

Analysis of the excess charge in WFPC2 overscans

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4 August 1998

ABSTRACT

We have found evidence for excess charge in the WFPC2 overscan columns, which appears to be increasing over the instruments lifetime (1994 to 1998). We characterize the excess charge and discuss possible explanations for the trend, including the possibility that it is deferred charge caused by a declining charge transfer efficiency (CTE) in the WFPC2 serial registers.

1. Introduction

The WFPC2 CCDs suffer from significant charge transfer efficiency (CTE) losses. CTE losses occur when a small number of electrons in an image are temporarily trapped (deferred) with each transfer of charge. The traps are thought to be impurities in the CCDs (Janesick, 1988). Charge can be deferred while being clocked down the CCDs (in the parallel or “y” direction), or while being read out (in the serial or “x” direction) from the shift register at the bottom of the chip. CTE losses are one of the most significant systematic calibration uncertainties that can affect photometry with the WFPC2, yet its cause and characteristics are still not well understood. The problem also appears to be getting worse with time, which makes it an important factor in assessing the functional “life expectancy” of WFPC2.

CTE losses can affect photometric accuracy (Whitmore & Heyer, 1997), and can also create faint residual images and trails in exposures which immediately follow images of bright objects (Biretta & Mutchler, 1998). Another possibly related effect is that short exposures appear to be missing charge relative to long exposures of the same target (Casertano & Ferguson, 1996). Previous analyses of WFPC2 CTE loss have primarily focussed on parallel (or Y) CTE loss. Whitmore & Heyer (1997) made photometric measurements of many stars (the globular cluster Omega Cen) scattered across the WFPC2 CCDs. They report parallel CTE losses (over 800 pixels) as high as 15% for faint stars, but

they also reported a serial or “X-CTE” loss which was roughly half of the corresponding parallel or “Y-CTE” for a given filter.

2. Measurements

Overscans are extra pixel readouts taken after the real pixels are read out. After each 800-pixel WFPC2 row is read out by the serial register, an extra 11 “virtual” pixels are read out or “overscanned.” We analyzed the overscan region of internal VISFLAT exposures for this study. VISFLATs are a good statistical sample since they are uniformly illuminated at high flux levels, and many VISFLAT exposures have been taken throughout the lifetime of WFPC2.

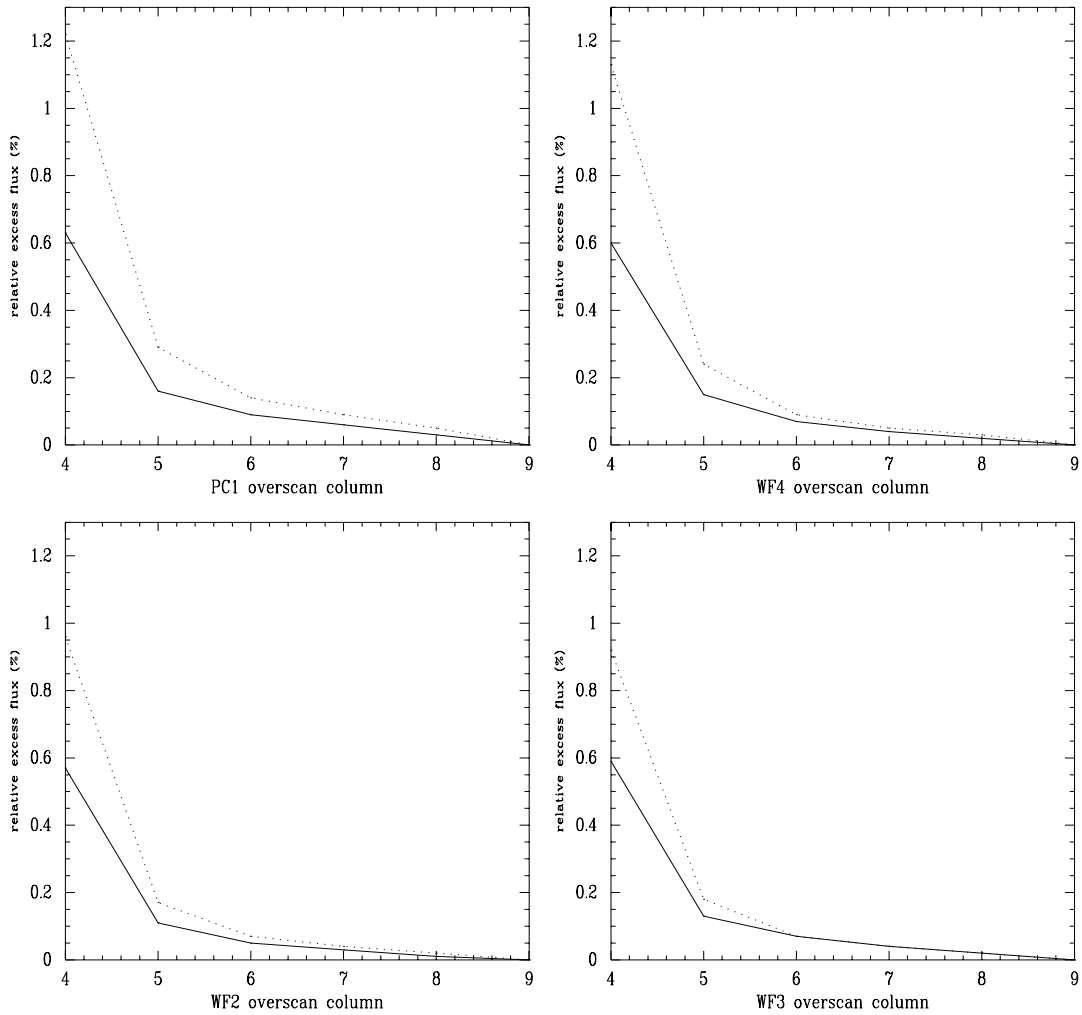
The WFPC2 overscan files (*.x0h and *.x0d files) consist of 14 columns and 800 rows. The first 2 columns contain engineering data, and are of no use here. Column 3 contains a copy of the last real column (column 800 of the *.d0d file). So column 4 is actually the first true overscan (Baggett, 1998).

Overscan flux levels usually flatten out to the bias level by the 6th overscan (column 9). In fact, WFPC2 bias levels are determined by averaging the flux measured in overscan columns 9-14, based on the assumption that any excess charge should have been adequately “drained” during the first 6 overscans. Our data confirms that this is a valid assumption (see Figure 1).

Therefore, to quantify the excess charge, we measured the flux in columns 4-8 and subtracted the mean flux in columns 9-14 (i.e. the bias level). The various filters used in a VISFLAT sweep produce varying flux levels, so we divided the excess overscan flux by the incident flux to normalize it. We estimated the incident flux by taking the mean of the last ten real CCD columns.

Figure 1 shows the excess overscan flux as a percentage of the incident flux for all four WFPC2 CCDs. Data from both 1994 (solid line) and 1998 (dashed line) are plotted to illustrate that the amount of excess charge found in the WFPC2 overscans is increasing over time.

Figure 1: The mean excess overscan flux as a percentage of the incident flux for all four WFPC2 CCDs. Data from both 1994 (solid line) and 1998 (dotted line) are plotted to illustrate that the amount of deferred charge found in the WFPC2 overscans is increasing over time.



3. Analysis

In this section we examine the dependence of the excess overscan charge on several factors. First we consider time effects. It takes about 13.4 seconds to read out one of the WFPC2 CCDs (811x800 pixels including the overscan), so each CCD row is read out in about 17 milliseconds, and each individual pixel is read out in about 20 microseconds. The decay timescale (half-life) of the flux profile is about half the pixel readout time or about 10 microseconds (Figure 1).

Figure 2 shows a plot of the mean flux across all 800 rows of the CCD. The flatness of these plots shows that the timescale for the trapping of charge in the serial register is much less than the CCD readout timescale of about 13 seconds. If the timescale was on the order of tens of seconds, we would expect to see a top-to-bottom gradient here.

Next we examine how the excess overscan charge depends on image intensity. Figures 3 and 4 show that the excess overscan flux levels are not dependent on the level of illumination of the CCD (i.e. the incident flux level)--at least at the higher levels of illumination present in these VISFLAT exposures. The exposures with higher flux levels did not produce any more excess charge than the exposures at lower flux levels. If the excess overscan flux were increasing along with the incident flux, we would expect the plot in Figure 4 to be flat. Instead, we see that the excess overscan charge represents a smaller percentage of the incident flux as the illumination level is increased.

As a null test, we also measured the excess flux in overscans of BIAS images. Since the BIAS images are presumably blank and they don't have high flux levels like VISFLATS, we expect to find much less excess charge in their overscan region. We found the BIAS overscans to have no more than 5% of the excess charge measured in the VISFLAT overscans. This verifies that the image is the source of most of the excess charge seen in the VISFLAT overscans.

There is a common method of measuring CTE losses known as 'extended pixel edge response' or EPER (McLean, 1997), which assumes that the excess charge in overscans is charge that has been deferred in the CCD. The overscan therefore allows for the recovery and analysis of some of the deferred charge, and a measurement the charge transfer efficiency (CTE) of the device.

The EPER CTE is defined as:

$$CTE_{EPER} = 1 - \frac{Q_d}{Q_o N}$$

where:

Q_d is the excess (deferred) charge in the overscan,

Q_o is the charge in the last few real pixels (i.e. the incident flux), and

N is the number of pixels transferred.

CTE can be expressed as (for example) “four nines of CTE” per transfer, which means that after each transfer, 99.99% (or 0.9999) of the original charge is successfully transferred to the next pixel. This example could equivalently be expressed as an 8% loss across the WFPC2 CCD, which has 800 pixels (transfers).

Figure 5 shows the EPER CTE for several epochs between 1994 and 1998, including one epoch before the CCDs were cooled from -77C to -88C (on 23 April 1994). It appears that most of the decline in transfer efficiency (increased excess overscan charge) occurs in the first year after WFPC2 installation. There is also a large (vertical) dispersion in the efficiencies, which is due to differing Q_o while Q_d appears nearly constant.

4. Discussion

Our measurements of the excess charge in WFPC2 overscans could have several interpretations. Here we will discuss a few models:

Model 1: Amplifier hysteresis.

It appears unlikely that the excess charge can be attributed to simple hysteresis or a simple signal decay timescale in the amplifier. As we have seen, the excess charge appears independent of signal strength, at least for large signals, whereas we might expect amplifier effects to vary with signal strength. Also, a simple decay timescale (e.g. observed ~10 microsecond decay) applied to the large VISFLAT intensity would greatly over-predict the excess charge in the overscan columns.

Model 2: CTE due to charge trapping.

Charge trapping appears as a likely cause of the excess overscan charge. In such a picture, charge might be trapped by impurity sites in the serial register and then released at a later time. Such a model would naturally account for the fact that the excess charge was independent of VISFLAT intensity (at least at high intensities) since there are a fixed num-

ber of traps, and once all the traps are filled, additional flux doesn't produce additional deferred charge.

At very low intensities there would still be a dependence on illumination, since only a fraction of the traps would be filled. Hence the result that there is little or no excess in BIAS images. The decay timescale would then indicate a half-life for charge to leave the traps of approximately 10 microseconds. This is much shorter than the 16 minute decay timescale found for residual images in parallel transfers (Biretta and Mutchler 1998), indicating a somewhat different process in the serial register, or different types of traps with different timescales.

Model 3: CTE due to CCD electronics.

A third possibility is that the excess overscan charge is due to inefficiency in the serial transfer process due to some electronic problem in clocking the serial register. For this case the EPER CTE formalism is appropriate. As Figure 5 shows, the efficiency per serial transfer is about 0.99999 (average) soon after WFPC2 installation, but then decreases to about 0.99998 (average) over the first year of operation. The primary objection to this model is that the excess charge shows a decay over several overscan pixels (Figure 1), whereas we might expect all the deferred charge to appear in the first trailing pixel. A second issue is that the excess charge is relatively independent of VISFLAT intensity, indicating that no single CTE efficiency can describe the process very well. This in fact causes a large (vertical) dispersion in CTE efficiencies in Figure 5. Such a picture is viable only if the transfer efficiency depends on the pixel intensity in some complicated fashion.

In summary, we have found that the CCD overscan columns contain excess charge above the nominal bias level, and that the amount of excess charge has increased since the installation of WFPC2. We argue that charge trapping in the serial register is the most likely cause of the excess charge, but other causes cannot be completely ruled out. Measurements of excess overscan charge may provide a useful diagnostic for tracking future changes in serial register CTE.

Figure 2:

The mean flux (in counts) in WFPC2 overscan columns 4-8 are plotted for all 800 CCD rows. In order of decreasing flux, the plots are for WF2, PC1, WF4 and WF3. Only the March 1998 F555W VISFLAT exposures were used to make this plot. The low values in the first 50 rows are due to the pyramid shadow.

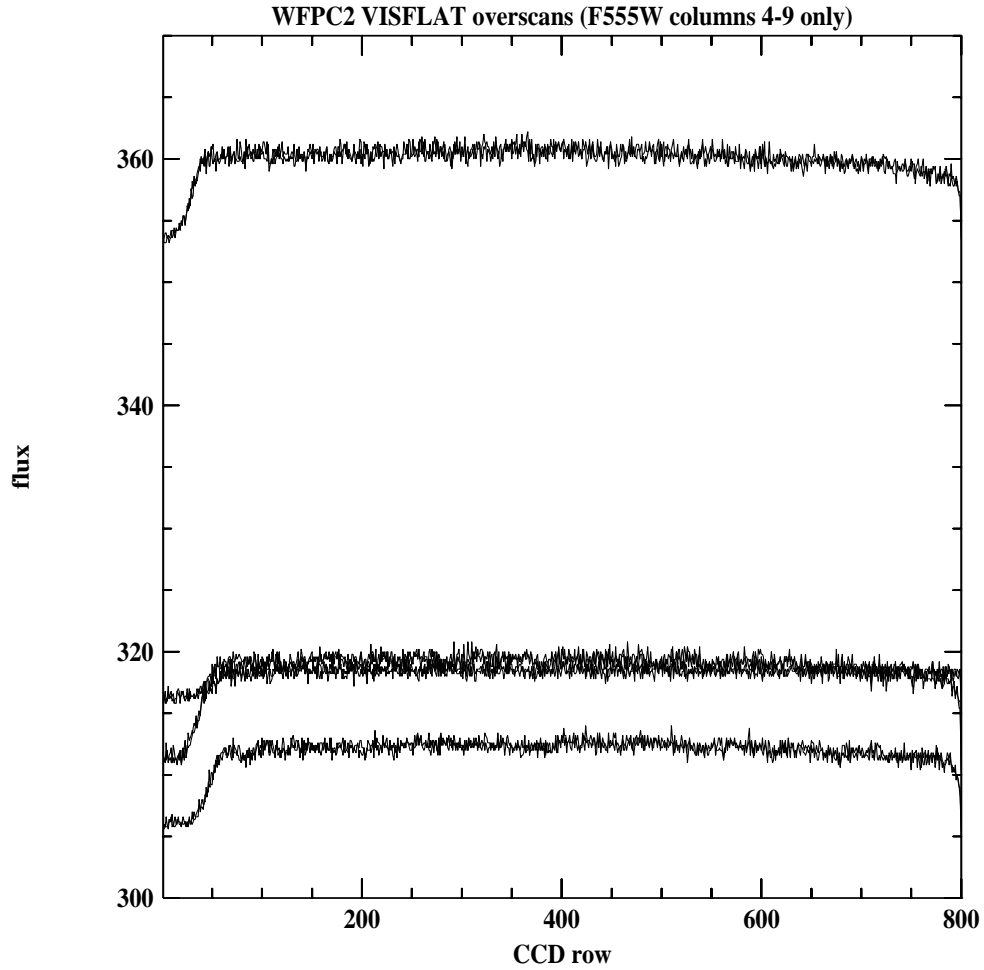


Figure 3: Excess overscan flux vs incident flux (from the last few real columns). The excess overscan flux does not increase as the CCD is illuminated at higher levels.

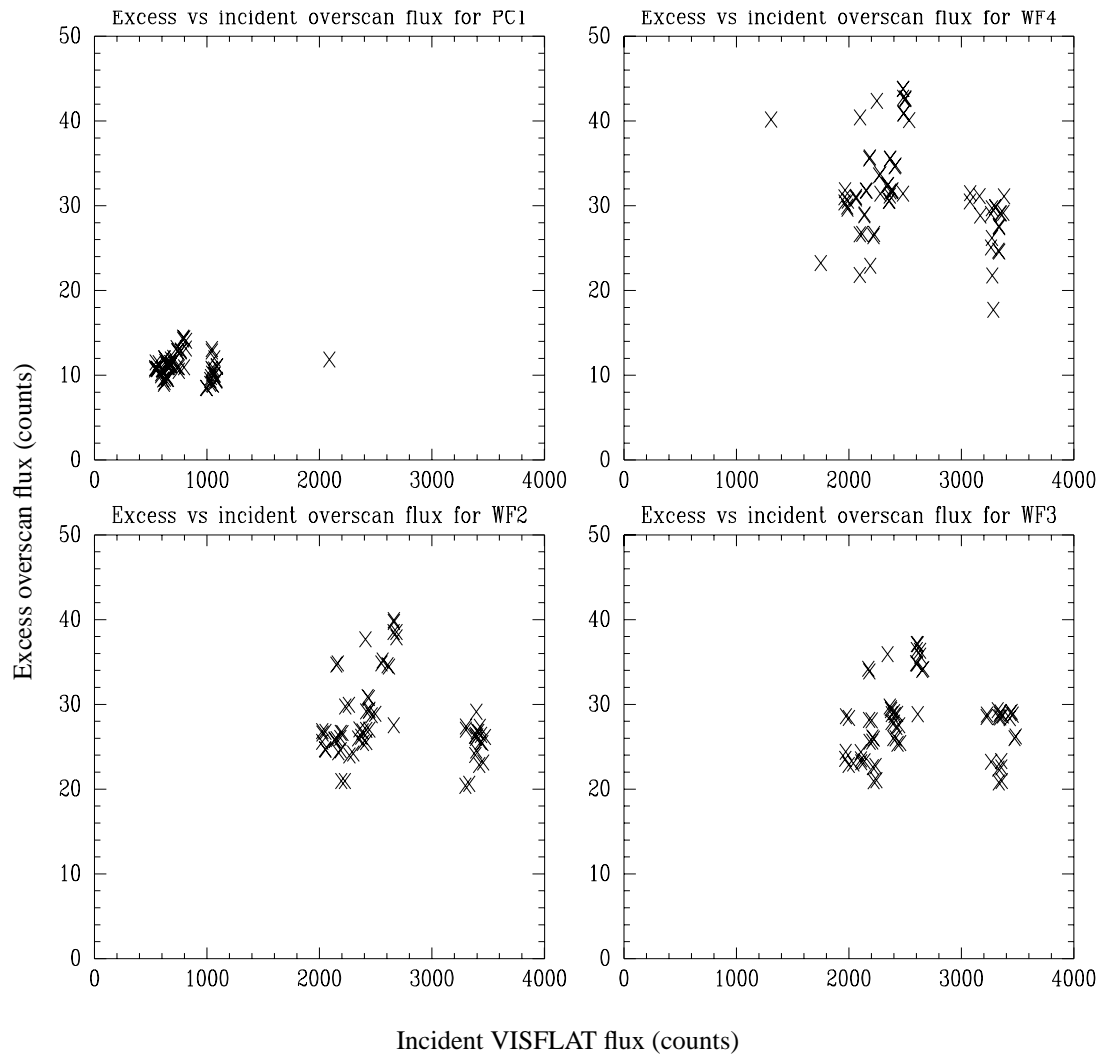
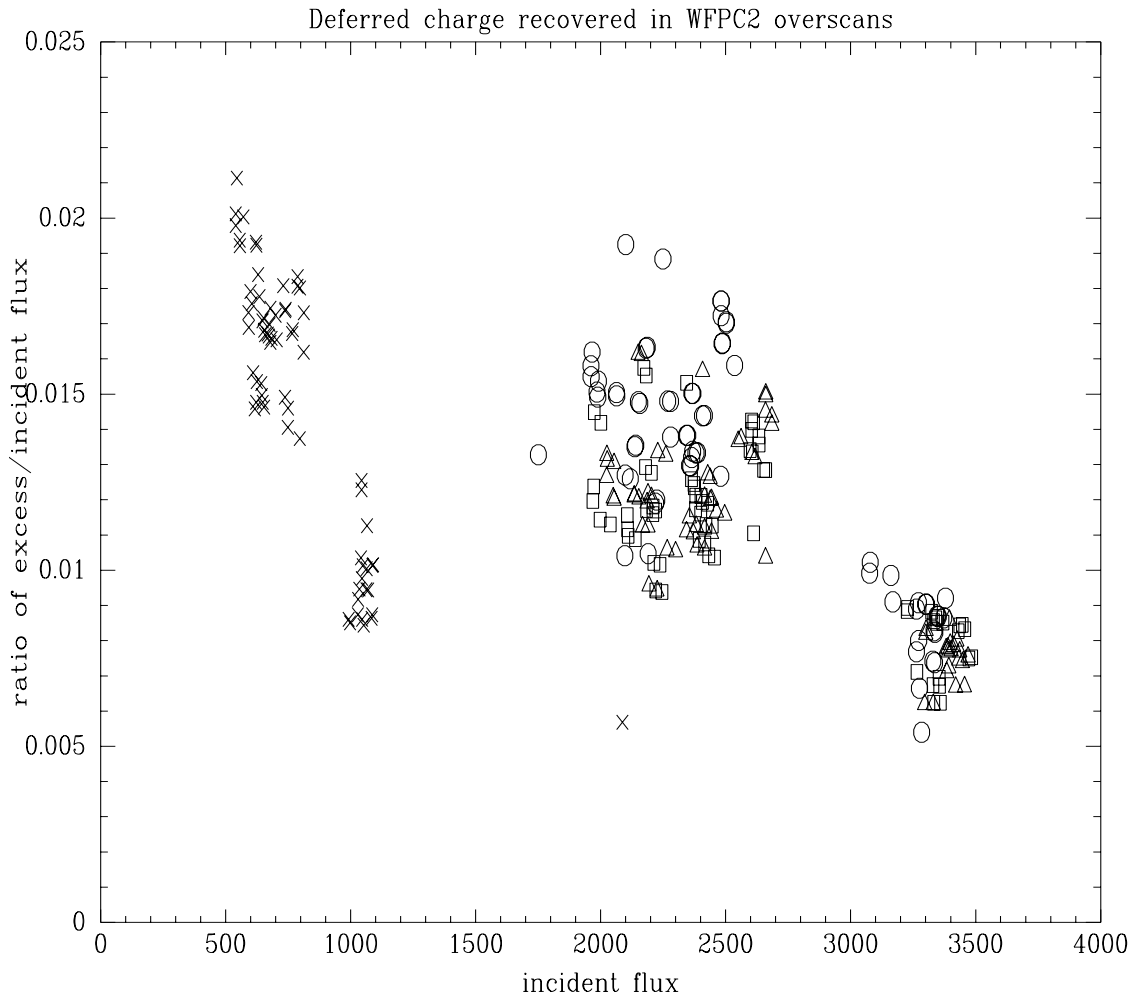


Figure 4: The ratio of the excess and incident flux vs the incident flux (in counts) for each CCD. The triangles, squares, and circles are for the WF2, WF3, and WF4, respectively. The X's are for the PC, which has smaller pixels and therefore less flux per pixel. Increasing the incident flux level does not increase the excess overscan flux.



5. References

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