Charge Transfer Traps in the WFPC2

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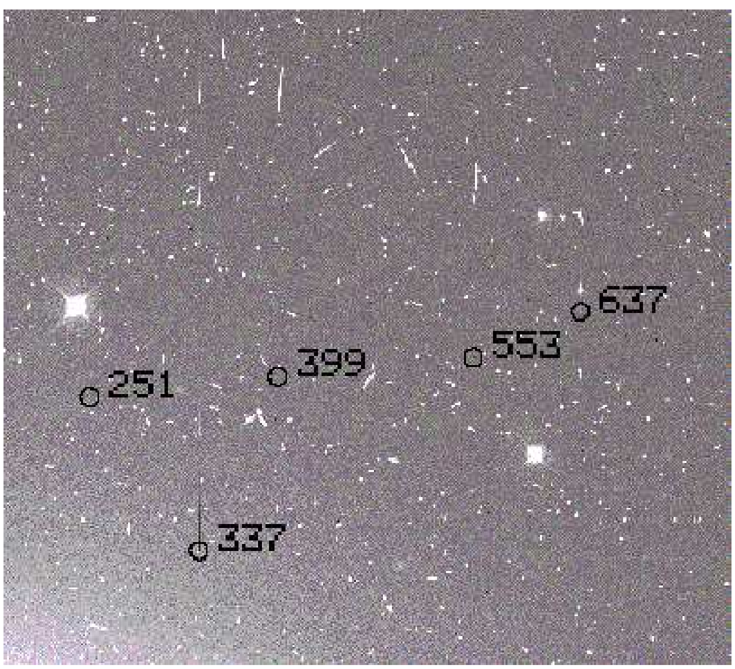
ABSTRACT

The characteristics of charge transfer traps in the WFPC2 are examined and the effect they may have on observations are discussed. The dark tail created just above the location of the trap, as well as any bright tail created in the column above the trap when a bright source is clocked out during the readout, can be modeled as simple exponential decays. Three previously unidentified traps on WF2 are added to the list of "bad pixels". There is no evidence of new traps forming.

Figure 1: A portion of a WF2 image (before cosmic ray removal) showing the location of five of the seven traps on WF2. The strongest trap is 2-337, which shows a dark tail just above the trap, and three bright tails where cosmic rays are clocked across the trap during the readout. Trap 2-637 shows both a bright tail from a cosmic ray, and a tail from a point source. The other traps are either too weak to show noticeable effects on this particular image, or did not happen to have strong cosmic rays crossing their columns.



1. Introduction

What makes CCDs possible is the fact that the charge deposited in a given pixel during the exposure can be efficiently transferred to adjoining pixels along the same column when the CCD is read out at the end of the exposure. The ideal CCD would have pixels with 100% charge transfer efficiency. While this is very nearly true for the vast majority of the 2,560,000 pixels on the WFPC2, there are about 30 pixels which do not transfer charge as efficiently. These “traps”, or “defects”, may transfer as little as 20% of the electrons during each time step of the readout. Only about 0.001% of the pixels are actually defective but about 0.4% of the image is affected since all the pixels in rows above the trap (i.e., higher value of Y) are clocked out across the bad pixel during the readout. The worst traps leave long tails, and are often known as “bad columns”.

Figure 1 shows a portion of an image from WF2 with the location of five of the seven known charge transfer traps on this chip. The strongest trap is at (337,201) which transfers only 19% of the charge during each time step. The rows below Y = 201 are unaffected since they are transferred down the column during the readout and hence never pass over the bad pixel. Figure 2 shows an idealized model of how the bright tail is created, assuming a uniform background of 8 counts in every pixel during the exposure.

Figure 2: Idealized Model of a Charge Transfer Trap Compared to Real Data

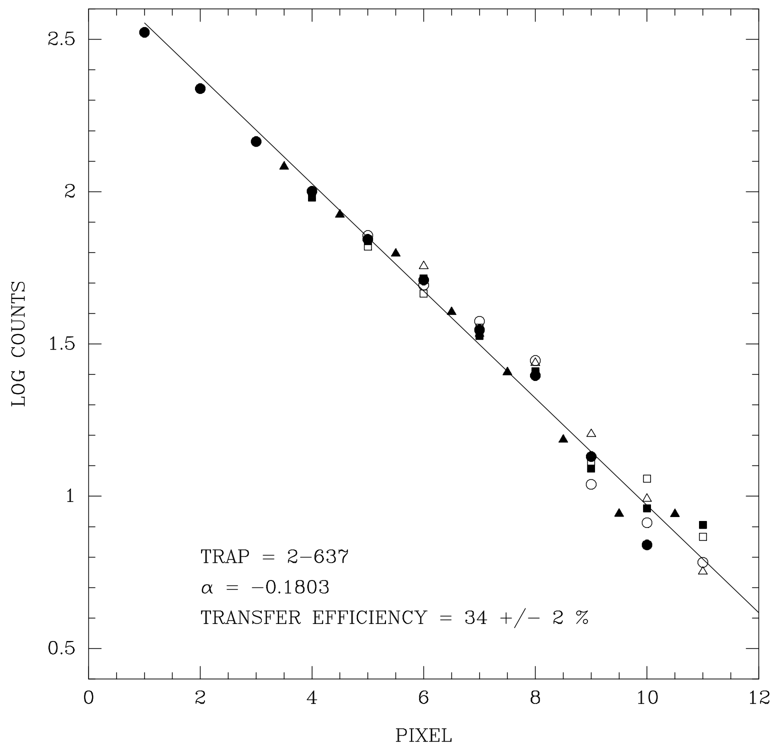
Parameters:
Trap Location (WF2) = (637,389)
Cosmic Ray Location = (637,645)
Transfer Efficiency = 34 %
Background = 8 counts

Pixel	Charge Deposited	Leftover Charge from Previous Pixel	Total Charge	Charge Transferred	Background Subtracted	C(J−1) / C(J)	Observed Value	C(J−1) / C(J)
(equilibrium producing a background of 8 counts)								
(637,644)	8	15.53	23.53	* 0.34 = 8.00				
(hit with a 989 count cosmic ray)								
(637,645)	989	23.53 − 8.00 = 15.53	1004.53	* 0.34 = 341.53	333.53		333.48	
(637,646)	8	1004.53 − 341.53 = 662.97	670.97	228.13	220.13	0.66	217.91	0.65
(637,647)	8	442.84	450.84	153.29	145.29	0.66	146.06	0.67
(637,648)	8	297.55	305.55	103.89	95.89	0.66	100.33	0.69

2. Characteristics of Traps

Figure 3 shows several tails resulting from trap 2-637. These tails were taken from a variety of observations, both before and after the April 23, 1994 cooldown of the WFPC2. The solid line shows a simple exponential decay, as described in our idealized model. It appears that the behavior of the bright traps has been relatively constant with time, and the simple exponential decay provides a fairly good fit to the data.

Figure 3: Tails created by trap 2-637, including the two tails shown in Figure 1 (filled circles and triangles), as well as several other tails from observations both before and after the April 23, 1994 cooldown of WFPC2.



The trap can therefore be characterized by the exponential scale length, α, defined by:

$$C = N_0 10^{\alpha \Delta Y}$$

where C is the number of counts above the background, N_0 is the deviation from the background at the start of the tail, and ΔY is the distance from the start of the tail. For example, trap 2-637 has a value of $\alpha = -0.1803$ for bright tails. The decay rate is simply 10^{α}, or 66%, and the transfer efficiency is $1 - 10^{\alpha}$, or 34%.

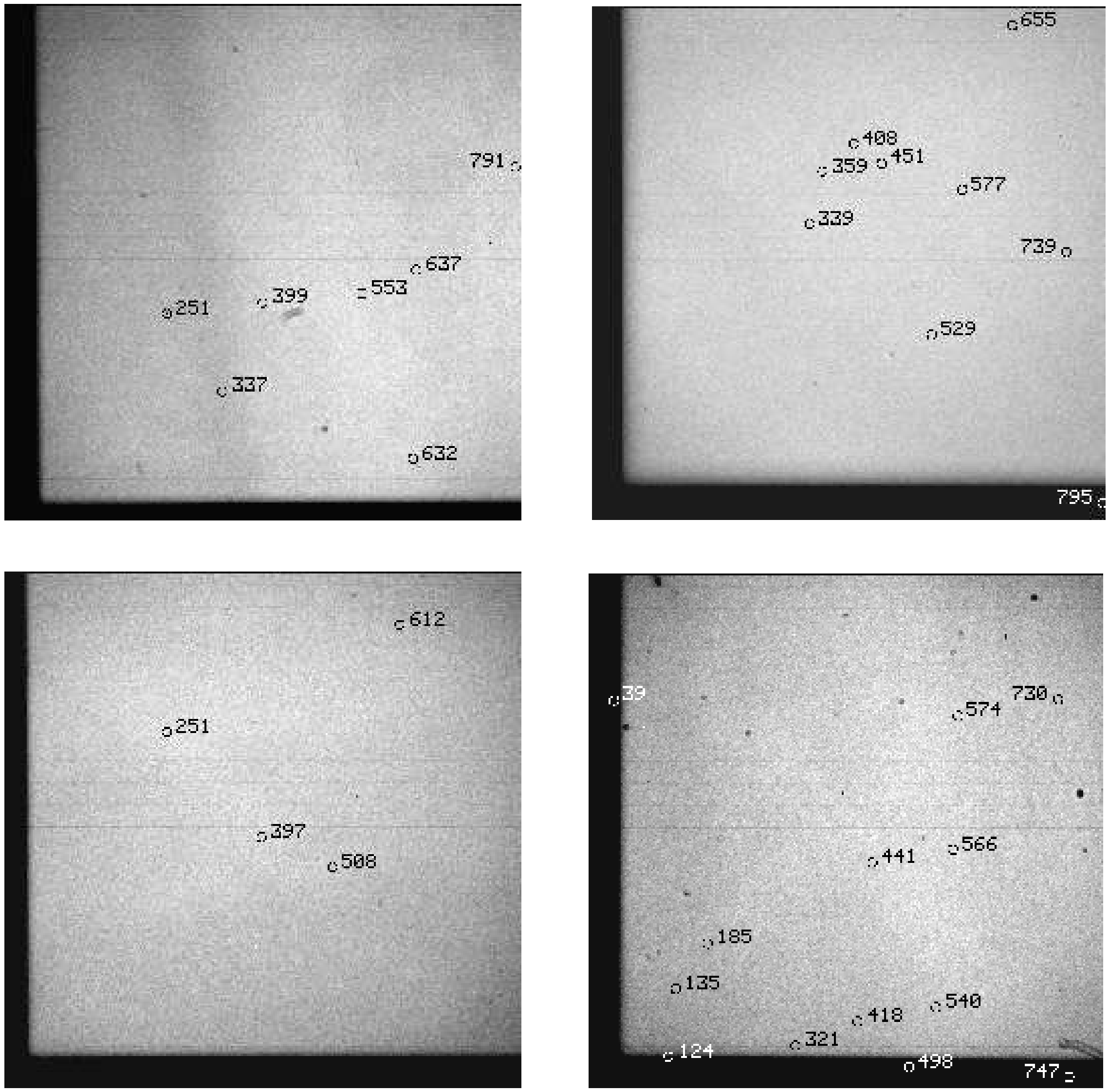
What about the dark tails seen just above some of the traps? *Although the decay rate for the dark tails are different than for the bright tail,* an exponential decline again fits the data quite well. For example, the dark tail decay rate for trap 2-337 is only about 3% while the bright tail decay rate is 19%. This difference can easily be seen in Figure 1, where the dark tail has a deviation from the background of only 13 counts and extends roughly 60 pixels, while the bright tails have deviations of about 50 counts but only extend about 20 pixels.

Table 1 lists the currently known traps, including three traps on WF2 which were previously unidentified. Examinations of observations taken shortly after the WFPC2 was installed (i.e., the observations of R136 taken February 2, 1994), as well as during thermal vacuum testing before launch, both indicate that these traps were already present. *There is no evidence of new traps forming in the WFPC2*. Figure 4 shows the locations of all known traps. Note that only the strongest traps can be measured reliably. The unmeasured traps generally have transfer efficiencies in the range ot 50–90%.

Table 1. (Tentative) Location and Characteristics of Traps

Camera	Trap	X	Y_{start}	$Y_{stop(old)}$	$Y_{stop(new)}$	α	%transfer
PC1	1-339	339	463	488	468	–0.080 +/– 0.010	17%
	1-359	359	544	550	548	—	—
	1-408	408	587	634	605	—	—
	1-451	451	557	575	565	—	—
	1-529	529	289	354	315	–0.170 +/– 0.0.030	32%
	1-577	577	516	576	530	—	—
	1-655	655	771	783	771	—	—
	1-739	739	418	435	425	—	—
	1-795	795	27	124	32	—	—
WF2	2-251 (NEW)	251	322	—	322	–0.260 +/– 0.060	45%
	2-337	337	201	800	800	–0.090 +/– 0.020 (bright) 0.012 +/– 0.002 (dark)	19% 3%
	2-399 (NEW)	399	338	—	350	–0.111 +/– 0.008	23%
	2-553	553	353	358	357	–0.470 +/– 0.060	66%
	2-632	632	97	112	97	—	—
	2-637 (NEW)	637	389	—	394	–0.180 +/– 0.010	34%
	2-791	791	549	597	563	–0.170 +/– 0.030	32%
WF3	3-251	251	553	648	580	–0.232 +/– 0.023	41%
	3-397	397	390	451	405	–0.323 +/– 0.136	52%
	3-508	508	344	360	348	—	—
	3-612	612	719	739	722	—	—
WF4	4-124	124	50	75	58	—	—
	4-135	135	155	162	155	—	—
	4-185	185	226	242	230	—	—
	4-321	321	67	83	72	—	—
	4-418	418	105	132	113	—	—
	4-441	441	352	672	382	–0.195 +/– 0.087	36%
	4-498	498	33	50	33	–0.390 +/– 0.020	59%
	4-540	540	127	160	135	–0.380 +/– 0.070	59%
	4-566	566	372	414	382	—	—
	4-574	574	580	800	800	–0.236 +/– 0.097	42%
	4-730	730	605	639	614	—	—
	4-747	747	18	44	50	–0.379 +/– 0.134	58%

Figure 4: Location of all known charge transfer traps on the WF2, PC, WF3, and WF4 CCDs, respectively.



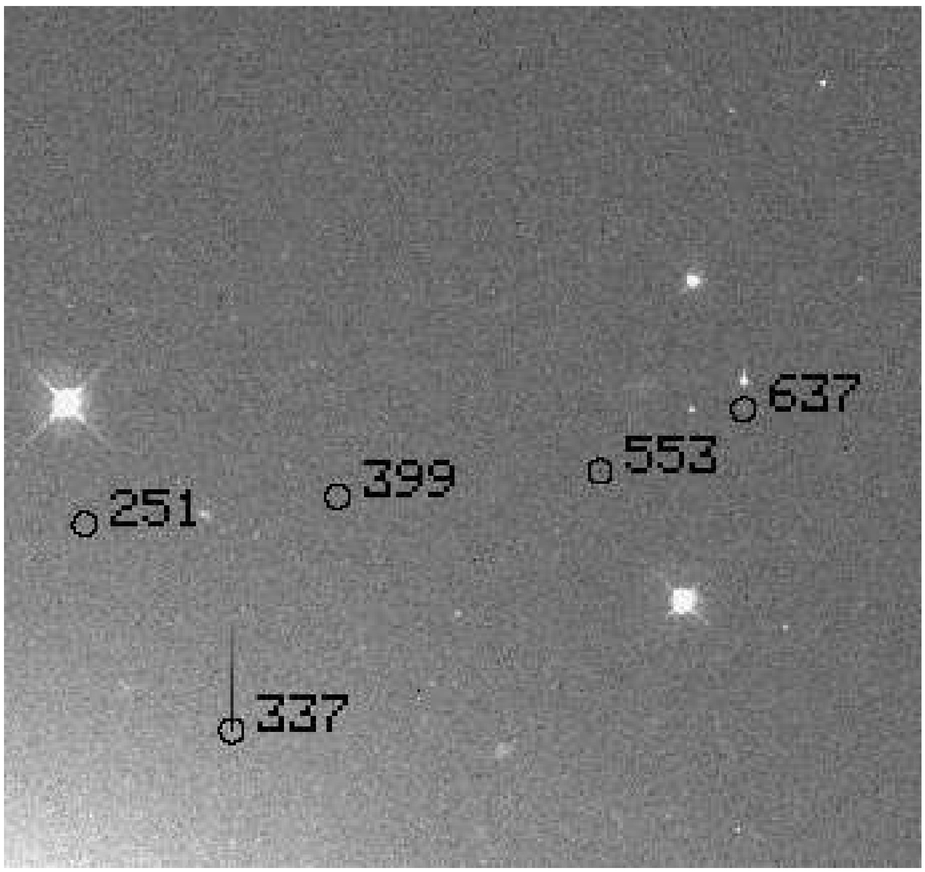
3. Removing the Effects of the Charge Transfer Traps

Figure 5 shows that in most cases where two subexposures have been taken, performing the standard cosmic ray removal procedures removes the majority of the tails. Exceptions are:

- the dark tail just above the actual trap, which can be treated with **wfixup** or **fixpix**,
- cases where real objects cross the bad column, such as the object just above 2-637 in Figure 5,

- the tails caused by cosmic rays which are too faint to be caught by the cosmic ray removal program (e.g., a very faint artifact can still be seen in Figure 3 above trap 2-337), and
- cases where only a single exposure is available.

Figure 5: The same region as shown in Figure 1, but after cosmic ray removal. The bright tails caused by the cosmic rays are now gone, since they only appear in one of the subexposures and are therefore removed along with the cosmic rays. The dark tail above 2-337 is still present, and can be removed via the **wfixup** or **fixpix** task. The bright tail in the object above trap 2-637 is still present, and will affect the photometric, astrometric, and size determinations.



The standard technique for removing the effects of traps (i.e., “bad columns”) is to use the `.c1h` (data quality) image which is included on the data tape, and the STSDAS task **wfixup** or the IRAF task **fixpix**. At present, the correction begins at the location of the trap and replaces the data in the column with an interpolation from either side of the affected column, up to a value of Y_{stop} (old) (see Table 1). While this provides a cosmetically cleaner image, it may occasionally affect your results, and hence may not always be recommended. For example, if a bad column falls precisely on the peak of a bright star, such as the object in column 2-637 of Figure 1, the central peak, which should be about 254 counts, is degraded to 123 counts. As will be discussed below, this can result in an error of several tenths of a magnitude when small aperture photometry is performed, and an increase of about a pixel in the FWHM.

Currently (before August, 1995), the bad pixels flagged by the `.c1h` file only cover the region immediately above the trap (i.e., are for the dark tails seen when sufficient background is present), except in the cases of 2-337 and 4-574 which are so bad, that they can generally be seen all the way to the top of the chip. However, any pixel clocked through the bad pixel during the readout is affected. These columns should be considered suspect all the way to the top of the chip. We are therefore planning to modify the `.r0h` reference files, and the corresponding `.c1h` data quality files that are sent to observers on their data tapes, to flag both the portion just above the trap with a value of 2 ("Defect") and the rest of the column above the trap with a value of 256 ("Questionable Pixel"). This is planned for August 1995, after **wfixup** has been modified to allow a switch to be set for the types of bad pixels to be modified.

Another problem with the `.c1h` image is that the length of the tail which is masked out is often much larger than actually required. We have therefore updated the `.r0h` and `.c1h` images, as described above. The only exception are traps 2-337 and 4–574, which will be flagged as 2 to the top of the column. We will also add the three new traps which have not been identified previously in the `.r0h` and `.c1h` images.

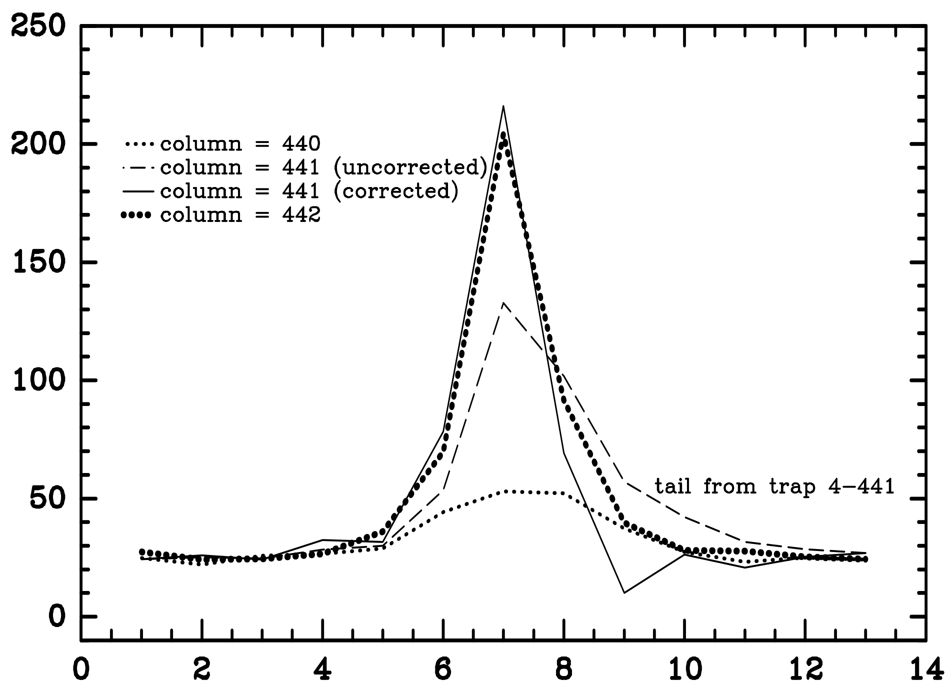
Since the tails follow a simple exponential decay, it should be a relatively straightforward task to reconstruct the original image using the measurements of α listed in Table 1.

The formula for this procedure is:

$$C_j^* = \frac{C_j - C_{J-1}(1-T)}{T} - B$$

where C_J^* is the corrected number of counts in pixel J, C_J and C_{J-1} are the observed number of counts in pixels J and J-1, T is the transfer efficiency from Table 1, and B is the background. Figure 6 shows the results for an object just above trap 4-441. (Note that trap 2-637 from Figure 1 and Figure 5 appears to be the only trap which leaks a small amount of charge in an "upstream" direction, thus we chose a more typical trap for this example.)

Figure 6: This is the result of using the reconstruction formula shown above on an object from an archival image just above trap 4-441. By chance, the center of the star was located at about column 441.5, hence the corrected profile for column 441 should match column 442.



The long tail is now gone and the central profile looks relatively similar to the unaffected column 442 profile. A potential problem with the procedure is the amplification of noise. This is most clearly seen by the behavior of the solid line from pixels 7 to 11.

4. How Charge Transfer Traps Affect Photometric and Astrometric Results

The object just above trap 2-637 in Figure 5 is a good example of how traps can affect the observations of point sources. While all the tails from cosmic rays disappear during cosmic ray removal, the tails on real objects appear in both exposures and hence are retained in the combined image. The effect on photometry, position, and size measurements will depend on several factors, including the strength of the trap, what part of the object falls on the bad column, and the technique for measuring the object (e.g., the size of the aperture).

In the case of the object above trap 2-637, the photometric magnitude measured within a 6-pixel aperture (i.e., radius = 3 pixels) is about 0.1 mag fainter than it should be, due to the tail taking light out of the aperture. The FWHM is increased from 1.5 pixels to 2.2 pixels.

Using **fixpix** to interpolate across the bad column makes things even worse, with the magnitude being 0.4 mag too faint, a positional shift of 0.5 pixels in the X direction (i.e., the interpolation makes the measurement very sensitive to slight asymmetries in the two adjoining columns), and an increase in the FWHM to 2.9 pixels.

Using the reconstruction formula (described earlier) to correct for the trap provides quite accurate corrections for the photometry and FWHM determination, (i.e., to a few percent).

Another relevant question is what percentage of objects are affected by charge transfer traps. There are only about 10 traps that are bad enough to cause easily measured effects, compared to the total of 4 x 750 = 3000 columns. If we assume the average trap is at row 400, and the average width of a target of interest is 6 columns, we would predict that about (10 x 1/2 x 6) / 3000 = 1/100 objects would be affected. This appears to be a fairly good estimate, based on our experience of doing photometry on point sources.