COS: NUV and FUV Detector Flat Field Status

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Abstract. There are two main requirements for the flat fields (FF) of the two (NUV and FUV) COS detectors. The first requirement is that the pixel-to-pixel variations (the P-Flats) of the detectors are uniform to ±20% for each of the two FUV detector segments, and ±6% for the NUV detector. The second requirement is that the derived FFs are able to support signal-to-noise (S/N) observations of 30 under routine observations, and are of sufficient quality to support S/N = 100 data for special observations. As illustrated here, the COS FFs obtained during ground calibration (October 2003) meet these requirements.

1. Introduction

The Hubble Space Telescope’s (HST) Cosmic Origins Spectrograph (COS) Far Ultraviolet (FUV) detector consists of micro-channel plates (MCPs) and time-delay anodes to provide photon counting and imaging capabilities. The COS FUV detector does not contain physical pixels, instead it uses time-delay circuits to compute the photon arrival location (in digital elements (DE)). The FUV resolution element (RE) is $6 \times 12$-20 DE, depending on cross-dispersion imaging properties of the grating (G130M, G160M, or G140L). The COS Near Ultraviolet (NUV) detector is the STIS spare MAMA, and has physical $25 \times 25$ µm pixels with a RE of $3 \times 3$ pixels independent of grating (G185M, G225M, G285, or G240L). During initial COS calibration (October 2003), data was obtained to characterize the flat field of both COS detectors. These results are presented here with additional discussion on the topics of dark counts, achievable signal-to-noise, and additional calibrations (and challenges) required for the FUV channel.

2. Status of the COS NUV Detector Flat Fields

There are no obvious structures in the NUV dark images and the count rates are extremely low. A total of 18221 dark counts (cts) were measured in 6800 seconds (s), or 2.68 cts/s. One pixel (p) contained 3 counts, 152 showed 2 counts (0.01%), and 17914 had a single count (1.7%). The average dark count rate is $2.6 \times 10^{-6}$ cts/s/p (1 ct/p every 4.5 days) or 0.41 cts/s/cm². However, the dark count rate is expected to be higher on orbit.

The NUV flat field (FF) illumination was provided by a combination of observations of the COS internal FF lamp and an external source. The total counts in the raw NUV FF image is 3.7 billion counts during an exposure time of 89250 seconds (24.8 hours). The average counts per pixel (p) in the spectral region is $\sim$8900 counts (S/N $\sim$95 per p), or $\sim$80,000 counts per $3 \times 3$ resolution element (RE) (S/N $\sim$285 per RE). The minimum S/N over any RE was $\sim$220, while the maximum was $\sim$340.

The smooth dispersion direction (DD) flat field (FF) profile allowed the illumination to be modeled for each column using low-order polynomials along the DD to construct the final 2-D model of the illumination of the spectral region (the L-Flat, left panel of Figure 1). Dividing the raw FF by the L-Flat gives the pixel-to-pixel variations inherent in the detector...
Figure 1: The left panel shows the modelled NUV flat field (FF) illumination (the L-Flat) obtained during COS October 2003 calibration. The right panel shows the COS NUV pixel-to-pixel response function (the P-flat). On both figures, the location of the science spectral stripes at x=620, 760, and 860 are indicated.

The pixel-to-pixel variations in the NUV P-Flat are ±2%, easily exceeding the ±6% requirement.

2.1. Achievable Signal-to-Noise

The pixel-to-pixel variations of the P-Flat determine the absolute maximum signal-to-noise ratio (S/N) achievable without flat field (FF) correction, Figure 2. For the NUV detector, this is a S/N of >50 per RE. Applying the known FF correction to spectral data obtained during initial calibration indicates that by applying a FP_SPLIT (dithering, 4 observations) + FF strategy S/N ~100 per RE should be achievable with the NUV channel of COS. In fact, the P-Flat variations are so small/uniform that FP_SPLIT data alone can approach this S/N.
Figure 2: COS NUV achievable signal-to-noise (S/N). A high S/N continuum source, observed during ground calibration, was reduced by a variety of calibration steps (described in the text). A continuum S/N ratio of 30-100 is easily obtained. (S/N decreases in the order of the labels at the upper left.)

3. Status of the COS FUV Detector Flat Fields

All FUV data must be thermally (TC) and geometrically corrected (GC). The accuracy of these corrections are vital to the calibration of COS FUV data. The GC attempts to compensate for non-linearities in the physical location to digital element (DE) mapping, whether caused by the electronics or the MCPs. The thermal correction prevents temporal drifts in this mapping. All FUV data presented hereafter have been TGC corrected.

There are obvious structures in the FUV dark images, but the count rates are extremely low, much lower than for the NUV detector. A total of 532538 dark counts (cts) were measured in 56301 seconds (s), or 9.5 cts/s, or $< 2 \times 10^{-6}$ cts/s per digital element (DE) for segment-A. The count rate for segment-B is similar ($\sim$10 cts/s). As shown in Figure 3, the majority of the dark counts are in hot spots or in non-science areas (upper and lower edges) of the detector. Over the science region of the detector ($450 < Y < 550$), the segment-A count rate is $< 10^{-6}$ cts/s/DE or $\sim$1 ct per DE per fortnight. Hot spots and high-count areas will be filtered during pipeline processing. The dark count images and the flat fields will be used to identify problem areas to be filtered during HST+COS calibration.

The FF illumination, was provided by multiple observations of the COS internal FF lamp. The total counts in each FF image is $\sim$200 million counts. The combined exposure time is 18900 seconds, over 95 sub-exposures (5.2 hours). The average count per digital element (DE) in the spectral region is $\sim$300 counts ($S/N \sim$17.5 per DE), or $\sim$18,000 cts per 5x12 resolution element (RE, $S/N \sim$135 per RE). Figure 4 shows details of the illumination of the segment-A FF.

Piecewise-linear dispersion direction (DD, X) modeling was used to derive the illumination (L-Flat) of the FUV FF. Dividing the FF by the L-Flat produces the pixel-to-pixel variations inherent in the detector (the P-Flat, a portion of which is shown in Figure 5).
Figure 3: The segment-A dark image shows a count rate of $2 \times 10^{-6}$ cts/s per digital element (DE). The vast majority of the dark counts are in hot spots or in non-science areas (upper and lower edges) of the detector. In the science region of the detector (dashed line), the count rate is $\sim 1$ ct per DE per fortnight ($8 \times 10^{-7}$ cts/s per DE). Circles in the extreme upper right and lower left indicate the non-physical, digital space, location of the electronic stim in the thermal correction (TC). The dispersion direction (DD) is the X axis.

Figure 4: The top figure shows the summed dispersion direction (X, DD) profile of the segment-A FUV raw FF illumination. The DD dropouts are shadows from the detector ion repulsion grid wires. The bottom figure shows the cross-dispersion direction (Y, XD) profile. Also indicated is the location of the spectrum from a point source centered in the primary science aperture (PSA).
Figure 5: A portion of the FUV segment-A P-Flat is presented in geometrically corrected (GC) physical units. The spectral region is indicated by the horizontal lines. Dead spots, hot spots, plate defects, grid wire, and Moiré patterns are all present, along with the inherent hexagonal micro-channel plate structure (the ‘hex’ or chicken-wire pattern).

The region displayed in Figure 5 was selected to display the grid wires, and the largest plate defect on the detector. The FUV L-Flat and P-Flats are of lower quality than the NUV flats due to lower count rates per DE, and the inherent structures present in the FUV detector segments. The pixel-to-pixel variations in the FUV P-Flat are ±19.4% for segment-A, and ±15.3% for segment-B, meeting the ±20% requirement. Improved techniques and FF photon statistics (obtained during final ground calibration) will only improve our knowledge of the detector segment P-Flats. Residual grid wire and Moiré pattern structures are present in the L-Flat, indicating that further improvement in characterizing the FUV FF is possible.
3.1. Achievable Signal-to-Noise

The pixel-to-pixel variations of the P-Flat determine the maximum signal-to-noise ratio (S/N) achievable without flat field (FF) correction, Figure 6. This is currently a FUV S/N of $\sim5.2$ (A) or $\sim6.5$ (B) per digital element (DE), depending on the segment (A or B). When calculated per resolution element (RE), S/N of 17-20 per RE should be achievable without FF correction. When combined with an FP\_SPLIT (FP, $\times4$) strategy, S/N per RE of 34-40 should be achievable. S/N measurements, taken from the continuum of a high S/N spectrum, after various combinations of calibration procedures are presented in Figure 6 versus counts/RE. Without an FP or FF, the S/N is limited to $\sim17$. With the FP the S/N increases as expected until S/N of $\sim34$. Inclusion of a FF correction does not increase the S/N. This is true whether the FF is applied before the GC (FP+FF-GC+TC) or after (FP+FF+GC+TC), however there is some indication (at the 1 $\sigma$ level) that applying the FF before the GC correction improves the measured S/N. It is unclear at this time whether this is an expected result, or a result of a misalignment between the FF data and the science data, which were obtained through different apertures. Without physical pixels, the FF relies upon the quality of the geometric correction (GC) to turn what would be a normal FF situation (division to correct for a variable response function) into a more complicated deconvolution of the response function.

The FUV channel has five overlapping central wavelength settings, each with an FP\_SPLIT ($\times4$) mode. Observing with all settings will provide 20 FP\_SPLIT observations which will boost the achievable S/N of $\sim40$ demonstrated here to $\sim100$.