Locating Traps for DES CCD's

S. Kuhlmann and H. Spinka
High Energy Physics Division
Argonne National Laboratory, Argonne, IL 60439

and

J. Estrada and D. Kubik
Fermi National Accelerator Laboratory, Batavia, IL 60510

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Abstract

A summary of the method used to identify traps in DES CCD's is described in this note, along with some unexpected observations during pocket pumping runs.

1. Introduction

Testing for "traps" in the DES CCD's is important to verify that few of these exist in each chip and to document their location. The traps prevent 100% charge transfer efficiency during readout, and thus could distort the image recorded from the telescope. They extract up to a fixed quantity of charge as the pixel data are clocked past the trap pixel, and then release the charge into following pixels. Details of various types of traps are given in Janesick (Ref. 1).

A technique termed "pocket pumping" is used to help locate and characterize the traps. First the CCD is exposed to an approximately constant light level per pixel. Then the CCD is clocked backwards by N rows (N usually is 10 for current studies), then forwards by N rows, and this is repeated for many cycles before the CCD is finally read out in the usual fashion. The charge builds up at the trap pixel (forward traps) or N rows away (reverse traps), and is depleted in nearby pixels. In general, the height of the charge buildup is dependent on the trap size, the illumination level, and the charge emission time constant.

Typically many pocket pumping runs are collected for each CCD, and medians from five runs are summed for the analysis. These five are generally taken from the middle of the set of runs. They are analyzed using C++ and ROOT software as described in this note.

A set of definitions is given in Sec. 2, which is followed by a description of the method to identify traps in Sec. 3. Examples and a table of results from five CCD's follow in Sec. 4 and Appendix A. Other appendices, including one (B) with some unexpected observations from CCD pb-22-13, conclude the note.

2. **Definitions**

The trap software attempts to distinguish true trap candidates from other conditions commonly encountered in the CCD's. These other conditions include "skyscrapers," "hot columns," and "light bulbs," and are described later. In addition, the trap candidates can be subdivided into three classes – "classic traps" (Fig. 1), "fireflies" (Figs. 2 and 3), and isolated "hot pixels."

Classic traps that are strong or deep will remove all the charge from the pixels in the N rows of the same column, with the enhanced pixel at one end or the other of the depleted set as seen in Fig. 1. Those that are not as strong will deplete charge from fewer pixels. The examples shown in Fig. 5.29(a) of Janesick (Ref. 1) are of this type, and there is a gap between the depleted pixels and the peak pixel. We have encountered *only one* such example, in CCD pb-22-01. Appendix C includes an explanation and table of pocket pumping similar to Fig. 5.28 of Ref. 1, using DES numbering conventions.

The fireflies are probably weak or shallow traps with short emission time of the trapped charge compared to the pixel clocking time. The most common type (including the mirror image) is shown in Fig. 2. This differs from traps shown in Janesick (Ref. 1), where the depleted and enhanced pixels would be expected to be about N rows apart. Other types of fireflies that are probably related are shown in Fig. 3, though it is not understood how these are formed. The right-most double firefly in Fig. 3 is the least common.

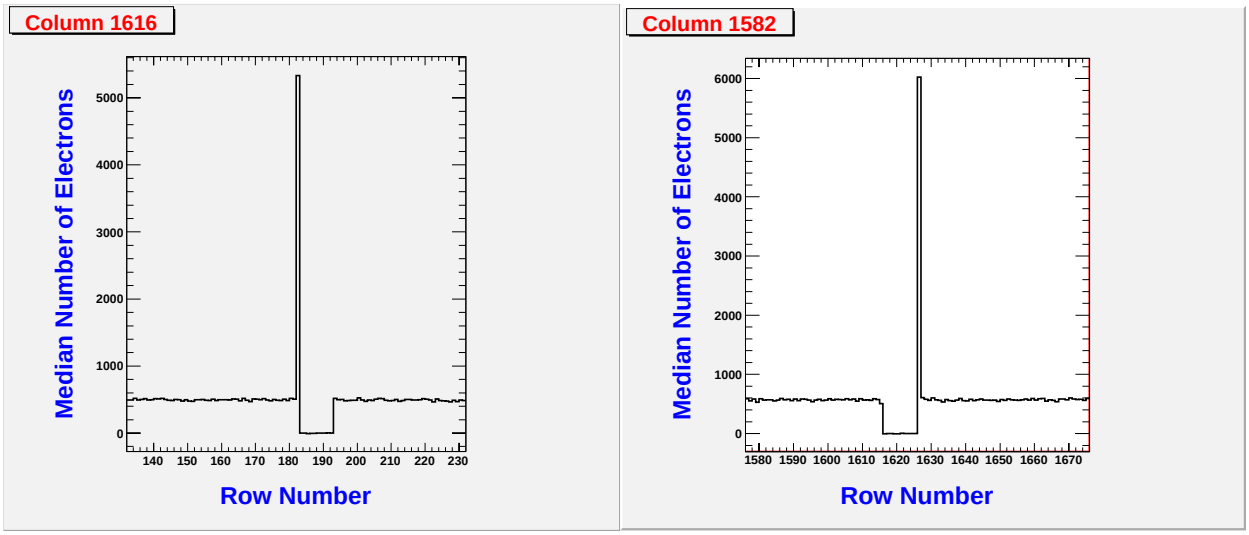

*Fig. 1. Classic traps in DES CCD's pb-22-13 (left) and pb-22-01 (right). Pocket pumping by 10 rows occurred for these data, and pedestal subtraction was performed. It can be seen that the charge from10 pixels is removed and appears in a single pixel. The left figure is believed to correspond to a forward trap, and the right figure to a reverse trap (*** check ***).*

Finally, hot pixels appear to be an isolated pixel with much larger median number of electrons than average, and with no neighboring low pixel(s) within ±N rows in the same column. These are not believed to be true traps. Given the observed variations in trap shapes, we have not found a robust way to reject the hot pixel events while retaining all the true traps and fireflies. This has not been a major concern for DES since the hot pixels are usually also identified in cosmetic defect tests.

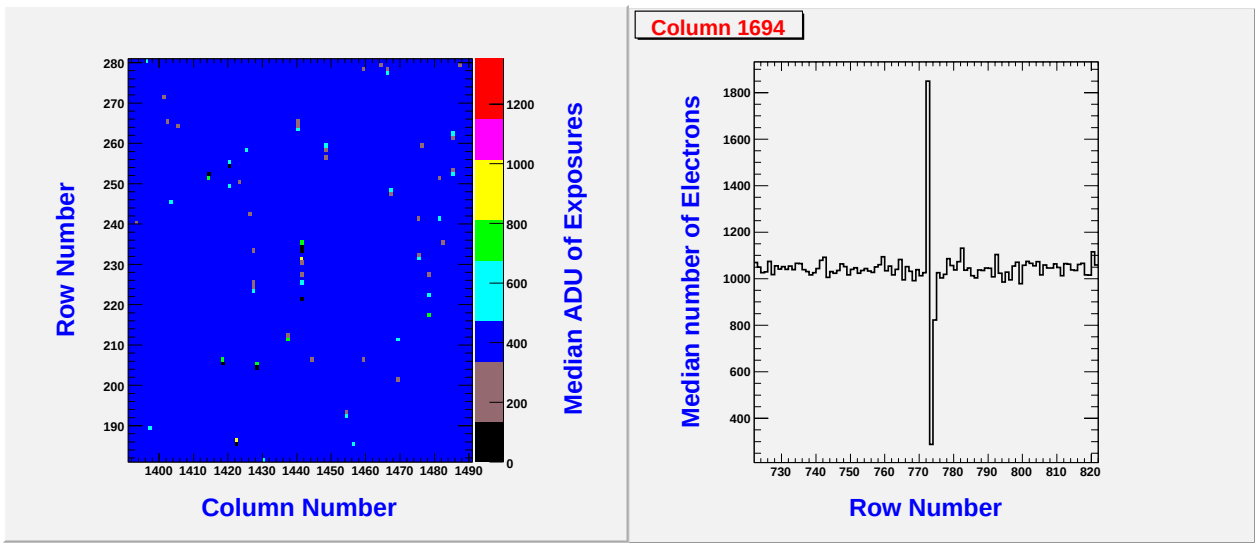

Fig. 2. Two dimensional histogram of a portion of DES CCD pb-22-13 showing many "fireflies" in the observed region (left). On the right is a single column display of a single firefly from CCD pb-22-26.

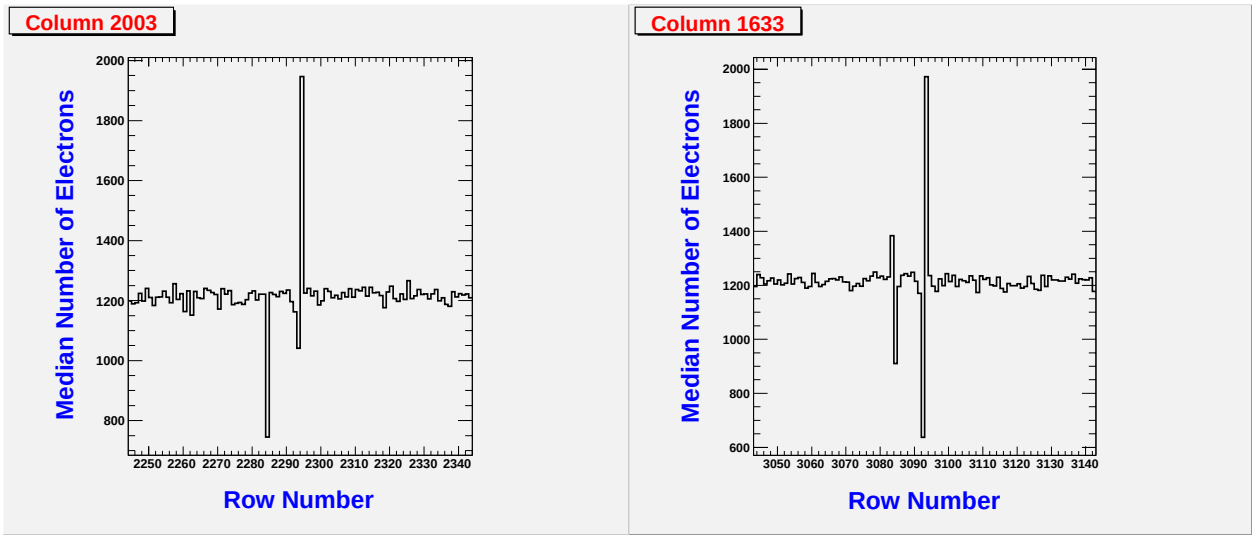

Fig. 3. Additional examples of fireflies. The leftmost is from DES CCD pf-24-28 and has a high pixel, and a neighboring low pixel, plus a low pixel about 10 rows away. The rightmost figure is also from CCD pf-24-28 and has two high and two neighboring low pixels.

Skyscrapers appear to originate from hot pixels that inject extra charge every time a pocket pumping operation is performed. Two examples are shown in Fig. 4. Hot columns have all pixels above a particular row in a column significantly above the mean value of surrounding pixels. Light bulbs are two dimensional regions of hot pixels, while hot columns are one dimensional.

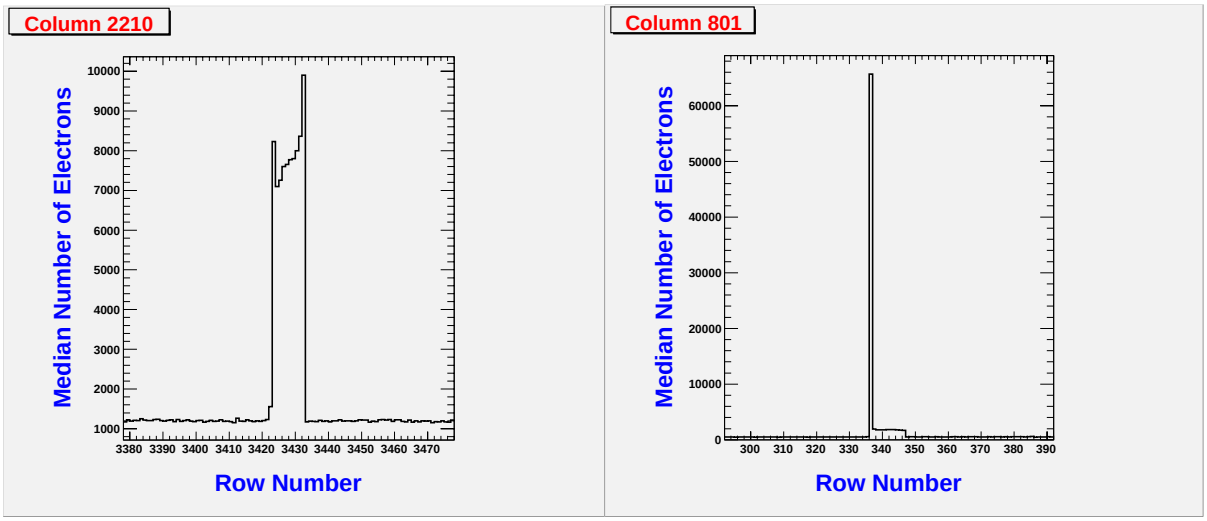

Fig. 4. Examples of skyscrapers from DES CCD's pf-24-28 (left) and pb-22-13 (right).

3. **Method to Identify Traps**

This section describes the present method used to identify traps and provides some justifications for the techniques employed. The steps include :

- For each pixel, compute the median ADU (analog to digital converter unit) for five exposures or sets of runs. Subtract pedestals from overscan regions.
- Correct these median ADU's for the separate gains (number of electrons per ADU) on the left and right sides of the CCD.
- Find the "Mean" of the gain-corrected pixel medians.
- For each pixel with gain-corrected median above the "Mean" + 700 electrons
    - i. If there are less than 2 additional pixels above "Mean" + 100 electrons for ±10 pixels in the same column AND
    - ii. If there are less than 2 additional pixels above "Mean" + 100 electrons for ±10 pixels in the same row THEN
    - iii. Call the pixel a TRAP.
    - iv. Otherwise, call it a skyscraper, light bulb, or hot column.

The choice of 700 electrons above the "Mean" is somewhat arbitrary, but corresponds to the expected sky background for DES in the g-band. A histogram of the gain-corrected medians from a typical CCD is shown in Fig. 5 before and after removal of skyscrapers, hot

column and light bulb pixels. In that case, pixels with medians above 1250 electrons would be considered trap candidates, and most are skyscrapers for this particular CCD. Excluding cases with hot columns or light bulbs, the number of pixels passing the "Mean" + 700 electron cut is usually less than 100. However, we have studied only a few CCD's so far.

Pixels in hot columns would be removed by the condition of the 2 additional pixels in the same column (i) above, and light bulbs by either or both the row / column conditions (i, ii). An unusual skyscraper in DES CCD pb-22-01 led to the adoption of the details for the conditions above. A two dimensional display of a region near this skyscraper is shown in Fig. 6 and one column histograms are given in Fig. 7. These are the typical five run medians with pedestal subtraction, and gain correction. It can be seen that four columns are affected and that without the condition (ii) on the pixels in the same row, two pixels in column 323 (and 326) would qualify as a trap; the other pixels in that column have gain-corrected median ADU's less than the "Mean" + 100 electrons.

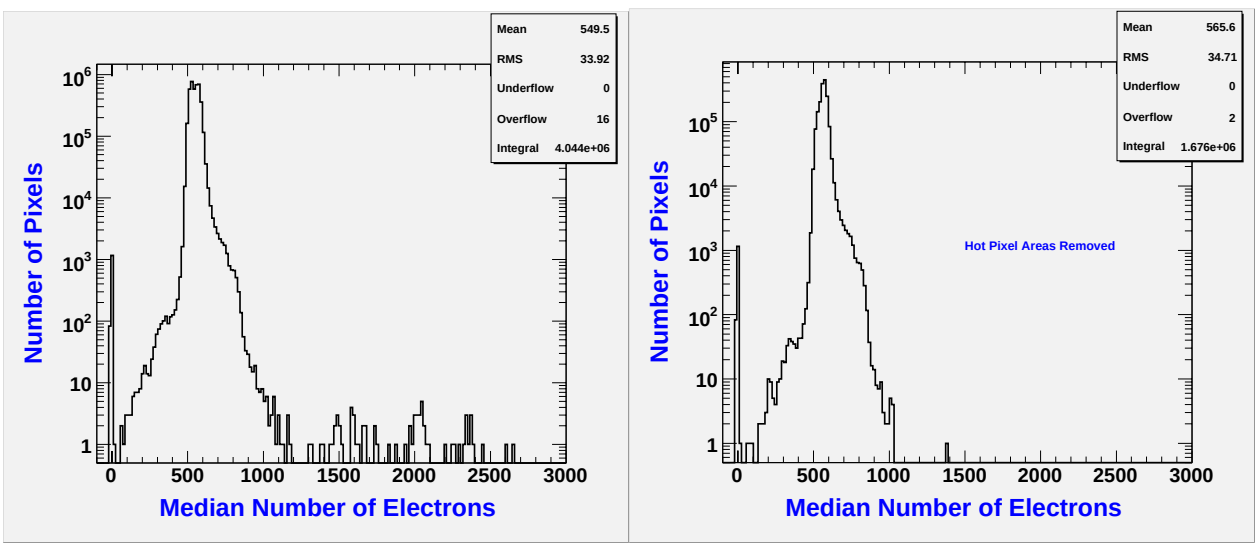

Fig. 5. Distribution of the median number of electrons from five pumping runs from DES CCD pb-22-01 – left with all pixels and right with skyscrapers etc. removed. Those with medians above 550 + 700 = 1250 electrons are considered possible trap candidates. For this particular CCD, only 3 remain after all conditions, while 83 are assigned to skyscrapers. Note there are 16 overflows in the left and 2 in the right histogram.

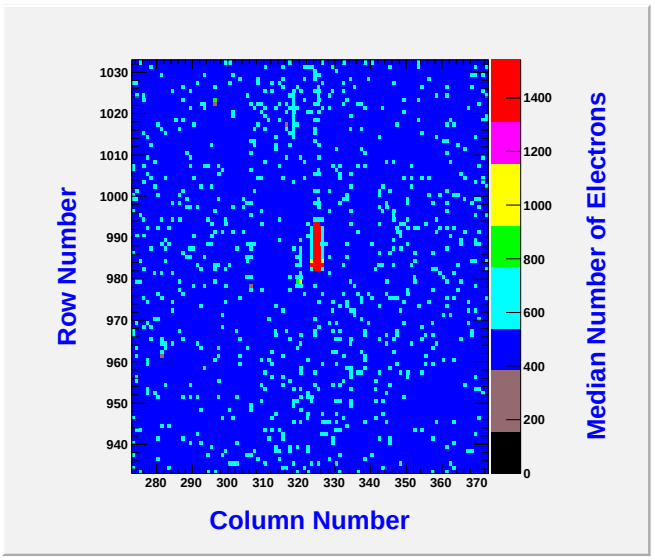

Fig. 6. Two dimensional display of the median ADU per pixel in the region of a skyscraper spanning four columns and a number of rows in DES CCD pb-22-01. In the outside two columns, the two high pixels would have been considered traps without condition (ii).

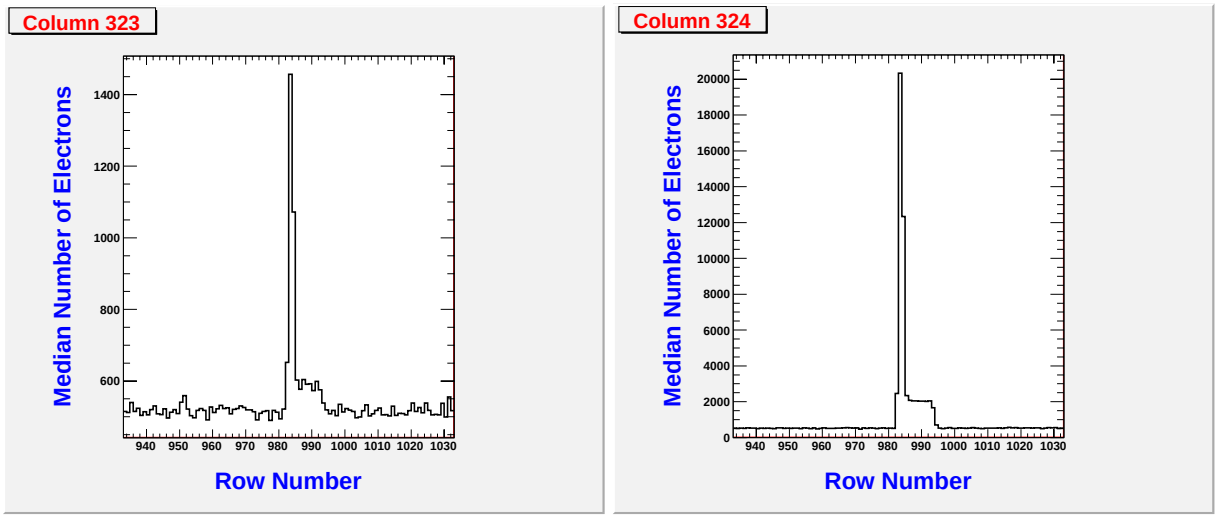

Fig.7. One dimensional histograms of two columns from Fig. 6 after pedestal subtraction and gain correction. The two high pixels in the left figure would have passed the trap cut in condition (i), but fail when adding condition (ii). The right figure shows the neighboring column, where many higher pixels are apparent in this skyscraper. Note these skyscraper pixels are included in Fig. 5 beyond 1250 electrons.

4. <u>Summary of Results</u>

A total of five DES CCD's were studied with pocket pumping to search for traps. One of the CCD's (pb-22-13) was measured twice. The results are summarized in the table below.

Details of the particular runs used, the left and right side gains, the mean number of electrons for all pixels, and (*** anything else from the logbook ?? light level ??***) are provided in Appendix A.

CCD	No. Traps	Skyscrapers	Comments
pb-22-01	3	83	1 firefly, 1 partial trap, 1 classic trap
pb-22-09	0	4	
pb-22-13	1, 3	28, 637	1 classic trap, 1 small skyscraper, 1 ???
pb-22-26	3	78228	Light Bulb, 2 fireflies, 1 hot pixel at edge
pf-24-28	35	4271	1 classic trap, various fireflies, hot pixels

CCD's pb-22-01 and pb-22-09 had few traps or skyscrapers. Two of the traps in pb-22-01 were classic – one strong, and the other not depleting the charge in all N = 10 pixels in the column with the trap. The third trap was a firefly near the edge of the CCD. Most of the skyscrapers for pb-22-01 are shown in Figs. 6 and 7. The four skyscrapers of pb-22-09 are located close together as well, in three neighboring columns. One has a long tail toward high row numbers with extra counts that do not pass the condition to be considered a trap.

The other three CCD's all appear to be special cases. CCD pb-22-26 was a special test case with a "light bulb" present, and the software successfully removed 78225 out of 78228 pixels corresponding to this feature. CCD pf-24-28 had a large number of skyscrapers, but about 4100 of the 4270 skyscraper pixels actually corresponded to hot columns 1687, 2135, and 2140. It also had one classic trap, 9 fireflies, and 25 hot pixels, where essentially all of these were located in a restricted area of the CCD; see Fig. 8. Finally, CCD pb-22-13 has a classic trap (Fig. 1) observed in both sets of runs separated by about 6 months, plus a trap/skyscraper (identified differently in the two runs, but found to be in the same location – see Fig. 9 in Appendix B), and an unusual feature described further in Appendix B.

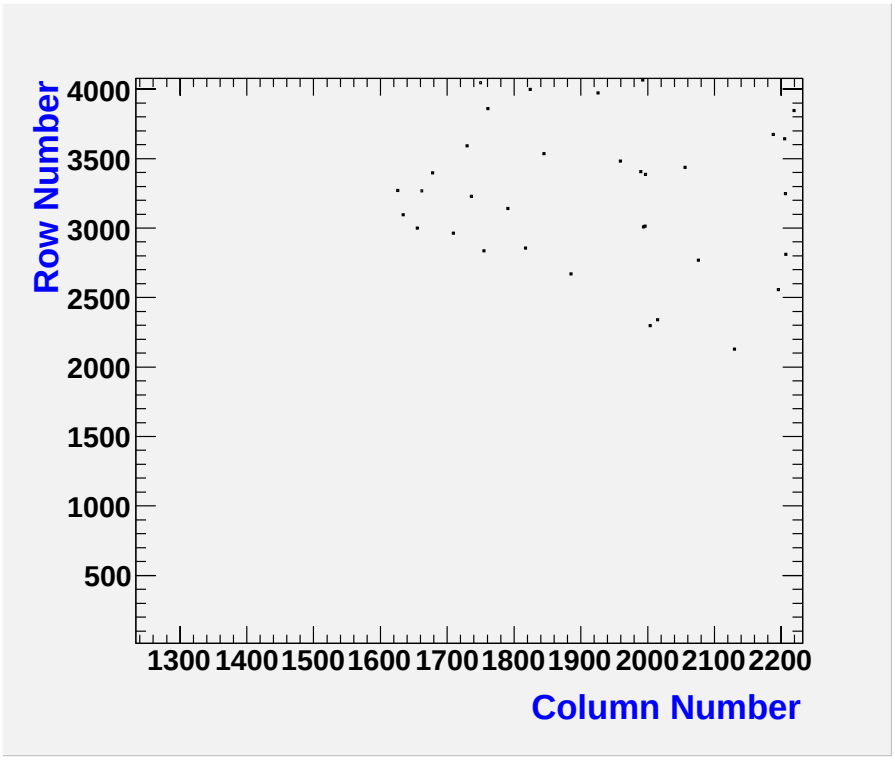

Fig. 8. Location of all but one trap in DES CCD pf-24-28. This concentration of traps has not been observed in other CCD's studied so far. The remaining (classic) trap is in column 126 and about row 340.

5. Appendix A. – Additional Details for the CCD Measurements

Some additional details of the runs, dates and files, and gains of the two sides (left and right) for the CCD's studied are included in the table below. There were always five runs used, spaced by four. Thus, for pb-22-01, runs 016, 020, 024, 028, and 032 were actually included in the analysis. The gains are listed either as a single number or as a product. In the second case, the factor of 2.5 was applied to the gain data in the software, whereas in the first case a factor of 1.0 was used.

_	Date	Runs	Gain_L	Gain_R
pb-22-01	08Nov2007_2	016 – 032	1.769	1.563
pb-22-09	16May2007_4	060 – 076	1.718	1.647
pb-22-13	08Jun2007_1	506 – 522	1.707	1.750

pb-22-13A	30Jan2008 trapQpump	012 – 028	2.5 * 0.7732	2.5 * 0.7877
pb-22-26	04Feb2008 _1Qpump	016 – 032	2.5 * 0.729	2.5 * 0.716
pf-24-28	11Dec2007_7	820 - 836	2.5 * 0.729	2.5 * 0.7164

6. Appendix B. – Some Unusual Observations in CCD pb-22-13

In addition to the classic trap in CCD pb-22-13, a skyscraper in the earlier runs was later identified as a trap; see Fig. 9. Note that t he numbering of the columns changed because of a switch between the left and right read-out between the two measurements. (The sum of the column numbers for the two cases is 2247.)

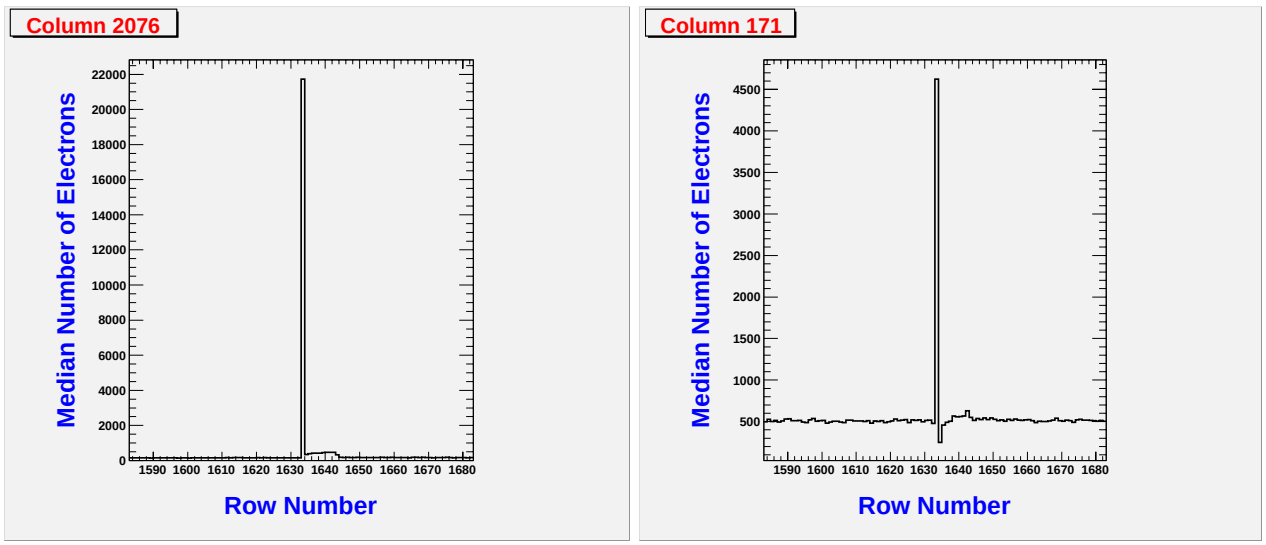

Fig. 9. Median number of electrons for DES CCD pb-22-13 from two measurements. The column number changed because of a left-right switch in read-out. In one case, this was called a skyscraper and in the other a trap.

Unusual behavior was also observed for DES CCD pb-22-13 in three adjacent columns. Figs. 10 – 12 show the comparison of the median number of electrons in each of the three columns. It can be seen that the response for the two measurements is somewhat different, and in neither case did these appear similar to other traps. However, charge seems to have been lost during the pocket pumping.

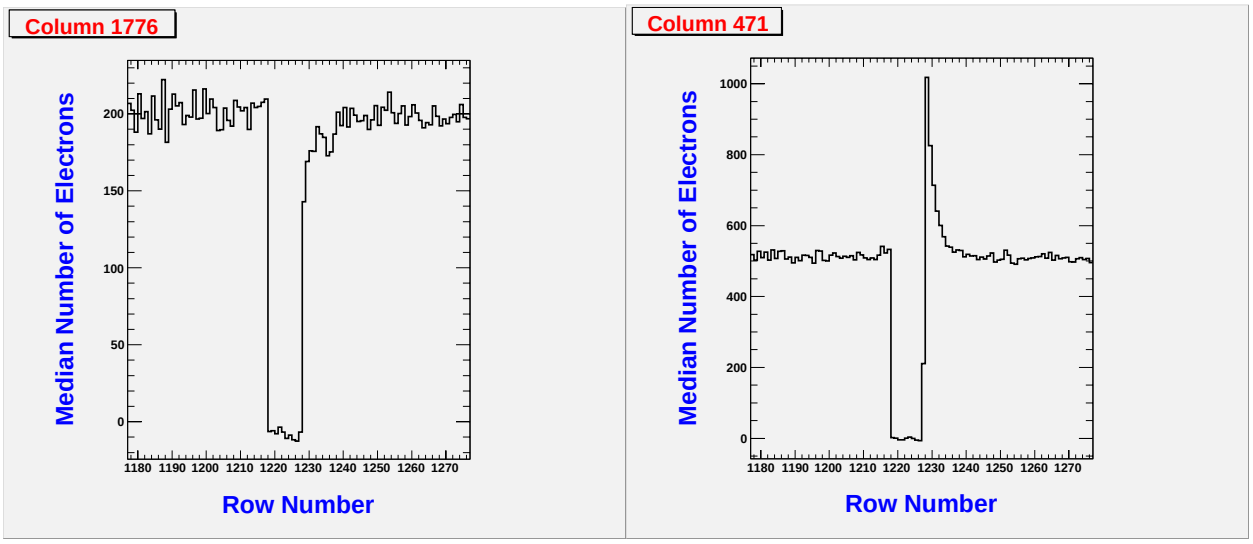

Fig. 10. Comparison of the median number of electrons for CCD pb-22-13 for two different measurements. These single-column histograms correspond to the same physical column in the CCD. Note the difference in shape and the ten pixels with depleted charge.

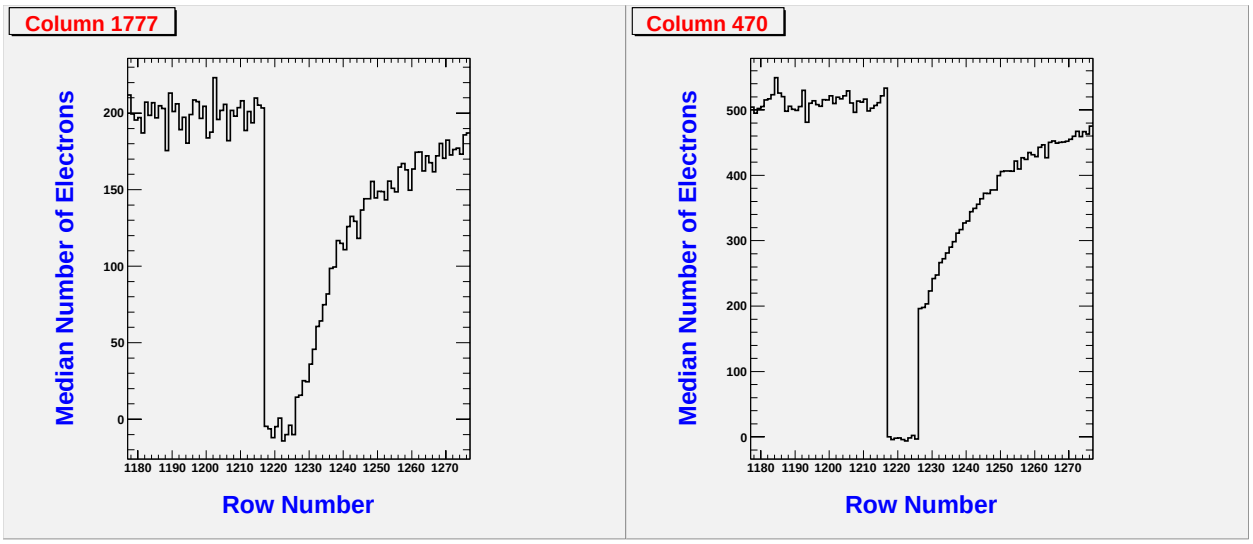

Fig. 11. Similar comparison as shown in Fig.10 but for an adjacent column. Note the difference in shapes again for the two different measurements. Charge is depleted over a large number of pixels in this column.

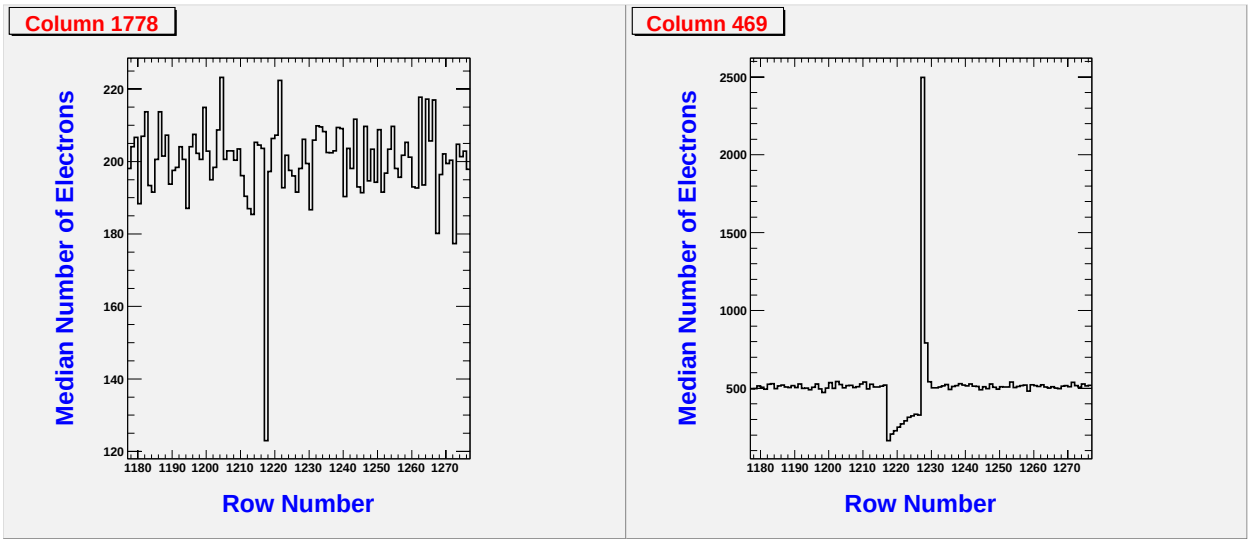

Fig. 12. Similar comparison as shown in Fig. 10, but for a third column. The right figure is suggestive of a trap, but the pixels are not completely depleted of charge and the fractional depletion changes. No suggestion of a trap is present in the other measurement.

7. Appendix C. – Simulation of Pocket Pumping

A simulation was performed similar to that shown in Janesick (Ref. 1) Fig. 5.28, but with the row numbering convention from DES, and a smaller size trap (1 electron, rather than 7). The results are shown below for a reverse trap (one that traps charge only on clocking in the reverse direction, that is to larger row numbers) with a large emission time constant. The first row gives a constant illumination for each of 10 pixels or rows in a particular column. This example uses N = 4 pocket pumping for ease of illustration. Thus, the first four operations are reverse clocking, and the next four are forward clocking. A total of three complete cycles is shown.

In the first step (reverse clocking), the trap in row 6 has retained one electron from the original 10 and passed on the remaining 9 to the pixel in row 7. In the next three steps, the trap in row 6 retains 1 electron from the 11, and passes on 10 electrons to row 7. In the next four steps of forward clocking, all pixels just pass the charge to the next lower numbered row; the reverse trap does not retain any charge when clocking in this direction.

Note that after complete cycles, the peak and the dip are separated by N = 4 rows, and the peak is NOT in the location of the trap (row 6), but rather is offset from it. If this process were to be continued for many cycles, the dip would become depleted of charge, and adjacent rows would then similarly become depleted, as described in Janesick (Ref. 1).

	Row Number											
SHIFT	1	2	3	4	5	6	7	8	9	10		
1	10	10	10	10	10	10	10	10	10	10	Exposure	
2	10	10	10	10	10	11	9	10	10	10	Reverse	
3	10	10	10	10	10	11	10	9	10	10	Reverse	
4	10	10	10	10	10	11	10	10	9	10	Reverse	
5	10	10	10	10	10	11	10	10	10	9	Reverse	
6	10	10	10	10	11	10	10	10	9	10	Forward	
7	10	10	10	11	10	10	10	9	10	10	Forward	
8	10	10	11	10	10	10	9	10	10	10	Forward	
9	10	11	10	10	10	9	10	10	10	10	Forward	End 1 cycle
10	10	10	11	10	10	11	8	10	10	10	Reverse	
11	10	10	10	11	10	11	10	8	10	10	Reverse	
12	10	10	10	10	11	11	10	10	8	10	Reverse	
13	10	10	10	10	10	12	10	10	10	8	Reverse	
14	10	10	10	10	12	10	10	10	8	10	Forward	
15	10	10	10	12	10	10	10	8	10	10	Forward	
16	10	10	12	10	10	10	8	10	10	10	Forward	
17	10	12	10	10	10	8	10	10	10	10	Forward	End 2 cycle
18	10	10	12	10	10	11	7	10	10	10	Reverse	
19	10	10	10	12	10	11	10	7	10	10	Reverse	
20	10	10	10	10	12	11	10	10	7	10	Reverse	
21	10	10	10	10	10	13	10	10	10	7	Reverse	
22	10	10	10	10	13	10	10	10	7	10	Forward	
23	10	10	10	13	10	10	10	7	10	10	Forward	
24	10	10	13	10	10	10	7	10	10	10	Forward	
25	10	13	10	10	10	7	10	10	10	10	Forward	End 3 cycle

Table 1. Simulation of reverse trap with N = 4 pocket pumping. The initial illumination of 10 electrons is assumed, and the trap is assumed to be in row 6. Note that after complete cycles, the peak is displaced from the trap.

8. **Appendix D.**

References

1. J.R. Janesick, "Scientific Charge-Coupled Devices," SPIE Press, Bellingham, WA (2001).