Strategies for the Removal of Fixed-Pattern Noise in the COS FUV Detectors

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Abstract

Far Ultraviolet (FUV) spectra taken with the Cosmic Origins Spectrograph (COS) on board the Hubble Space Telescope are subject to fixed-pattern noise introduced by both the detector and the illumination pattern. These features include artifacts such as shadows from the quantum efficiency grid-wires, hexagonal boundaries due to the multifiber bundles on the microchannel plates, and surface imperfections from production, assembly, and launch. Prior to on-orbit operations, the planned mitigation strategy for these features was to employ 2D flat-field images taken while on the ground. These ground-based flats were subsequently found to be inconsistent with data taken after launch, thus making it necessary to develop new flat-fielding strategies using on-orbit data. Discussed here are both the currently implemented corrections and those still under development. These include partial two dimensional flat fields to correct large-scale non-uniformities common to all modes, grating and position specific one-dimensional flats to correct smaller scale and grating-specific features, and enhanced flagging of questionable or uncorrectable data.

Changes to COS/FUV Flat Field Calibration

Detailed analysis of the fixed-pattern noise features in the COS detectors has led to an improved understanding of the individual components. This has led to a change in the handling and correcting of these features by the CalCOS calibration pipeline. The COS team has separated the fixed pattern noise correction into two groups; global corrections that apply to all data for each grating and those that apply only at specific detector locations. Those that are solely detector dependent have been grouped together into the COS FUV flat-field reference image (FLATFILE) that will apply to all FUV data. These features include the correction for the grid-wire shadows, the "imposter" grid-wires, and the low-order response curves (L-flat).

These corrections have all been incorporated into a new version of the FLATFILE, and will be released into the on-the-fly-reprocessing pipeline (OTFR) later this fall.

Grid-wire Correction for all Gratings

The largest component of the fixed-pattern noise for the COS FUV detectors are the shadows introduced by the quantum efficiency grid-wires. These wires cast shadows at 17 different locations on each detector with depths of ~25% that cover ~50 pixels. Although previous flat-field reference files assume that a different correction is needed for each of the three COS gratings, recent analysis shows that the shape and depth of the grid-wire shadows is independent of the grating used. Therefore, a single correction has now been derived that applies to all G130M, G160M, and G140L spectra. For G130M and G160M data, which has already been using a grid-wire flat-field, changes will be negligible. For G140L data, which previously has had no flat-field applied, the grid-wire shadow depressions will now be corrected and no longer excluded from final calibrated products. This results in more useful data in each observation and better S/N in combined observations. An example can be seen in Figure 1.

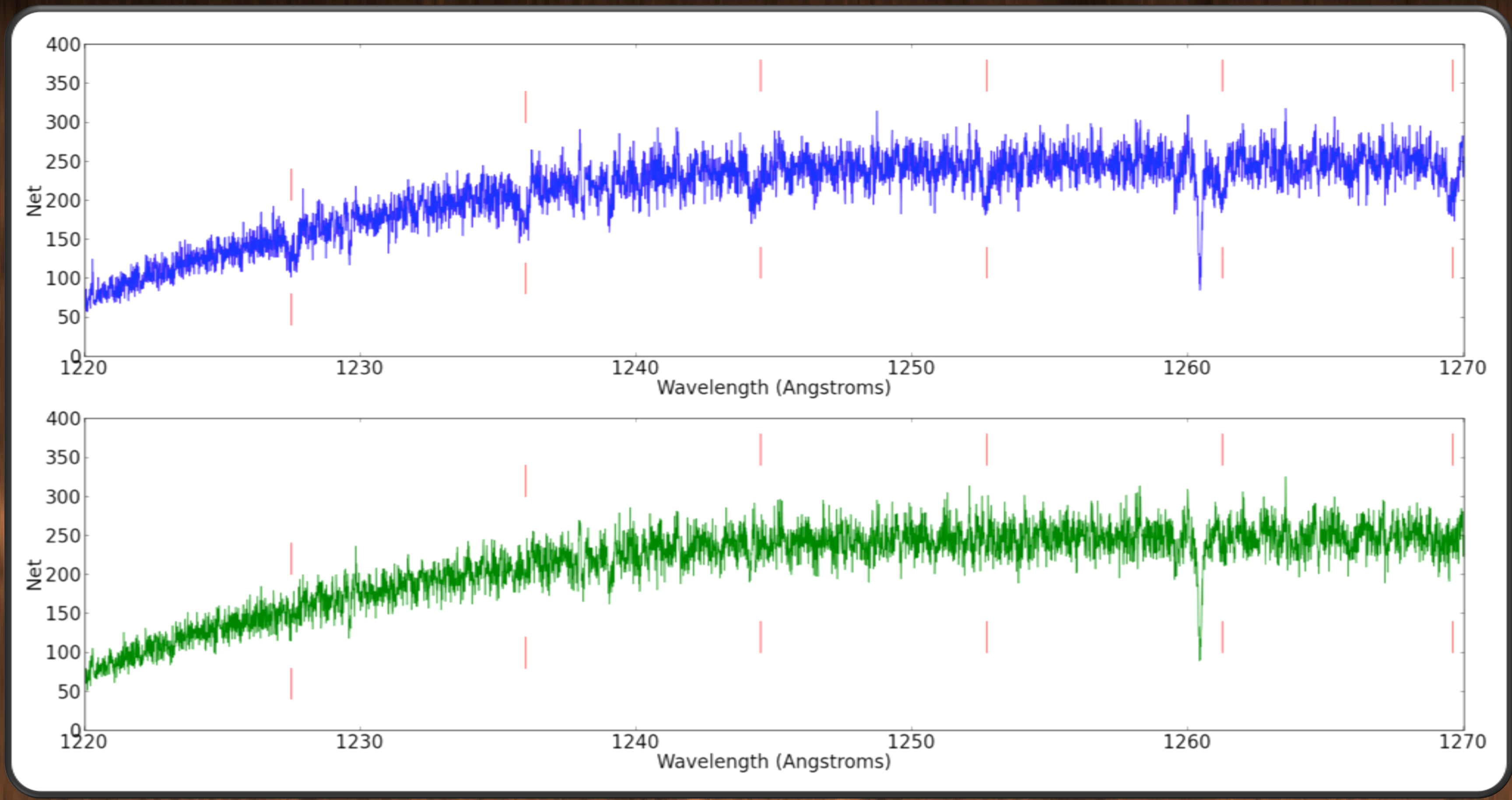


Figure 1: Sample x1d extracted spectrum showing data with (bottom, green) and without (top, blue) the grid-wire flat-field correction. Red lines above and below each spectrum indicate the centers of the grid-wire shadows. Without the grid-wire correction, x1d datasets will show depressions at each of the gridwire locations, which are then flagged and thrown away from the final x1dsum extracted spectra. After implementation of the new flatfield reference file, all G130M, G160M, and G140L observations will have these features corrected in data calibrated through the CalCOS pipeline.

"Imposter" grid-wires

On FUV Segment B, there are 6 detector locations that show depressions of a similar magnitude and extent as the grid-wire shadows. Previously, while operating at only a single lifetime position (LP), these features could be effectively treated as if they were gridwires. The current implementation of the FLATFILE was derived as if these features are grid-wire shadows, from data at LP1. After moving to LP2, these 6 features are found to vary significantly with y-location on the detector, and thus needed to be derived separately from the grid-wire shadow correction, which is y-location independent. Because of the semi grid-wire appearance of these features, we refer to them is "imposter" grid-wire shadows.

The imposter features are found to be evident even in the dark data, and summing together all dark exposures to date produces a dataset with adequate signal to derive a correction. Spline fitting a surface over the depressed areas gives a 2D correction that will be incorporated into the FLATFILE reference file and is able to compensate for the position dependent structure of the features.

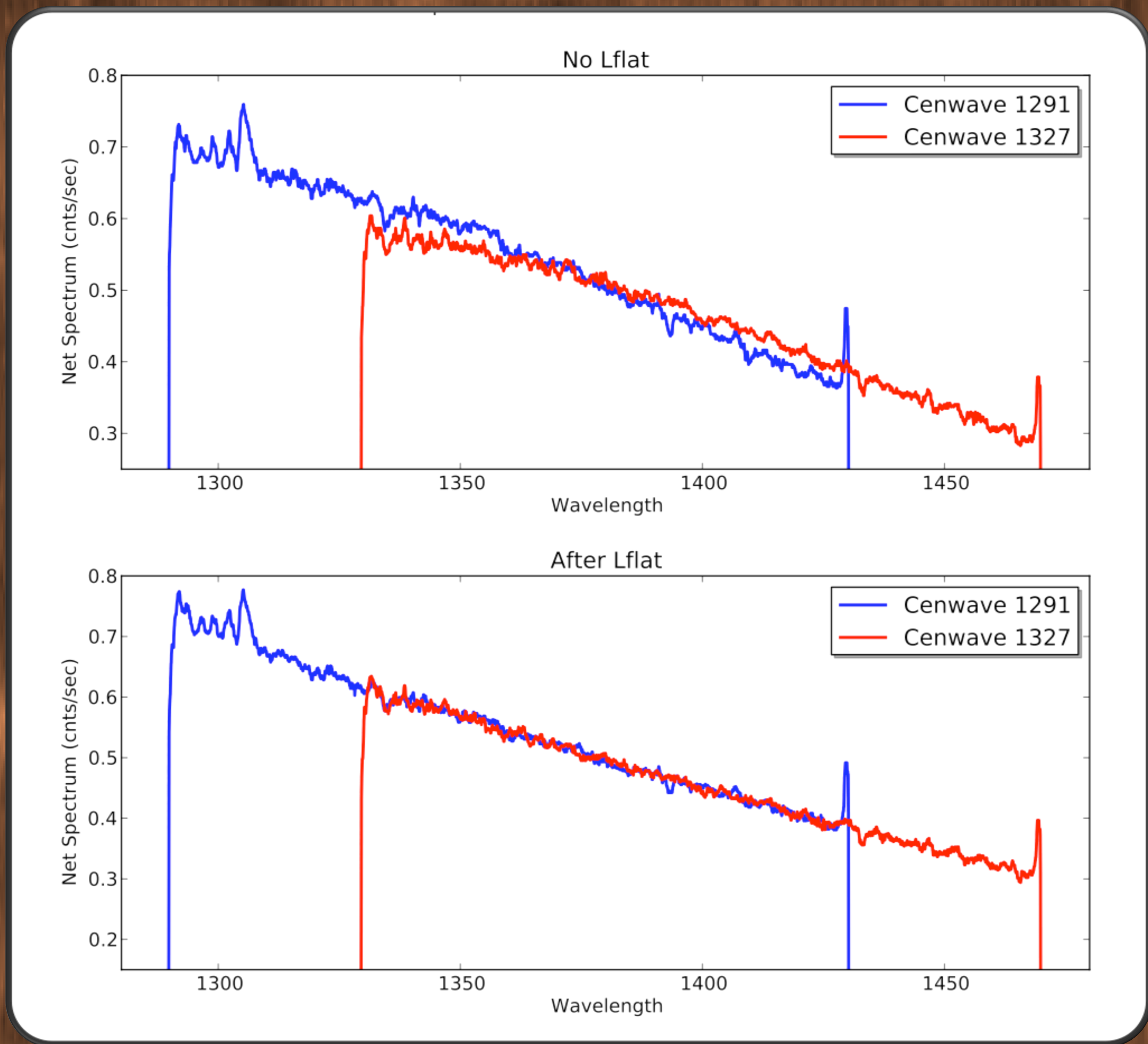
Low-Order Flat Fields (L-Flats)

Recent analysis of NET (cnts/s) spectra have shown a slowly varying response curve across each detector segment. The maximum amplitude of this effect is ~6% for Segment A and ~2% for Segment B with a curve that is stable across both LPs to date. The effect of this L-flat correction can be seen clearly in Figure 2, which compares the NET spectra of two different CENWAVES both with and without the L-flat applied.

The implementation of this correction necessitates the derivation of a new set of flux-calibrations for the COS FUV modes, and these two calibrations will need to be implemented simultaneously. Because of this, deployment of the L-flat into the OTFR pipeline is not expected until the fall or winter of 2013.

Figure 2: Example spectra to demonstrate the effect of the L-flat are shown. Data without the L-flat applied are shown in the top frame, and those that include the correction are shown in the bottom. Data shown are from two different G130M cenwaves, 1291 in blue and 1327 in red, in order to show the increased agreement in the overlapping segments.

This change allows for better aligned NET spectra, with allows more accurate flux calibration curves to be derived. The COS team is currently re-deriving a new flux calibration that takes these L-flats into account. To prevent introducing errors in the flux calibration, these two corrections must be implemented at the same time. As such, the L-flat correction is not expected to be available to OTFR data until late 2013.



Pixel to Pixel Variations

After removing the effects of the grid-wire shadows, imposters, and low-order response differences, pixel-to-pixel noise variations in the spectrum still remain. These features are caused by the detector itself; including contributions from the hex pattern inherent in the micro-channel plate design and surface imperfections from fabrication, handling, or use. Because these features are caused by imperfections in the detector where each spectrum is taken, these features vary greatly with y-location and a single correction for all data cannot be derived.

1D Pixel-to-Pixel Flat Fields (P-Flats)

Methods have been developed to derive 1D P-flats for specific locations using suitable high S/N observations of white dwarfs. These templates will be made into a new reference file and applied in a new calibration step of the CalCOS pipeline. Instead of being applied as a 2D flatfield, these P-flats will only be applied to the extracted spectra, and are only suitable to spectra that fall within +/-2.5 pixels from the derived location. Data taken outside this range are more likely to see noise features introduced rather than removed, as the underlying detector characteristics have changed significantly. An example of the effectiveness of this 1D P-flat can be seen in Figure 3.

The reference files and CalCOS code changes for this new calibration are still undergoing development and testing, but is expected to be implemented within the next year.

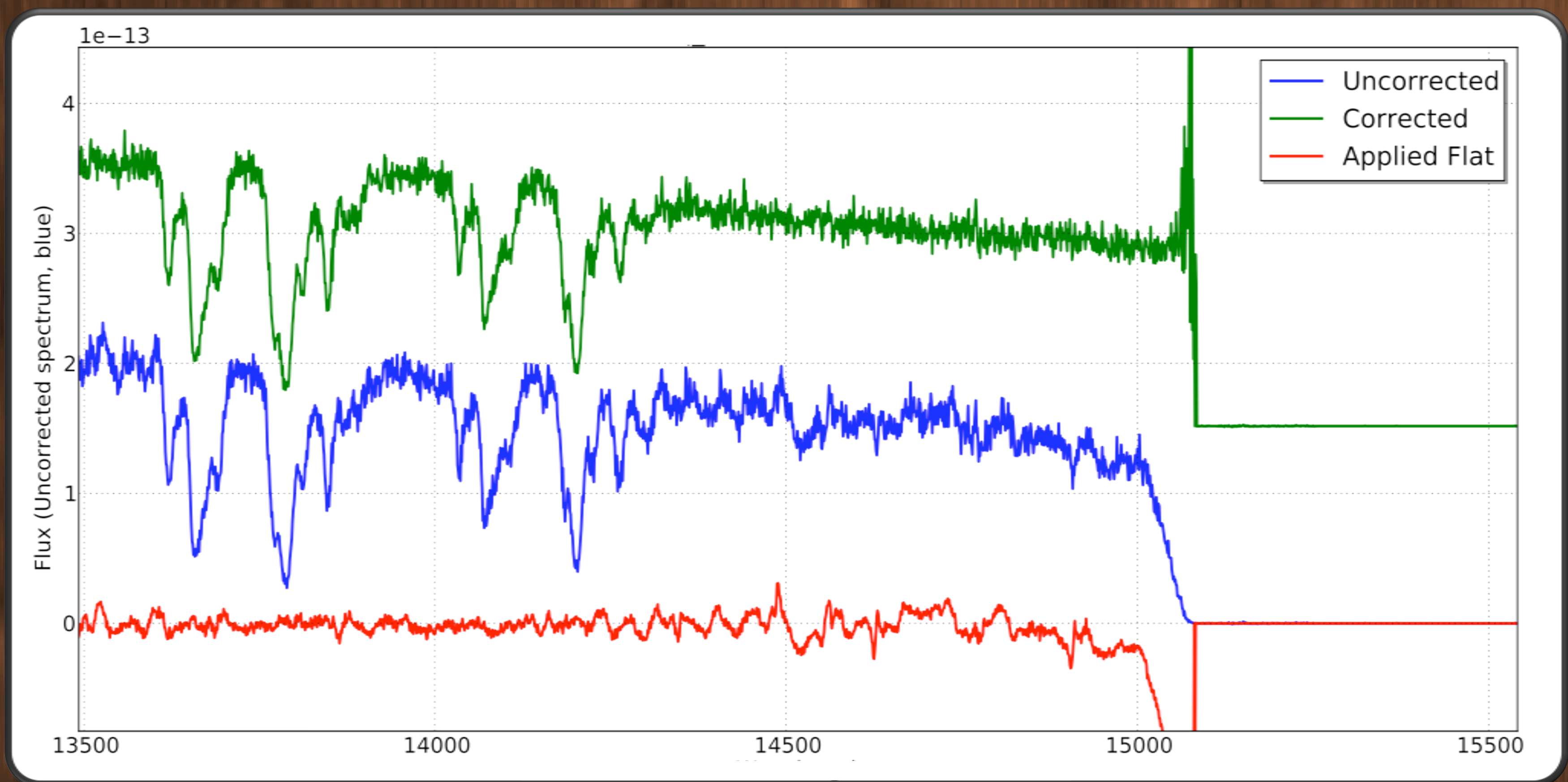


Figure 3: Shown here is an example of the effectiveness of the P-flat calibration step. Plotted are data calibrated with an experimental P-flat (green), without any flat (blue), the P-flat itself. The flux on the Y-axis corresponds to that of the uncorrected spectrum, while the corrected spectrum and P-flat have been offset for viewing.

The fixed pattern features that the P-flat is correcting can be seen in the background of the poster, which shows an image of the detector. Any deviation from uniformity will be visible in spectra with high enough signal to noise ratios.

As can be seen from the detector, any move up or down from where the flats are defined will mean a significant change to the fixed-pattern noise.