detect and remove pixels affected by reseaux, cosmic ray hits, camera artifacts that appear in very long exposures, and other blemishes, both in sky regions and on the spectrum.

Two related optimal extraction methods have already been developed based on (1) empirical or (2) gaussian models of the spatial profile. These methods already give up to a square root of two improvement in signal-to-noise relative to IUESIPS, particularly in cases of high background. Both methods, with slight modification, should be suitable for automatic extraction of IUE spectra. The final choice between these two approaches, a hybrid algorithm, or a narrower extraction slit should be based on validation tests with a small number of representative IUE images, including ranges of signal-to-noise, background, saturation, trailed and untrailed observations, emission line spectra with and without continua, featureless spectra, rich absorption line spectra, and for both high- and low-resolution images. Thought should be given to whether the final algorithm should be applied to the photometrically corrected images rather than to line-by-line files.

Each optimally extracted spectrum should have an associated uncertainty vector (or a means for calculating one) that best estimates both the random and systematic errors in converting ultraviolet photons to calibrated flux. This

uncertainty vector should take into account all characteristics of the cameras and of the processing. Such 1-d error-bar spectra are already automatically produced by the existing gaussian and optimal extraction algorithms. These computed errors take into account variance estimates of individual pixels based on the adopted noise model, and thus should also reflect the chi-squared values obtained in fitting spatial profiles at each wavelength.

The revised flux calibrations should be determined using the agreed upon spectral extraction algorithm.

The main issues to be addressed in validating the final extraction algorithm are:

(1) Is the spatial profile a smooth function of wavelength?

(2) Is it gaussian, and what systematic errors result if departures from a gaussian are neglected?

(3) Does the empirical profile model become unstable at very low signal-to-noise?

(4) Can the gaussian model be used as is or simply extended to treat trailed spectra?

(5) For high resolution spectra, spectra for all orders must be solved for simultaneously. Details of how to do this are TBD.

(6) Does the extraction algorithm give good estimates of the flux even if several pixels in the spectrum are saturated?

C. Development of Templates to Flat-Field IUE Spectra.

The use of templates to flat-field IUE spectra will be needed if the FPN can not be removed substantially by improvements to the ITFs. The more complete removal of the FPN either by better ITFs or by templates could lead to a situation where the dominant remaining noise is random, so that the summation of N spectra will enhance the signal-to-noise proportional to th square root of N.

Preliminary tests have already demonstrated that it is possible to identify FPN reliably in IUE spectra, to construct template spectra in which the noise is due primarily to the FP, and to use such templates to decrease the FPN from program star spectra. These tests have demonstrated that the noise can be reduced by typically 10-30% compared to uncorrected spectra. As a result, weak features in the flat-fielded spectrum are more reliably identified, and spurious weak features due to the FP can be more easily removed. These tests explicitly remove the FPN in a way that does not require the FPN to be periodic. In view of the utility of this technique, we recommend that the following questions be investigated (in conjunction with the previously described investigation of the characteristics of the FPN itself):

(1) Explain the lack of complete consistency between templates constructed from different sets of spectra obtained at different times or using different stars. Does this lack of consistency indicate that the FP is not constant with time?

(2) Determine how applicable templates constructed from spectra with particular exposure characteristics (i.e. location in aperture, multiple/single/trailed exposures, DN level,...) are to spectra with other exposure characteristics. How many templates are needed to cover all program star spectra? What existing spectra could be used? What new observations would be needed?

(3) Determine how best to construct and use templates. How many spectra are needed to construct a template? Should fractional pixel shifts be used? Should templates be divided into or subtracted from program star spectra? How can one speed up what is presently a rather hard to automate process?

D. Absolute Flux Calibration.

The absolute flux calibration for optimally processed archival images should be as accurate as feasible, should be compatible with the adopted extraction procedure, and should be determined with the precision permitted by the improved extractions. Ultimately, the scientific utility of the archived images will be limited by either instrumental effects or residual calibration errors (or both). In order to maximize the utility of the archives for the scientific community, both effects should be reduced together as far as is practicable.

E. Ripple Correction Algorithm for High Resolution spectra.

The present ripple correction algorithm used in IUESIPS permits the dispersion constant to vary with order and is thus unphysical. We recommend that this problem be studied. In particular, the present algorithm might be compensating for insufficiently accurrate processing prior to the ripple correction.

F. Conclusions.

(1) The quality of the final IUE archives can be enhanced significantly by reducing the fixed pattern noise and optimizing the spectral extraction procedure. These improvements will be of enormous benefit to future IUE users and to users of the HST and other missions.

(2) The first required task is a concerted effort to understand the nature of the fixed pattern noise and how it depends on time, camera temperature, and other parameters. Work should begin immediately on this task, starting with the SWP camera.

(3) A considerable portion of the fixed pattern noise might disappear with the proper construction and implementations of new ITFs for all three operational cameras. In particular, immediate implementation of the new LWP ITF, even before the absolute flux calibration is available, is required to improve the signal-to-noise by the use of 4 rather than 1 image per level. Additional signal-to-noise improvement should result from proper geometrical registration of the raw images with the ITF images.

(4) The best spectral extraction procedures to use for different types of spectra should be determined.

(5) If the implemenation of new ITFs with proper geometrical registration of the raw images does not remove most of the fixed pattern noise, then the use of templates to flat-field the spectra should be investigated. These optimally extracted spectra should form a new G.O. file for each archival image.

(6) Effort should continue to determine the best absolute flux calibration and ripple correction algorithm.

(7) In order to meet the December 1989 deadline for beginning the processing of the final archive, all of this work should be completed by December 1988. This task will require a minimum of two man-years of effort before December 1988 by the NASA IUE Project and a corresponding effort by the ESA and SERC Projects. The Three Agencies should divide this work among themselves and oversee both the preparatory work and the final archive processing.

(8) The NASA IUE Project should contract out a major portion of this task to interested and knowledgeable IUE users at universities or astronomical institutes. In view of the limited time available, the NASA IUE Project should consider how to start these contracts expiditiously.

Sincerely yours,

Jeffrey L. Linsky
Workshop Chairman

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