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WFC3/UVIS EPER CTE 2009 - 2020

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Abstract

This report examines the changes in Charge Transfer Efficiency (CTE) as computed by the Extended Pixel Edge Response (EPER) technique. The data for the study were acquired from Cycle 17 through Cycle 26 (August 2009-present). Over the last 10 years, the CTE has declined below 0.9990 for the lowest signal level (160 e-). In our analysis and report from 2016 we determined that the rate of decline is no longer well-matched by a linear fit but by a quadratic function instead. In 2016 we noted that this may indicate that the CTE decline is leveling off or reducing with time. Given the 10 years of data collected, we observe the periodic nature of the linear fit residuals and find that it is anti-correlated to solar activity. This is the first time this effect has been observed in practice in the WFC3 EPER data.

Introduction

Charge Transfer Efficiency (CTE) loss is a degradation in on-orbit CCDs that is expected and has been tracked in all HST CCD detectors: WFPC2 (e.g. Golimowski and Biretta 2010), STIS (Dixon 2011 and references therein) and ACS (Ubeda and Anderson 2012 and references therein). The CTE loss in the UVIS channel of the Wide-Field Camera 3 (WFC3) instrument is monitored by the Extended Pixel Edge Response (EPER) technique developed during the April 2007 Ambient Calibration campaign (SMS UV02S01, Robberto 2007). It takes advantage of a special readout mode that provides a larger-than-normal overscan area (extended pixel region) within which to measure CTE trails. The internal flat-field lamp provides the stimulus.

In this paper we present analysis results of the on-orbit internal WFC3/UVIS EPER observations acquired for all data from Cycle 17 (in 2009) to Cycle 26 (2019-2020). This paper serves as an update to the previous UVIS EPER CTE measurements (Khandrika, Baggett, and Bowers 2016, and references therein).

Data

UVIS EPER data were acquired through the programs listed in Table 1. For each proposal, short internal flat-field observations are taken in pairs with two different filters at various exposure times to achieve specific illumination levels. The exposures and visit structures have been kept identical over the cycles to provide a stable dataset from which to measure the EPER CTE. The pair of EPER visits are outlined in Table 2. The measurements of the CTE loss from the on-orbit EPER observations were developed into an IDL script as described in Kozhurina-Platais et al. 2011, and used in subsequent analyses (Bourque and Kozhurina-Platais 2013 and therein).

Table 1: List of CTE EPER proposals.

Proposal ID	**Cycle**	**Principal Investigator**	**Frequency**
11924	17	Kozhurina-Platais	Once a month
12357	18	Kozhurina-Platais	Once a month
12691	19	Kozhurina-Platais	Once a month
13082	20	Bourque	Once a month
14011	21	Bowers	Every other month
14377	22	Khandrika	Every other month
14540	23	Khandrika	Every other month
14989	24	Fowler	Every other month
15575	25	Fowler	Every other month
15720	26	Fowler	Every other month

Table 2: Observational parameters for a two-visit pair, where n is the first visit in the series and n+1 is the second.

Visit	**Image Type**	**Filter**	**Exp. Time (sec)**	**Illumination Level (e^-/pix)**
n	DARK	-	0.5	-
n	TUNGSTEN	F390M	9.2	160
n	TUNGSTEN	F390M	22.9	400
n+1	DARK	-	0.5	-
n+1	TUNGSTEN	F390W	6.4	800
n+1	TUNGSTEN	F438W	7.6	1600
n+1	TUNGSTEN	F438W	22.7	5000

Results

UVIS EPER CTE analysis is based on the method outlined in Kozhurina-Platais et al. 2011 with updates and further details in Khandrika, Baggett, and Bowers 2016 (hereafter: KBB

2016). The same procedures as with previous analyses were followed and the resulting plot of CTE as a function of time and illumination level is shown in Figure 1. As observed in KBB 2016, the CTE of the WFC3/UVIS detectors has continued to decline with time and the fainter illumination levels have more CTE loss and steeper slopes than the brighter illumination levels (Anderson et al. 2012). The overall levels of decline in the CTE is listed in Table 3, along with the rate of decline in CTE per year. For the lowest signal level, the CTE has declined by up to 0.0011 over the last 10 years with a rate of decline of 0.0001 per year.

In the previous study (KBB 2016), various fits including quadratic, log, and double linear functions were performed to the data. The EPER CTE decline was found to be non-linear, especially for the lower illumination levels. It was noted in that study that this might indicate that the CTE decline is reducing or leveling off with time. Given the addition of three years of new data we can examine if these trends continue or if alternate trends are uncovered. A linear, quadratic, and cubic fit were performed to the data. Table 4 lists the chi-squared and minimum and maximum residuals of these fits for all illumination levels. The largest residuals are for the linear fit, confirming it is not the best functional form to use to describe the time evolution for the EPER CTE data. The best fit of the three, with the lowest reduced chi-squared (closest to 1) and smallest residuals, is the quadratic fit. Figure 2 shows the three fits (linear, quadratic, and cubic) along with the residuals of each fit to the data for all illumination levels. From the residual plots, we note that there is a periodic trend with the lowest illumination level for the linear fit residuals.

The trend for the lowest level linear fit residuals appear to have a cycle of at least 10 years, the range of data available in this study. The decadal pattern of the residuals to the linear fit was suggestive of the solar cycle. To explore this further, sunspot activity data were obtained from the Sunspot Index and Long-term Solar Observations (Royal Observatory of Belgium, Brussels). Figure 3 shows the last 10 years of sunspot activity as compared to the linear fit residuals of the 160 electron level illumination data. Both of the datasets have been normalized to their respective maxima in order to be placed on the same relative scale: the CTE residuals are anti-correlated with the sunspot counts i.e. solar activity. These EPER findings form a consistent picture with what was found in external data after the installation of WFC3. At that time (2009), the CTE losses in WFC3 were developing at a faster-than-expected pace. The ACS instrument had not experienced such strong degradation when it was installed 7 years earlier. The authors of a CTE white paper (Baggett et al. 2011) suggested that the solar minimum played a role: the strength of the South Atlantic Anomaly, a region particularly damaging to instruments, is inversely correlated to the solar cycle. Based on data from the ESA ERS and ENVISAT satellites and the Casadio SAA index (Casadio, Arino, and Serpe 2010) as a measure of the SAA radiation environment, the exposure levels were significantly higher at the start of the WFC3 mission (2009) than they were at the start of the ACS mission (2002), in agreement with the external CTE measurements early in the lifetimes of those instruments.

Summary

This report summarizes the behavior of the Charge Transfer Efficiency as measured via the Extended Pixel Edge Response method. The analysis has been updated to include all on-orbit data from Cycles 22 to Cycle 26 (present). As expected, the CTE has 1) continued to decline with time and 2) is steeper for the fainter signal levels. The CTE has declined by as much as 0.11% over the last 10 years for the lowest illumination level of 160 e^-, corresponding to a decline rate of $\sim$ 0.01% per year. We re-confirm the findings from 2016 that found that the rate of decline is no longer well-matched by a linear fit but instead, is better fit by a quadratic or cubic function. However, given the 10 years of data collected, we observe a cyclical nature of the linear fit residuals and find that it is inversely correlated with solar activity. This is the first time this effect has been observed in practice in WFC3.

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Illumination level (e^-)	Overall CTE decline	Linear decline per year
159	0.001047	-0.000099
411	0.000513	-0.000049
810	0.000315	-0.000030
1665	0.000190	-0.000018
5009	0.000093	-0.000009

Table 3: Overall decline in the CTE rates with time for all illumination levels, corresponding to the points seen in Figure 1. A linear fit to each of the illumination levels was made and the slope is shown here as the linear decline in CTE level per year.

Table 4: Various fits, residuals, and chi-squares for the different illumination levels

Illumination level (e^-)	**Fit**	**Chi-squared** (reduced)	**Residual Min** ($\times 10^{-5}$)	**Residual Max** ($\times 10^{-5}$)
159	Linear	1.455	-4.332	7.329
	Quadratic	0.353	-4.589	3.184
	Cubic	1.493	-2.371	2.356
411	Linear	2.115	-2.395	3.408
	Quadratic	0.515	-1.984	1.719
	Cubic	2.171	-1.105	1.091
810	Linear	3.504	-1.205	2.176
	Quadratic	0.907	-1.156	0.824
	Cubic	3.596	-0.436	0.546
1665	Linear	5.018	-0.720	1.252
	Quadratic	1.058	-0.570	0.386
	Cubic	5.150	-0.218	0.214
5009	Linear	9.523	-0.310	0.557
	Quadratic	2.038	-0.383	0.185
	Cubic	9.774	-0.110	0.070

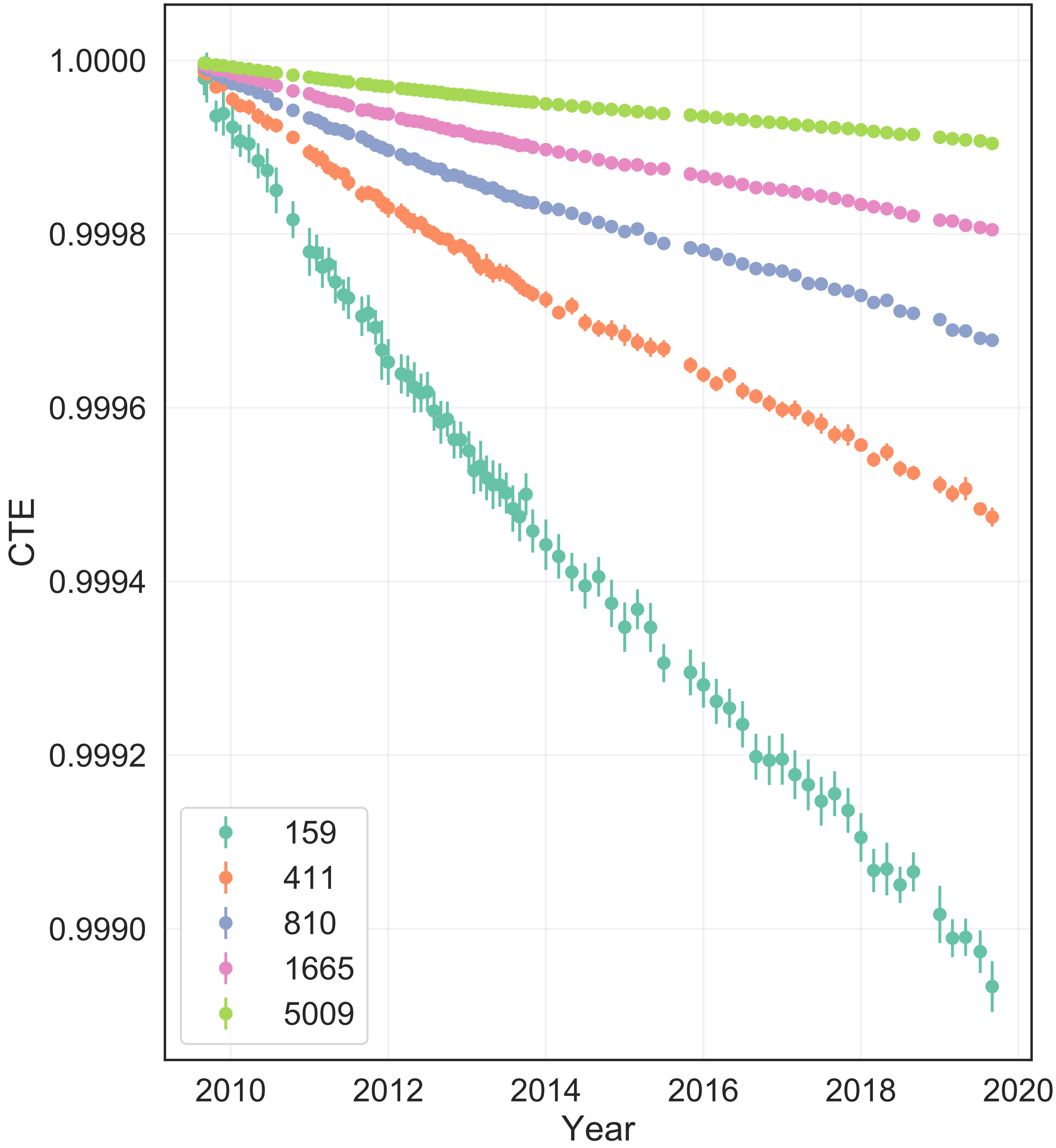
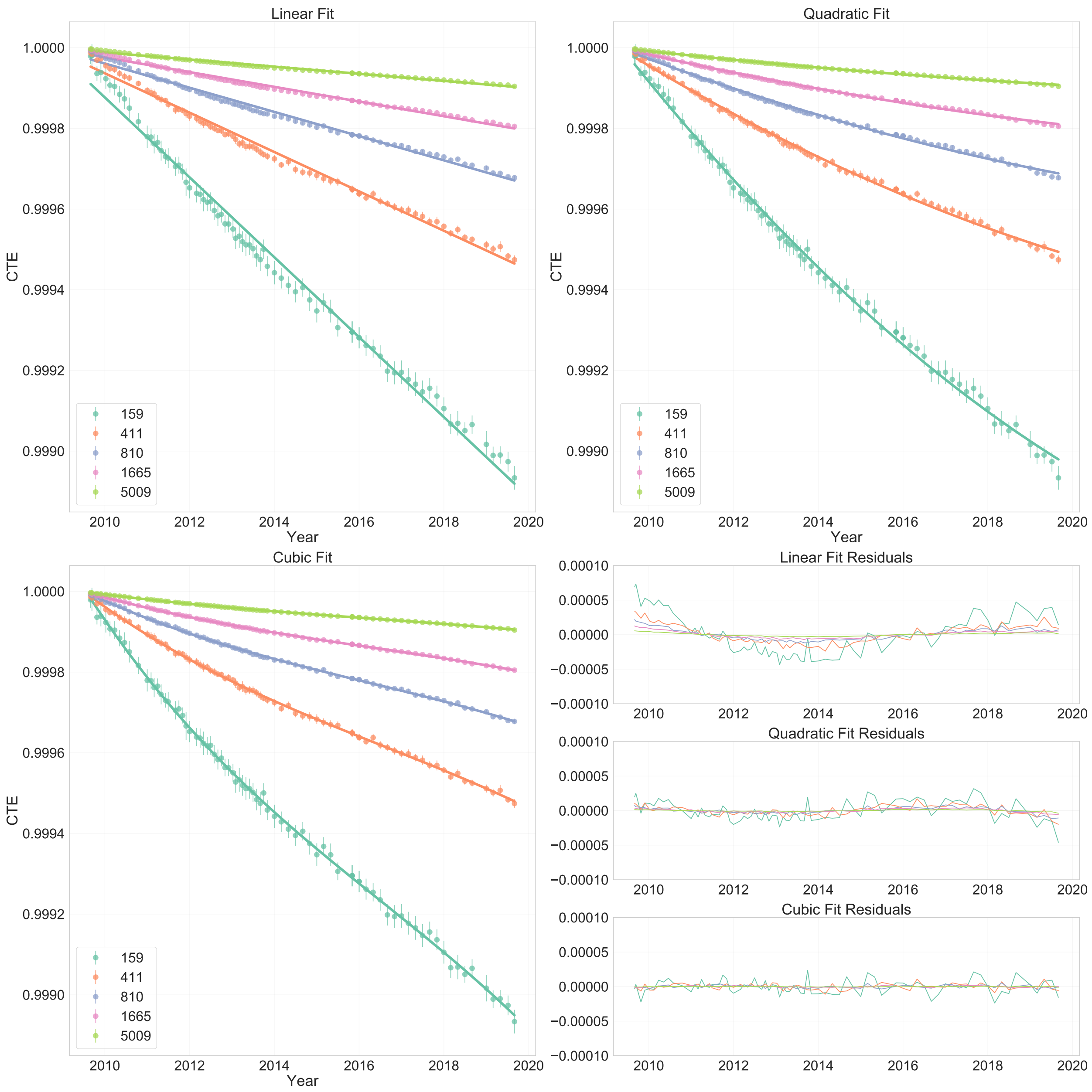


Figure 1: Decline of EPER CTE over time for various illumination levels in electrons (e^-). The values shown in the legend represent the average illumination level for each set.



Linear Fit

Quadratic Fit

Cubic Fit

Linear Fit Residuals

Quadratic Fit Residuals

Cubic Fit Residuals

Figure 2: Top left: Decline of EPER CTE over time as a function of illumination level (electrons) with overplotted linear fits to the data. Top right: Quadratic fit to the CTE measurements versus time. Bottom Left: Cubic fit. Bottom Right: Residuals of each fit to the data points. The equivalent illumination level remains the same as in the other figures.

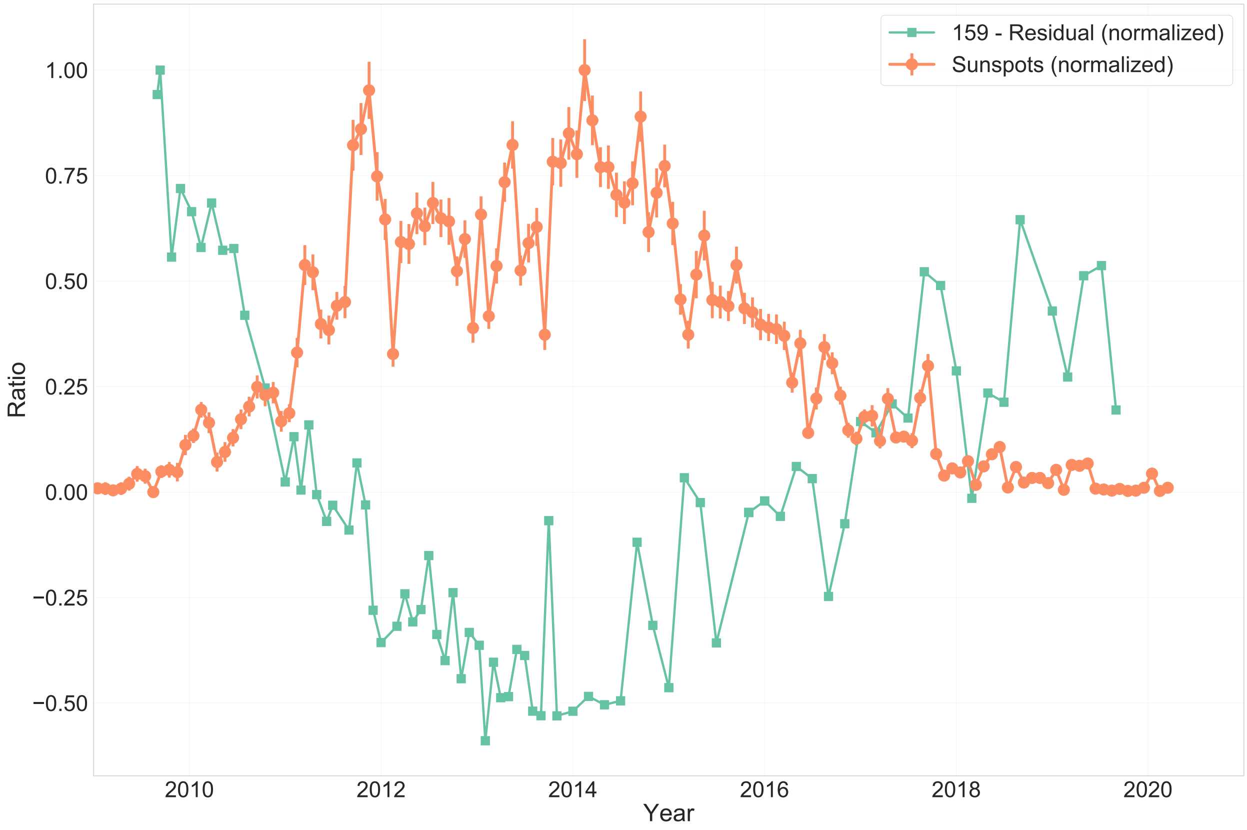


Figure 3: Sunspot activity versus time as compared to the residuals of the 160 e^- illumination level. Both the sunspot data and the residuals are normalized to their respective maximum values, in order to fit on the same scale.