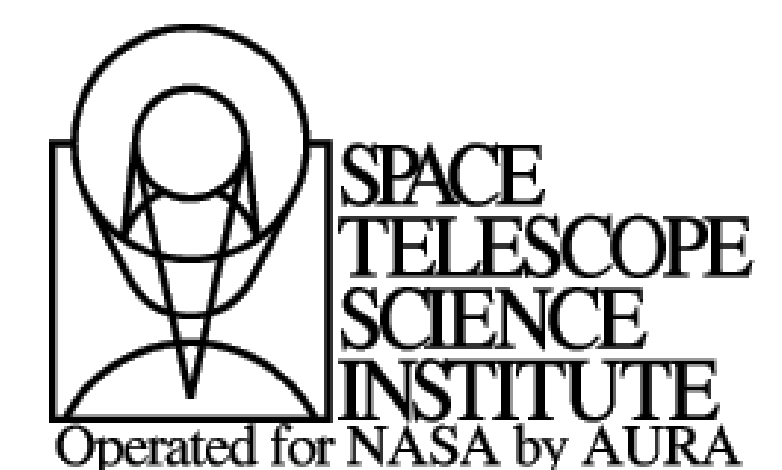




Recent Improvements to STIS Pipeline Calibration and STIS Data Analysis Tools

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Introduction

In August 2004, the Space Telescope Imaging Spectrograph (STIS) suspended operations due to a failure in a low-voltage power supply. After this failure, a uniform recalibration was initiated of all available STIS data.

The improvements to the calibration of STIS made as part of this effort include substantial improvements to the flux calibration for many modes, in particular for the echelle modes, an improved algorithm to calculate corrections for charge transfer inefficiency losses (CTI) for first order CCD spectra, improvements to spectral traces for first order modes, and changes in the handling of non-standard wavelength calibration observations and non-standard grating/aperture combinations that allow more observations to be fully calibrated.

All existing STIS data have now been recalibrated with these and other improvements. Since the calibration reference files and software are now stable, copies of the raw and calibrated files for all STIS observations were saved and used to produce a static archive, which is currently being used by the HST MAST archive to satisfy user data requests in place of the usual On-The-Fly-Reprocessing (OTFR) procedure.

In addition, a number of new post-pipeline analysis tasks have been made available as part of the STIS package in the STSDAS distribution. These are: CTESTIS, a task that can be used to estimate CTI effects for STIS CCD imaging observations, MKTRACE, a task for determining the best trace alignment for first order spectral data, and WX2D, which rectifies spectral images by iteratively fitting and redistributing the integrated flux along a column as an alternative to the bilinear point interpolation employed by X2D.

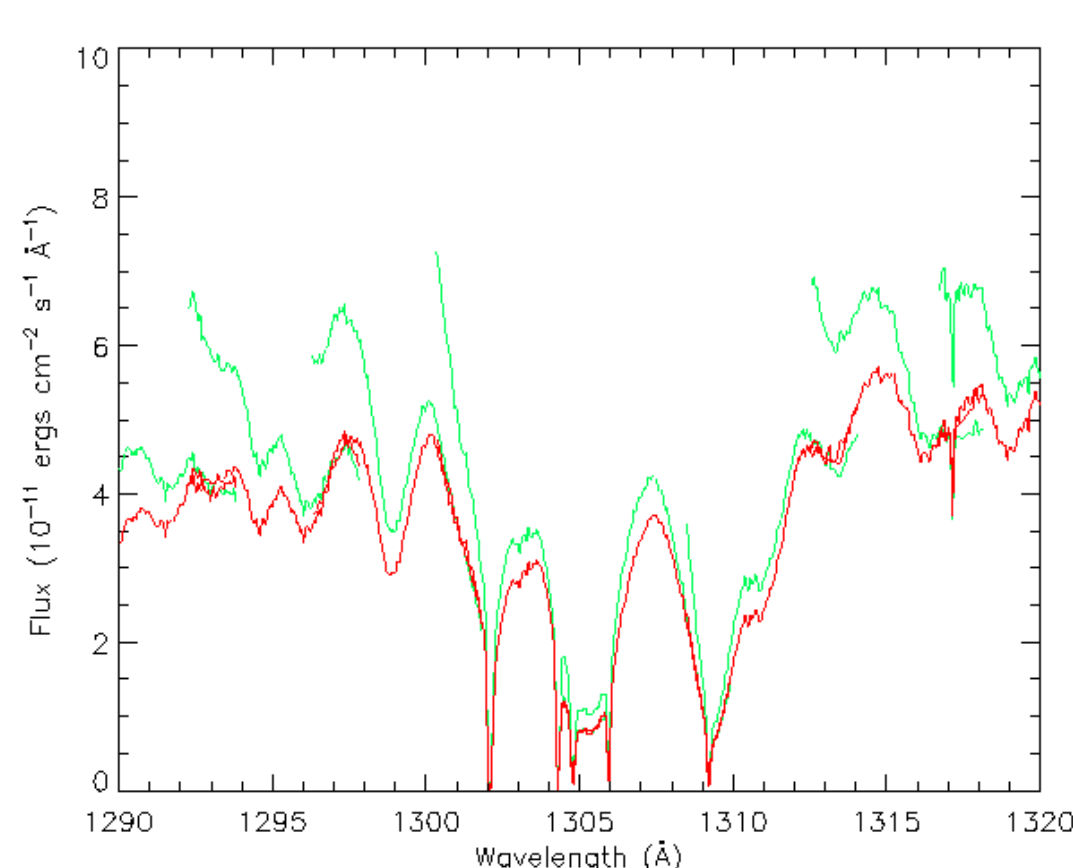
Improved Echelle Flux Calibration

New throughput curves for all MAMA medium- and high-resolution echelle spectroscopic modes were obtained based on calibration observations of the fundamental WD standard star G 191-B2B. For the prime modes, the revised on-orbit sensitivity curves were derived using data taken in the time period 1998-2001 (HST program IDs 7657, 8067, 8421, and 8915) which involved zero as well as non-zero monthly offsets of the Mode Select Mechanism (MSM); these offsets are recorded in science header keywords MOFFSET1 and MOFFSET2 for the two detector axes). For the secondary echelle modes, new on-orbit sensitivity curves were derived from data taken in 2001 at non-zero MSM offsets (program 8915). Throughputs have generally increased and the differences between the old and new values are of the order of 3% or less, apart from the E140H prime modes where such differences can be as high as 5-10%.

The blaze shift correction for the echelle prime modes was slightly revised. This correction is necessary to properly take into account how the echelle blaze function shifts as a function of time and position on the detector. For the spatial component of the blaze shift, the new correction makes use of the same coefficients derived by Lindler in March 2002. New coefficients and zero points as functions of order and side of STIS operations (Side 1 or Side 2) were inferred for the temporal component of the blaze shift (for a description on how these parameters were derived, please refer to the forthcoming STIS ISR by Aloisi: "Blaze Shift Correction for STIS echelle Prime and Secondary Modes"). The new blaze shift correction reduces the flux offset between adjacent orders from about as much as 10-15% to less than 1-2%.

The blaze shift correction is now applied for the first time to the echelle secondary modes in the same way it is applied to the prime modes. This has been possible thanks to the availability of the new on-orbit sensitivity measurements for such modes. The improvements in the flux calibration of the echelle secondary modes reduce the flux uncertainties between adjacent orders from as much as about 30% to less than 1-2%.

On 2006-Nov-03, a number of new photometric throughput (pht) reference files were delivered which include all the above mentioned improvements to the flux calibration of the STIS medium- and high-resolution echelle modes. Echelle observations using prime or secondary wavelength settings and the 0.2X0.2 aperture should now have typical flux accuracies of the order of ~5%, although isolated individual observations may occasionally be sufficiently miscentered in the 0.2X0.2 aperture to have a more noticeable flux loss.



Comparison of Old vs. New Echelle Sensitivity Calibration.

Archival STIS data of the pre-main-sequence star HD 158643 observed in May 2003 in the echelle secondary mode E140H 1380 Å. The old sensitivity calibration is indicated in green. It is based on pre-launch throughputs and does not include the application of the blaze shift correction. The new sensitivity calibration based on-orbit throughputs and including a blaze shift correction, is indicated in red. The dramatic improvement of the data with the new calibration is evident. Relative flux uncertainties between adjacent orders drop from ~30% to less than 1-2%.

Updated Calibration Reference Files

Several updates to calibration files for use in the STIS calibration pipeline have been delivered:

- PHT tables contain the throughput as a function of wavelength for each STIS mode. The CCD throughput measurements were revised, taking into account the latest CTI correction, revised sensitivities and optical red leaks for the imaging modes. New throughput tables for the echelle modes were derived; they include extensive revisions of throughput curves for all MAMA medium- and high-resolution echelle modes, coefficients characterizing the echelle blaze shape and shift as a function of both time and the position on the detector, new coefficients and zero points as a function of order for Side 1 and Side 2 electronics characterizing the time dependence of the blaze shift, as well as an improved scattered light correction.
- TDS files allow STIS flux calibrations to be corrected for throughputs which vary with time or detector temperature. Updated TDS tables, derived from all the sensitivity monitor data collected, were delivered for the CCD, the NUV-MAMA, and the FUV-MAMA detectors.
- NUV-MAMA dark current is dominated by a phosphorescent glow from the detector window. This glow scales with temperature over short time scales but shows more complicated behavior over long time scales. The coefficients stored in the Temperature Dark Correction (TDC) table are used to scale the average NUV-MAMA dark as a function of temperature. Both the baseline

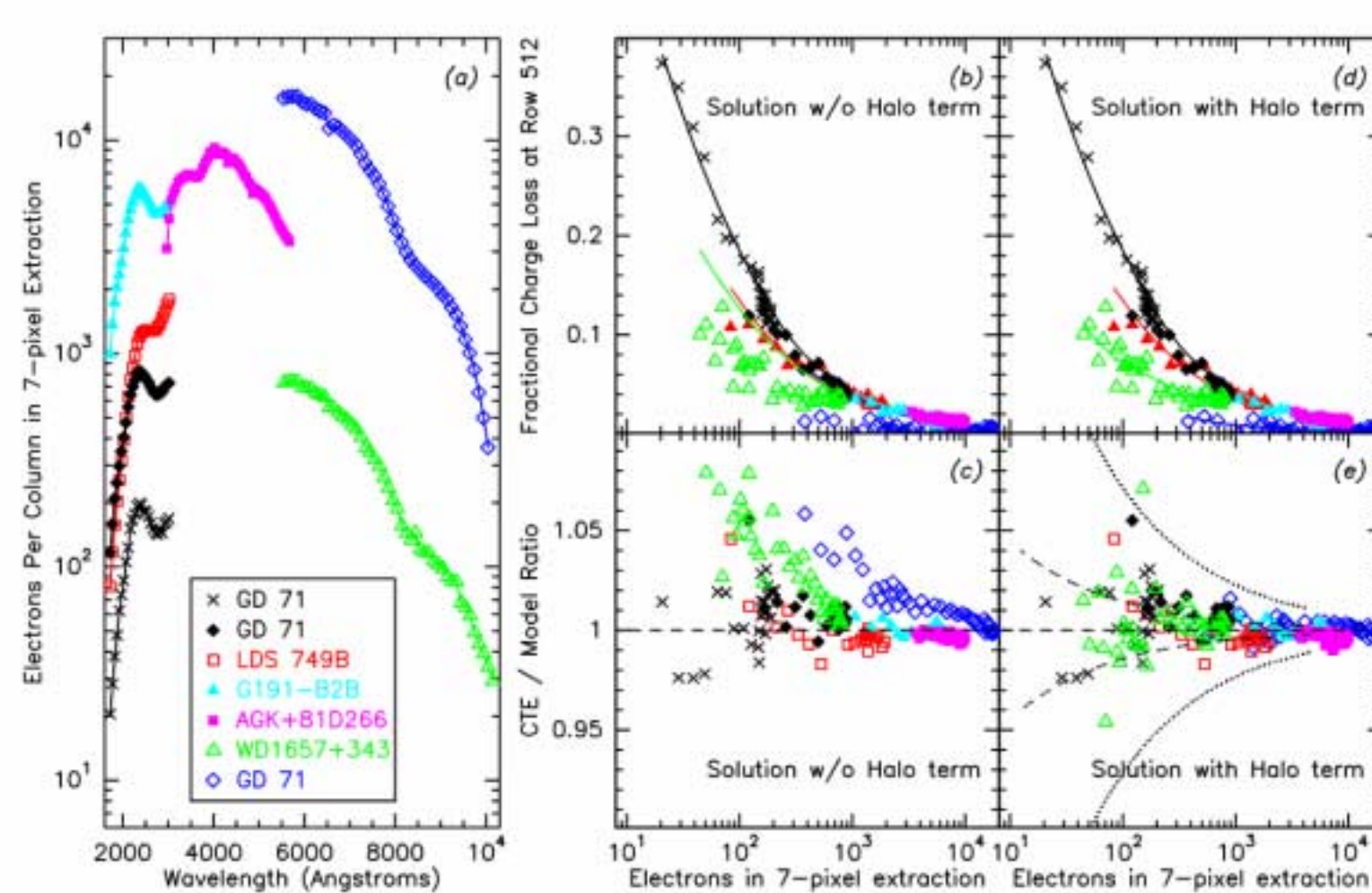
dark current (DRK) and TDC files were updated using all dark monitor data available. DRK files for several epochs are available.

- FUV-MAMA dark current exhibits an irregular glow which has become both brighter and more frequent over time. This glow, which increases with detector temperature as well as with how long the detector has been powered on, cannot be predicted reliably enough to be included in the pipeline calibration. The DRK files, excluding this glow, and containing only the baseline dark current and the hot pixels, were updated using all dark monitor data available. Images of the glow are available from the STIS web site at STScI.

Improved CTI Correction

In CCDs, the transfer of charge from one pixel to the next is not perfect. This so-called Charge Transfer Efficiency (CTE) is quantified by the fraction of charge successfully transferred between adjacent pixels; Charge Transfer Inefficiency (CTI) is defined as 1-CTE. Observationally, CTI manifests as the apparent dimming of a target the farther that target's position is away from the readout amplifier. CTE effects can be considerable: charge losses on the order of 10-25% were seen before STIS suspended operations in 2004. Since charge loss increases with on-orbit time, as the detector accrues radiation damage, the CTE correction is expected to be even more important in Cycle 17 and thereafter.

The CTI losses for STIS CCD spectrophotometry of point sources has been newly characterized, allowing for dependence on the observing epoch, signal level, background level, and the charge trap filling effect of the red halo of the STIS CCD PSF longward of ~8000Å. Systematic residuals of corrected observed data stay within 1.5% (RMS) throughout the entire wavelength range covered by the CCD grating modes. This CTI correction has been incorporated into the CALSTIS and OTFR pipelines and is available for use as the stand-alone task CTESTIS in the STIS package of STSDAS.



Impact of the New CTE Correction Algorithm for STIS CCD Spectra.

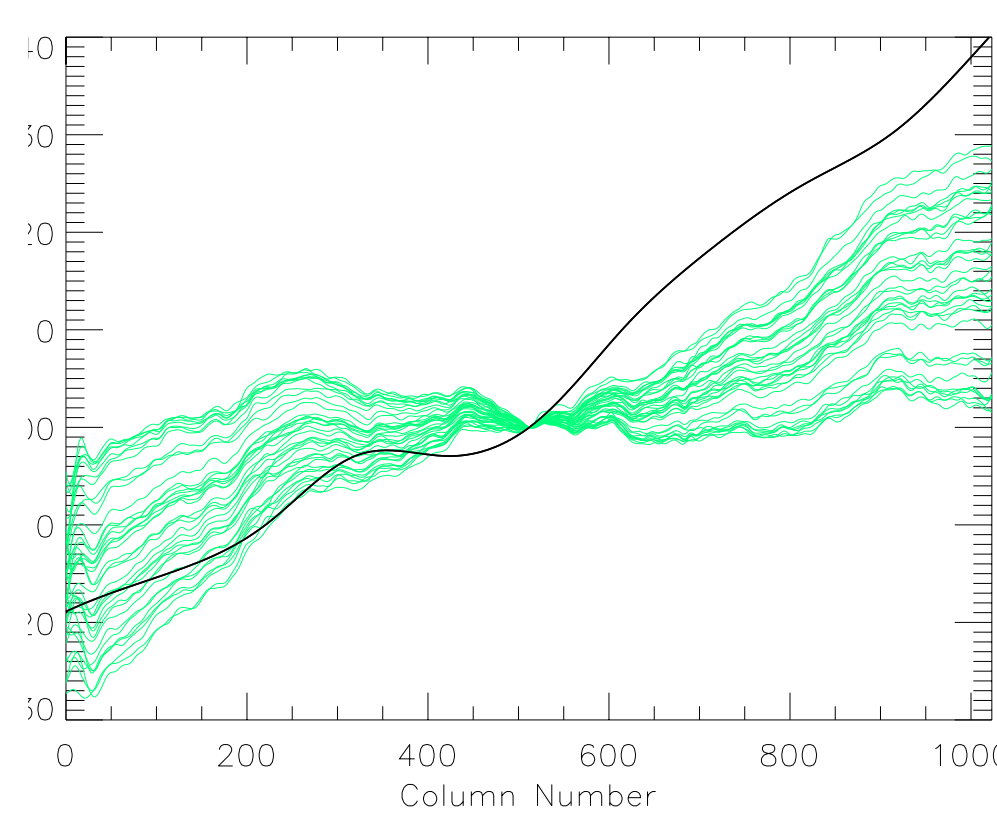
(a) Smoothed flux standard star spectra used to determine functional form of CTE loss of STIS CCD in spectroscopic mode. (b) Fractional charge loss at central row of CCD vs. extracted signal level. Smooth curves represent predictions of the previous CTE model for those data. (c) Ratio of measured CTE values and model predictions shown in (b) versus signal level. (d) Same as (c) but now using new CTE model. Note the much better fit to the data beyond 7500 Å. (e) Same as (c) but now using new CTE model. Dashed lines represent uncertainty due to Poisson noise associated with the binned spectra shown in (a) as a function of signal level. Dotted lines represent Poisson error associated with a resolution element of unbinned spectra. (Goudfrooij, STScI Newsletter, Fall 2006)

Improved First Order Spectral Traces

The spectral trace is the track delineated by the spectrum of a point source in a raw spectral image. First order spectral traces are nearly linear but not perfectly aligned along the detector's X axis; spectral traces may cross several rows of pixels as they span the detector. In order to rectify the spectrum, that is, to align the spectrum with rows and linearize the image in the spatial dimension, it is necessary to resample the flux along columns relative to a measured or calibrated trace.

The extraction and rectification of STIS spectra are carried out utilizing the spectral trace (1DT) reference files. The 1DT files contain a set of traces, spanning the detector for each grating and central wavelength setting. The 1DT files predict the spectral location and displacement in the spatial (cross-dispersion) direction as a function of the pixel location in the dispersion direction. To obtain a reference trace for a position between those positions contained in the file, interpolation is used.

As part of STIS close-out calibrations, the spectral traces of stars and other compact sources were examined for the most commonly used gratings and central wavelengths. The tilt of the traces on the detectors was found to vary systematically over time. This time dependence was characterized and quantified. New 1DT reference files were made, incorporating the rotation of the traces with time. Additionally, the shapes of the traces were uniformly established. CALSTIS was modified to apply the rotation described in the new 1DT files. For the less commonly used grating/cenwave combinations whose time evolutions were not determined, the trace-rotating script MKTRACE was added to PyRAF.



Time Evolution of Spectral Trace Tilts.

The green lines are spectral traces for G430L(4300) from 39 exposures of a standard star, displaying clockwise rotation over the lifetime of STIS. The black line is the old reference file trace, measured before a reset of the commanded tilt of the grating. The mismatch illustrates the need for an improved trace shape and for time dependent trace rotation. (Dressel et al., STIS ISR 2007-03.)

Static STIS Data Archive

The newly recalibrated STIS data has been stored in a static archive. On-The-Fly-Reprocessing (OTFR) is currently turned off for STIS data. Archive requests for STIS data will be fulfilled using the data from the static archive; this results in significantly faster data retrievals. OTFR will be turned on for data acquired in Cycle 17 and thereafter.

New Associations For GO-Wavecals

A wavelength calibration spectrum (wavecal), coincident in time with the science exposure, is needed by CALSTIS to determine the wavelength scale and aperture location zero points and produce flux calibrated spectra.

Normally, at least one wavecal is automatically taken for each group of spectroscopic science exposures observed at the same MSM position (grating tilt). Observing programs needing particularly stringent wavelength accuracies were permitted to substitute user-specified wavecal exposures (GO-wavecals) in place of the auto-wavecals.

The STIS data archive did not originally handle GO-wavecals in the same manner as the auto-wavecals. Auto-wavecals were combined with the affiliated science exposures into data "associations", all members of which were automatically downloaded with the science exposures and handled appropriately by the calibration software. GO-wavecals however, were not originally associated with their science exposures. As a result, the GO-wavecal exposures had to be separately retrieved from the archive, the calibration flags in the science headers had to be manually reset, and CALSTIS had to be run locally.

These previously unassociated GO-wavecals have now been identified and associated with their science exposures. They are now treated identically to the auto-wavecal associations. One consequence of these new associations is that the names of some datasets have changed in the archive. Tables mapping the old file names to the new association names are provided on the STIS web site at the following URL: http://www.stsci.edu/hst/stis/faqs/faq_asn_mapping.html.

For data acquired in Cycle 17 and beyond, GO-wavecals are expected to be automatically associated with the science exposures.

Calibration of Selected Non-Standard Modes Supported

As part of this recalibration effort, several non-standard grating/aperture combinations were identified and the calibration rules which determine which datasets may be fully calibrated were revised. The resulting fully calibrated 1D and 2D spectral extractions are now available from the archive.

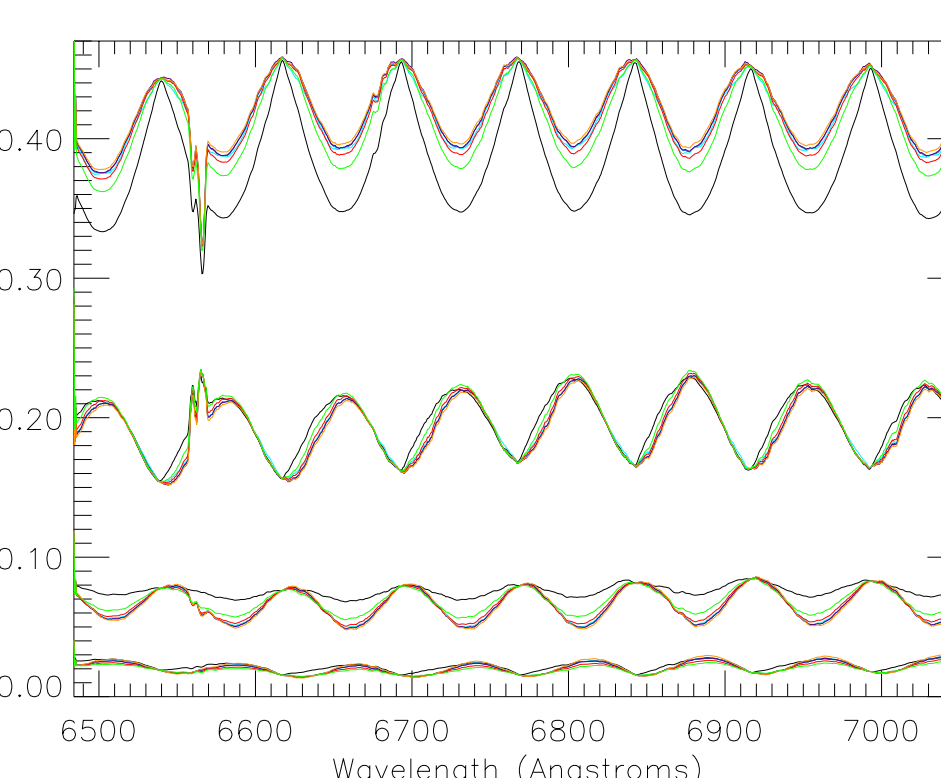
FRNGFLAT Header Keyword Populated

For G750L and G750M observations redward of 6000 Å, in order to obtain the best signal to noise ratio possible, the user must de-fringe the data using a contemporaneous fringe flat. For every external G750L and G750M science exposure, the name of the appropriate fringe flat (if one exists) has been stored in the science header keyword FRNGFLAT. The fringe flats will be automatically delivered by the archive when the uncalibrated science exposures are requested for delivery.

New Post-Pipeline Analysis Tasks

Three new post-pipeline analysis tasks have been made available as part of the STIS package in the STSDAS distribution:

- CTESTIS: The CTESTIS task is designed to correct STIS CCD imaging photometry of point-like sources for CTI effects, based on the observing epoch, signal level, background level, and the charge trap filling effect of the red halo.
- MKTRACE: The MKTRACE task generates a new 1DT file with a trace rotation custom-made for a specific science image, for any wavelength setting of any M or L first order grating. MKTRACE determines the trace of the science target, starting at either the default aperture position or a user-specified row. A linear fit is made to all or part of the trace, excluding user-selected sections. A linear fit is also made to the trace interpolated from the standard 1DT file, using the same trace sections as in the science image. The trace rotation correction is the difference in the tilts of the science and reference traces. A new 1DT file is created, with the rotation correction applied, and covering the entire detector.
- WX2D: This task resamples a 2-D spectral image to rectify it in the spatial dimension. Because the PSF is undersampled along the slit, resampling inevitably produces artifacts in STIS spectral images of targets with spatially unresolved components. In each row of the resampled image, the unresolved flux is modulated with a periodicity that depends on the tilt of the trace. The modulation can be clearly visible in an intrinsically featureless spectrum, or, more problematically, it can be blended with real spectral features. The PyRAF routine WX2D was developed to produce smaller spectral modulations near the centers of point sources than those produced by the bilinear interpolation used in CALSTIS and X2D. It repeatedly subdivides the pixels in each column into pairs of sub-pixels, using polynomial fits to the integrated flux along the column to redistribute the flux among the sub-pixels. Optional convolution along columns with a PSF kernel further diminishes the spectral modulation at the expense of spatial resolution. No resampling is done in the dispersion direction, to avoid needless spreading of the flux in bad pixels or loss of spectral resolution. To perform resampling in the dispersion direction, and as one method of flux calibration, one can use the output from WX2D as input for X2D.



Comparison of Peak Rows for X2D and WX2D.

The spectrum in the peak row of dataset o5d101010 and the next 3 rows down, normalized by the spectrum summed over 21 rows. Reductions using X2D are shown in black. Reductions using WX2D, with varying parameters are shown as follows: green (3rd order, 8 sub-pixels), red (5th order, 8 sub-pixels), aqua (7th order, 4 sub-pixels), blue (7th order, 8 sub-pixels), violet (7th order, 16 sub-pixels) and orange (9th order, 8 sub-pixels). The WX2D images have smaller fluctuations in the central row than the X2D image. For all but the lowest order fit, the fluctuations in that row are about 13% of the maximum flux in the WX2D images, and about 24% of the maximum flux in the X2D image. The fluctuations in the central row of the X2D image have sharper peaks, which may have more influence on the fitting of spectral lines in the vicinity of the peaks. (Dressel, STIS ISR 2007-04)

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