Spatial Resolution Studies with IUE

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With each passing year, as the IUE satellite continues to gather new data, the value of its archival database to future researchers increases. Recognizing this, we recently submitted a successful proposal to the Astrophysical Data Program to pursue a broad range of scientific investigations using IUE archival spectra of spatially resolved targets. The enormous wealth of important information in the majority of such spectra has yet to be tapped, largely due to the complexity of the analyses and to the lack of a software reduction package adequate to deal with them. To answer the latter need we proposed to substantially enhance our existing analysis procedures, building on our past experience with such projects as well as with current programs, and to make the completed set of analysis routines available to the entire IUE community. The procedures are to be written in IDL (Version 2), with options that will allow the user to run the package on a SUN platform, or on a VAXstation with windowing capabilities, and will incorporate many of the features discussed below.

The purpose of this short communication is to alert users of spatially resolved IUE data to the work in progress, and to encourage suggestions for enhancements which will make the program more useful in specific applications.

Most of the earlier studies using IUE spatially resolved spectra in which we have participated are based on Altner's POLYSTAR technique, or a variant thereof (see Altner 1989 and references therein). Our objectives for the ADP program require that we significantly improve the existing code, *i.e.,* by fixing known problems and "kludges", by installing new options, by making the top-level routines much more user-friendly, and by evaluating new approaches which enable research programs one would not otherwise attempt. Some of the enhancements we are working on are:

- **Deconvolution:** We are currently investigating improvements in the spatial extractions one gets when using iterative image deconvolution methods, such as the Richardson-Lucy algorithm (Richardson 1972, Lucy 1974). This method is especially well suited to digital data, and, unlike maximum entropy methods, makes no assumptions about the distribution of the noise. The only requirement is that the point-spread function *PSF*, or any distribution of "error", be well known, which is certainly the case with IUE data (see Cassatella, Barbero, and Benvenuti 1985). The essential result of applying this method is that the instrumental signature is removed from the data, as effectively as possible, allowing the analyst to fit the resultant spectrum without further consideration of the contaminating effects of the asymmetry and wavelength dependence of

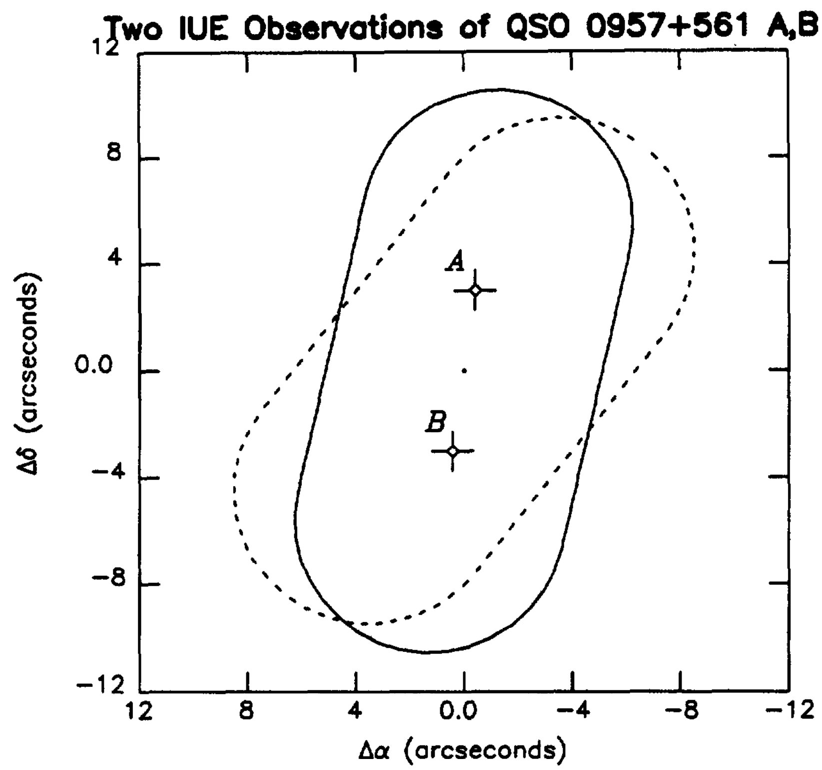

Figure 1: Spatial distribution of two sources in the IUE large aperture. This figure depicts the relative positions of the A and B components of the gravitationally lensed quasar QSO 0957+561, and representations of the actual aperture orientation for LWP 1888 (solid curve) and LWP 1603 (dashed curve). The severity of overlap of the two sources depends on the aperture position angle as well as the actual distance between them (see also Figure 2). The true separation between the A and B images is 6″.06, whereas the separation of the peaks in the line-by-line file, a projection of the true separation along the "major axis" of the aperture, is 5″.89 and 4″.72 for LWP 1888 and LWP 1603, respectively (Altner and Heap 1988). As described in the text, projection along the "minor axis" (*i.e.*, the dispersion direction) also results in different wavelength shifts in the two images (1.6 Å and 4.2 Å, respectively). Our enhanced procedure will determine the size of this wavelength shift automatically.

the *PSF*. This means that any spectrum decomposition method can then be applied to the deconvolved data, and any model can be used to represent the input data based on physical, not instrumental, constraints. Initial results using this algorithm are very promising (Altner and Shore 1990; Shore, Michalitsianos, and Kafatos 1992). The "sharpened" line-by-line data inreases ones confidence that the spatial decomposition model is the correct one (see Figures 1 and 2).

- **Improved treatment of extended sources:** In its present form, POLYSTAR performs a simultaneous non-linear least-squares fit to the spatially resolved data, assuming there are N point sources present in the large aperture. However, several applications have involved targets in which one or more of the spatially resolved components is truly an extended source (Reichert *et al.* 1988; Danks *et al.* 1991). The present approach to this problem is to allow the width of the (*PSF*) for an extended

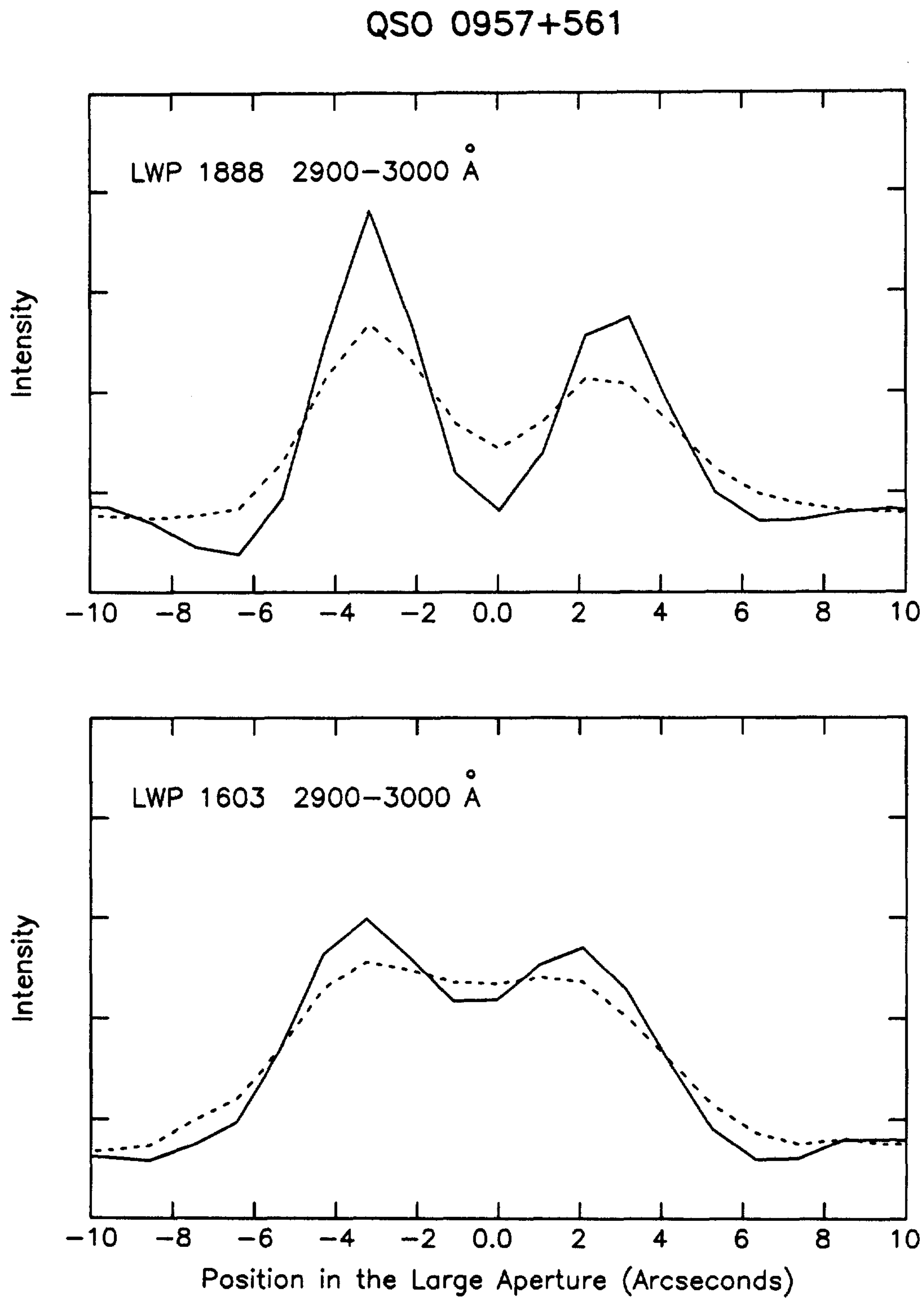

Figure 2: Cross-dispersion profiles from the line-by-line files of the two IUE spectra of the double quasar 0957+561 discussed in Figure 1: LWP 1888 (top) and LWP 1603 (bottom). In both cases the dashed line shows the original profile while the solid line shows the same profile after processing with our implementation of the Richardson-Lucy algorithm. Spatial decomposition of LWP 1888 is easily achieved using POLYSTAR on the original data, because of the wide separation between the A and B components. However, it is not obvious for LWP 1603 that only two sources are present, due to the severe overlap of the profiles. Deconvolution of the spectrum inreases our confidence that the spatial solution with $N = 2$ is the correct one.

component to be as large as it needs to be, in the least-squares sense. However, we are currently investigating a better method, *e.g.,* one using an empirically-derived, wavelength-dependent cross-dispersion profile for extended sources based on actual observations.

- **Wavelength shift compensation:** The dispersion constants used in generating a wavelength scale for spectra taken in the large aperture are modified based on the distance between the small aperture (through which calibration spectra are taken) and the center of the large aperture. Absolute errors of more than 5Å can result, say, if a star is placed near one edge of the SWP large aperture instead of the center, and a *relative* shift of twice that size can occur if two sources have a projected separation of the full extent of the aperture ($10''.4$), along the dispersion direction (see Tables 2-2 and 2-4 of Turnrose and Thompson 1984; see also Figure 1). Since the FWHM of the *PSF* can be as small as $4''.5$ in low dispersion with the SWP camera (Cassatella, Barbero, and Benvenuti 1985), such shifts are not negligible. At present, POLYSTAR returns the same wavelength scale for all of the separated sources, with no shift applied. Cross-correlation techniques, which are quite adequate for high dispersion data, are much less so in the low dispersion case, so a calculation of the wavelength shift(s) in those fields where the relative astrometry is known *a priori*, or is derived using Altner's (1988) method of 2-dimensional reconstruction, is a desirable feature of the procedure.

- **Use in cases of known offsets:** We are simplifying the extraction in the case of multiple exposures in the large aperture. Investigators in search of higher time resolution than the IUE normally allows for single exposures with a given camera, due to READ + SPREP overhead (23 minutes for SWP and 28 minutes for LWP), use the technique of moving the large aperture over the target in order to obtain two (and sometimes three) exposures more closely spaced in time. Since the offsets are always the same size (21 FES units), it is straightforward to make such extractions an option in the revised code. Existing standard reduction procedures are not really adequate for this purpose, especially with the broad, asymmetrical *PSF* seen in SWP data (see Newmark *et al.* 1992). Pre-processing with the Richardson-Lucy algoritm may even allow the use of smaller offsets, as indicated in Figure 2.

- **Standardization:** POLYSTAR was originally written for a specialized application, without concern that it conform to any external standards, such as those of the Regional Data Analysis Facility (RDAF). As the number and variety of applications of the code expanded, so did its complexity, and many of the subroutines which are called in the procedure are themselves customized routines which have no analogs in the RDAF libraries. We are presently modifying the code to acceptable RDAF standards *e.g.,* adherence to conventions of input/output, system variable usage, error checking, and documentation, so that the procedures will also be available to local and remote users of the RDAF.

We are presently incorporating the above improvements into a revised version of POLYSTAR. The following features are also being considered for future work, although they constitute more of a "wish list" than an actual description of work in progress:

- **High dispersion line-by-line data:** One of the goals of the IUE Final Archive Definition Committee is to provide, ultimately, a rotated line-by-line file for IUE high dispersion spectra, and we will implement an option in the code to work on high dispersion data. These rotated images will allow limited spatial resolution studies at high dispersion.

- **Non-uniform throughput and stray light:** The present program does not correct for partial occultation of a source near one of the edges of the aperture, although several studies suggest that the large aperture throughput is non-uniform (Clarke and Moos 1980, Altner 1988, Altner and Matilsky 1992). Nor does it attempt to account for the effect of stray light from outside the aperture, which can be significant in certain cases (Schiffer 1982, Carpenter *et al.* 1987). Such effects are difficult to estimate quantitatively, even if the spatial morphology of the source and the aperture pointing and orientation are known in advance. Recent inspection of pre-flight photographs of the IUE aperture plates show that the shape of the large aperture in both cameras is more rectangular than previously believed, and that the edges are somewhat jagged (Perez and Loomis 1991), so the problem may be even more complicated than previously believed. Nevertheless, it may be possible to incorporate an approximate correction option into the program, based on present and future studies of the problem.

Users wishing to be notified of the availability of the revised POLYSTAR package and of news of future upgrades, or those who would like to recommend specific features to be incorporated into the programs, are encouraged to contact Bruce Altner by regular mail (8201 Corporate Drive, Landover, MD 20785) or e-mail (altner@fosvax.arclch.com).

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