COS Data Processing Improvements Based on HST SMOV Results

Thomas B. Ake[1], P. Hodge[2], A. Aloisi[2], R. Diaz[2], P. Ghavamian[2], C. Keyes[2], D. Massa[2], S. Niemi[2], C. Oliveira[2], R. Osten[2], C. Proffitt[1], B. York[2], D. Sahnow[3], S. Beland[4], S. Penton[4], E. Burgh[4], K. France[4], J. McPhate[5]
[1]Space Telescope Science Institute/ Computer Sciences Corporation, [2]Space Telescope Science Institute, [3]Johns Hopkins University, [4]University of Colorado, [5]University of California, Berkeley

After the Cosmic Origins Spectrograph (COS) was installed onboard the Hubble Space Telescope (HST) in May 2009, it underwent an extensive calibration and characterization check-out during the Servicing Mission Observatory Verification (SMOV) period. The results from this program were used to update reference files and make changes to CALCOS, the COS data processing software. Improvements to the standard data products are discussed. For the FUV channel, we have begun development of a flat-field correction. As an intermediate step, grid wire shadows are now ignored when combining FP-POS exposures. Pulse-height filtering has been activated to reduce background features. For the NUV channel, vignetting corrections are incorporated in the flat field file. For both channels, improvements have been made in the wavelength scales, flux calibration, and data quality flagging. Additional data are included in the FITS products to allow users to perform customized processing.

The current version of CALCOS is 2.12 (April 22, 2010). It replaced 2.11, in use since Sept 14 2009. A detailed description of the CALCOS processing steps and reference files can be found in Chapter 3 of the *COS Data Handbook.* The latest information on CALCOS changes can be found at *http://www.stsci.edu/hst/cos/pipeline/CALCOSReleaseNotes.*

FUV QE Grid Wires

The FUV detector employs a wire grid above the microchannel plates (MCP) to improve quantum efficiency. The wires cast shadows on the MCPs that appear as regularly spaced depressions in extracted spectra (X1D files), about 20% deep every 840 pixels. When CALCOS coadds different FP-POS exposures with the same central wavelength into an X1DSUM spectrum, these features are reduced in depth, but appear in more places. The affected locations can be identified by the data quality flags (DQ=4).

- It is expected the grid wire shadows can be removed with a flat field, but a methodology for flat fielding the FUV detector is still being developed.

- *In the meantime, X1DSUM processing has been modified so that the gird wire regions are not included in the sum. See Figure 1.*

- For observations with two FP-POS positions, the contributions from only one exposure are present in the X1DSUM in the shadows; for four FP-POS steps, typically three exposures contribute to those locations. If no FP-POS stepping was performed, the X1DSUM spectrum will have gaps where the shadows lie.

FUV Pulse Height Filtering

The FUV detector in TIME-TAG mode transmits a scaled pulse height value (0-31) for each detected event. The pulse height amplitudes (PHA) from photons have a different distribution from background events. Noise events typically have very large or very small PHAs. CALCOS PHACORR can be used to limit the range of PHA values to reduce the background when constructing spectra.

- *During SMOV, FUV segment B was found to exhibit pseudo-emission lines with PHA=0. To eliminate these features and reduce detector noise, CALCOS now uses PHA values 4-30 for TIME-TAG exposures. See Figure 2.*

- ACCUM observations cannot be filtered and the features in segment B may be present in the data. They will be flagged with DQ=4096.

- PHA filtering changes the flux calibration by a small amount. For the time being, CALCOS uses the same sensitivity curves for TIME-TAG and ACCUM data, until it is updated to select calibrations based on pulse height.

Wavelength Assignment

CALCOS uses PtNe lamp data, which are taken during TIME-TAG exposures or, for ACCUMs, just before or after the exposure, to convert X pixel values to wavelengths through WAVECORR. The lamp data are extracted as spectra and are cross-correlated with reference file templates to compute offsets to the grating dispersion relations.

- In the pre-SMOV version of CALCOS, the lamp templates and dispersion relations were based on the default FP-POS=3 setting for each central wavelength and aperture. Other FP-POS exposures were cross-correlated with the one template for that central wavelength.

- In addition, for the NUV detector, the PtNe data from the three stripes were collapsed into a single spectrum for the cross-correlation. Differences in the actual shifts needed for each stripe led to misalignments of FP-POS spectra.

- *The current version of WAVECORR uses separate lamp templates for each FP-POS position (with known offsets from the FP-POS=3 dispersion relation), and for NUV, each stripe is processed separately. The cross-correlation routine was also modified. These changes have improved the wavelength accuracy of COS spectra. See Figure 3 and COS ISRs 2010-05 and -06 for details.*

Customized Processing

CALCOS is used not only in the STScI pipeline, but runs in the STSDAS environment, allowing the user to customize his/her data processing. Also it is expected that GOs will develop their own tools to work either in concert with or in addition to CALCOS processing.

- The corrected time-tag event list (corrtag file) is the primary intermediate product most useful for customized processing. Two modifications to CALCOS have been made for this so far.

- *CALCOS will allow corrtag files to be read in as input, not just rawtag files.* This allows the user to manipulate a pre-existing corrtag file and use CALCOS to perform the final spectrum extraction and merging afterwards.

- The corrtag file has also been modified. *A new wavelength column has been added to the table.* After wavelength calibration is computed as part of preparing for spectral extraction, CALCOS assigns a wavelength to each event. This will allow users to combine and extract spectra directly without converting the data into images. Table 1 lists the columns in the new corrtag file.

Table 1: Corrected event list (corrtag) parameters

Parameter	Type	Description
TIME	FLOAT	Time of event from beginning of exposure (secs)
RAWX	INT	Uncorrected position along dispersion (pixel)
RAWY	INT	Uncorrected position cross dispersion (pixel)
XCORR	FLOAT	Thermally and geometrically corrected RAWX (FUV)
YCORR	FLOAT	Thermally and geometrically corrected RAWY (FUV)
XDOPP	FLOAT	XCORR corrected for HST Doppler shift at this time
XFULL	FLOAT	XDOPP shifted to wavecal frame
YFULL	FLOAT	YCORR shifted to wavecal frame
WAVELENGTH	**FLOAT**	**XFULL wavelength assignment (Å)**
EPSILON	FLOAT	Deadtime, flat field correction factor
DQ	INT	Data quality flag
PHA	BYTE	Pulse height amplitude (0-31)

Other Improvements

Other enhancements have been incorporated into CALCOS since SMOV. Data quality flags have been redefined to mark additional detector characteristics. Corrections for NUV vignetting have been integrated into the flat field file pending the decision to implement 1-D flats. The usefulness of the G140L grating below 1150 Å has been demonstrated, requiring wavelength calibration changes since the PtNe lamps do not extend into that region. Further improvements are planned for the future.

Table 2 lists the reference files used by CALCOS, sorted by their installation dates. Many files created pre-SMOV and presently in use were not expected to change. Some processes (bad time and burst corrections) are not needed yet. Time dependent sensitivity corrections are expected to begin in July 2010.

Table 2. Chronological listing of reference file installations

File Type	FUV File Name	NUV File Name	Description
Pre-SMOV			
FLATFILE	n9n20182l_flat.fits		Flat field image (unused)
GEOFILE	s7g1700cl_geo.fits		FUV geometric correction
BADTTAB	s7o1739kl_badt.fits		FUV bad times (unused)
BPIXTAB		s7g1700pl_bpix.fits	Bad pixel locations
BRFTAB	s7g1700el_brf.fits		FUV baseline reference frame
BRSTTAB	s7g1700fl_burst.fits		FUV burst rejection (unused)
DEADTAB	s7g1700gl_dead.fits	s7g1700ql_dead.fits	Deadtime correction
TDSTAB	t2314312l_tds.fits	t2314314l_tds.fits	Time dependent sensitivity (unused)
WCPTAB		t2314313l_wcp.fits	Wavelength calibration parameters
Sep 11, 2009			
FLATFILE		t9b18111l_flat.fits	Flat field image
Sep 17, 2009			
PHOTTAB		t9h1220sl_phot.fits	Sensitivity curves
Jan 29, 2010			
DISPTAB	u1t1616ml_disp.fits	u1t1616pl_disp.fits	Wavelength dispersion relations
LAMPTAB	u1t1616nl_lamp.fits	u1t1616ol_lamp.fits	PtNe lamp templates
WCPTAB	u1t1616ql_wcp.fits		Wavelength calibration parameters
PHATAB	u1t1616ll_pha.fits		Pulse height screening
Mar 10, 2010			
BPIXTAB	u381724gl_bpix.fits		Bad pixel locations
Apr 14, 2010			
XTRACTAB	u4d1930sl_1dx.fits	u4d1930tl_1dx.fits	Spectrum extraction regions
Apr 29 2010			
PHOTTAB	u4t18348l_phot.fits		Sensitivity curves

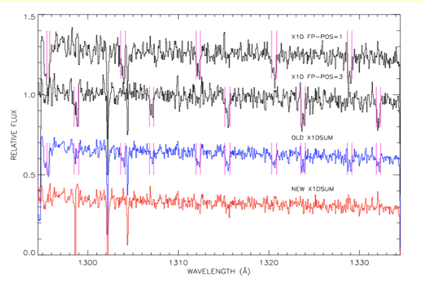

Figure 1. FUV G130M spectra of WD0320-539, offset by an arbitrary amount, taken at two FP-POS settings (X1D spectra) and coadded as an X1DSUM spectrum product. Only two lines, O I λ1302 and Si II λ1304, are real. The top two spectra are the individual exposures. Violet bars indicate grid wire regions. The blue spectrum is the sum of the two (old X1DSUM). The shadows are reduced by a factor of 2, but occur in twice as many places. The red spectrum is the current CALCOS processing, where the grid wire regions in the individual spectra are ignored in the coaddition.

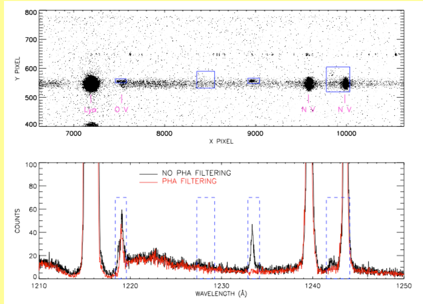

Figure 2. FUV G130M spectrum of Lin 358 showing pseudo-emission features in segment B. *Upper panel*: COUNTS image showing areas (blue) in the FUV bad pixel table where the artifacts occur. *Lower panel*: Extracted spectra with (red) and without (black) event pulse height filtering, illustrating how the filtering removes the contaminating features. The effects of the artifacts range from distorting some line profiles to inducing false emission lines. Note that CALCOS cannot eliminate these features in ACCUM exposures.

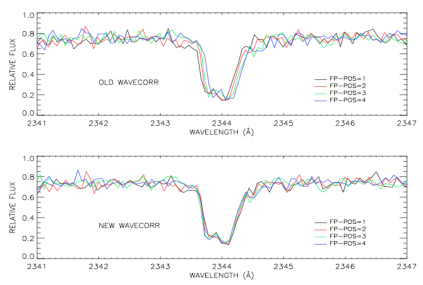

Figure. 3. NUV G225M spectra of Feige 48 with the pre-SMOV and current CALCOS versions of WAVECORR. The FP-POS spectra with the old processing show wavelength misalignment errors that have been removed with the current technique.