Cosmic Origins Spectrograph: Flat Fields And Signal-to-Noise Characteristics

Thomas B. Ake\textsuperscript{1}, D. Sahnow\textsuperscript{2}, E. Burgh\textsuperscript{2}, K. France\textsuperscript{3}, S. Penton\textsuperscript{2}, J. McPhate\textsuperscript{2}, C. Keyes\textsuperscript{2},
STScI COS Team, COS IDT Team

\textsuperscript{1}Space Telescope Science Institute/ Computer Sciences Corporation, Johns Hopkins University.
\textsuperscript{2}University of Colorado, University of California, Berkeley, \textsuperscript{3}Space Telescope Science Institute

The Cosmic Origins Spectrograph (COS) employs different microchannel plate detectors for its two channels: a cross delay line (XDL) for the FUV, and a multi-anode microchannel array (MAMA) for the NUV. These detectors show non-uniformities due to the intrinsic ‘chicken wire’ and more patterns of the microchannel plates, dead spots, hot regions, and for the XDL, shadowing by the quantum efficiency (QE) grid wires. Signal-to-noise (S/N) improvements can be achieved by applying a high-quality flat field before data reduction. For the highest S/N, multiple exposures can be taken using the FP-POS technique, where spectra are shifted to different locations on the detector. During the COS Servicing Mission Observation Verification (SMOV) program, observations of bright astronomical targets and an internal deuterium lamp were made in both channels to investigate methodologies to improve the S/N of on-orbit observations. For the NUV channel, flat field exposures were obtained with the onboard lamp. Comparisons with a flat field constructed from prelaunch data indicate that there have been no changes, and a high S/N flat has been built by combining ground and flight data. Analysis indicates that S/N = 100 per pixel is achievable using flat-fielding alone. For the FUV channel, which does not have a high-quality flat field, exposures were obtained of white dwarfs at various cross-dispersion locations on the detector. Comparisons of different reduction techniques for this data set are presented. Until high-quality flat fields are implemented in standard pipeline processing, high S/N spectra are best achieved by the FP-POS technique, which has demonstrated S/N of > 50 per resolution element.

FUV On-Orbit Technique

- Thermal vacuum (TV) tests demonstrated S/N improvements are possible by flat fielding, but a high-quality FUV flat was not obtained.
- An SMOV plan was devised to obtain an improved flat field by mapping out the detector with a bright external target.
- The G130M and G160M flats were taken with different cross-dispersion positions with G130M, and each with G160M and G140L to sample the whole illuminated detector area. Different central wavelength and FP-POS settings were used at each position.
- Below are the separation of spectral and detector features in the analysis while covering the range of detector Y locations where spectra occur.

FUV On-Orbit Flat

- Flat fields were created for each grating and segment, summing all data in pixel space to average out spectral features.
- The spectral slope was removed by polynomial fit normalized to the center of the detector.
- Possible flat field changes with event pulse height were characterized and were found to be measurable but small.
- The G130M and G160M flats in their overlap region do not match at all locations, indicating a possible illumination angle dependency.

FUV S/N Evaluation

- High S/N observations were made of WD0047+857 (G130M, G140L) and WD0157+119 (G160M).
- Different methodologies were tested to study S/N improvement:
  - FP-POS summing, smoothing out detector structures
  - 1-D correction, extracting a 1-D vector from the flat field image as in spectral extraction, then dividing it into the spectrum.

NUV Ground Flat

- Data were obtained during thermal vacuum (TV) testing in 2003 and 2006 with the G190M grating.
- The internal D2 lamp was observed through the flat field calibration aperture (FCA).
- An external D2 lamp was observed through the primary science aperture (PSA), moving it in the cross-dispersion direction to map the science area.
- Most counts came from the external lamp and were taken in ACCUM mode.
- A pixel-to-pixel flat (P-flat) was generated.

FUV S/N For A Single Grating Setting

- As expected prior to launch, for observations at one grating setting, even deep exposures are limited by inherent fixed pattern noise of the segments.
- Flat fielding is applied pixel-to-pixel, while characterization is measured by resolution element (pixel binning).
- A combination of FP-POS summing with flat fielding improves the S/N significantly.
- The spectral iteration technique achieves the highest S/N results, but this methodology requires the observations themselves to be of high S/N.

NUV On-Orbit Flat

- Thirty-six 1800-sec internal D2 lamp exposures were taken in SMOV as in TV 2003.
- The program was designed to check that the ground flat was still valid after launch.
- Image ratios between on-orbit and ground flat indicate alignment is better than 1 pixel.
- Detector bleedthroughs are in the same location, consistent with no detector format shift.
- On-orbit and ground data were combined to create a superflat for CALCOS processing.

NUV Vignetting

- Observations of external targets show a depression in count rates at the left edge of the detector.
- This was traced to vignetting at the camera mirrors after final instrument alignment.
- The profile is the same in all three spectral strips for the M gratings (\(\sim 2.5\%\)).
- The G230L grating may be slightly different, but higher S/N data are needed.
- An average vignetting profile was constructed from M grating data.

NUV Combined Flat

- The vignetting profile was incorporated in the NUV P-flat reference file for CALCOS.
- COS FLT images have the vignetting removed, but the COUNTS images contain the original count rates.
- A change to CALCOS is being made to allow use of different flat fields for the M gratings and G230L.
- We are considering modifying CALCOS to use L-flat, which would include the vignetting instead.

NUV S/N Evaluation

- High S/N exposures were taken of G191-B28 with all M gratings (+/- 2.5%)
- Different central wavelengths and all FP-POS settings were used.
- The program was designed to achieve S/N > 30 per resolution element for all settings and demonstrate S/N > 100 per pixel at least one setting.
- Studies indicate that the Poisson limit can be reached for S/N > 70. S/N > 100 was demonstrated for the SMOV high S/N program.