

Snowballs in Euclid and WFIRST Detectors

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ABSTRACT

Snowballs are transient events observed in HgCdTe detectors with a sudden increase of charge in a few pixels. They appear between consecutive reads of the detector, after which the affected pixels return to their normal behavior. The origin of the snowballs is unknown, but it was speculated that they could be the result of alpha decay of naturally radioactive contaminants in the detectors, but a cosmic ray origin cannot be ruled out. Even though previous studies predicted a low rate of occurrence of these events, and consequently, a minimal impact on science, it is interesting to investigate the cause or causes that may generate snowballs and their impact in detectors designed for future missions. We searched for the presence of snowballs in the dark current data in Euclid and Wide Field Infrared Survey Telescope (WFIRST) detectors tested in the Detector Characterization Laboratory at Goddard Space Flight Center. Our investigation shows that for Euclid and WFIRST detectors, there are snowballs that appear only one time, and others that repeat in the same spatial localization. For Euclid detectors, there is a correlation between the snowballs that repeat and bad pixels in the operational masks (pixels that do not fulfill the requirements to pass spectroscopy noise, photometry noise, quantum efficiency, and/or linearity). The rate of occurrence for a snowball event is about 0.9 snowballs/hr. in Euclid detectors (for the ones that do not have associated bad pixels in the mask), and about 0.7 snowballs/hr. in PV3 Full Array Lot WFIRST detectors.

Keywords: Euclid, WFIRST, snowballs, MCT

1. INTRODUCTION

Several authors have noticed the appearance of snowball events in HgCdTe photodiode arrays in the past. These features were observed, for example, in $\langle i \rangle V V \backslash Y \backslash G d U W$ Wide Field Infrared Survey Telescope (WFIRST) detectors, and in the NIRSpec and NIRCams instruments of the James Webb Space Telescope (JWST). In all cases, they had low rates of occurrence, and it was very difficult to present a clear picture of what may be the source of the snowball. During the past years, several hypotheses have been proposed about its origin, from decay of radioactive contaminants to cosmic rays.

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In our work, we investigated the presence of these artifacts in Euclid and WFIRST detectors. These detectors have been characterized during the last 3 years at B 5 G 5 Goddard Space Flight Center. Euclid is a European Space Agency (ESA) mission designed to accurately measure the expansion history of the universe and the growth of cosmic structures. The Euclid instruments are provided by the ESA member states, with NASA contributing to the NISP (near-infrared spectrometer and imaging photometer). WFIRST is a NASA observatory designed to perform wide-field imaging and spectroscopic surveys of the near infrared sky. The main goal of the mission is to answer essential questions in exoplanet and dark energy research and will advance topics ranging from galaxy evolution to the study of objects within the Galaxy and within the Solar System.

B. Hilbert¹ searched for snowballs within two epochs of WFC3 data. The first data set was taken in the Detector Characterization Laboratory (55 hours) and the second came from the instrument thermal test (45 hours). He found a snowball rate between 0.4 and 0.8 snowballs per hour. A snowball affected between 11 and 34 pixels in those detectors, and contains between 200,000 and 900,000 electrons.

After compiling different pieces of evidence, P. McCullough² extensively discussed the possibility that the snowballs could be originated by alpha particles emitted from either naturally radioactive thorium and/or uranium, and/or unknown radionuclides inside the HgCdTe detector, at ~ 1 ppm concentrations within the device.

Later, M. J. Durbin et al.³ created a catalog of 7392 snowball detections based on all in-flight WFC3 data (6200 hours of exposure time). They concluded that the rate at which snowballs were observed was approximately constant over time, suggesting that if the source of snowballs is radioactivity in the detector or bonding material, the primary contaminant is U-238.

On the other hand, B. J. Rauscher, et al.⁴ observed that the snowball rate in the NIRSpec instrument of the JWST, went down with time, with a decay rate that is consistent with known radioactive isotopes that are used during the fabrication process at the detectors. They predicted that when JWST flies in 2018, the snowball rate would be negligible. (The JWST launch date has subsequently slipped and is now 2020).

B. Hilbert⁵ searched for snowballs in NIRCam ground testing data. Examining a total of at least 32.6 hours of exposure time for each of nine of the NIRCam detectors, he found that snowballs appear in the data at a rate of $0.2 \text{ } \dot{\pm} \text{ } 0.6$ snowballs per hour. Typical snowballs in the shortwave detectors covered an area of roughly 250-400 pixels and contained 280,000 $\dot{\pm}$ 490,000 DN. On average, snowballs in the longwave detectors were roughly the same size, but brighter by about a factor of two. Several of the snowballs he observed were repeaters, falling on the same location of a previous snowball. He concluded that radioactive decay from within the detector material, may be the source of the snowballs.

For WFIRST engineering detectors 18241, 18242, and 18244, D. Cottingham⁶ reported a rate between 0.5 and 1 snowballs per hr., for snowballs with charge deposited larger than 10^5 electrons and at least 9 pixels affected. The method of analysis is similar to this paper. In addition, data from engineering MCT detectors manufactured by Raytheon, and from a total of 208 hours of darks on four different detectors found a rate of 0.03 to 0.2 snowballs/hr for deposited charge greater than 10^5 electrons.

In this work, we quantified the presence of snowballs in Euclid and WFIRST detectors. We discussed the rate, pixels affected, total charge deposited, spatial distribution, and if the snowballs repeat or not at the same localization. With the goal to find out the origin of snowballs events, we analyzed their correlation with bad pixels in the operational mask (for Euclid detectors), and we compared snowballs with cosmic ray events, to evaluate if the first could be subsets of the second.

This paper is organized as follows: in the next section, we describe the data used for our snowball search; in section 3, we outline the method and algorithm used in our search; section 4 compiles our findings for Euclid and WFIRST detectors. Finally, we discuss our results in section 5.

2. DATA COLLECTION

The data used for this analysis was collected in the Detector Characterization Laboratory (DCL) of B 5 G 5 Goddard Space Flight Center (GSFC) between 2015 and 2018.

In the case of Euclid detectors, we searched for snowballs in the data from Sensor Chip Subassemblies (SCS) classified U g ' í Zrãdē] [" \ 19 U [Wonsistōt a Sensor Chip Assembly (SCA), SCE/SIDECAR ASIC, connected together with a Cryo Flex Cable (CFC). Euclid detectors are 2048x2048 HgCdTe photodiode arrays with pixel pitch of 18 μm . The detectors are surrounded by a band of reference pixels. These pixels are not light sensitive and are used to correct the remaining 2040x2040 pixels. All Euclid flight detectors were tested in the Big Dewar of the DCL, which allows simultaneous testing of four SCS. We performed six Flight Runs (FR), with each run consisting of four SCS. The Euclid Flight detectors were operated at a temperature of 100K, a detector bias of 0.5V, a gain setting of 15dB, and a frame time of 1.4548 seconds. In Flight Run 2, one of the detectors, SCS 18275_005-2_0007F020, was an engineering unit. After the initial cool down and optimization of all SCS units it was determined that the engineering SCS did not function at the operating temperature, and it was powered down to enable testing of the remaining detectors. In Flight Run 6, one of the units incorporated the newly designed and assembled Option B SCE, but with a non-flight SCA. We did not perform snowball searches in either of these two detectors.

We searched for snowballs in 2-hour dark current data, to assure low background signal. Each exposure of dark data consisted of 10 saved frames with 549 dropped frames between saved frames, uniformly spaced over 2 hours. Table 1 summarizes the total number of hours where we searched for snowballs in each Flight Run of Euclid detectors.

The WFIRST detectors are 4096x4096 HgCdTe photodiode arrays with pixel pitch of 10 μm . As with the Euclid detectors, the image pixels in WFIRST detectors (4088x4088 array) are surrounded by a band of reference pixels. We performed several tests of WFIRST detectors in different Dewars at the DCL (HyC, IR4, and JMAPS), at different temperatures and biases. For our snowball search, we only used the 2-hour dark current data collected at 100 K and detector bias of 1.0 V, with a frame time of 5.4 seconds. For each 2-hour dark exposure, we took 101 frames with 13 drops between frames uniformly spaced over 2 hours of exposure time (sample up the ramp).

We looked for snowballs in the WFIRST PV3 full array lot detectors. This lot consisted of 13 engineering-grade SCAs, but only 11 were analyzed for snowballs due to performance problems with two detectors. Table 6 shows the total number of hours of dark current data used to search for snowballs in each WFIRST detector.

We also looked for snowballs in the engineering WFIRST PV2A detector 18138 that was tested several times between August 2016 and May 2017 at the DCL. We analyzed a total of 94 hours of dark current for this detector.

3. METHOD AND ALGORITHM APPLIED

For each ramp of 2-hour dark current data, for both Euclid and WFIRST detectors, we applied the standard method of reference pixel correction and conversion gain.

We selected a snowball event if it met the following criteria: the value of the pixel was above the Gaussian mean plus 50 times the Gaussian standard deviation of the background signal level in the frame; the pixel exceeded this threshold less than 70 percent of the time (to avoid hot pixels); the event was kept only if the 4 nearest neighbor pixels were above the Gaussian mean plus 25 times the Gaussian standard deviation of the signal level in the frame; and if the second nearest

neighbors were above the Gaussian mean plus 10 times the Gaussian standard deviation in the frame. We only reported results if the total charge collected in the event was greater than 10^5 electrons, and the size of the snowball was larger than 9 pixels. To count an event as a snowball we considered only those that are circular in shape, and not the ones that appear elongated, as in cosmic rays impacts.

For all cases, after applying this algorithm to the data, we performed a visual check to verify the presence of a snowball event.

We computed for each snowball its localization, number of pixels affected, total charge, and the time when the snowball appeared. We also recorded if the snowball repeated at the same spatial localization. For the case of the events that repeated in the same position, we looked at the flat field to see if these events corresponded to any visible feature in the detector.

In the case of Euclid detectors, we also took into account if the central pixels in the snowballs were correlated to bad pixels in the operational mask (pixels that do not fulfill the requirements to pass spectroscopy noise, photometry noise, quantum efficiency, and/or linearity).

For the Euclid detectors of Flight Run 3, we also searched for cosmic rays traces and compared them with the snowballs found in the same detectors. As with snowballs, we performed a visual check for each of the cosmic rays found. The algorithm to search for cosmic rays was similar to the one used for our snowball compilation, but instead of looking for events of circular shapes we searched for elongated events where one axis was larger than twice the other axis, and as for snowballs, we recorded the cosmic ray events with deposited charge larger than 10^5 electrons.

4. RESULTS

4.1 Snowballs in Euclid detectors

After analyzing 600 hours of dark 2-hour data from Euclid Flight detectors, we found that the rate of occurrence of a snowball event is on average 1.34 snowballs per hour. If we remove snowballs that have central pixels that correlate with bad pixels in the operational mask (pixels that do not fulfill requirement for spectroscopy noise, photometry noise, linearity, and/or quantum efficiency) that value drops to 0.92 snowballs per hour.

Considering the size of the Euclid detectors (approximately 13.6 square centimeters), the rate of occurrence of a snowball event is 0.1 snowballs per hour per cm^2 for all events, and 0.07 snowballs per hour per cm^2 for events where the central pixels could not be associated with bad pixels in the operational mask.

As an example, Figure 1 shows the larger snowball that appeared in the detector SCS 18279_011-3_0020F038 during Flight Run 6.



Figure 1. Snowball in Euclid detector SCS 18279_011-3_0020F038 (81 pixels affected, charged deposited $\sim 3 \times 10^6$ e-).

Table 1 outlines our results for each detector. We found that on some occasions a snowball event repeats in the same location. A snowball that repeats is more likely to occur in pixels that are associated with bad pixels in the operational mask, as seen by comparing the last two columns of Table 1. For the snowballs reported in Table 1, we could not find any visible features in the flat fields of the detectors at the snowball positions.

We could not find any correlation in the elapsed time between two snowballs that appear at the same position, and we noticed that on some occasions, there are repetitions but with less deposited charge than 10^5 electrons.

Table 2 presents the average rate and standard deviation for each Flight Run, for snowballs that do not correlate with bad pixels in the operational mask. Notice that for Flight Run 2, we analyzed fewer detectors for fewer hours, so the discrepancy between this Flight Run and the others is larger, due to lack of enough statistics.

Figure 2 shows the position of snowball events for Euclid detectors in Flight Run 3, where we have more accumulated data. Blue dots correspond to the positions of snowballs that do not have central pixels associated with bad pixels in the operational mask, while orange dots correspond to snowballs with central pixels associated with bad pixels in the operational mask. The distribution of snowballs in these detectors is spatially homogeneous.

FR	detectors	total hours	Number of snowballs	snowballs/hr	Number of snowballs without bad pixels in op. mask	snowballs/hr without bad pixels in op. mask	Number of repeated snowballs with bad pixels in op. mask	Number of repeated snowballs without bad pixels in op. mask
FR1	18249_001-4_0008	018	20	2.50	9	1.13	8	4
FR1	18278_001-5_0010	014	8	1.00	3	0.38	0	0
FR1	18284_008-1_0012	016	29	3.63	7	0.88	23	0
FR1	18268_004-5_0014	018	5	0.63	4	0.50	0	0
FR2	18278_001-5_0013	048	10	1.25	7	0.88	3	0
FR2	18458_010-3_0015	019	37	4.63	19	2.38	17	2
FR3	18453_002-4_0019	030	113	1.88	77	1.28	29	18
FR3	18632_008-5_0020	039	52	0.87	52	0.87	0	0
FR3	18452_005-4_0021	060	43	0.72	41	0.68	2	0
FR3	18269_007-2_0023	049	52	0.87	51	0.85	0	0
FR4	18280_011-4_0019	037	45	1.13	45	1.13	0	1
FR4	18282_008-3_0020	039	56	1.40	50	1.25	3	10
FR4	18548_011-2_0021	040	45	1.13	38	0.95	6	9
FR4	18285_006-4_0023	049	25	0.63	25	0.63	0	0
FR5	18221_003-5_0019	030	16	0.80	16	0.80	0	0
FR5	18272_004-2_0020	039	15	0.75	15	0.75	0	0
FR5	18267_012-4_0021	040	12	0.60	11	0.55	0	0
FR5	18223_012-5_0023	049	22	1.10	22	1.10	0	2
FR6	18628_005-2_0019	037	16	0.67	13	0.54	2	0
FR6	18279_011-3_0020	039	21	0.88	21	0.88	0	2
FR6	18250_012-4_0023	049	26	1.08	23	0.96	3	6
Total		600	668	1.34	549	0.92	96	54

Table 1. Snowballs in Euclid Detectors. Columns are: Total hours analyzed, total number of snowballs, snowballs per hour, total number of snowballs without central pixels associated with bad pixels in the operational mask, rate of snowballs without central pixels associated with bad pixels per hour, number of repeated snowballs with central pixels that correlate with bad pixels in the operational mask, number of repeated snowballs without central pixels that correlate with bad pixels in the operational mask.

FR	snowballs/hour	standard dev
FR1	0.72	0.34
FR2	1.63	1.06
FR3	0.92	0.26
FR4	0.99	0.27
FR5	0.80	0.23
FR6	0.79	0.22

Table 2. Average rate of snowballs per hour and standard deviation for each Euclid Flight Run for snowballs that do not correlate with bad pixels in the operational mask.

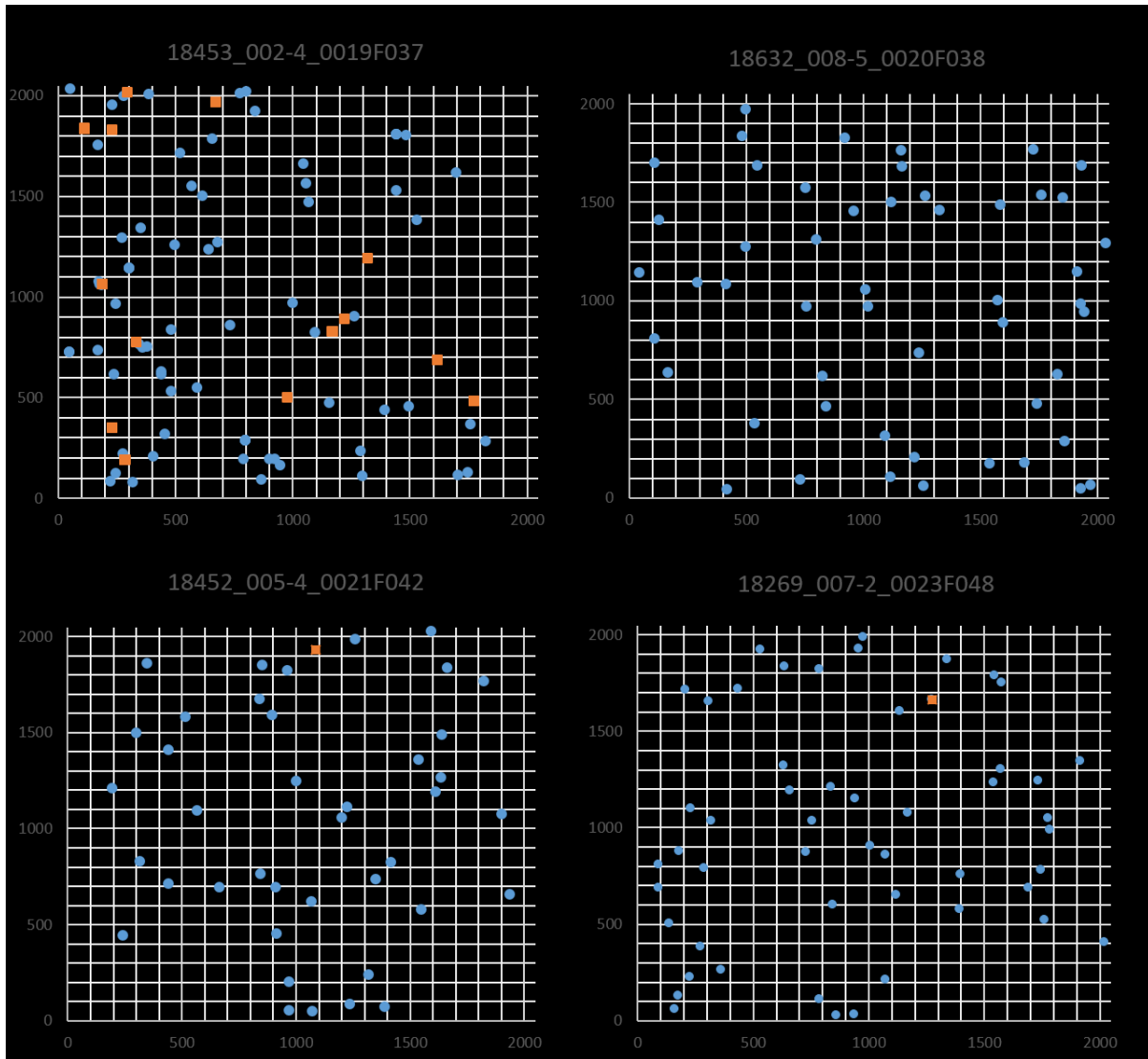


Figure 2. Spatial distribution of snowballs in detectors from Flight Run 3. Accumulation time: 60 hours.

The number of pixels affected in a snowball event (for charge deposited larger than 10^5 electrons) was on average 25 pixels. The maximum number of pixels affected, 126 pixels, occurred in detector SCS18632_008-5_0020F038 during Flight Run 3. The total charge deposited in a snowball event had a median of $\sim 6 \times 10^5$ electrons with an average maximum between all Euclid detectors of about 3×10^6 electrons. Table 3 summarizes the results for each detector, with the total number of hours analyzed, mean, median, standard deviation, maximum of pixels affected, and charge deposited. Note that the numbers for the charge deposited in a snowball event reported here are lower limits. The central pixels in the snowballs could be saturated; they do not collect more charge after saturation.

FR	detectors	total hours	pixels affected				charged deposited [e-]			
			mean	median	stddev	max	mean	median	stddev	max
FR1	18249_001-4_0008F015	8	30.4	26	9.7	49	8.60E+05	7.43E+05	2.88E+05	1.57E+06
FR1	18278_001-5_0010F014	8	24.5	25	5.6	32	6.86E+05	6.78E+05	2.33E+05	1.11E+06
FR1	18284_008-1_0012F016	8	27.3	29	7.7	44	7.77E+05	7.31E+05	2.55E+05	1.15E+06
FR1	18268_004-5_0014F017	8	21	20	7.2	28	6.09E+05	5.96E+05	2.68E+05	8.77E+05
FR2	18278_001-5_0013F043	8	31.6	28	9.9	45	6.57E+05	6.24E+05	2.36E+05	1.09E+06
FR2	18458_010-3_0015F019	8	25.4	26	10.8	46	7.60E+05	7.04E+05	3.82E+05	1.39E+06
FR3	18453_002-4_0019F037	60	44.6	36.5	21.2	99	7.87E+05	6.86E+05	3.14E+05	1.70E+06
FR3	18632_008-5_0020F038	60	38.7	33	20.2	126	7.15E+05	6.44E+05	2.70E+05	1.65E+06
FR3	18452_005-4_0021F042	60	41.5	35	21.7	123	7.28E+05	6.34E+05	3.44E+05	1.87E+06
FR3	18269_007-2_0023F048	60	33.7	30.5	14.4	77	6.23E+05	5.79E+05	2.36E+05	1.20E+06
FR4	18280_011-4_0019F037	40	24.1	22	8.5	48	7.00E+05	6.38E+05	3.50E+05	1.72E+06
FR4	18282_008-3_0020F038	40	24.7	22	9.2	53	7.75E+05	6.80E+05	3.24E+05	1.79E+06
FR4	18548_011-2_0021F042	40	22.73	20	6.9	38	7.05E+05	5.90E+05	2.76E+05	1.27E+06
FR4	18285_006-4_0023F048	40	21.48	21	4.7	34	6.67E+05	6.19E+05	2.16E+05	1.17E+06
FR5	18221_003-5_0019F037	20	24.4	21	10.2	55	7.17E+05	6.41E+05	3.07E+05	1.50E+06
FR5	18272_004-2_0020F038	20	20.3	19	6	37	5.90E+05	4.92E+05	2.45E+05	1.21E+06
FR5	18267_012-4_0021F042	20	20.7	21	6.3	30	6.45E+05	6.30E+05	2.21E+05	9.73E+05
FR5	18223_012-5_0023F048	20	24.8	21.5	13.3	70	7.25E+05	6.71E+05	4.13E+05	2.19E+06
FR6	18628_005-2_0019F037	24	22.2	19.5	8.4	45	6.60E+05	5.70E+05	2.57E+05	1.25E+06
FR6	18279_011-3_0020F038	24	24.7	20	14.3	81	8.08E+05	6.23E+05	6.14E+05	3.14E+06
FR6	18250_012-4_0023F048	24	23	20	9.9	51	6.98E+05	5.68E+05	3.65E+05	1.71E+06
Total:		600	27.23	24.57	10.77	57.67	7.09E+05	6.35E+05	3.05E+05	1.50E+06

Table 3. Mean, Median, Standard Deviation, Maximum Number of pixels affected, and charge collected in a snowball event for each Euclid detector. Pixel pitch: 18 μm .

To compare between snowball events and cosmic ray hits, we looked for cosmic ray events during Flight Run 3 using the same data set used in our snowball search. For a charge deposited larger than 10^5 electrons, Table 4 shows the number of snowballs and the number of cosmic rays found in each detector during 60 hours of data, while Table 5 compares the pixels affected. For the range of deposited charge we analyzed, cosmic rays hit the detector only 30% as often as snowballs events. In Figure 3 we plotted the deposited charge versus the number of pixels for each detector for snowball events and cosmic rays. From the mentioned figure (with the exception of a few cosmic ray events), the snowballs and the cosmic ray traces look like they come from different populations: snowballs need fewer pixels to collect the same amount of charge. As an example of a cosmic ray event, Figure 4 shows a huge cosmic ray that hit detector SCS 18269_007-2_0023F048 during Flight Run 3, with more than 300 pixels affected.

FR3 detectors	Total Number of snowballs	Number of snowballs without bad px in the mask	Total Number of cosmic rays
18453_002-4_0019F037	113	77	11
18632_008-5_0020F038	52	52	12
18452_005-4_0021F042	43	41	20
18269_007-2_0023F048	52	51	24

Table 4. Total number of snowballs and cosmic ray events (with deposited charge larger than 10^5 electrons) found during Flight Run 3.

Figure 7. Snowball in WFIRST PV3 detector 18237 (83 pixels, charge deposited $5.7e5 e^-$).

Table 6. Snowballs in PV3 Full Array Lot detectors: Total hours analyzed, total number of snowballs, snowballs per hour, number of non-repeated snowballs, non-repeated snowballs per hour.

As for Euclid detectors, we recorded the number of pixels affected and the charge deposited. Table 7 shows the results for each detector, with an average of about 42 pixels and a maximum of 112 pixels affected in detector 18438.

detectors	total hours	pixels affected				charged deposited [e-]			
		mean	median	stddev	max	mean	median	stddev	max
18237	26	59.5	59.5	33.2	83	4.08E+05	4.08E+05	2.34E+04	5.74E+05
18238	14	48.3	33.0	28.6	100	2.86E+05	2.09E+05	1.27E+05	4.92E+05
18239	8	34.7	35.0	8.5	43	1.76E+05	1.97E+05	5.84E+04	2.21E+05
18240	14	34.0	32.0	14.1	49	2.34E+05	2.49E+05	1.01E+05	3.28E+05
18241	28	37.5	33.0	15.4	85	2.00E+05	1.83E+05	6.24E+04	3.96E+05
18242	8	38.0	39.0	16.5	54	2.45E+05	2.37E+05	1.04E+05	3.54E+05
18243	14	37.2	33.0	15.1	88	2.20E+05	2.05E+05	8.51E+04	4.82E+05
18244	22	61.0	60.0	24.1	102	3.50E+05	3.58E+05	1.27E+05	5.55E+05
18438	40	39.6	32.0	21.4	112	2.15E+05	2.14E+05	6.50E+04	3.16E+05
18440	40	36.1	32.5	13.1	66	1.89E+05	1.69E+05	6.68E+04	3.27E+05
18443	40	34.8	35.0	8.5	51	2.01E+05	1.95E+05	6.44E+04	3.01E+05
Total	254	41.9	38.5	18.0	76	2.48E+05	2.39E+05	8.04E+04	3.95E+05

snowballs that repeat, but there were no evident features in the flat fields. Finally in detector 18443, there are 2 snowballs that repeated with nothing evident in the flat field.

For the PV2A detector (18138) we searched for snowballs in the six occasions this detector was tested between August 2016 and May 2017 in the HyC Dewar at the DCL. The snowball rate in this detector was low (0.28 snowballs per hour) and we could not see a decrease or increase in the snowball appearance during the time that was tested. Table 8 summarizes the results of the different runs where the detector was evaluated. Three snowballs repeated in this detector. Two snowballs repeated twice and one snowballs repeated three times. These repetitions occurred during the same run: two of them during the same exposure, and one of them in two consecutive exposures.

Table 8. Snowballs in PV2A detector 18138: Total hours analyzed, total number of snowballs, snowballs per hour, number of repeated snowballs (with number of repetitions for each case).

5. DISCUSSION

In this work, we searched for snowballs in Euclid and WFIRST detectors. After analyzing 600 hours of dark data from Euclid Flight Detectors, we found that the rate of occurrence of a snowball event (for a deposited charge larger than 10^5 electrons) is on average 1.34 snowballs per hour. If we do not consider the snowballs that have central pixels associated with bad pixels in the operational mask, the value drops to 0.92 snowballs per hour. For the size of the Euclid detectors, these values correspond to a rate of 0.1 snowballs per hour per cm^2 for all events, and 0.07 snowballs per hour per cm^2 for events where the central pixels are not associated with bad pixels in the operational mask.

For WFIRST detectors we looked into 254 hours of dark data from the PV3 Full Array Lot and 94 hours of data from PV2A detector 18138. On average between all PV3 Full Arrays Lot detectors, we found a rate of 0.70 snowballs per hour, or 0.04 snowballs per hour per cm^2 , but we saw a significant variation between detectors. We found some snowballs that repeat at the same spatial location. Without taking into account the snowballs that repeat, the rate of occurrence of a snowball event in WFIRST detectors dropped to 0.43 snowballs per hour or 0.03 snowballs per hour per cm^2 .

NIRCam detectors are comparable in size with Euclid detectors, and WFC3 detectors are 1/4 of the previous detectors in size. That implies that we have found, on average per area, about twice as many snowballs in Euclid detectors compared to NIRCam⁴ detectors, and about one half as many as found in WFC3¹ detectors. For WFIRST detectors (about 20% larger in size than Euclid detectors), the snowball rate per area was very similar to that found in NIRCam detectors⁴.

For Euclid we collected 10 frames in each 2-hour dark data file, while for WFIRST we collected 101 frames. In Euclid detectors. The sampling time or number of frames appear to be correlated to an increase or decrease in the number of

date	total hours	total snowballs	snowballs/hr hours	repetitions
Aug-2016	18	6	0.33	0
Sep-2016	26	6	0.23	0
Oct-2016	10	3	0.30	0
Nov-2016	12	2	0.17	0
Apr-2017	18	12	0.67	3(2, 2,3)
May-2017	10	0	0.00	0
total	94	29	0.28	3

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