Changes in the COS/FUV Dark Rate: Impact on the Monitoring Program and Background Extraction Regions

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ABSTRACT

The dark rate of the Far Ultraviolet (FUV) detector of the Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope (HST) varies across the detector and over time. Detector segment A (FUVA) experiences sporadically increased dark counts along the edges of the detector. The enhanced counts along the edges lead to an increased overall dark rate of the detector and an artificially inflated background. The overall detector dark rate calculations are used to update the Exposure Time Calculator (ETC). Here we describe the updates made to the COS Dark Rate Monitor script to better track the dark count rate along the edges of the detector so that the determination of the dark rate for FUVA takes the edge effects into account and does not bias the dark rate value calculated for the ETC. We also present changes made to the Lifetime Position 4 (LP4) FUVA background extraction regions to provide a more accurate background subtraction.

Contents

1. Introduction

The FUV dark rate monitoring programs have been ongoing since Servicing Mission Orbital Verification (SMOV) after Hubble Servicing Mission 4 (SM4). The dark monitor programs are designed to monitor changes in the dark rate and check for developing detector problems of the FUV cross delay line (XDL) detector. They are also used to provide a value to be used in the ETC. Starting in Cycle 20 (Program 13121, PI J. Ely, "FUV Detector Dark Monitor"), dark observations have been taken with a cadence of five 22 minute exposures every week for a total of 260 orbits every cycle. Additional orbits were used for Cycle 22 (Program 13968, PI J. Ely, "FUV Detector Dark Monitor") to monitor the dark rate at different high voltage levels (HV). Extra orbits were not repeated for the following cycles because no significant difference in dark rate for different high voltage levels was found. In Cycle 26 (Program 15533, PI C. Magness, "COS/FUV Detector Dark Monitor"), the HV levels were set to 163 for both segment A and B of the FUV detector because they are the HV levels used for the science observations. (See Appendix A for more information on HV level history.) All FUV dark rate monitoring programs are shown in Table 1.

As mentioned above, the results from the dark monitoring programs are used to update the COS Exposure Time Calculator (ETC). We adopt a dark rate estimate for the ETC that corresponds to the 95% level in the probability distribution function determined from dark measurements over a period of the previous 6 months to 1 year. Along with variations over time, there is also a spatial variation across the detector in the dark rate of the FUVA segment. We have updated the dark rate monitor script used to visualize the data to better track this varying dark rate and have updated the LP4 background extraction regions for segment A. The move to LP4 was made to mitigate the effects of gain sag by updating the detector position where the science spectra fall

Table 1. COS FUV Dark Rate Monitoring Programs

Program ID	Start	End	Cycle	Orbits
11482	6/30/09	9/27/09	SMOV	30
11895	9/22/09	10/25/10	17	325
12423	11/8/10	10/25/11	18	130
12716	11/1/11	10/16/12	19	130
13121	11/1/12	10/24/13	20	260
13521	11/1/13	10/24/14	21	260
13968	10/31/14	9/28/15	22	430
14436	11/2/15	10/22/16	23	260
14520	10/31/16	10/23/17	24	260
14940	10/31/17	10/28/18	25	260
15533	11/11/18	–	26	260

in the cross-dispersion (XD) direction to ≈ 5" below LP1. Special considerations were necessary for the background box locations used by the COS calibration pipeline (CalCOS) for background subtraction for LP4 because of the LP4 position on the detector. (See Section 2.1 in the COS Instrument Handbook for more information on Lifetime Positions.)

2. Spatial Structure in the Dark Rate of the FUVA Detector

The dark rate of FUVB remains relatively constant over time while that of FUVA experiences occasional baseline increases from its nominal value. The edges along FUVA, specifically the top, bottom, and left edge, experience enhanced dark counts. The parameters used to define these regions are shown in Tables 2 and 3. Figures 1 and 2 show the mean dark rate over time for each of these regions. Dark exposures with enhanced edge rates show increased dark rates even away from the edges. The intensity of the enhanced edges varies with time and position on the detector where the increased counts are seen. There is a visible "structure" formed by increased dark counts that appears to cascade from the top edge diagonally across the detector and appears to shift in the along-dispersion direction. Figures 3, 4, and 5 show an example of how the dark rate across the detector has been found to vary from 2014 May to 2018 December.

These enhanced counts seen along the edges of FUVA were thought to be correlated with solar activity, but the most recent dark rate excursions coincide with low solar activity. There are also no significant differences in dark rate for different HV levels. The characteristics and nature of these edge effects seem consistent with field emission at the edges at FUVA (i.e., ions generated by electrons interacting with residual gas). FUVA and FUVB are two independently operated segments of the XDL detector, each composed of its own microchannel plate (MCP) stack, that convert

Table 2. FUVA Regions Monitored Individually

Region	XCORR Min	XCORR Max	YCORR Min	YCORR Max
Inner	1260	15119	375	660
Left	1060	1260	296	734
Right	15119	15250	296	734
Bottom	1060	15250	296	375
Top	1060	15250	660	734

Table 3. FUVB Regions Monitored Individually

| Region	XCORR Min	XCORR Max	YCORR Min	YCORR Max
Inner	1000	14990	405	740
Left	809	1000	360	785
Right	14990	15182	360	785
Bottom	809	15182	360	405
Top	809	15182	740	785

incident photons to electronic pulses. Each segment has an active area of 85 mm $\times$ 10 mm, and they are placed end to end with a $\sim$ 9 mm gap separating the two, as shown in Figure 6. The brazed detector body, shown in Figure 7, clamps the two stacks of MCPs in place and provides the high-voltage electrodes for the top and bottom of both stacks. The manner in which the detector has been assembled and MCPs clamped in place may have caused minor damage along the edges of the MCP surface. Either the structure of the detector surfaces generates ions near these possibly damaged edges, or the ion interacts with a field that brings the ion there. In order for the edges to light up simultaneously, there must be a causal agent to communicate across the detector, which implies that there is some residual gas in the detector. Field emissions may be exacerbated by local pressure increases, explaining the variation over time. Differences between the segments are due to intrinsic differences in the MCPs and variations in the clamping pressure and other mechanical properties of the segments (Vallerga, personal communication, 2018).
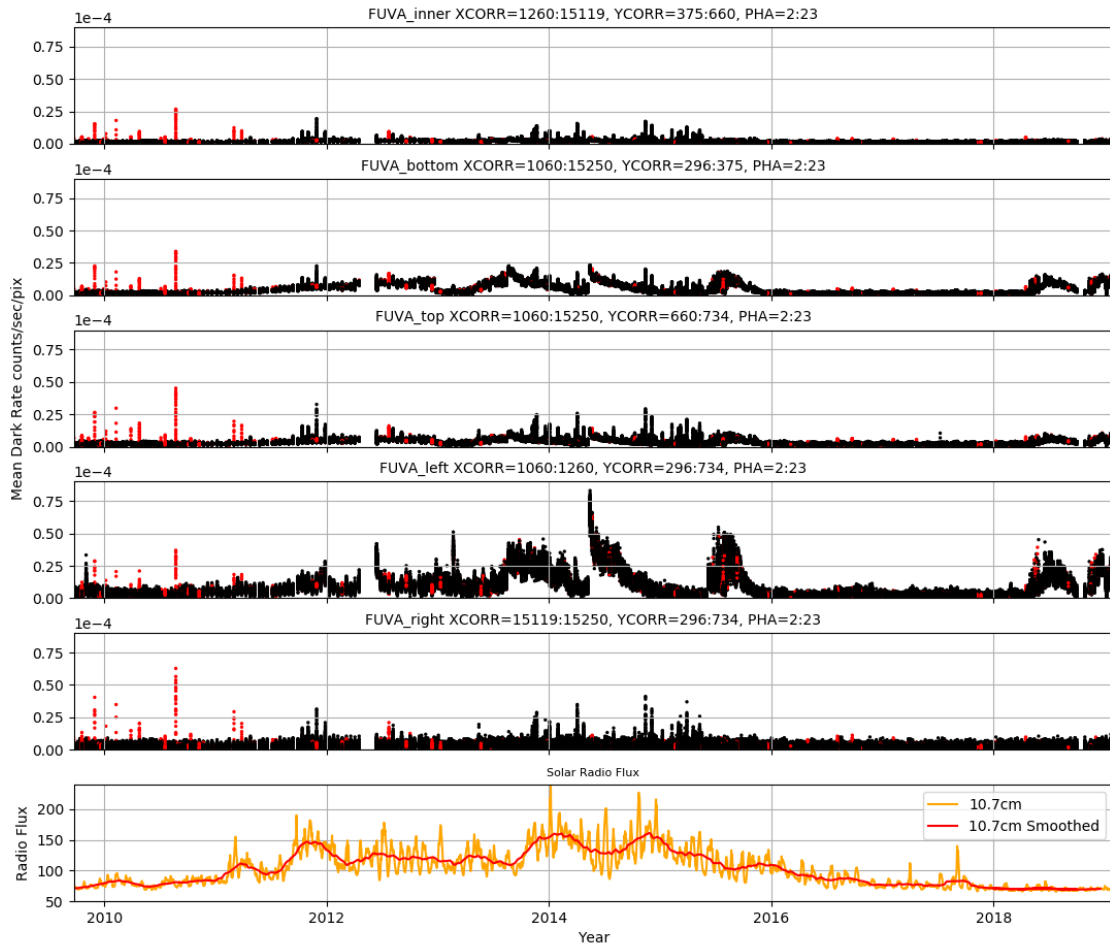
Figure 1. COS/FUV dark rates on FUVA as a function of time for each of the different areas on the detector monitored. The top five panels show the measured dark rate in 25 s increments throughout every exposure. The red dots represent dark rates that were observed close to when HST was passing over the South Atlantic Anomaly. The bottom panels display the 10.7 cm solar radio emission, tracking the solar cycle.
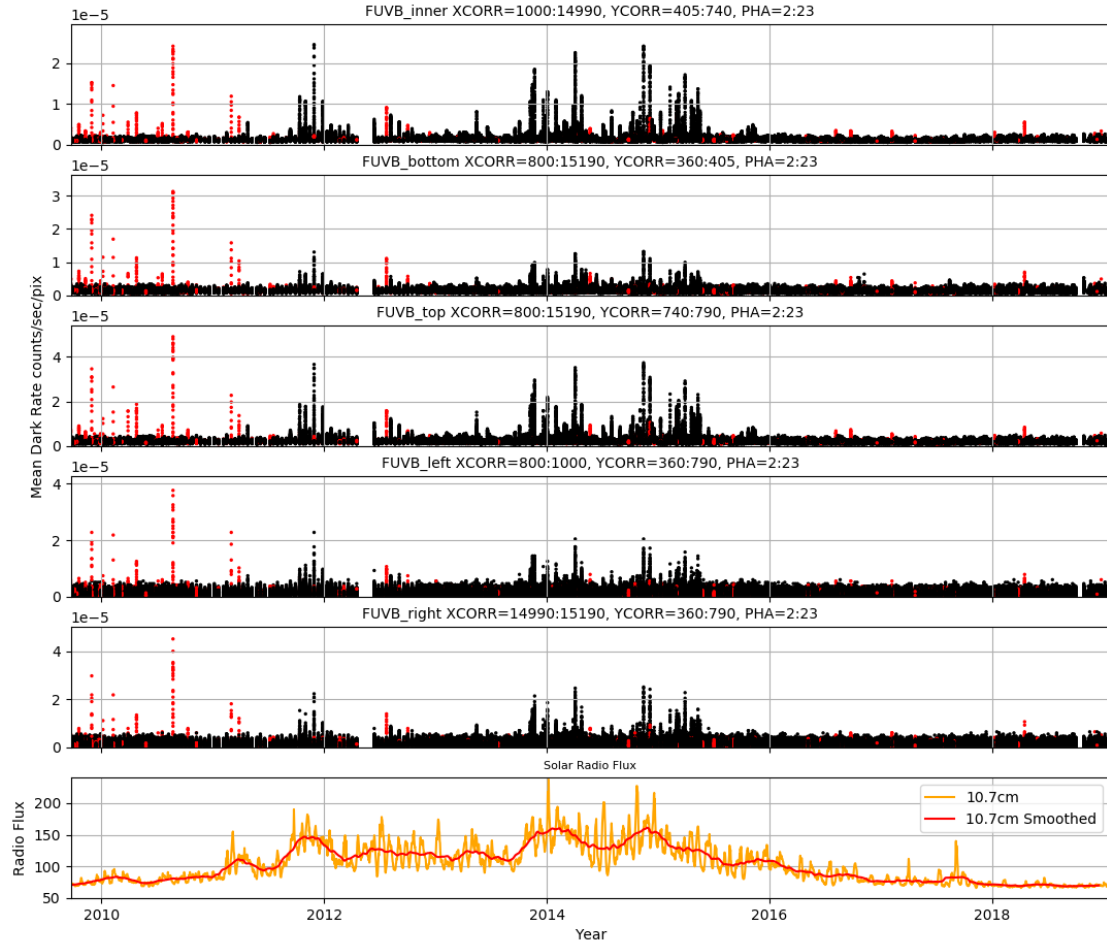
Figure 2. Same as Figure 1, but for FUVB.
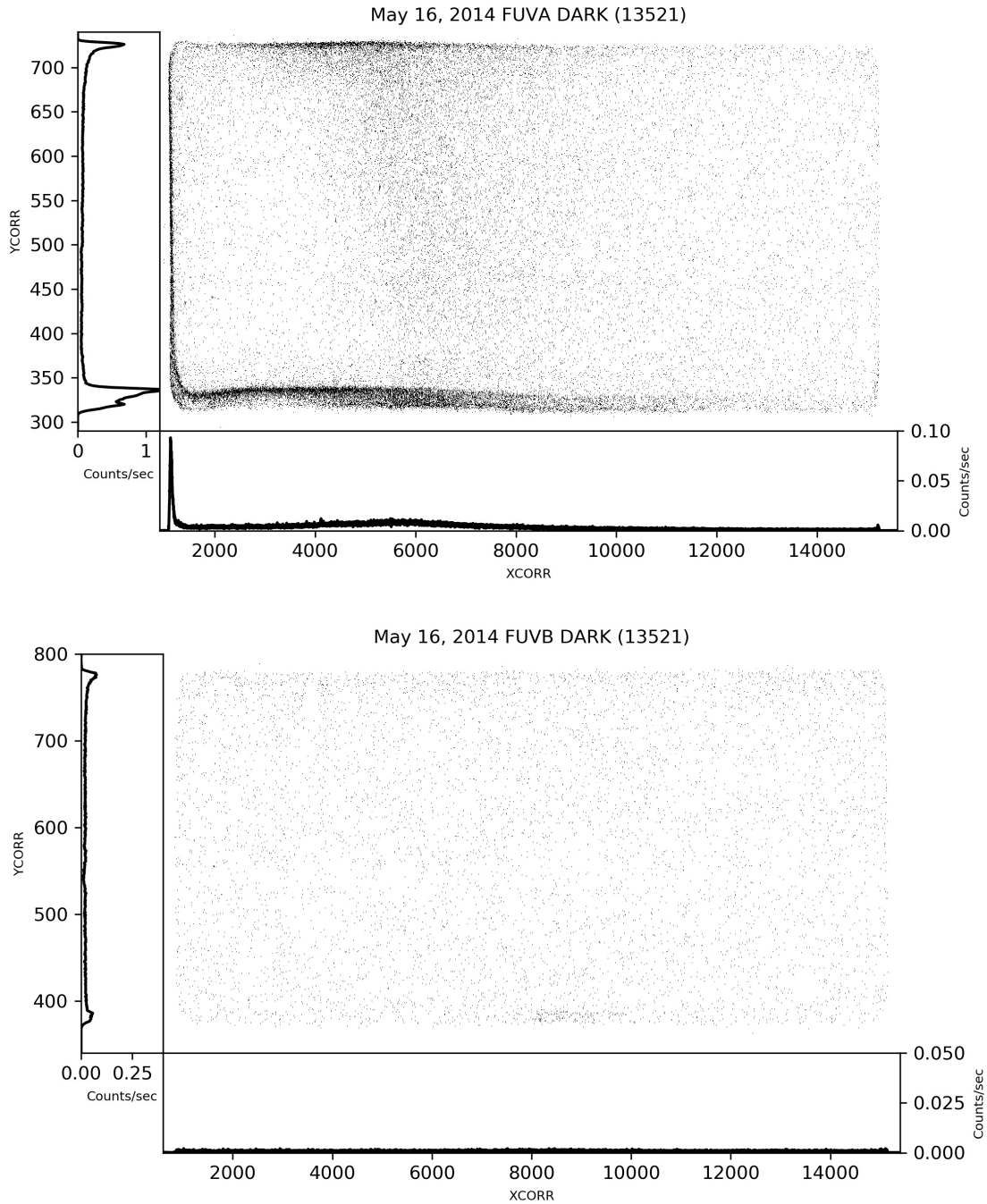
Figure 3. Images from dark exposures of FUVA (top) and FUVB (bottom) with pulse heights 2 to 23. Each dark image is the sum of five 22 minute exposures from a single visit for a total exposure time of ~ 6650 s. The profiles along the images were created by collapsing the dark counts in the along-dispersion and cross-dispersion direction to provide a projection of the two dimensional dark rate in counts s^{-1} for each XCORR or YCORR position. This set of dark exposure images is from when the dark rate along the bottom edge of FUVA was at its peak.

June 12, 2017 FUVA DARK (14520)

June 12, 2017 FUVB DARK (14520)
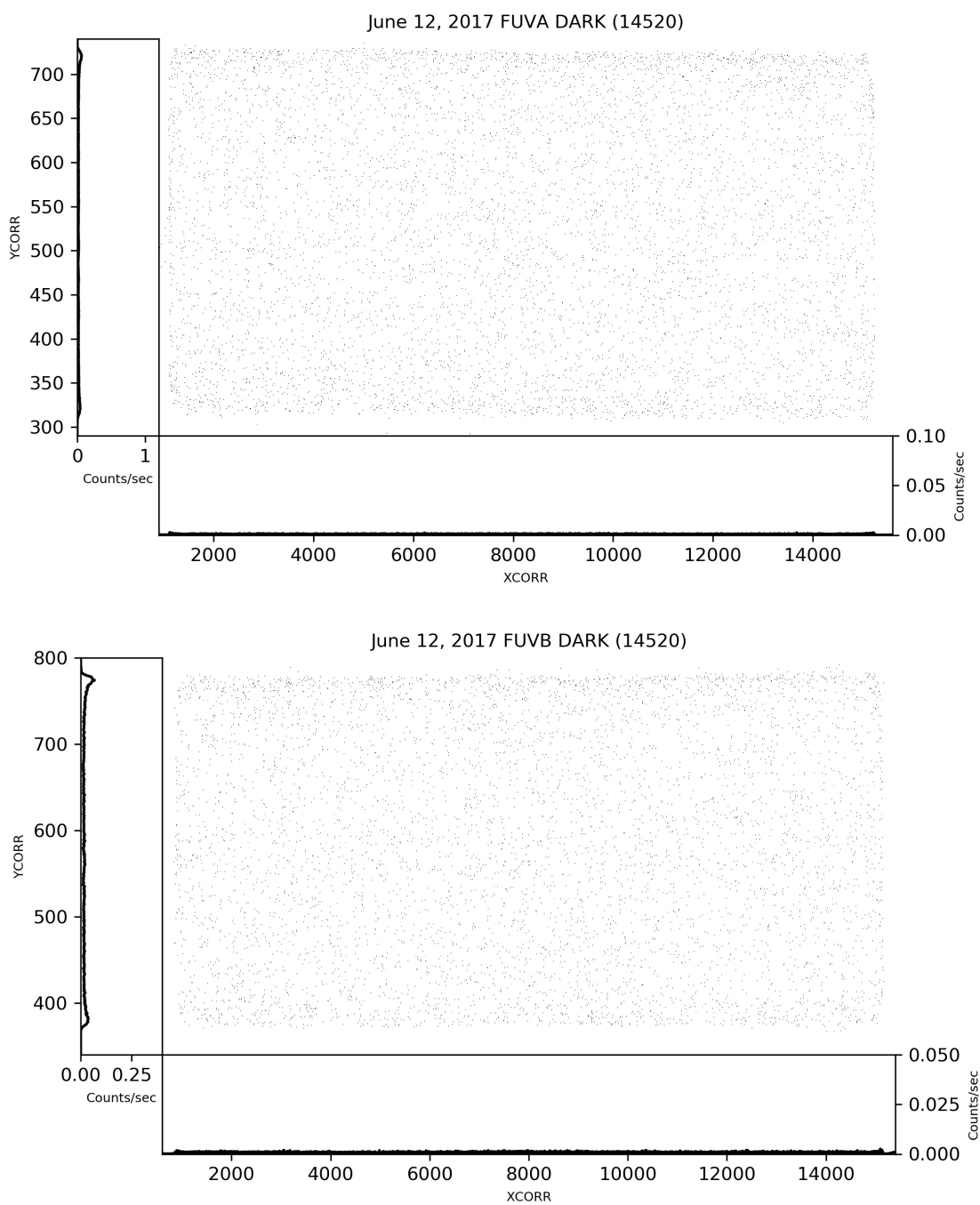
Figure 4. Same as Figure 3. These exposures were taken when the dark rate was at its baseline value.

December 24, 2018 FUVA DARK (15533)
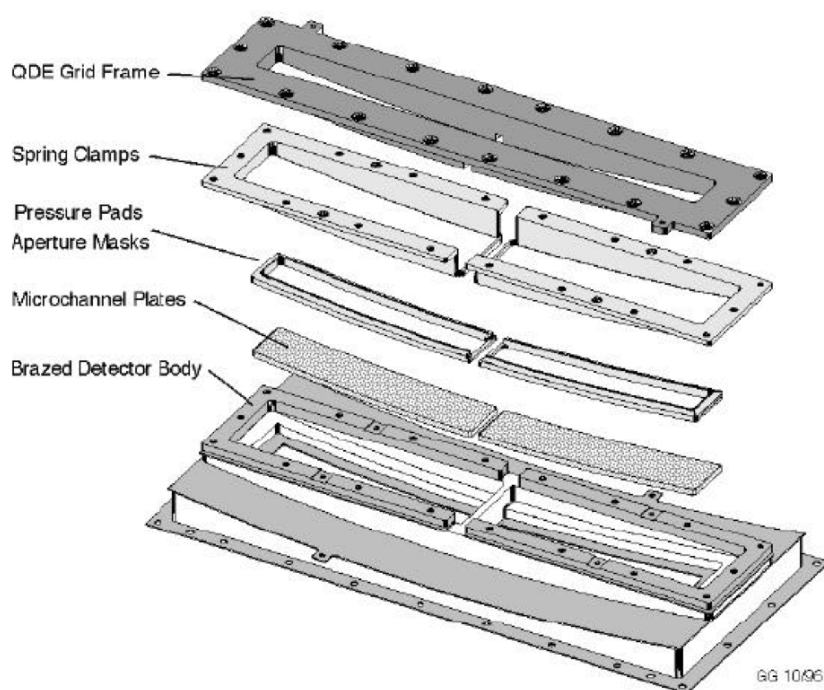

December 24, 2018 FUVB DARK (15533)
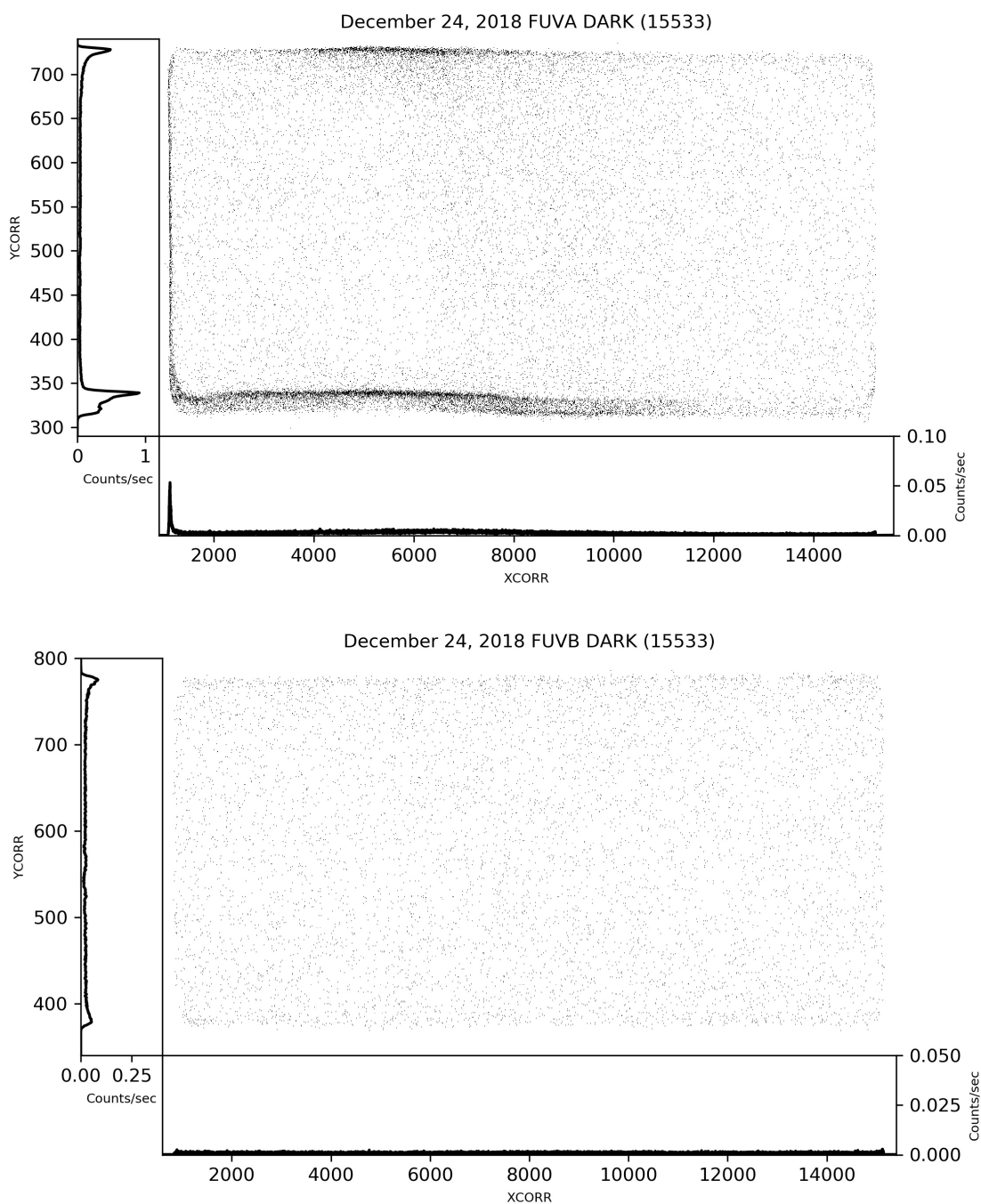
Figure 5. Same as Figures 3 and 4. These exposures were taken during the last time the dark rate along the edges had a significant increase.
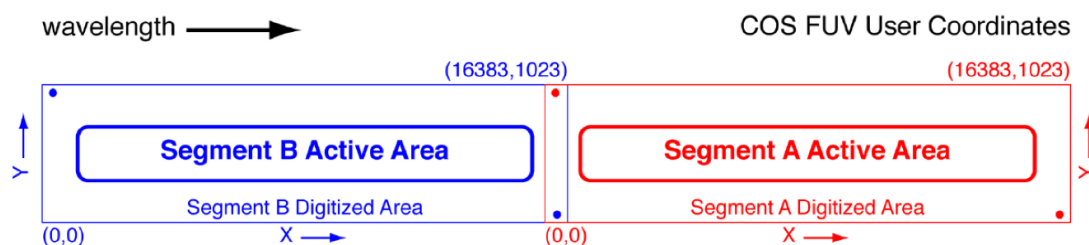
Figure 6. Diagram (to scale) of the relative positions of Segment A and Segment B of the FUV XDL Detector.

Figure 7. FUV Detector Body Assembly.

There is no reason to believe that the increased counts along the edges of FUVA are harmful to the detector. The enhanced edges have not been getting worse, they simply have been found to vary and return to baseline. There has also been no impact on operations due to these edges until the spectra were moved to LP4 and the increased counts affected the background extraction region of FUVA used by CalCOS for background subtraction. We have since made updates to the dark rate monitor script to better track these edges and have updated the LP4 FUVA background boxes to mitigate the effects of the enhanced edges. The dark rate values used in the ETC exclude the enhanced edges. No other updates were made to account for the changing "structure" of dark counts that appears diagonally across FUVA.

3. Update to the FUVA Background Extraction Regions

Detector dark counts contribute to the background and are removed during background correction. Background correction is performed by the CalCOS module BACKCORR. The BACKCORR module computes the counts in the background regions, scales them by the sizes of the regions, and subtracts them from the extracted spectrum at each wavelength. These background extraction region parameters are set in the XTRACTAB and TWOZXTAB reference files used by the pipeline. Each background region is a parallelogram that is defined by its slope, y-intercept, and height. (See Section 3.4.19 of the COS Data Handbook for more information on the BACKCORR module.) Originally, for FUVA data at LP4, there was one background region defined above and one below the object spectrum. The y-intercepts and heights of the lower background boxes (background box 1) for each grating/cenwave combination are listed in Tables 4 and 5 for the XTRACTAB and TWOZXTAB, respectively. With these parameters, background box 1 overlapped with the enhanced dark rate region along the bottom edge. The original position of the lower background box would therefore provide background rates that were not representative of the background under the science extraction region. This could therefore lead to the pipeline overestimating the background subtraction and overcorrecting the spectrum. To mitigate the effects of an inflated background, we have updated the parameters of the LP4 XTRACTAB and TWOZXTAB background regions for FUVA to avoid the enhanced region at the edges of the segment. Background extraction regions on FUVB are not affected by the enhanced dark counts and have been left in their original positions.

The functional upper and lower limit of the bottom and top enhanced edge, respectively, were defined by inspecting collapsed dark count plots from exposures taken during a time of enhanced dark rate (Figure 8). Detector regions within YCORR = [375, 660] were chosen as safe limits for background box placement because the summed counts along this region are fairly constant and the dark counts begin to rapidly increase outside this limit (Figure 8). However, moving the lower background box just above YCORR = 375 puts the background region too close to the LP4 primary science aperture (PSA) position, so we would risk PSA light contaminating the background region. Both background boxes were therefore moved above the science extraction region, located between the WCA extraction region and below the upper safe limit (YCORR = 660) at YCORR = 630 for G130M and G160M modes and YCORR = 615 for G140L. The background regions for G140L modes were moved lower in order for it to be fully contained in the profile region defined in the PROFTAB defined for LP4, `2bj2256ql_profile.fits`. Both boxes were set to a height of 31 pixels. The updated XTRACTAB and TWOZXTAB reference files, `2bj2256il_1dx.fits` and `2bj2256nl_2zx.fits`, respectively, were delivered to CRDS for use starting on 2018 November 20.

**Table 4.**   Original and Updated PSA XTRACTAB Background Extraction Regions

Grating	Cenwave	Original BKG1	Original HGT1	Original BKG2	Original HGT2	Updated BKG1	Updated HGT1	Updated BKG2	Updated HGT2
G130M	1222	362.86	33	577.94	51	580	31	630	31
	1291	368.11	35	570.25	35	580	31	630	31
	1300	367.74	35	569.56	35	580	31	630	31
	1309	367.19	35	569.26	35	580	31	630	31
	1318	366.76	35	569.01	35	580	31	630	31
	1327	365.86	35	568.39	35	580	31	630	31
G160M	1577	361.89	32	562.42	35	580	31	630	31
	1589	361.44	32	562.49	35	580	31	630	31
	1600	361.45	32	562.39	35	580	31	630	31
	1611	361.23	32	561.87	35	580	31	630	31
	1623	361.31	31	561.45	35	580	31	630	31
	1533[1]	580	31	630	31	580	31	630	31
G140L	1105	365.96	32	587.22	48	580	31	615	31
	1280	366.2	32	589.41	49	580	31	615	31
	800[1]	580	31	615	31	580	31	615	31

[1]Cenwaves 1533 and 800 are new, and their original background extraction region placement took into account this knowledge of the enhanced edges.

Table 5.   Original and Updated PSA TWOZXTAB Background Extraction Regions

Grating	Cenwave	Original BKG1	Original BKG2	Original BWIDTH	Updated BKG1	Updated BKG2	Updated BWIDTH
G130M	1222	362.86	577.94	33	580	630	31
	1291	368.11	570.25	35	580	630	31
	1300	367.74	569.56	35	580	630	31
	1309	367.19	569.26	35	580	630	31
	1318	366.76	569.01	35	580	630	31
	1327	365.86	568.39	35	580	630	31
G160M	1577	361.89	562.42	31	580	630	31
	1589	361.44	562.49	31	580	630	31
	1600	361.45	562.39	31	580	630	31
	1611	361.23	561.87	31	580	630	31
	1623	361.31	561.45	31	580	630	31
	1533[1]	580.0	630	31	580	630	31
G140L	1105	365.96	587.22	31	580	615	31
	1280	366.2	589.41	31	580	615	31
	800[1]	580	615	31	580	615	31

[1]Cenwaves 1533 and 800 are new, and their original background extraction region placement took into account this knowledge of the enhanced edges.
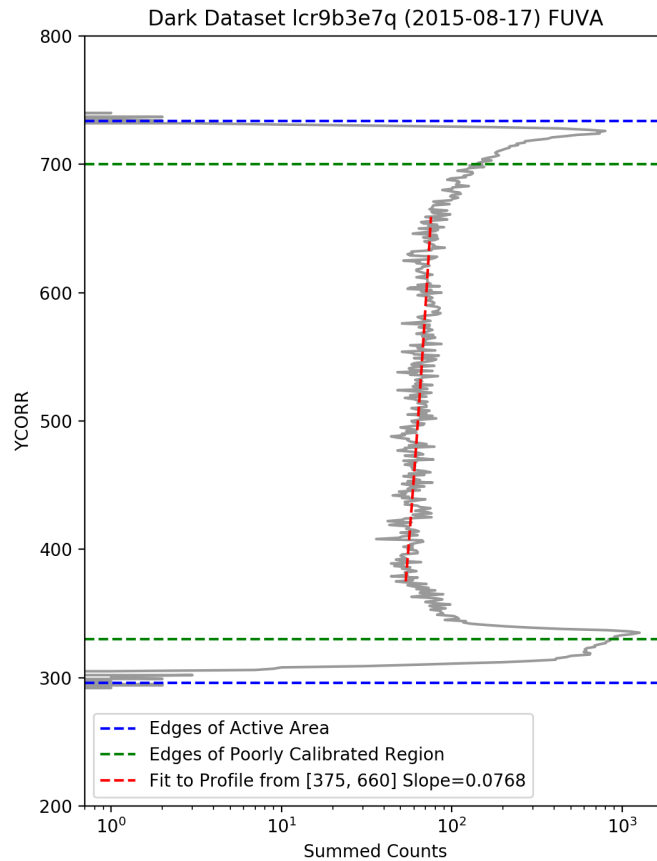
Figure 8. Dark counts from a single FUVA dark exposure with increased edge counts collapsed along the dispersion direction. Blue and green dashed lines mark the edges of the active area and the poorly calibrated region, respectively. The red dashed line marks the areas defined as the safe limits suitable for background extraction box placement. The summed counts along this safe limit area are fairly constant, while the dark counts outside the red dashed line begin to rapidly increase toward the edges of the detector segment.

Testing was performed using LP4 data to verify that no new "features" due to the dark structure across the FUVA detector segment were inadvertently introduced into the data. The dark "structure" is evolving and cannot be predicted. Through testing it was determined that the new background boxes provide a more accurate background estimate, and the change was necessary to avoid the possibility of including the extremely enhanced lower edge. In cases of elevated dark rates (see Figure 1 around 2014.5), it is still possible to have localized over-subtraction due to the variation of the dark rate across the detector. This cannot be completely avoided with the current

background correction in CalCOS in combination with the spatial variation of the dark rate changing with time. The effect of an increased dark rate has a small impact on the overall background correction and does not significantly impact the majority of observations. As always, it is recommended that extra precaution is taken with faint, background-limited targets. (See section 4.2.1 of the COS Instrument Handbook for more information on the FUV dark rate.)

4. Dark Monitor Updates

As part of updating the dark-rate monitor script, we first determined parameters that would define the "edges" of each detector segment. The outer limits of the regions were simply selected to be the active region of the detector segment. The inner limits for the FUVA edge regions were selected based on the BPIXTAB (Bad Pixel reference file) and by inspecting collapsed dark count plots. The BPIXTAB identifies poorly-calibrated regions as DQ = 8, which defines four rectangles that surround the "well-calibrated" region for each segment. The data quality in these poorly-calibrated regions falls for various reasons, including a build-up of dark counts. Using the BPIXTAB, we identified the edges of the "well-calibrated" region as YCORR = [330:700], XCORR = [1260:15119] and set those as the inner limits for the edges. From there, the parameters of the lower and upper edge regions were adjusted based on collapsed dark plots that were used to update the background extraction regions in Section 3. FUVB does not experience enhanced dark counts along its edges to the extent that FUVA does, so the edges for FUVB were selected to have similar dimensions as FUVA. The XCORR and YCORR positions used to define the edges for FUVA and FUVB, that are monitored separately in the dark monitor, are listed in Tables 2 and 3, respectively.

Figure 9 illustrates how the edges are defined. It is important to note that the corners of the top and bottom edge regions overlap with the left and right regions, and, thus, the overall dark rate of the detector cannot simply be calculated from combining the dark rates of each edge portion.

4.1 FUV Dark Rate Monitor Analysis

The dark rate of every exposure in the dark rate monitoring program is measured in 25 s intervals for each previously defined region (top, bottom, left, right, inner) as a function of time, for each segment. Figures 1 and 2 show the dark rate for these regions as a function of time for FUVA and FUVB, respectively. The figures also show the solar radio flux (bottom panel). The overall trend in the dark rate has been constant for segment B, while segment A experiences occasional jumps from the baseline dark rate. Enhanced counts along the edges of the detector coincide with increased counts in the inner portion of the detector, although to a much lesser extent. It is important to note that although the increased counts as compared to baseline may appear large, the actual dark count rate is still very low and has a very small effect on the overall data.
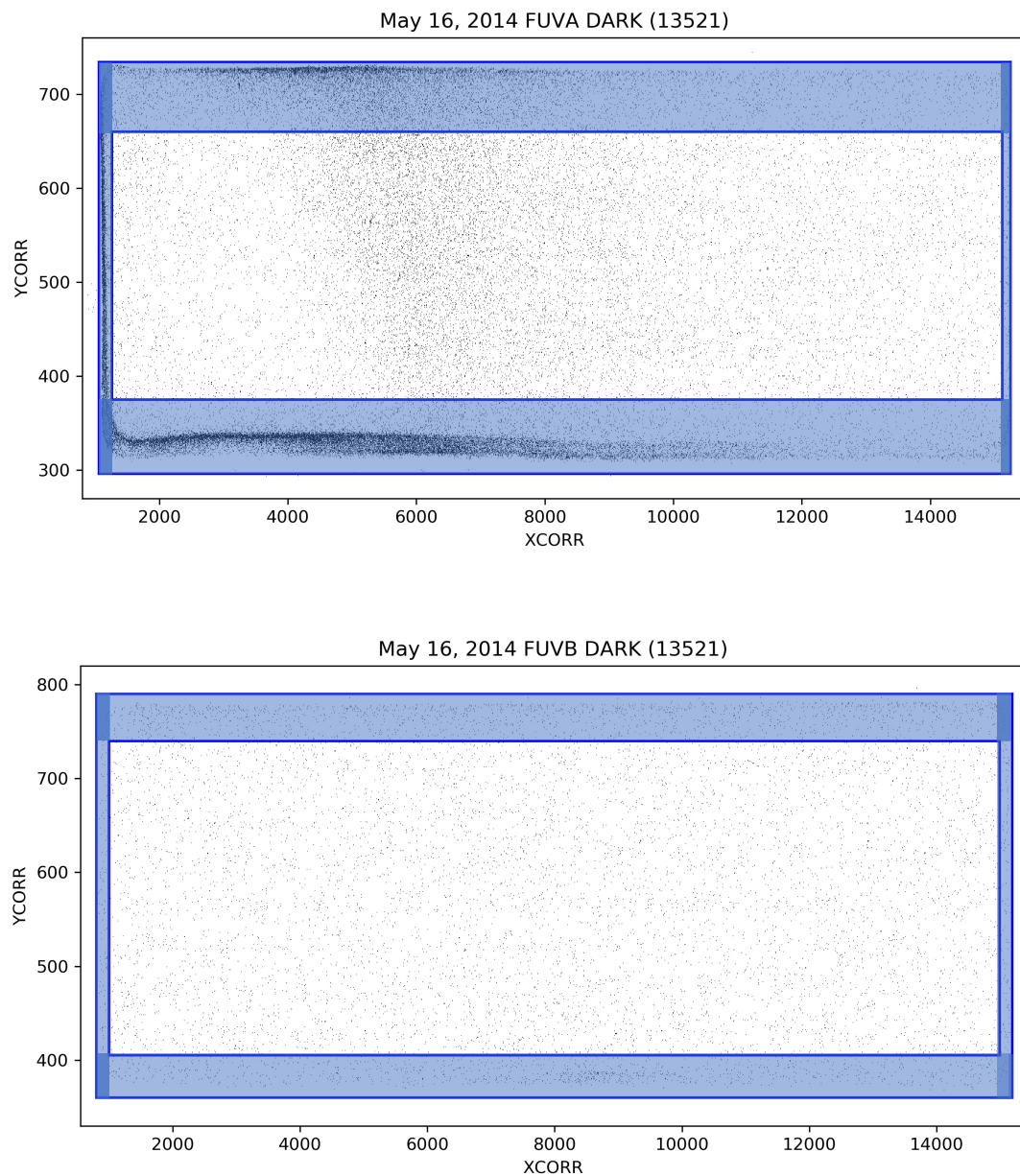
Figure 9. Overlay of the new edge regions used to separately monitor the dark rate on top of a dark image for FUVA (top) and FUVB (bottom). The dark image is composed of five 22 minute exposures from 2014 May 16 as part of Program 13521. Note the overlap of the corners.

5. Summary

Segment A of the COS/FUV detector experiences a time-dependent enhancement in the dark count rate along the edges of the detector. These dark rate enhancements are not thought to be harmful to the detector and their nature has not changed over time. To avoid having these enhanced regions contaminate the extraction regions used for background subtraction by the pipeline, the LP4 background extraction regions for FUVA defined in XTRACTAB and TWOZXTAB were adjusted, placing both background boxes above the science spectrum. Background box 1 and 2 are now located at YCORR = 580 and YCORR = 615 for G140L modes or 630 for G130M and G160M modes, with heights of 31 pixels. The FUV dark rate monitor was also updated to better track the dark rate at these edges over time individually and remove them from the calculation of the overall detector dark rate that is used for ETC simulations.

Change History for COS ISR 2019-11

Version 1: 9 August 2019 – Original Document

References

Fischer, W. J., et al. 2019, *Cosmic Origins Spectrograph Instrument Handbook*, Version 11.0 (Baltimore: STScI)

Rafelski, M., et al. 2018, *Cosmic Origins Spectrograph Data Handbook*, Version 4.0 (Baltimore: STScI)

Appendix A. High Voltage Change History

Lifetime Position and Nominal High Voltage Values (Segment A/B) for the COS FUV Detector

Grating:	G130M				G160M	G140L	
Central Wavelengths:	1055,1096	1222	1291	1300, 1309, 1318, 1327	1577, 1589, 1600, 1611, 1623	1105	1280
Mode:	Blue	1222	Standard				
5/11/2009	Not Used	Not Used	LP1 **178**/**175**	LP1 **178**/**175**	LP1 **178**/**175**	LP1 **178**/100	LP1 **178**/**175**
8/12/2009	LP1 169/167	LP1 169/167	LP1 169/167	LP1 169/167	LP1 169/167	LP1 169/100	LP1 169/167
3/8/2011	LP1 169/**175**	LP1 169/**175**	LP1 169/**175**	LP1 169/**175**	LP1 169/**175**	LP1 169/100	LP1 169/**175**
3/26/2012	LP1 **178**/**175**	LP1 **178**/**175**	LP1 **178**/**175**	LP1 **178**/**175**	LP1 **178**/**175**	LP1 **178**/100	LP1 **178**/**175**
7/23/2012	LP2 167/163	LP2 167/163	LP2 167/163	LP2 167/163	LP2 167/163	LP2 167/100	LP2 167/163
6/24/2013	LP2 167/169	LP2 167/169	LP2 167/169	LP2 167/169	LP2 167/169	LP2 167/100	LP2 167/169
7/21/2014	LP2 167/**175**	LP2 167/**175**	LP2 167/**175**	LP2 167/**175**	LP2 167/**175**	LP2 167/100	LP2 167/**175**
11/3/2014	LP2 173/**175**	LP2 173/**175**	LP2 173/**175**	LP2 173/**175**	LP2 173/**175**	LP2 173/100	LP2 173/**175**
2/9/2015	LP2 173/**175**	LP3 171/167	LP3 167/163	LP3 167/163	LP3 167/163	LP3 167/100	LP3 167/163
1/18/2016	LP2 173/**175**	LP3 171/169	LP3 167/169	LP3 167/169	LP3 167/169	LP3 167/100	LP3 167/169
10/17/2016	LP2 173/**175**	LP3 171/**175**	LP3 167/**175**	LP3 167/**175**	LP3 167/**175**	LP3 167/100	LP3 167/**175**
10/2/2017	LP2 173/**175**	LP4 163/167	LP3 167/**175**	LP3 167/**175**	LP4 163/163	LP4 163/100	LP4 163/163
			LP4 163/163	LP4 163/100			

Notes:
1. A commanded high voltage of 100 means that no data is collected on that segment
2. In Cycle 17, the 1280 Central Wavelength replaced 1230
3. Segment High Voltage in volts = -(Commanded*15.69+2500)
4. Red text shows changes; **bold** text shows the current maximum value
5. Table updated 10/17/17