Spatially Resolved STIS echelle Spectroscopy

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Abstract

The combination of the HST near-diffraction-limited imagery in the ultraviolet with the STIS echelle high dispersion modes provide unique spatial information of very complex systems. While much emphasis was placed on spatially-resolved first order long slit spectra, little was done for the echelle modes largely because of close order spacing in the cross-dispersion direction. A selection of small apertures provide for moderate spatial samplings along with high spectral resolutions. Binary star systems, stars with high mass loss and circumstellar material were observed in these echelle modes with the STIS. A line-by-line extraction procedure was developed using the STIS GTO IDL software to provide spectral extractions for these apertures. Examples will be provided using echelle data of η Car and its circumstellar structures know as the Weigelt condensations and neutral analogs. Foreground absorptions of the Homunculus and Little Homunculus prove to be mapable in both the echelle and CCD long slit data recorded over the 6 year period from 1998.0 to 2004.3.

Introduction

The HST/STIS provides the current state of the art capabilities to resolve astronomical sources and to obtain relatively uncontaminated spectra of discrete substructures. The STIS development team put much effort in to developing an instrument with clean instrumental response and expended major efforts to provide both pre- and post-launch calibrations demonstrating the instrumental capabilities. A lineage of predecessor instruments can be traced from the imaging Cassegrain spectrographs at Kitt Peak and Cerro Tololo, the International Ultraviolet Explorer and the Goddard High Resolution Spectrograph. All, including STIS, suffered from limited data analysis tools developed in parallel with the instrument development. Indeed first observations were necessary to sort out what tools would be useful to the user community. Users have had to wait at least through the first series of observations that demonstrated the instrument capabilities.

For STIS the problems were unique. For this visible and ultraviolet spectrograph seeing conditions nor the detector format were no longer limiting spatial (and spectral) resolution, but the limit was diffraction of the telescope. Indeed the spectral coverage from 1175 to 10300Å defined the spatial resolution as a function of wavelength. Near-diffraction-limited performance became possible especially in the 2000-3000Å spectral region. Shortward of this region, the mirror performance contributed, longward, the CCD pixel size contributed to the limits of spatial resolution.

Along with the new spatial capabilities of the instrument came the need for more efficient display tools. Given the rich spatial structure of the ejecta around η Car (know as the Homunculus), we found the need for good two-dimensional displays that provided wavelength along with spatial information. An imaging display tool under IDL was modified to provide this display mode, and expanded to allow for comparing two longslit spatial spectra side by side. As it was used for η Car data, it was dubbed Etacar_Compare. We show some of its capabilities in this poster.
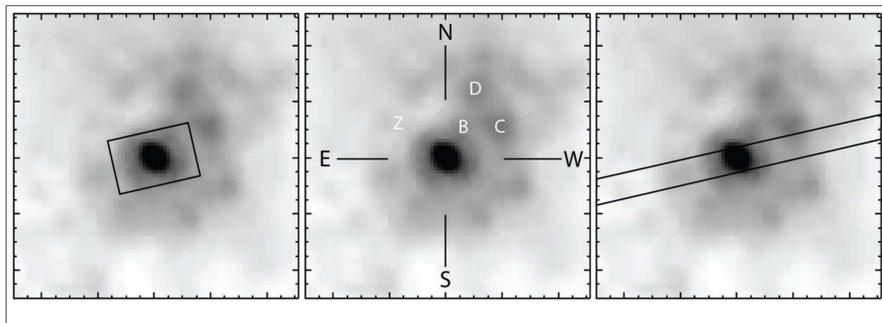
Figure 1: Left: 2200Å image with the 0."3X0."2 aperture used for the echelle E230H observations (Figure 3). Middle: Schematic showing η Car, Weigelt B, C, D plus the northeastern blob Z. Right: longslit (52"X0."1) aperture used for the G230MB observations centered on η,Car (see Figure 2L). The position angle, 104 deg, is that used for observations on July 29/31, 2003 during the depths of the X-Ray minimum. A second slit position was centered on Weigelt D at the same position angle (Figure 2R). The field is 1"×1" recorded in October 2002 under Program 9420 with the ACS/HRI (Smith et al. 2004).

Observational Data

The data used in this analysis were observed during the STIS GTO program 9973 within the η Car Treasury program in late July 2003. Figure 1 shows the positions of the STIS 52"X0."1 aperture for G230MB observations and for the 0."3X0."2 aperture used for E230H observations described in Figs 2 & 3. Reduced CCD spectra (Figure 2) are from the updated reduction procedure developed by K. Davidson and K. Ishibashi and were downloaded in the August 2005. The E230H reduction was with the STIS IDT IDL procedures adapted for extended aperture. The primary differences in reduction was definition of the detector background between echelle orders as normal reduction is designed for a point source. The emphasis, besides preserving spectral information, was to preserve spatial information on the 0."0129 scale.

First Order Spectra

Examples of the display format for Etacar_Compare are presented in Figures 2 and 3. The central 128 extracted rows (sampled at half pixel intervals), or approximately 3."24, are displayed for the two spectra. The left hand spectrum is centered across the star, η Car, and extends over much of the Little Homunculus, an ionized structure associated by proper motion with the 1890's brightening of η Car. The right hand spectrum is centered upon Weigelt D. With this display, we can compare the structures, with wavelength, interactively. For each spectrum, a lower left hand display is the intensity color scale. Immediately above the complete spectrum is displayed for reference. At the top is s subset of the spectrum displayed. The slide bar below the display can be used to scan the spectrum in wavelength. The spatial display changes automatically to accommodate up to 256 rows, then the vertical slide comes into application to scan the spatial structure. To the right middle is an enlarged display for detailed view. Zoom by factor of 2 can be used from X2 to X16. The right hand spectral spatial display is slaved to the left hand manipulations. However manipulations can be done on the right hand spectrum separately.

The color range displays are automatically scaled upon entry to Etacar_Compare, but the color table can be selected by the control button which brings up a subtablet. Linear, log, square route and histogram equal dynamic ranges can be selected along with minimum and maximum range.
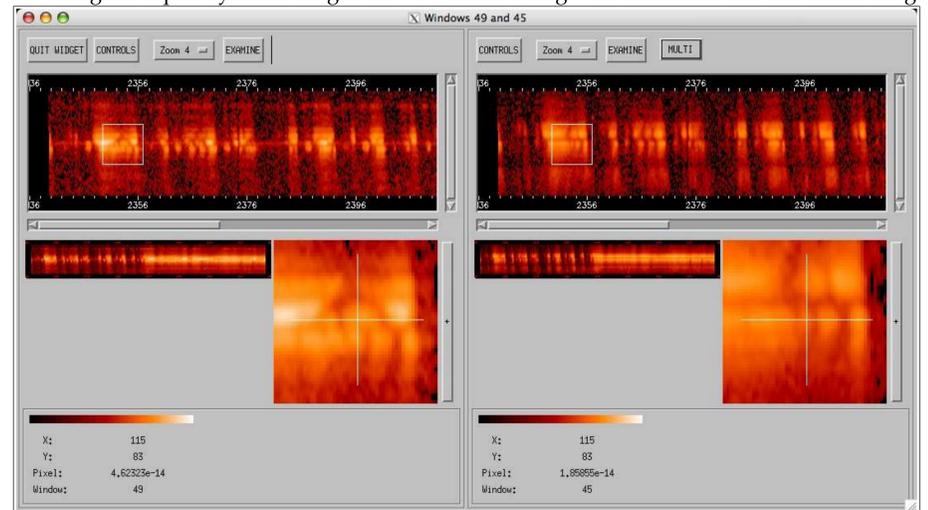
Figure 2: Example of Etacar_Compare applied to comparing two spectra: Portions of the CCD G230MB spectra centered at 2416Å. Left is the spectrum of the star and nebulosity extending above and below for a few arcseconds. Right is the spectrum recorded immediately afterwards, but offset onto Weigelt D, a very bright emission knot within several hundred AU of the star. The complex absorption and emission structures are A) the extended wind of η Car, B) the central source (η Car A, 15,000K and η Car B: 35,000K), and the bright Weigelt D, directly excited by the two stars during the bright maximum and only η Car A during the minimum.

Echelle Spectra

Echelle spectra can be displayed (Figure 3) and analyzed with Etacar_Compare either individually or with a second spectrum. For the individual spectrum the full orders (as with first order spectra) can be displayed. In the example shown in Figure 3, 34 rows (including detector background) are displayed. The software has also been adapted recently to analylze 64 row extractions of the Very Large Telescope/Ultraviolet Echelle Spectrograph (VLT/UVES) data.

Included in Etacar_Compare are some limited extraction tools. Profiles along the aperture and along the dispersed spectrum can be extracted for arbitrary numbers of rows or columns spectral or spatial plots. Various images and plots can be created and saved. Extracted data sets can also be saved. A multigaussian fit and an equivalent width routine are included. Moreover, various extractions can be scaled to match other extractions by an amplifier factor to allow visual inspection of differences, or similarities, in the plots.

The software tool has been incorporated into the STIS GTO IDL software package. We have been successful in storing STIS idl save files and .fits files into small, external 100 GByte disks, allowing portability on Mac G4 computers.

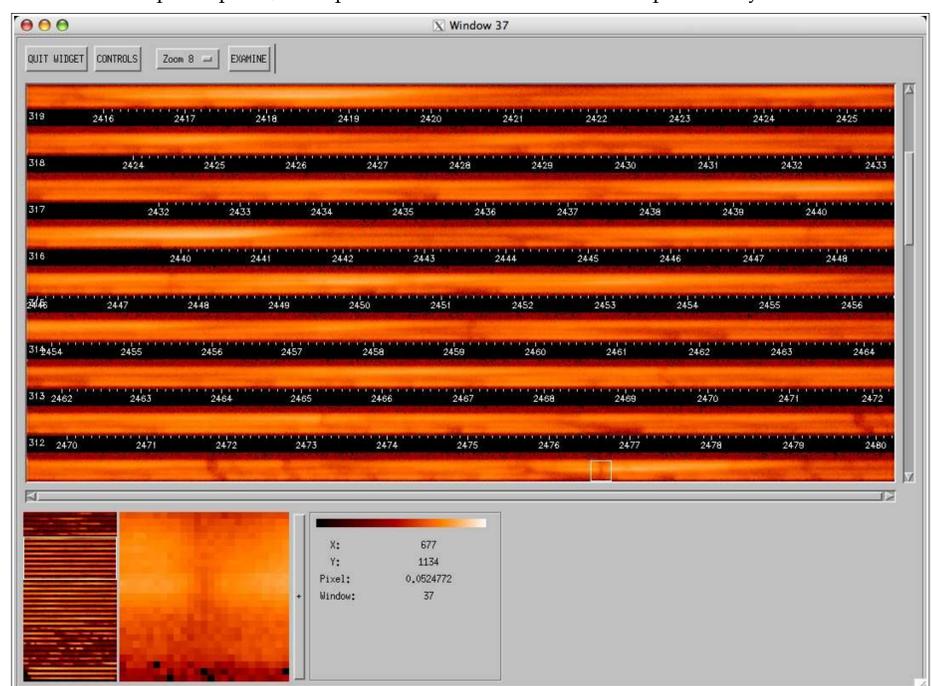For interested participants, examples can be demonstrated on the portable system

Figure 3: Example of Etacar_Compare applied to an echelle spectrum for the 0."3X0."2 aperture. Samples are every 0.0129" along the 0."3 length of the aperture.

Summary

The Etacar_Compare tool under IDL is a very useful tool for analyzing both first order and echelle STIS spectra. It has also been adapted to analyze VLT/UVES data. The visual display of spatially resolved spectra with wavelength display has greatly speeded up spectral analysis of complex structures with time variability. Don Lindler and Keith Feggans contributed much to the development of this very useful tool. This work is based upon observations made with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5 − 26555. Funding for this activity was through STIS GTO resources which ended December 2004.