Current and Future Developments of the Medipix Technology for Space Radiation Applications

Lawrence Pinsky
Physics Department
University of Houston

The Principal Acknowlegments…

L. S. Pinsky[1], A. Empl[1], L. Tlustos[1], M. Kroupa[2,3],
T. Campbell-Ricketts[1], R. Rios[2,3], N. N. Stoffle[2,3],
E. J. Semones[2], C. Amberboy[2,3], B. G. Swan[2],
A. A. Bahadori[2], S. A. Wheeler[2], D. Turecek[1,5],
S. Pospíšil[5], J. Jakubek[5], Z. Vykydal[5],
H. Kitamura[6], & S. Kodaira[6], S. P. George[1,2,7]

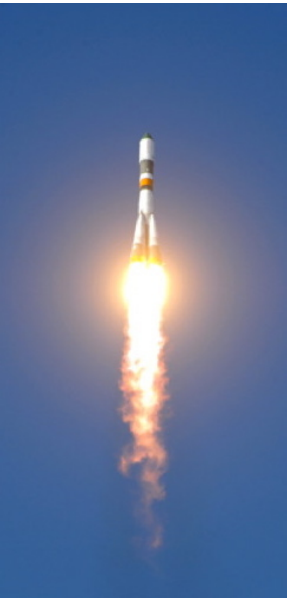
AND the Medipix2, Medipix3 and soon to be Medipix4 Collaborations

[1] Physics Department, University of Houston, Houston, TX, USA <pinsky@uh.edu>
[2] NASA Johnson Space Center, Houston, TX, USA
[3] Lockheed Martin , Houston, TX, USA
[4] University of Houston-Downtown, Houston, TX, USA
[5] Institute of Experimental and Applied Physics, Czech Technical University in Prague, Czech Republic
[6] National Institute for Radiological Sciences, Inage, Japan
[7] ARDENT Program, CERN, Geneva, Switzerland

Medipix Devices in Space-ISS

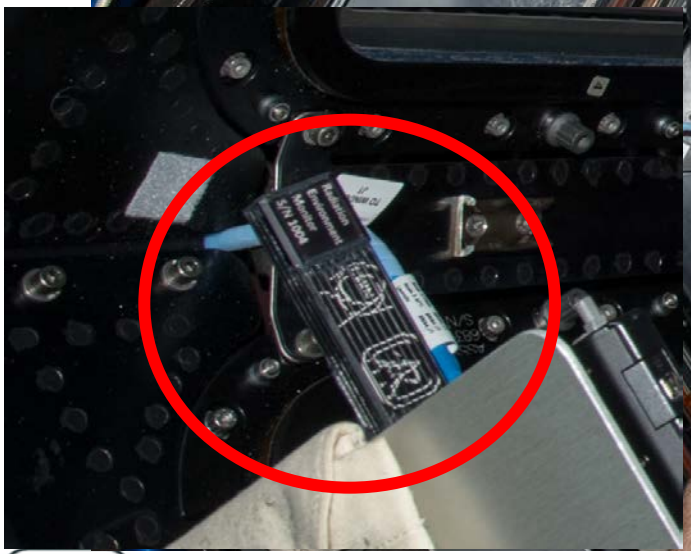
NASA—ISS (Univ. of Houston + IEAP—CTU Prague

- A total of 7 separate Timepix devices (Radiation Environment Monitors—REM) have been placed inside the ISS (at 425 Km 51.6° orbit) since Aug. 2012
- 4 are still fully functioning and producing daily detailed dosimetry reports…
- (Two have been returned for evaluation, but as yet no Timepix chips have failed in space…)



S114E7221

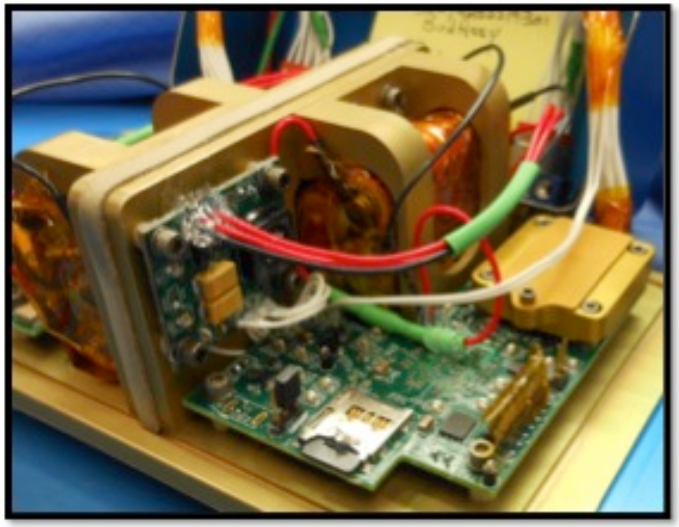
Onboard ISS



Medipix Devices in Space On Orion (EFT-1)

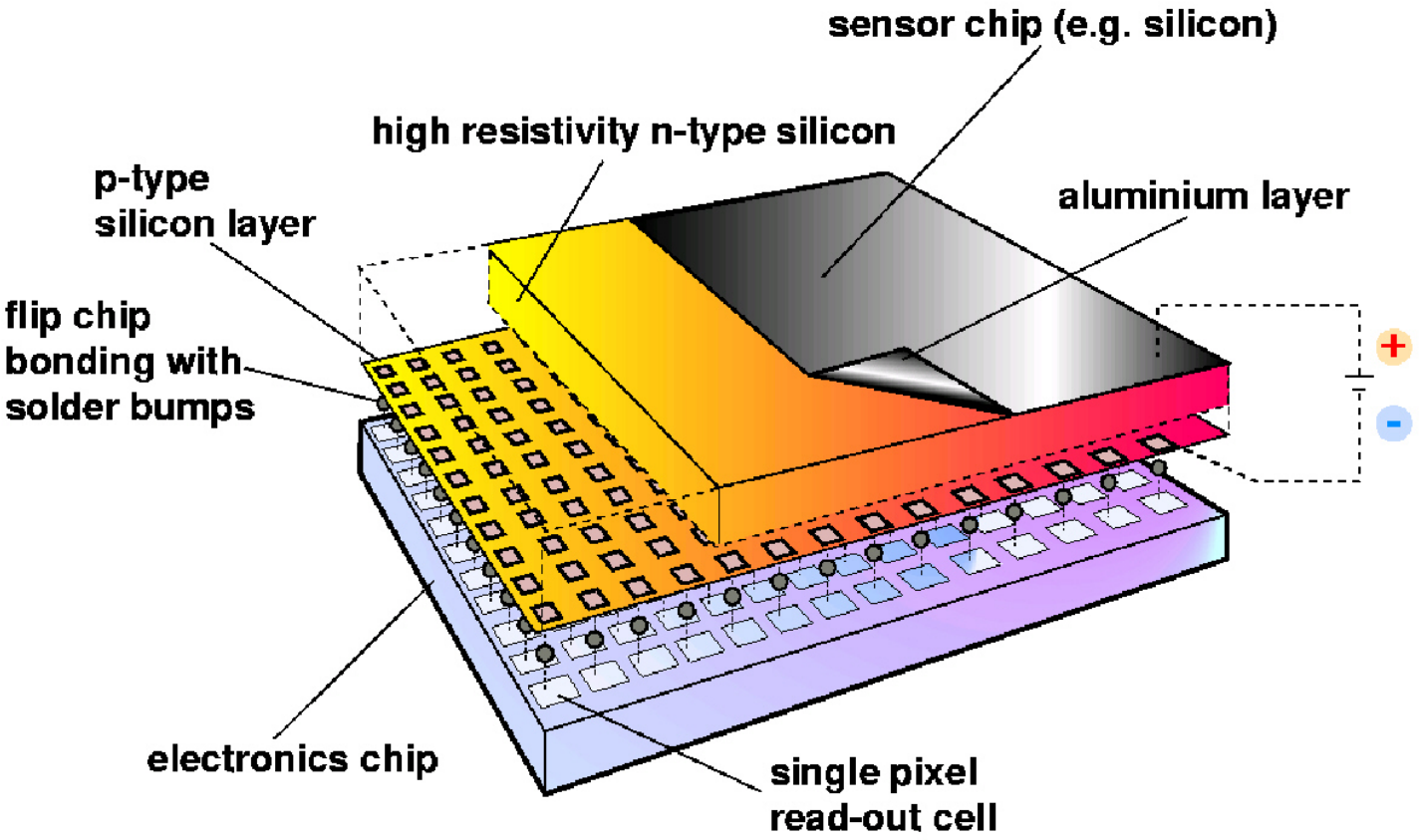
- BIRD (Battery-operated Independent Radiation Detector) worked exceedingly well as already described earlier in this meeting…
- Based onTwo independent Timepix-based devices…

BIRD @ NASA Space Rad. Lab @ Brookhaven Nat. Lab in NY



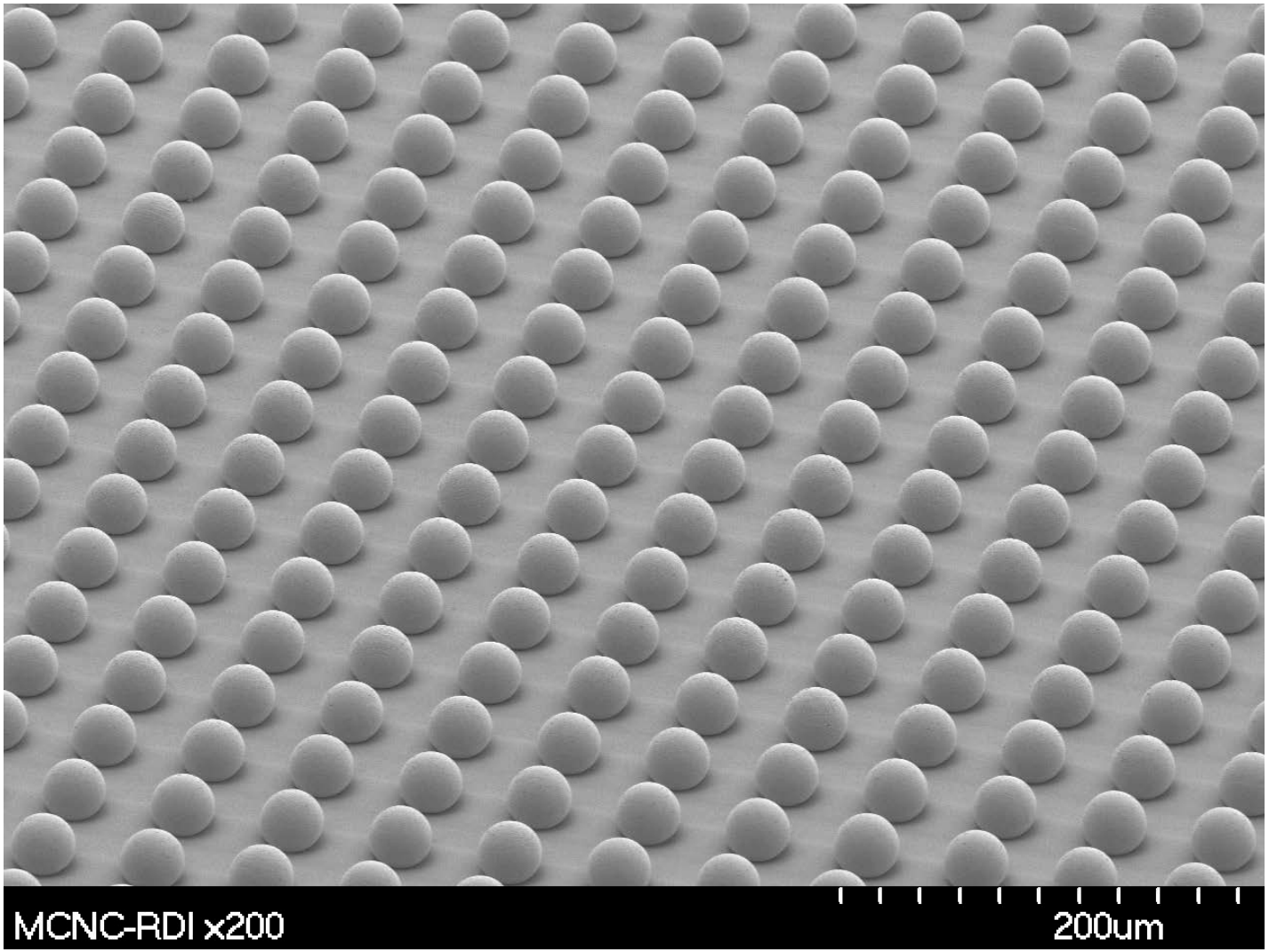
BIRD with the cover off…

Hybrid Pixel Detectors

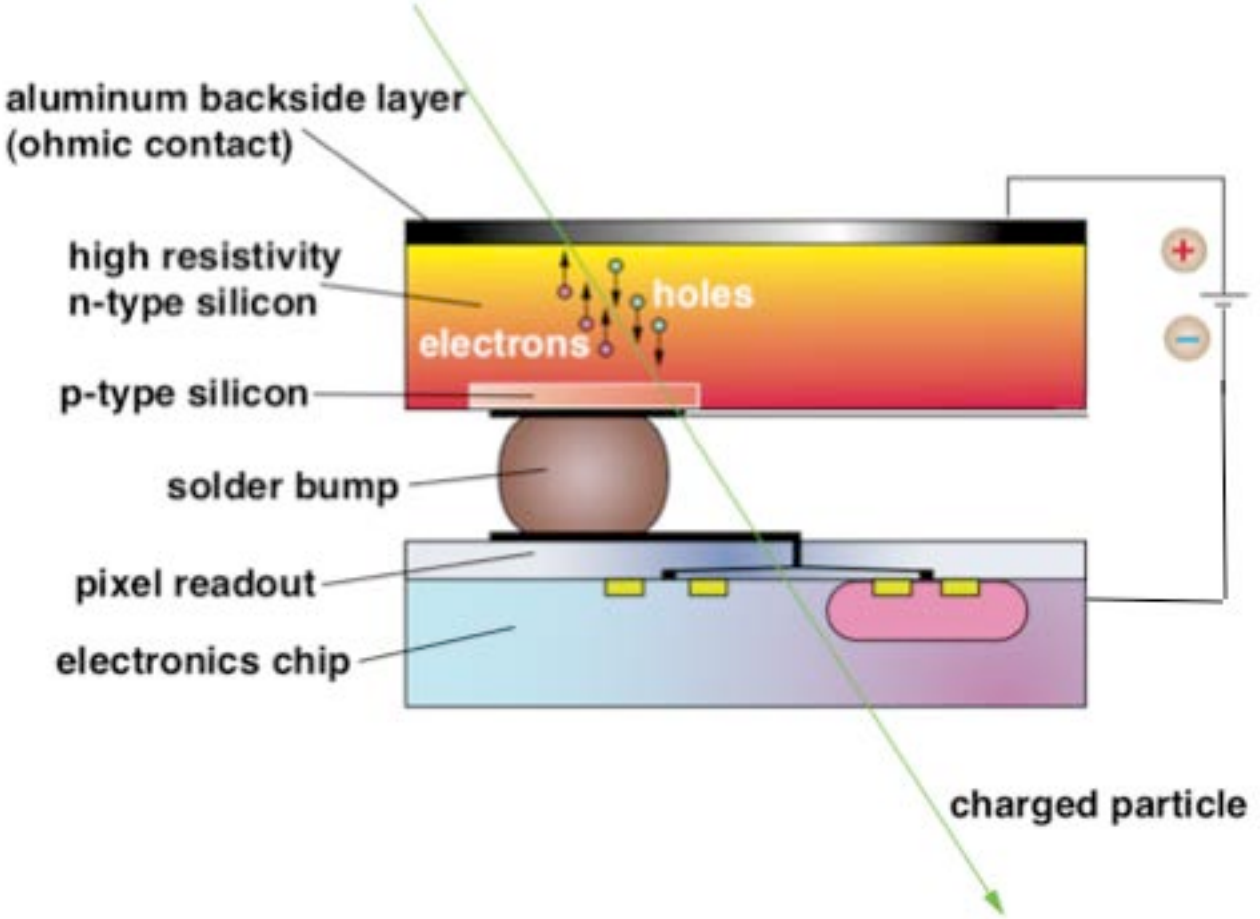


Detector and electronics readout are optimized separately

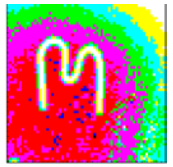
Bumps on the readout side



Hybrid Pixel Detector - Cross Section

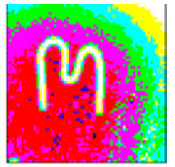


The Medipix Collaborations General Goal: to Evolve the Hybrid Pixel Detector Technologies for Use in Other Areas (e.g. Medical Imaging)



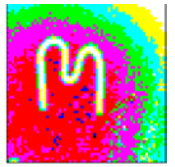
- **Medipix(1) Collaboration**
  - Formed at CERN in ~1995 with 5 institutions
  - 64 x64 pixel x-ray counting chip
- **Medipix2 Collaboration**
  - Formed in ~2000 (eventually with 17 institutions)
  - Two chips produced: MXR (2003) *Timepix* (2006)
  - Both chips 256 x 256, 55 μm pixels = 2 cm^2.
  - Frame-based readout—*Timepix* (4 modes incl. TOT or TOA).
  - *Timepix2* in final design process (2015-2016).
- **Medipix3 Collaboration**
  - Formed in 2008 (Currently 22 institutions) 256 x 256, 55 μm
  - Medipix3, Medipix3.1, Medipix3RX (Charge summing chips)
  - *Timepix3* (2013) Data-driven Readout-simultaneous TOT & 1.6 ns TOA.

Timepix v. Timepix3 v. Timepix3



- **Timepix (2006)**
  - **…Has been around since 2006 (250 μm CMOS technology)**
  - **Well characterized, including a few issues with work-arounds…**
  - **256 x 256 55 μm pixels either in 14 bit pseudo-random TOT mode or in the TOA mode with 10 ns resolution pixel-by-pixel.**
- **Timepix2 (In Final Design Process)**
  - **To be "plug-n-play" control compatible with the Timepix.**
  - **Functionally changed significantly (new technology 135 μm CMOS).**
  - **Zero-suppression, BOTH TOT and TOA simultaneously measured, fungible output counter, new front-end to accommodate higher inputs, and other known Timepix issues cleaned up…**
- **Timepix3 (2013)**
  - **Data-Driven readout (No dead-time up to 81 MHz – pixel hits)**
  - **Both TOT and TOA (1.6 ns) and new Front-end electronics**
  - **Still in the process of being characterized (higher power consumption than the Timepix2…**

AND… Medipix4 is FORMING NOW!



- Unlike the previous Medipix Collaborations, Medipix4 will simultaneously design the Medipix4 (counting chip) and the Timepix4.
- It will employ the latest CMOS technology… (With Power Control Options…)
- The Chips will be much larger than the current ones and the Timepix4 will have smaller pixels..
- The Timepix4 will be able to function in either the frame-based or data-driven (500 Mhits/s) modes.
- Each pixel will have fungible output registers, and both TOT & TOA with ~ 780 ps time resolution, as well as a reduced threshold < 1 KeV (That is total per pixel and NOT KeV/μm)! These detectors are 100% efficient for penetrating charged particles…

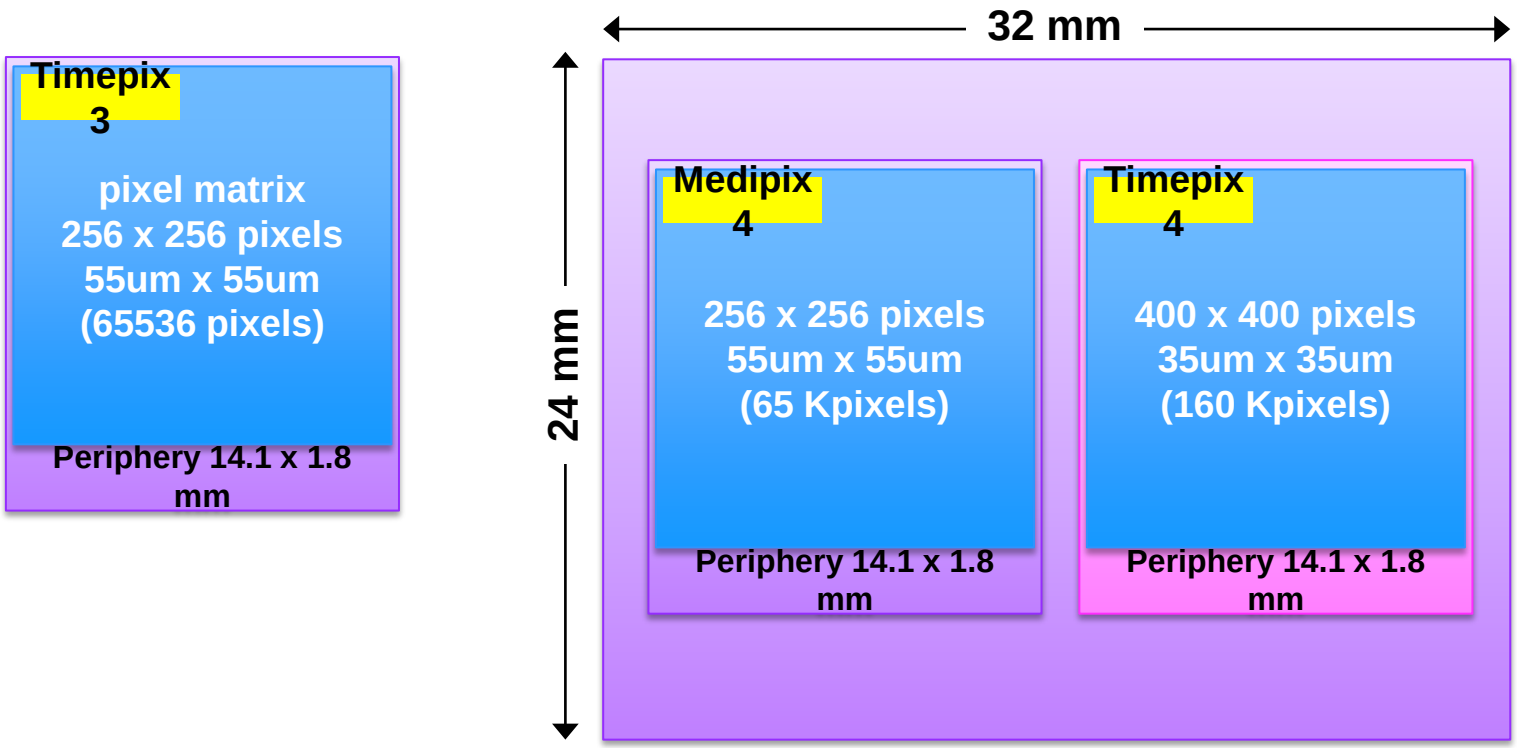
Timepix4 Specs

		Timepix3	Timepix4
Pixel Size		55 x 55 µm	35 x 35 µm
Pixel arrangement		256 x 256	400 x 400 (Option A) 285 x 911 (Option B1) 628 x 457 (Option B2) 628 x 911 (Option C1) 685 x 857 (Option C2)
Operating Modes		TOA and TOT PC and iTOT	
Zero-Suppressed Readout	Data driven	< 80 MHits/s	< 500 MHits/s
	Frame based	YES	YES
TOT energy resolution		< 2KeV	< 1Kev
Time resolution		1.56ns	~781ps
Readout bandwidth		5.12Gb (8x SLVS@640 Gbps)	20.48 Gbps (4x 5.12 Gbps)

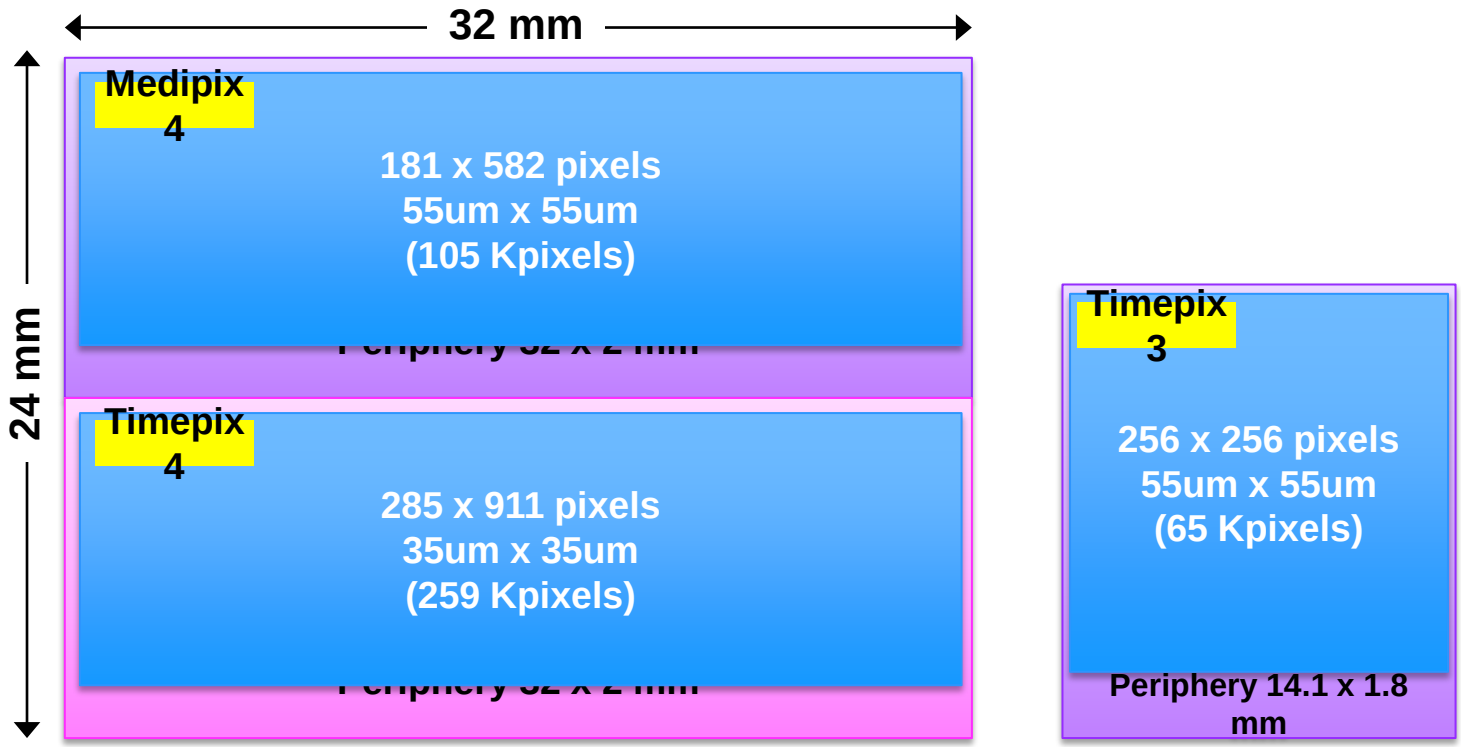
Towards Timepix4

- **Improve energy resolution (TOT) and time resolution (TOA):**
  - **TOT resolution limited by ENC only:**
    - **Minimize the quantization error**
    - **Target < 1 KeV**
    - **> 5 MeV *per pixel* in sensor sensitivity**
  - **TOA resolution limited by front-end bandwidth, pixel noise and VCO frequency**
    - **Doubling local VCO frequency will half the TOA resolution**
- **Provide Power Consumption Options**
  - **Low Power modes (Partial Chip or Power down digital until needed. Also sensor current monitor modes possible.**

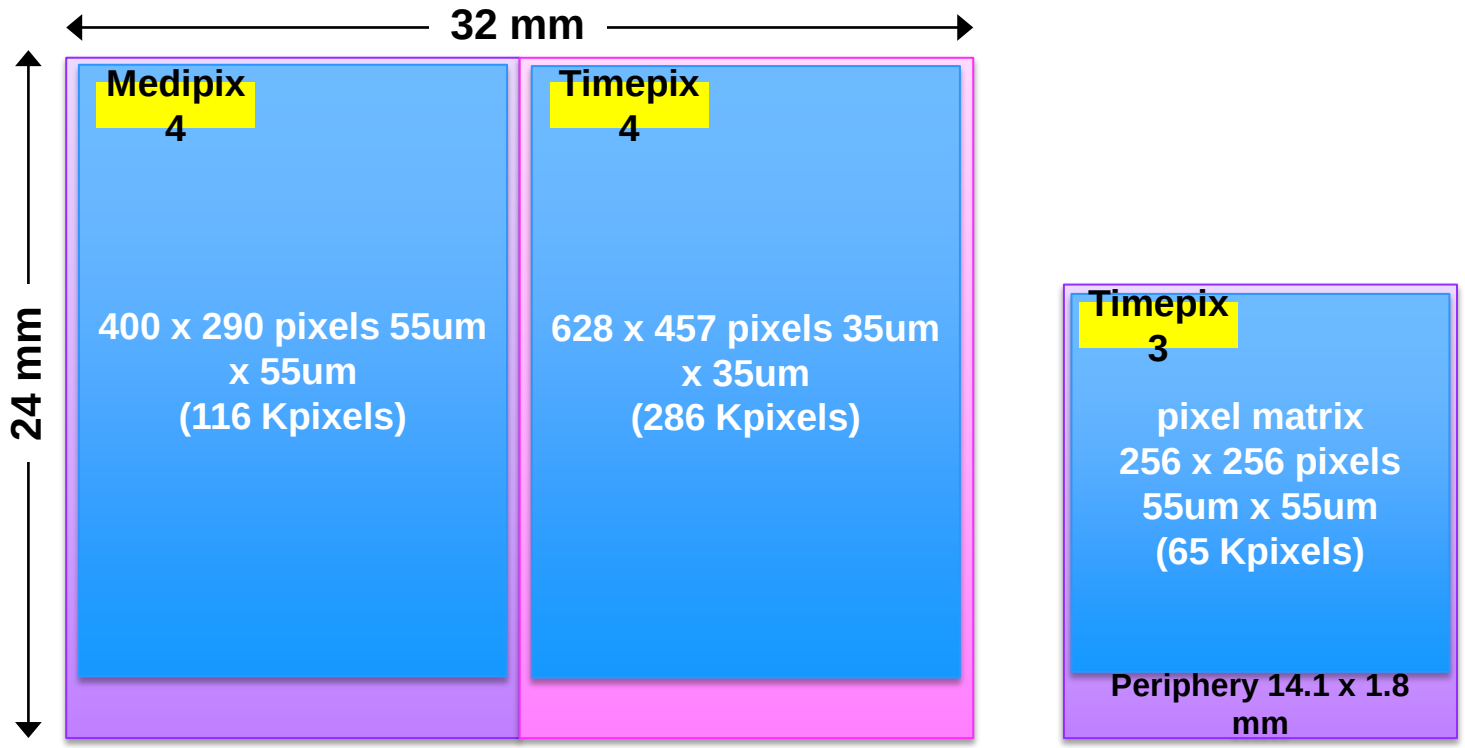
Floorplan: Option A



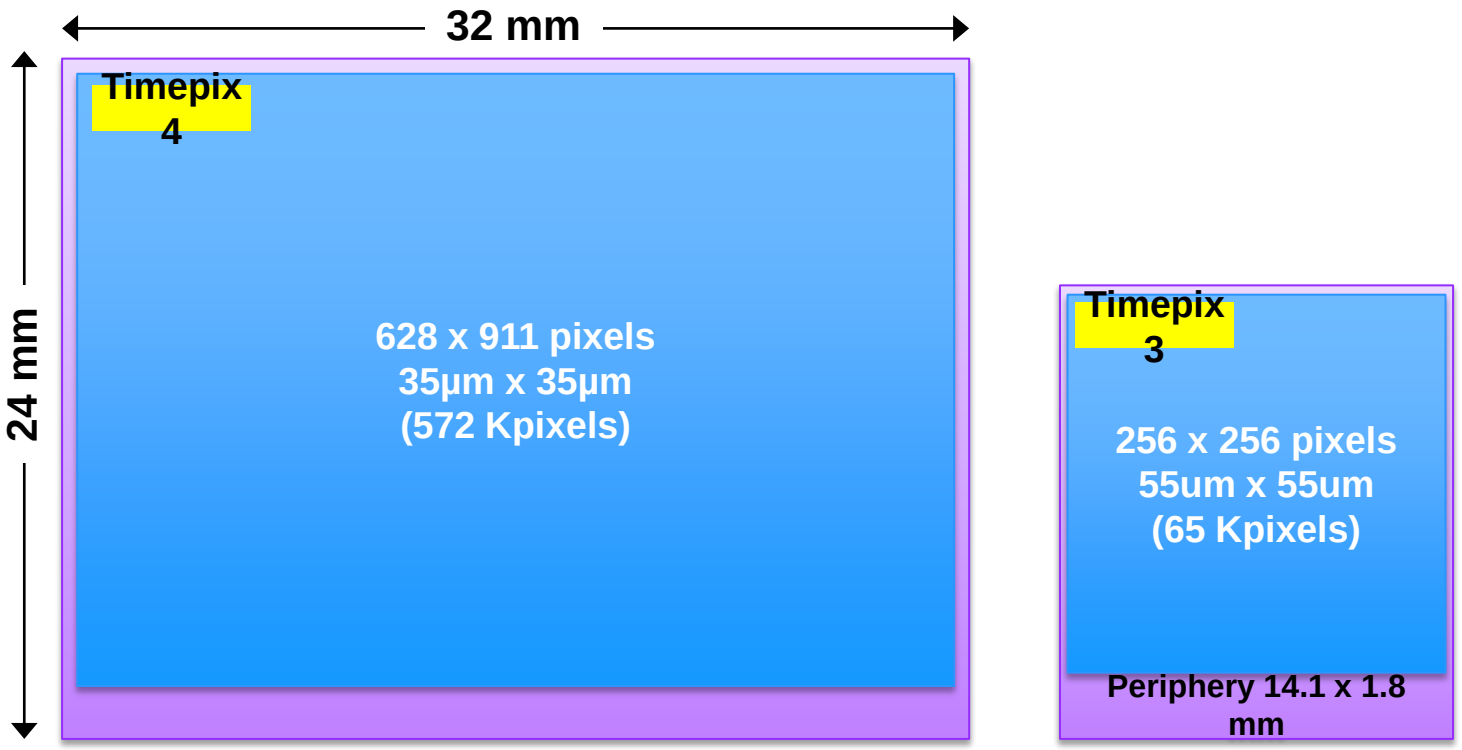
Floorplan: Option B1



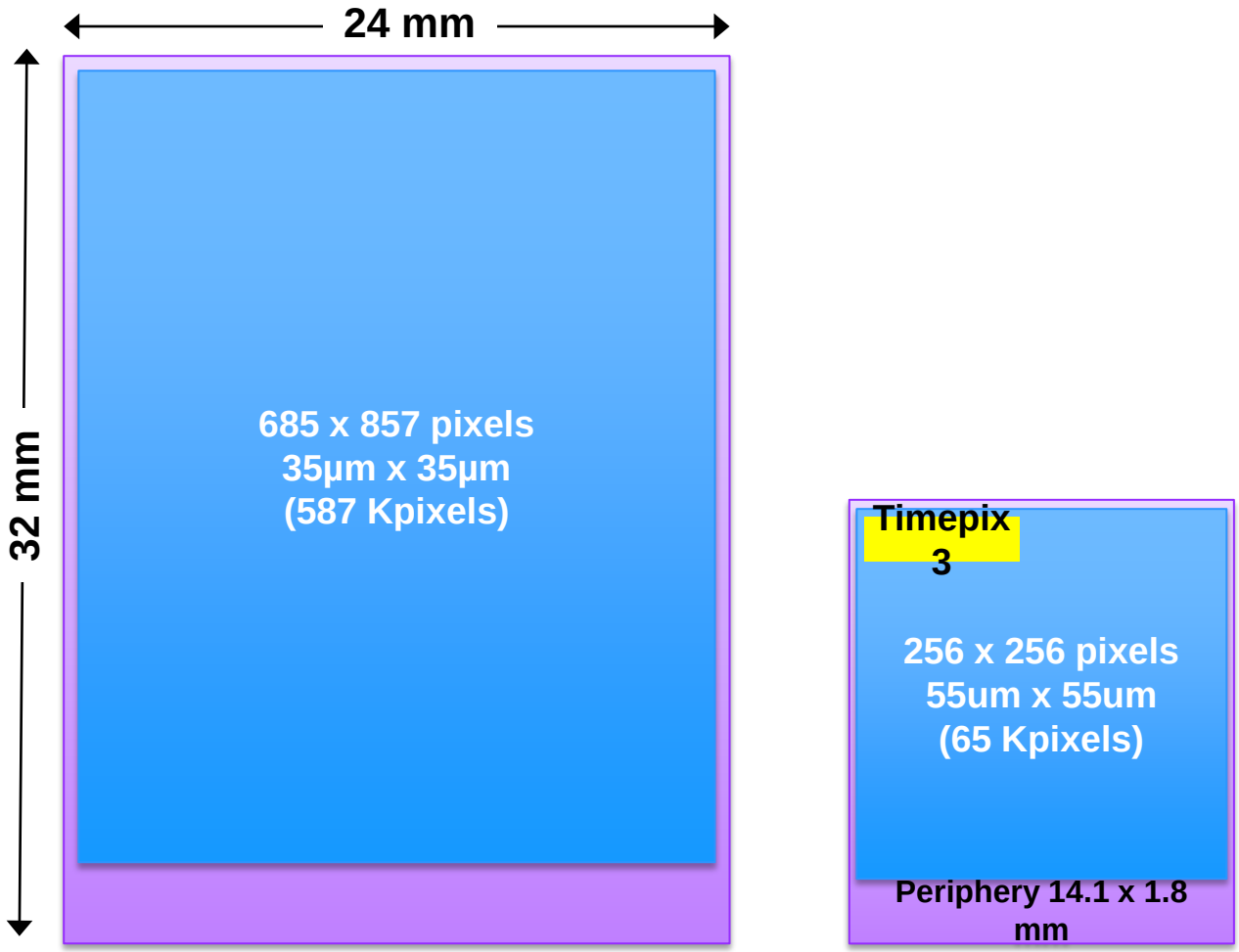
Floorplan: Option B2



Floorplan: Option C1



Floorplan: Option C2



Expected Yield

	Wafer size	Reticle Size	Good Chips	Yield (A)
Timepix3	200mm	14.1 x 16.21	105	~60% (meas)
	300mm		250	~60%
Option A	300mm	28.3 x 16.21	125 + 125	~60%
Option B	300mm	32 x 24	70 + 70	30% ??
Option C	300mm	32 x 24	70	15% ??

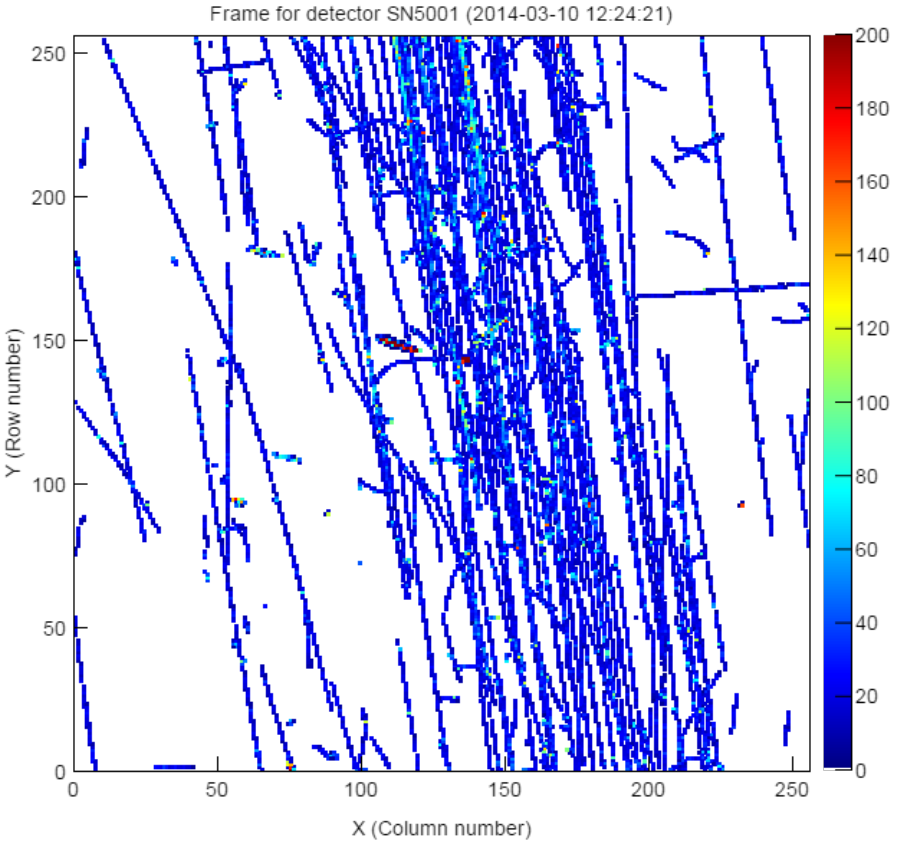
- **Large designs will require an robust architecture to improve yield:**
  - **Triple modular redundancy (TMR)**
  - **Avoid long shift registers**
  - **Error detection and correction**

Common features for both chips

- **High Speed serializers (>5 Gbps)**
  - **Clock Data Encoding**
  - **PLL**
- **Analog Periphery**
- **Synchronized clock for counting:**
  - **Avoid counter glitches**
- **On chip threshold calibration**
- **Compatible pinout and readout for both chips?**

Thank you for your attention…

Showers


Frame for detector SN5001 (2014-03-10 12:24:21)
Y (Row number)
X (Column number)
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50
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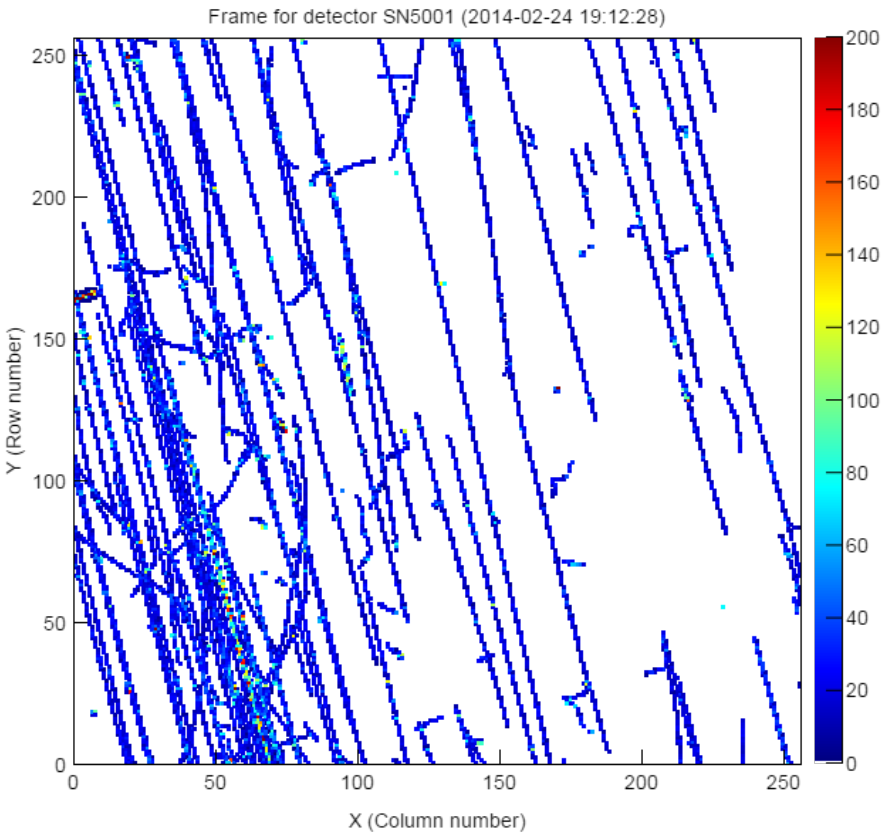
150
200
250
0
20
40
60
80
100
120
140
160
180
200


Frame for detector SN5001 (2014-02-24 19:12:28)
Y (Row number)
X (Column number)
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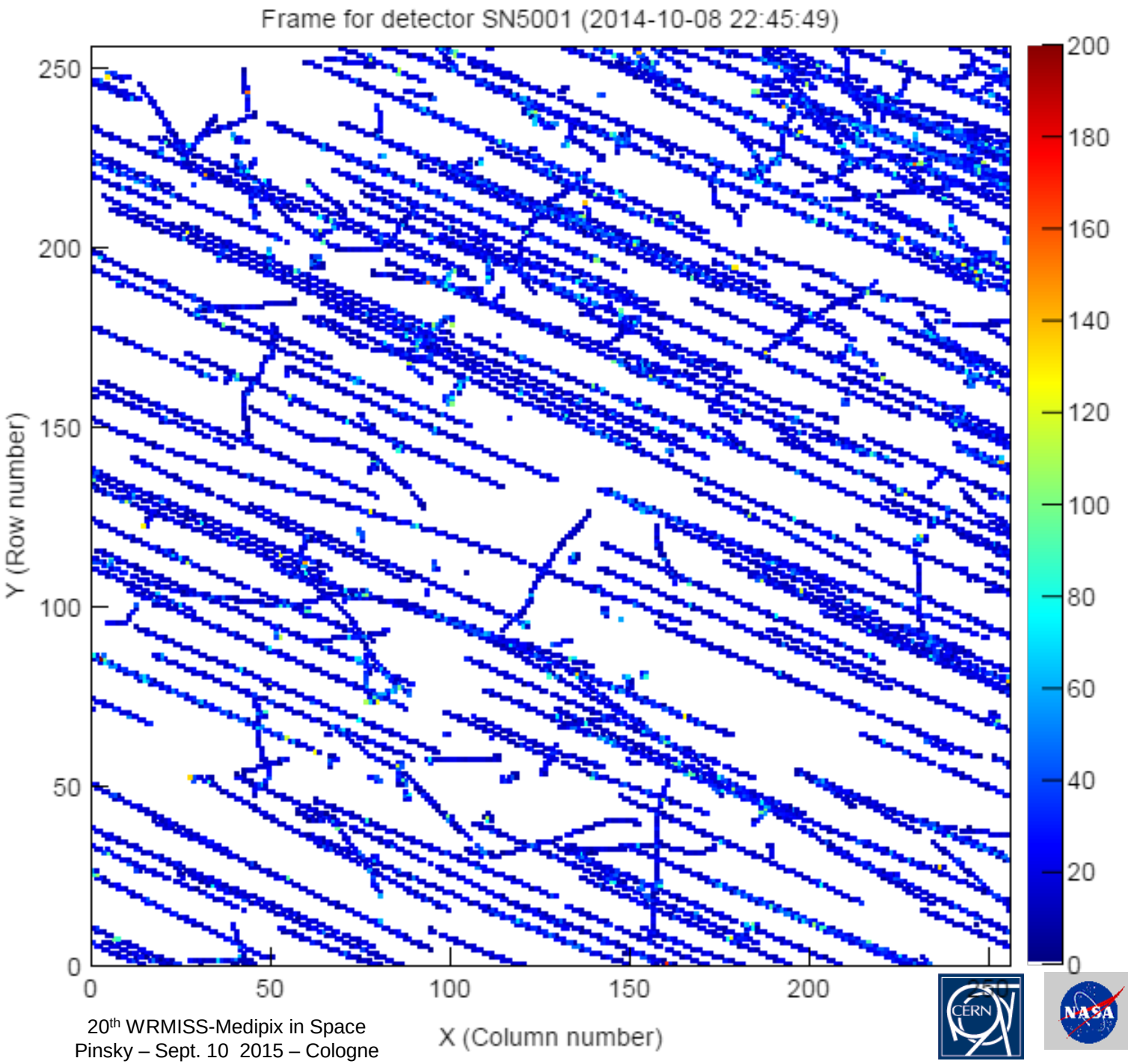
60
80
100
120
140
160
180
200


Frame for detector SN5001 (2014-10-08 22:45:49)
Y (Row number)
X (Column number)
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200
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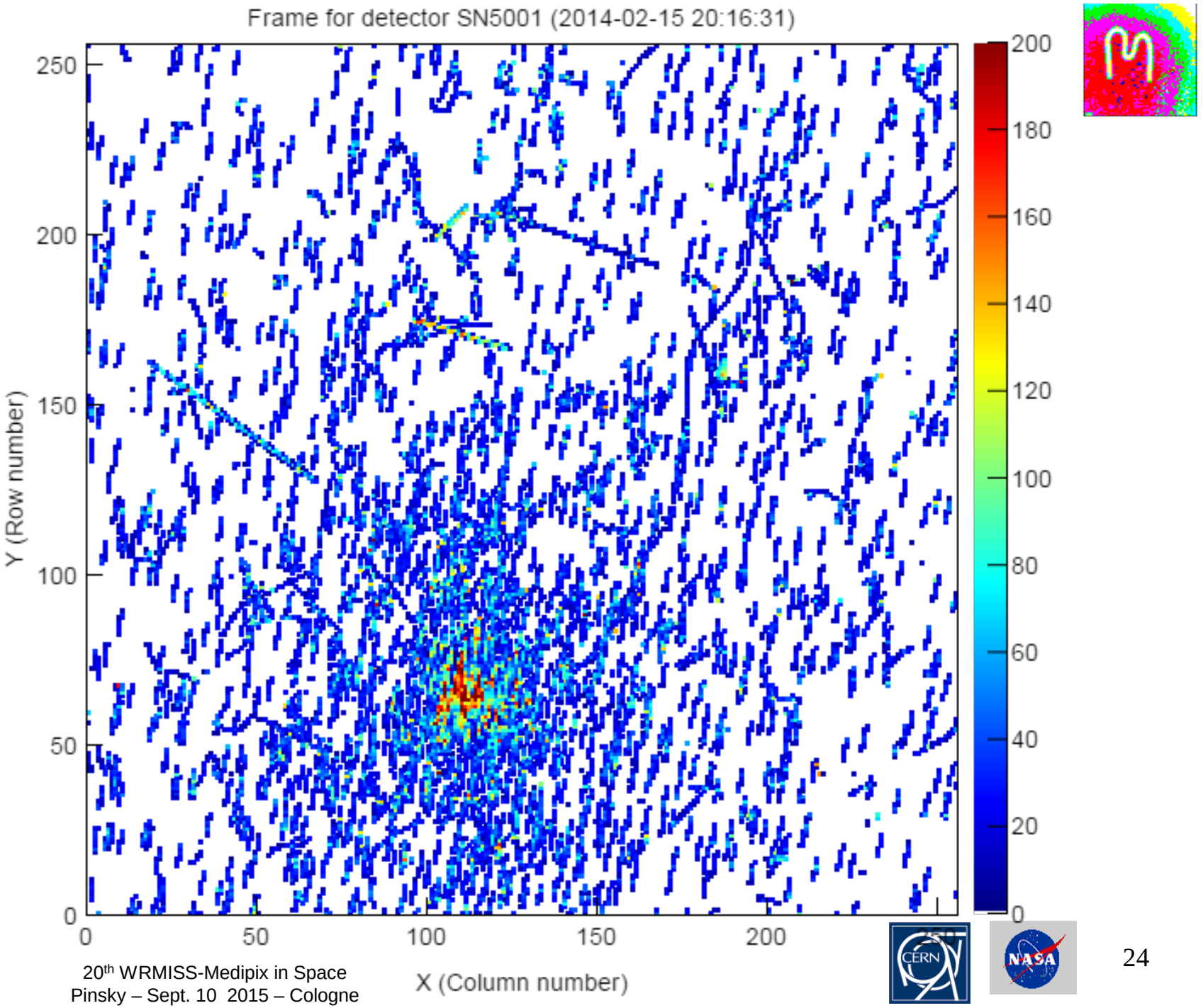
0
20
40
60
80
100
120
140
160
180
200


Frame for detector SN5001 (2014-02-15 20:16:31)
Y (Row number)
X (Column number)
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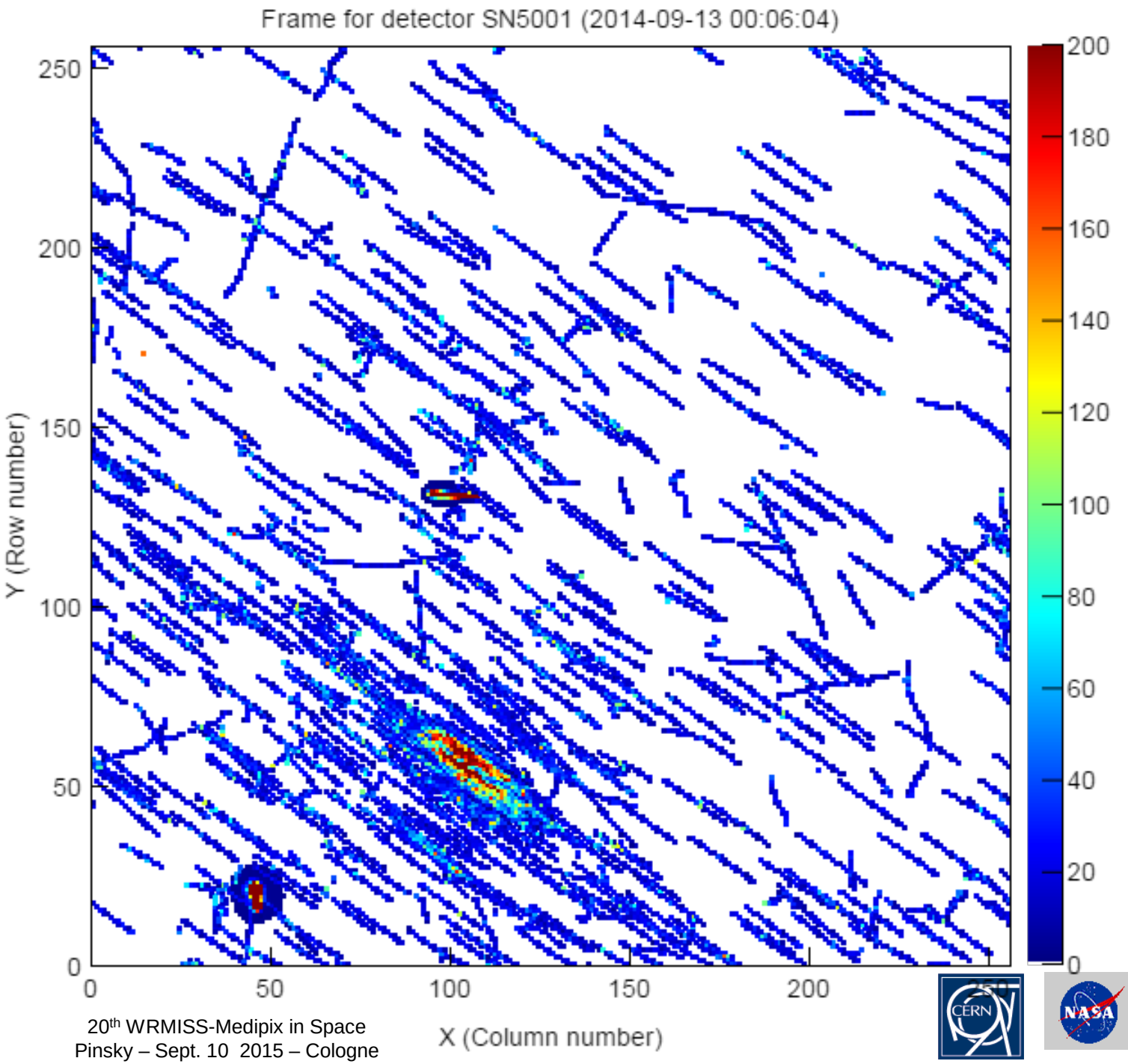
150
200
250
0
20
40
60
80
100
120
140
160
180
200


Frame for detector SN5001 (2014-09-13 00:06:04)
Y (Row number)
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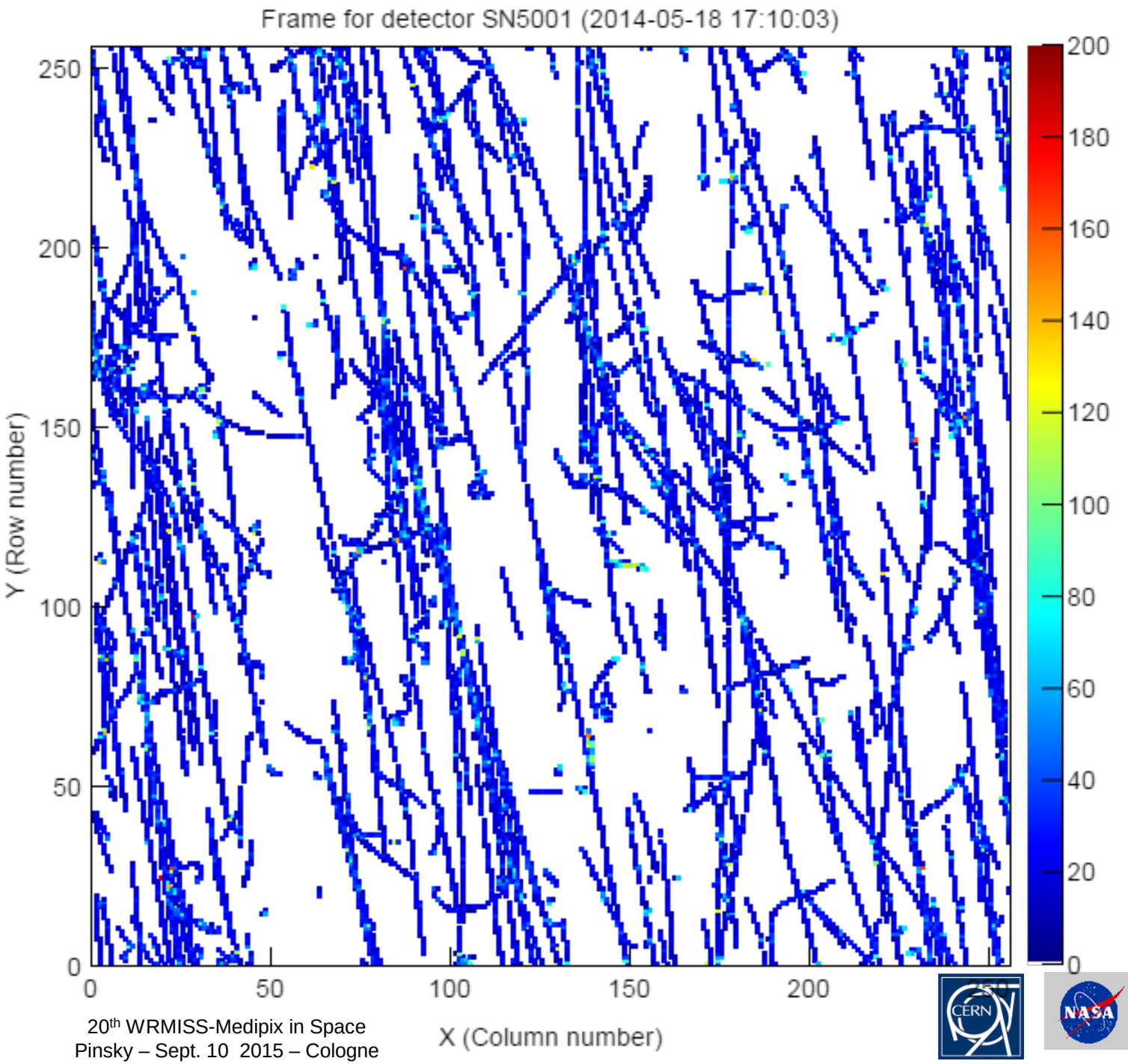
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200


Frame for detector SN5001 (2014-05-18 17:10:03)
Y (Row number)
X (Column number)
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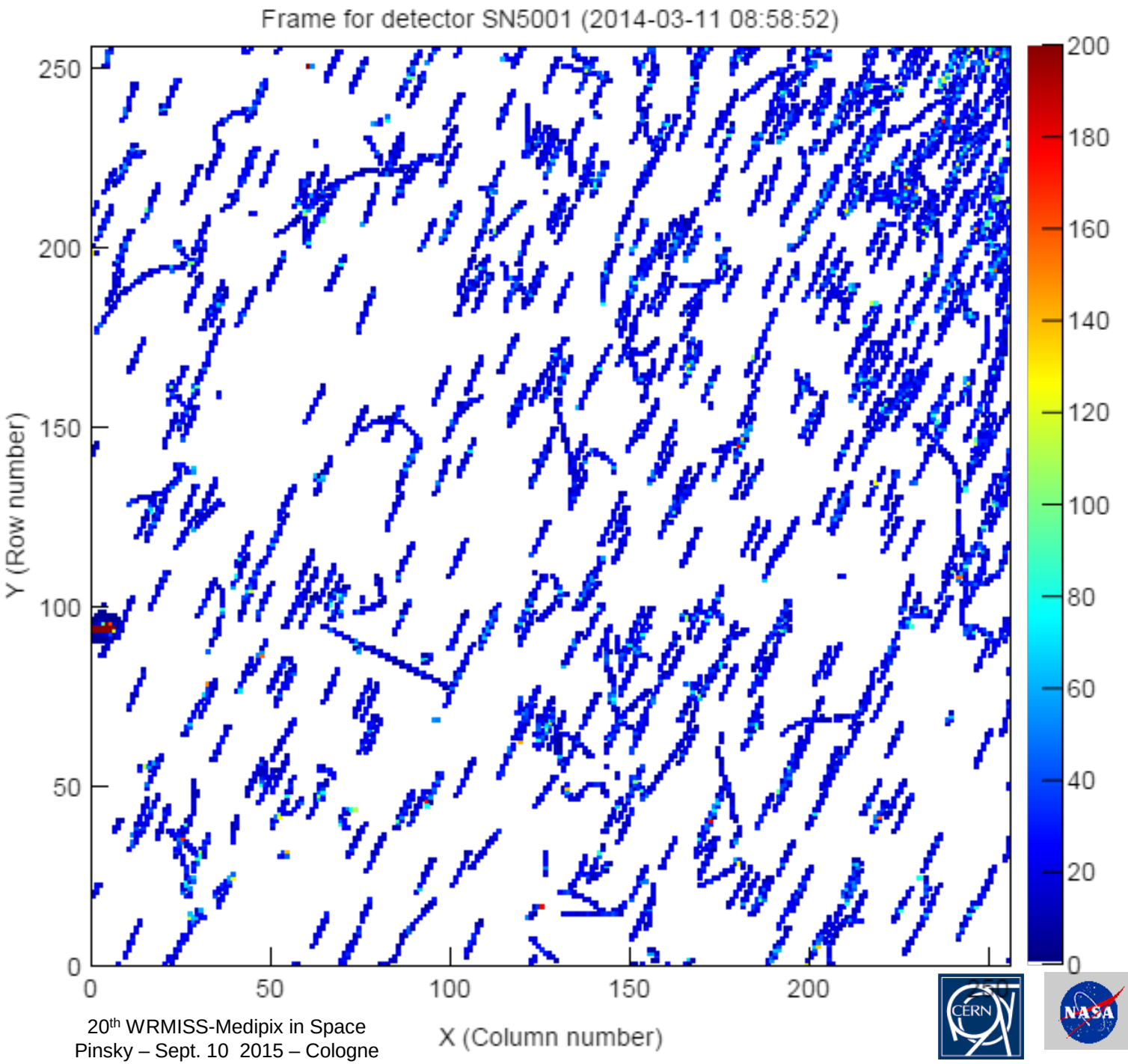
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200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X (Column number)
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100
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200
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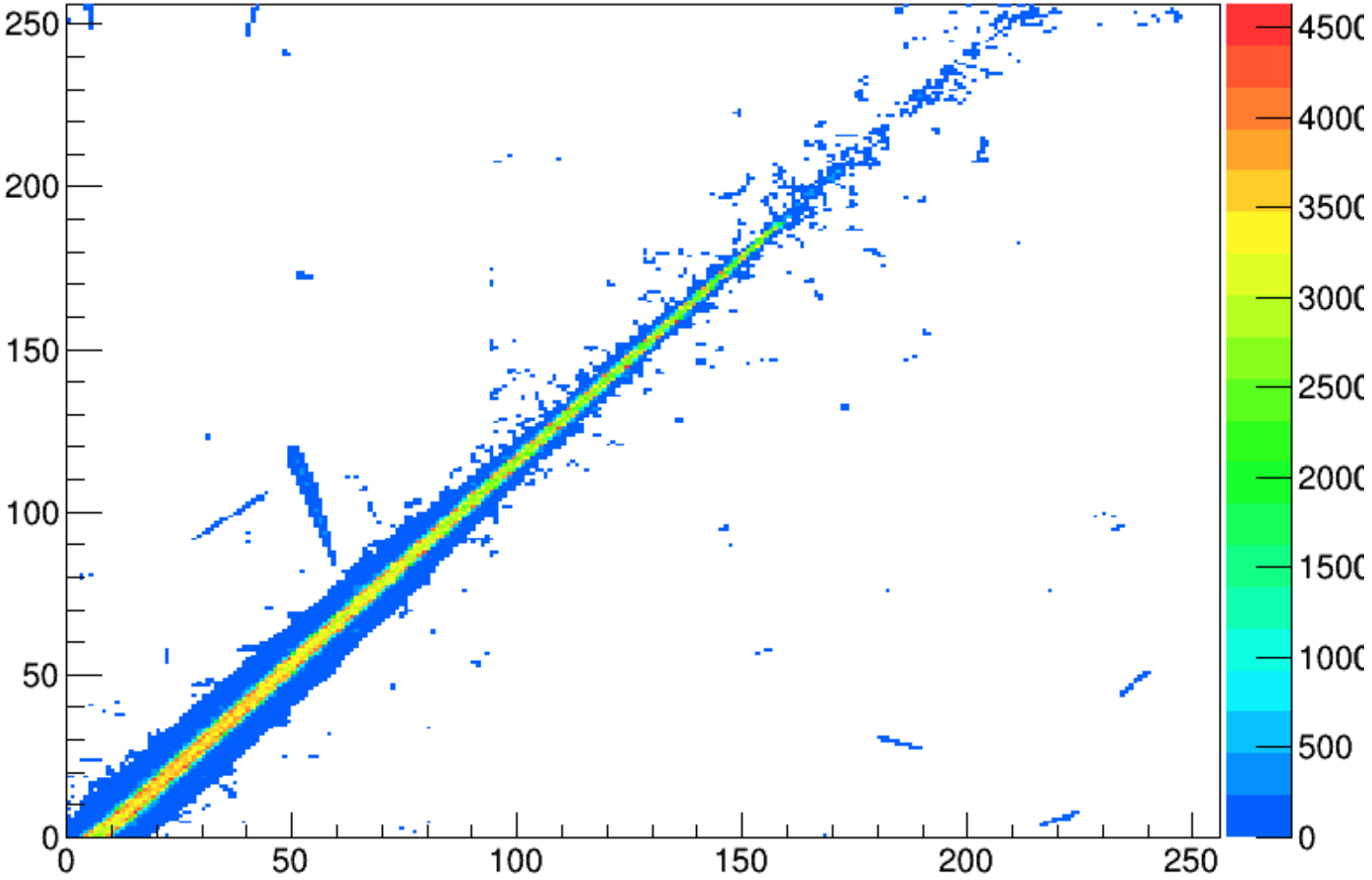
60
80
100
120
140
160
180
200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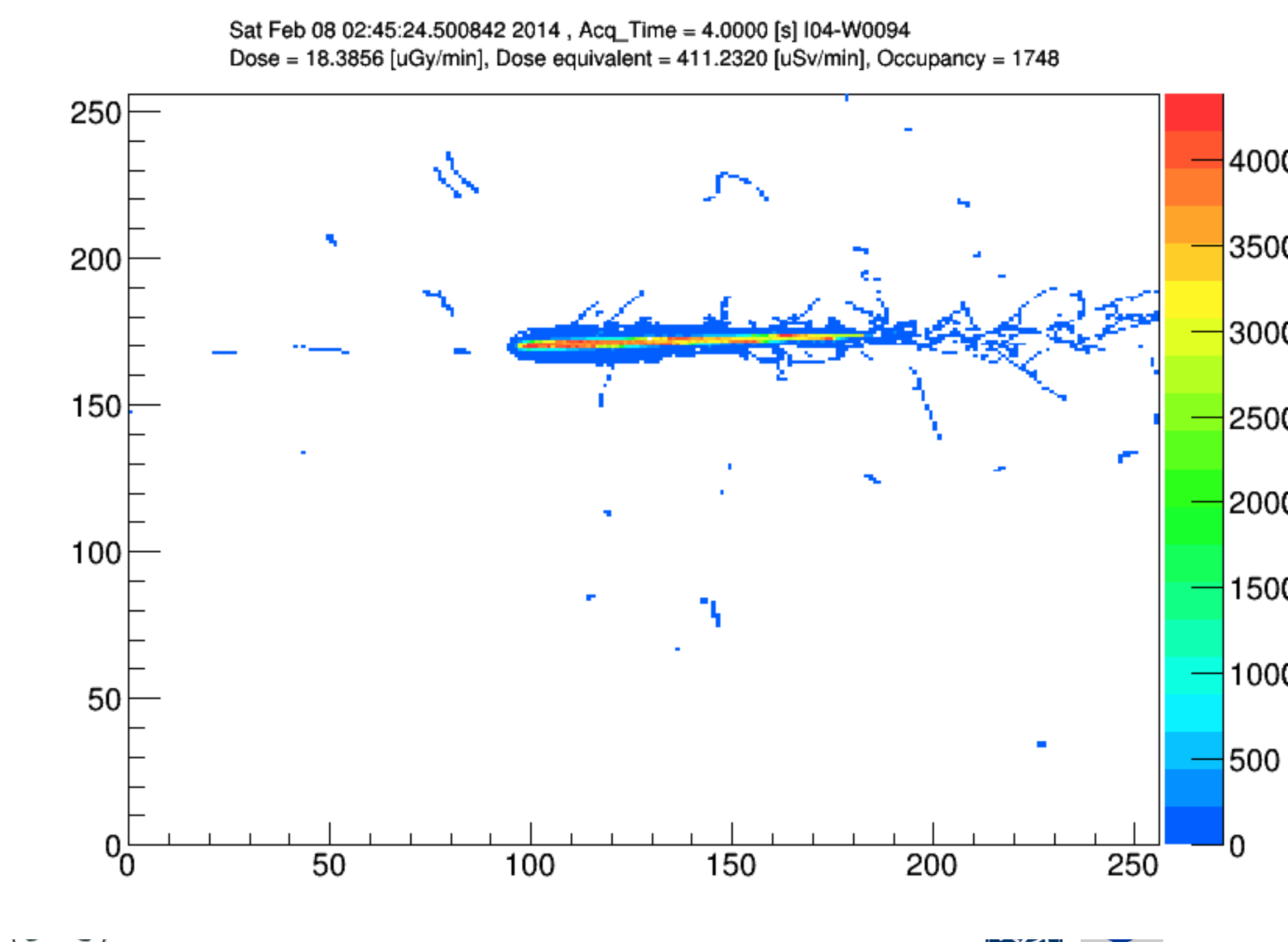
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0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0
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50
100
150
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3500
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2500
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1500
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500
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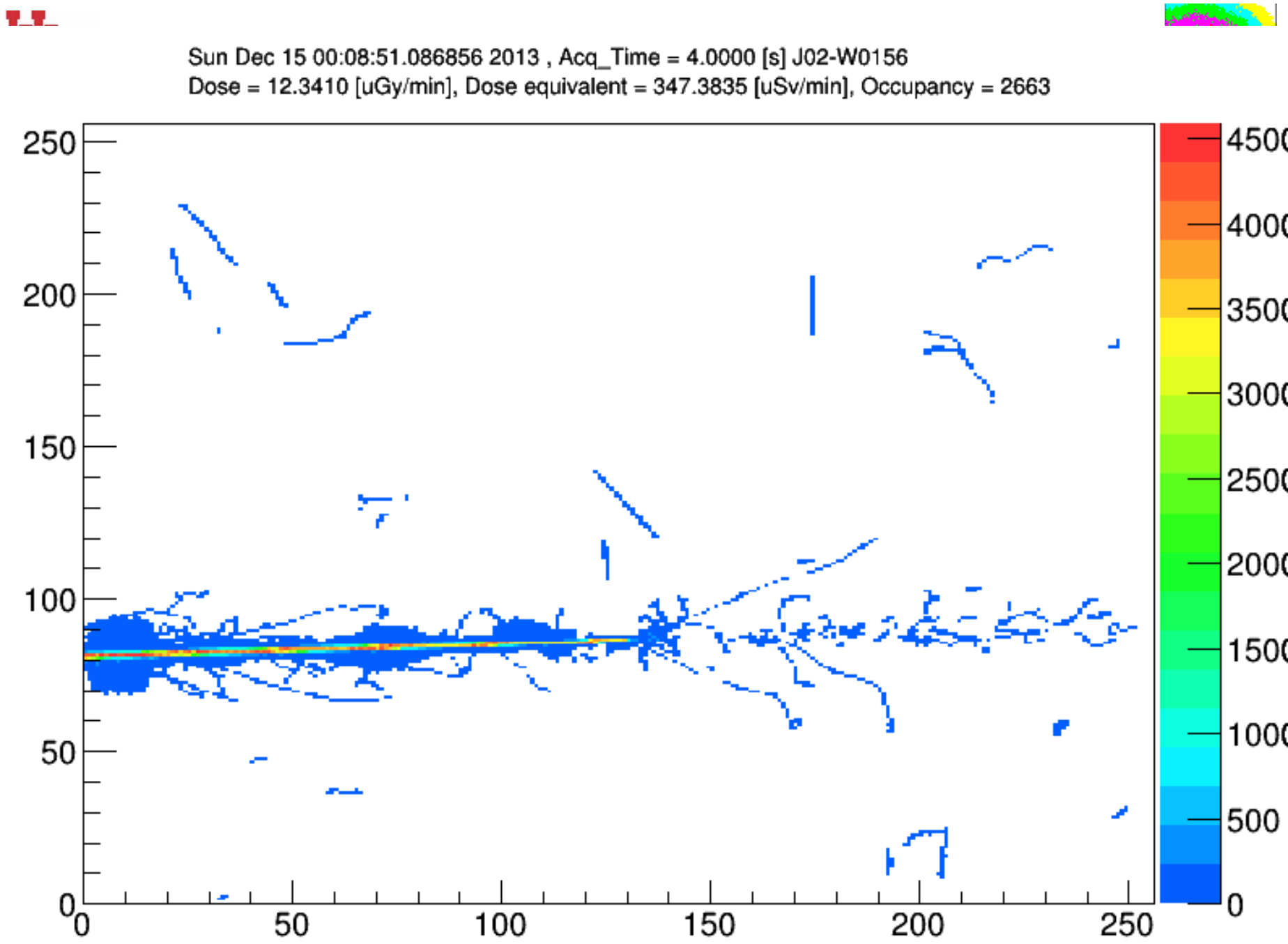
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200
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100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
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500
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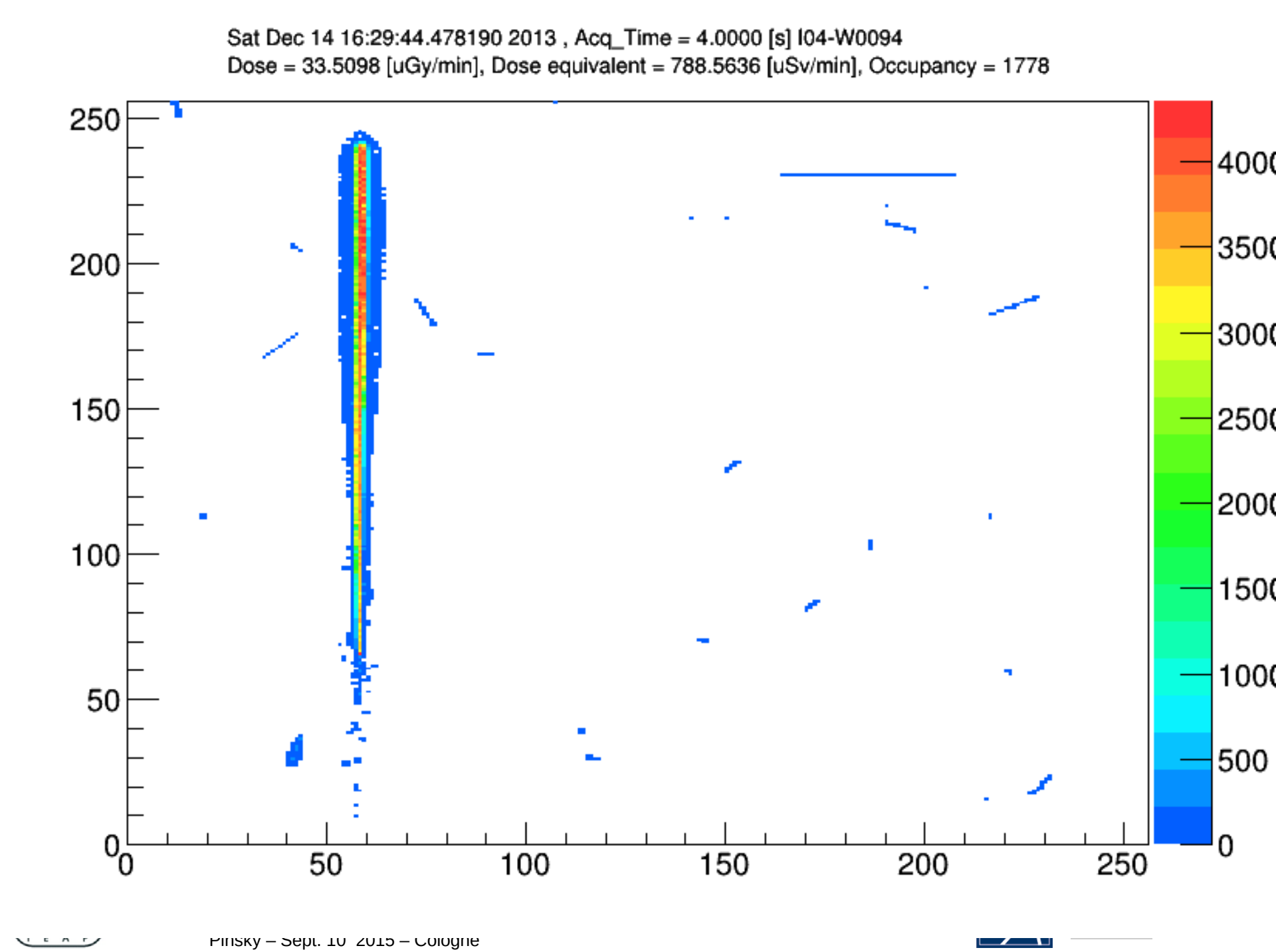
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100
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0
0
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100
150
200
250
4000
3500
3000
2500
2000
1500
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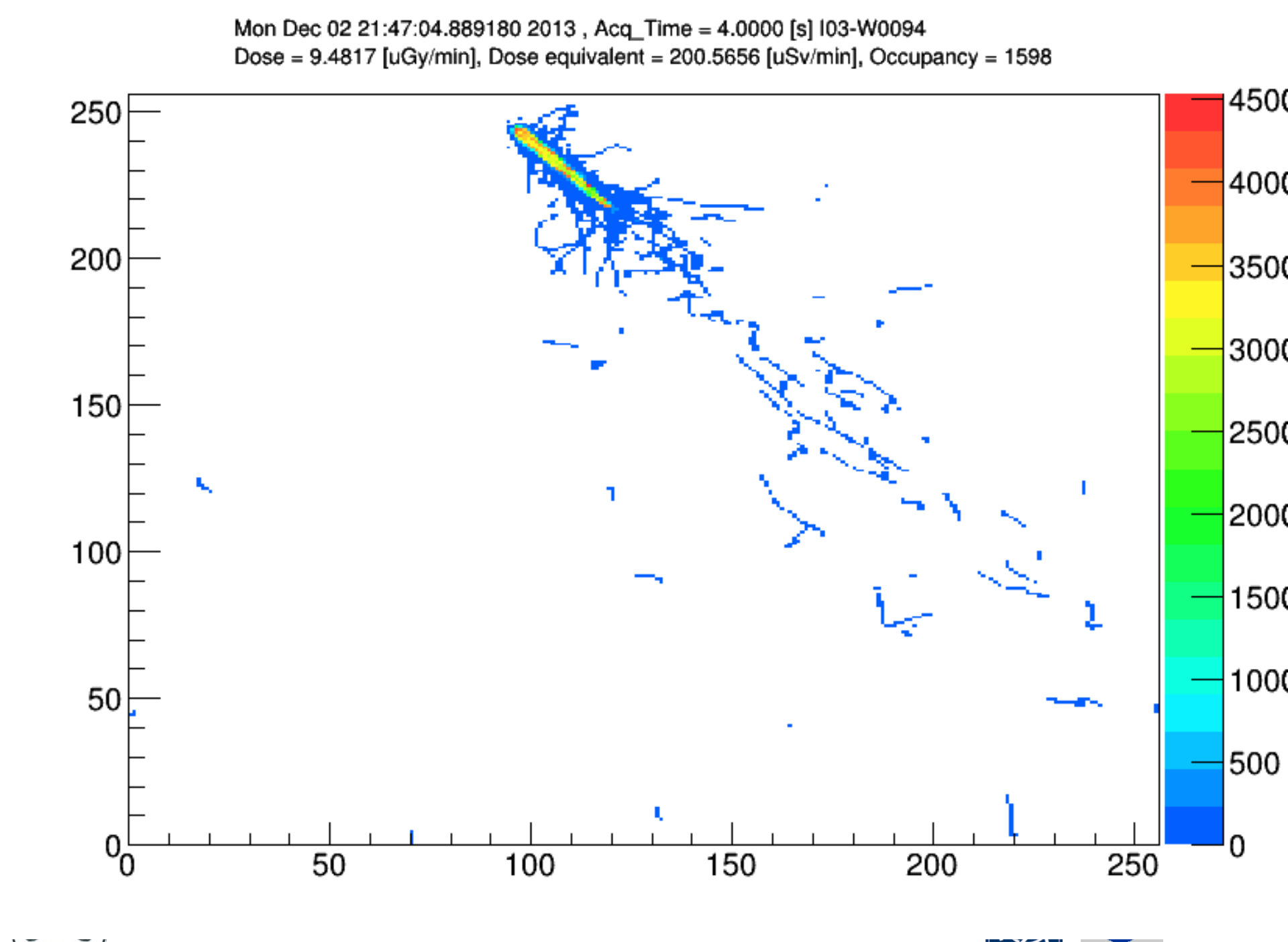
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200
150
100
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0
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200
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4500
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3500
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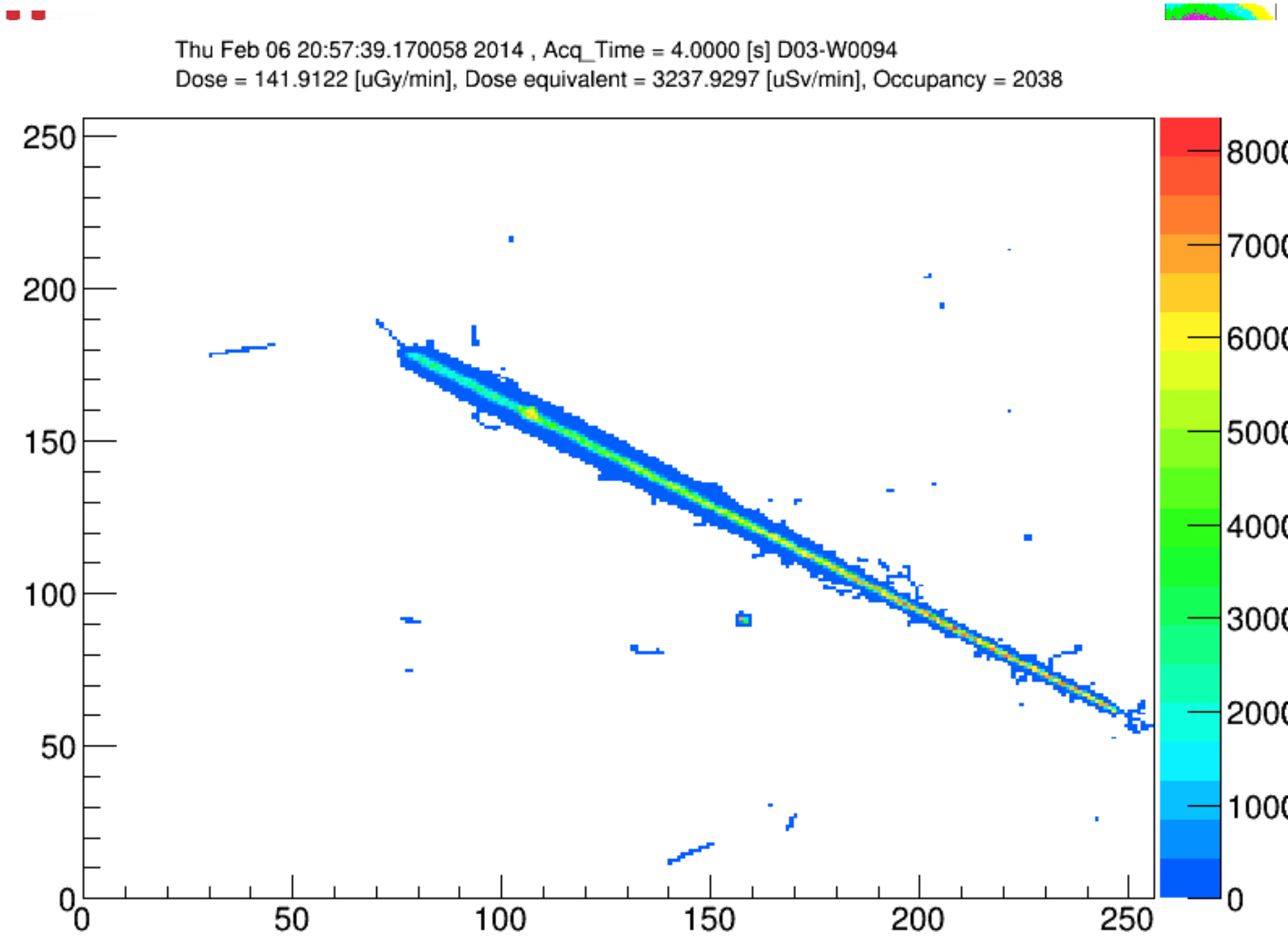
500
0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150
200
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6000
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3000
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1000
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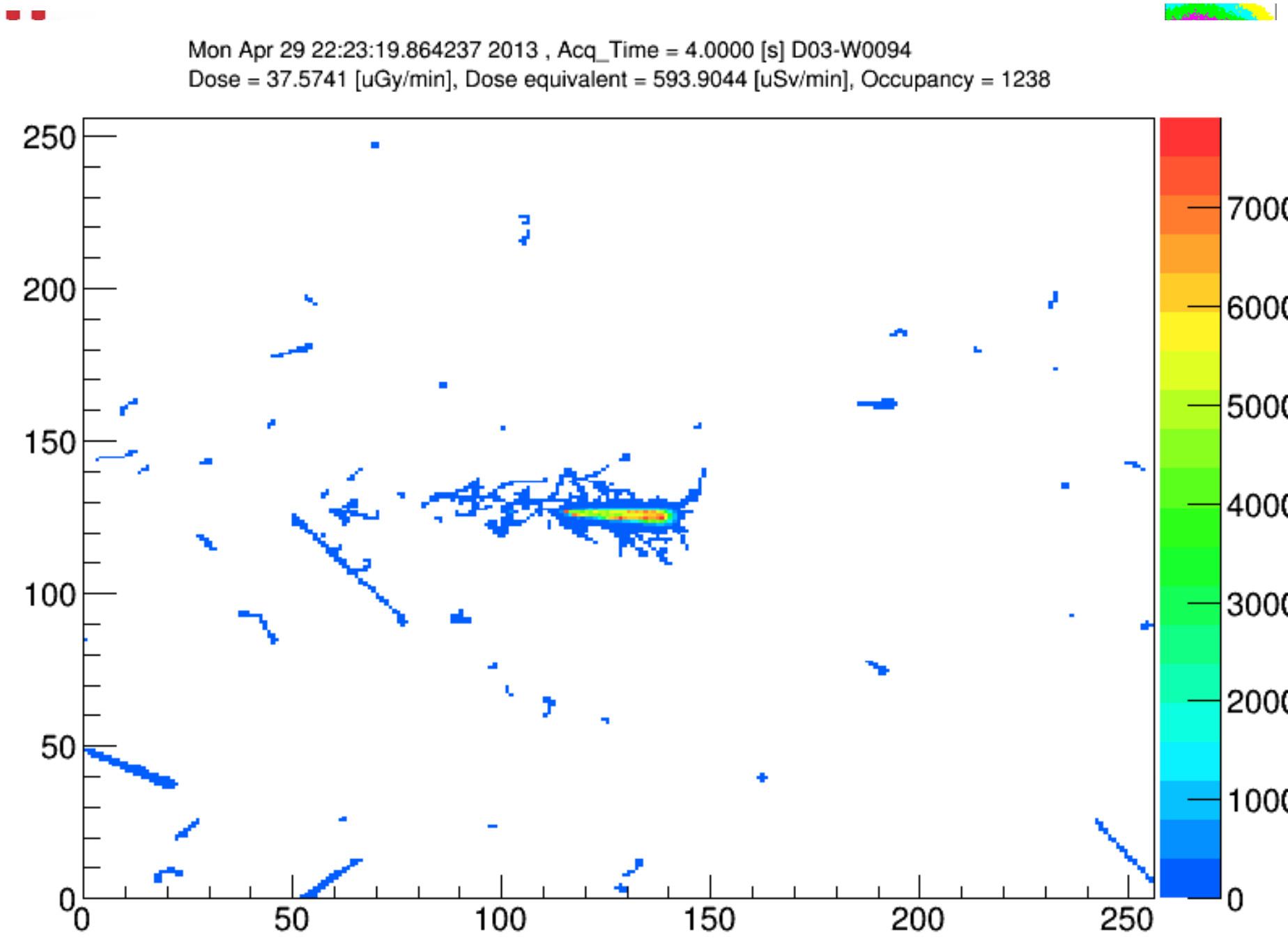
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0
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7000
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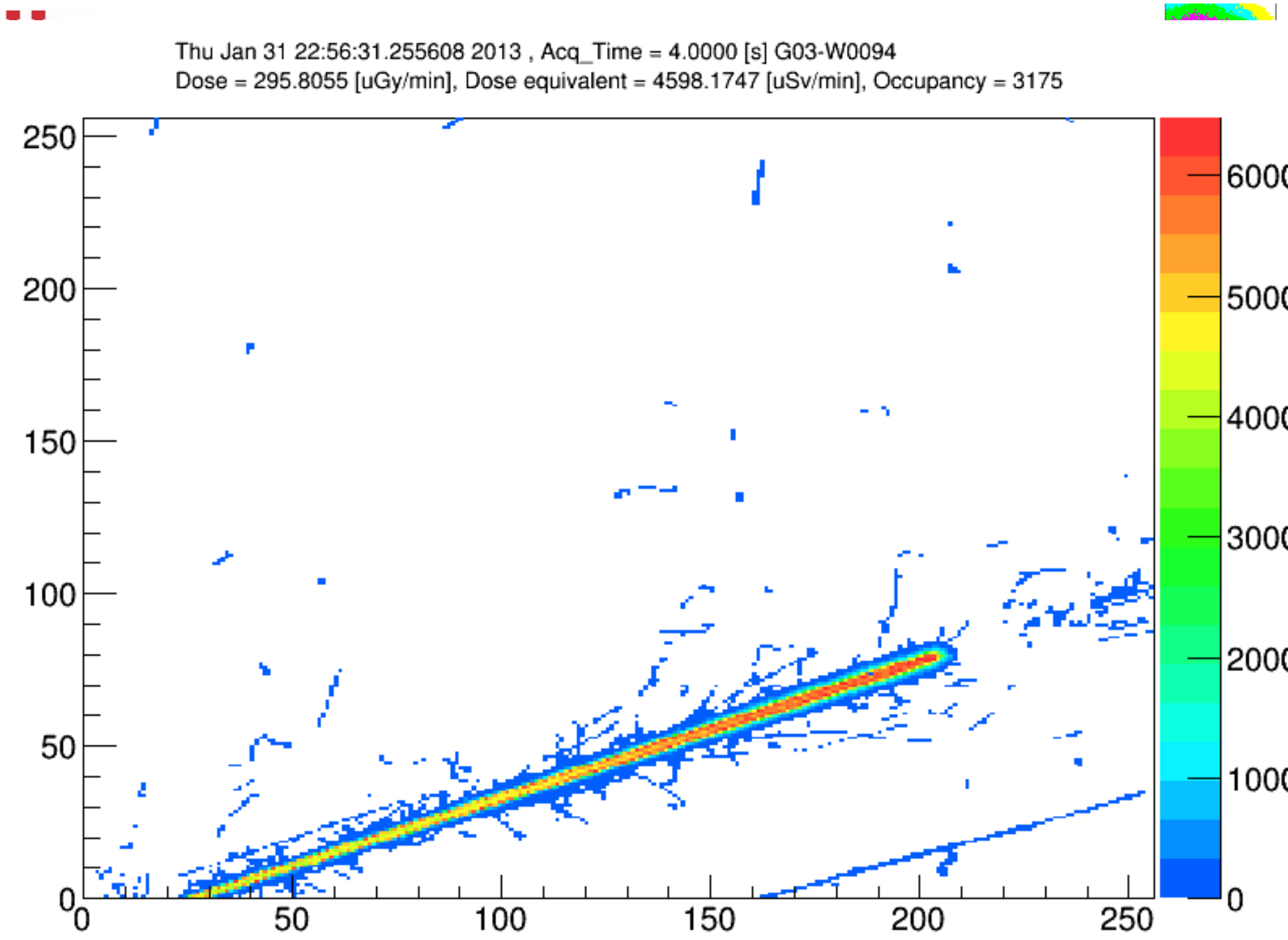
3000
2000
1000
0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50
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50
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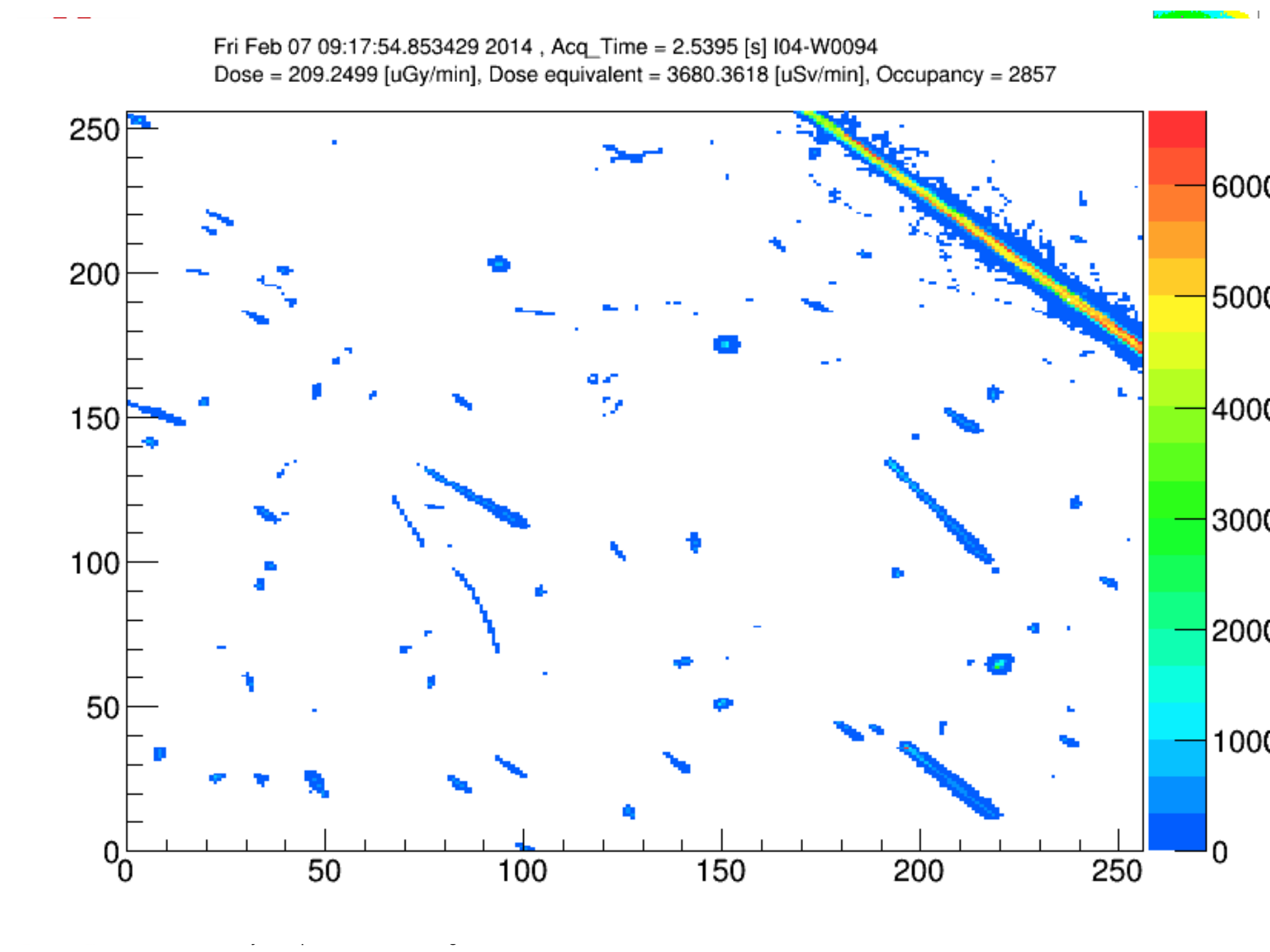
200
250
6000
5000
4000
3000
2000
1000
0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250
6000
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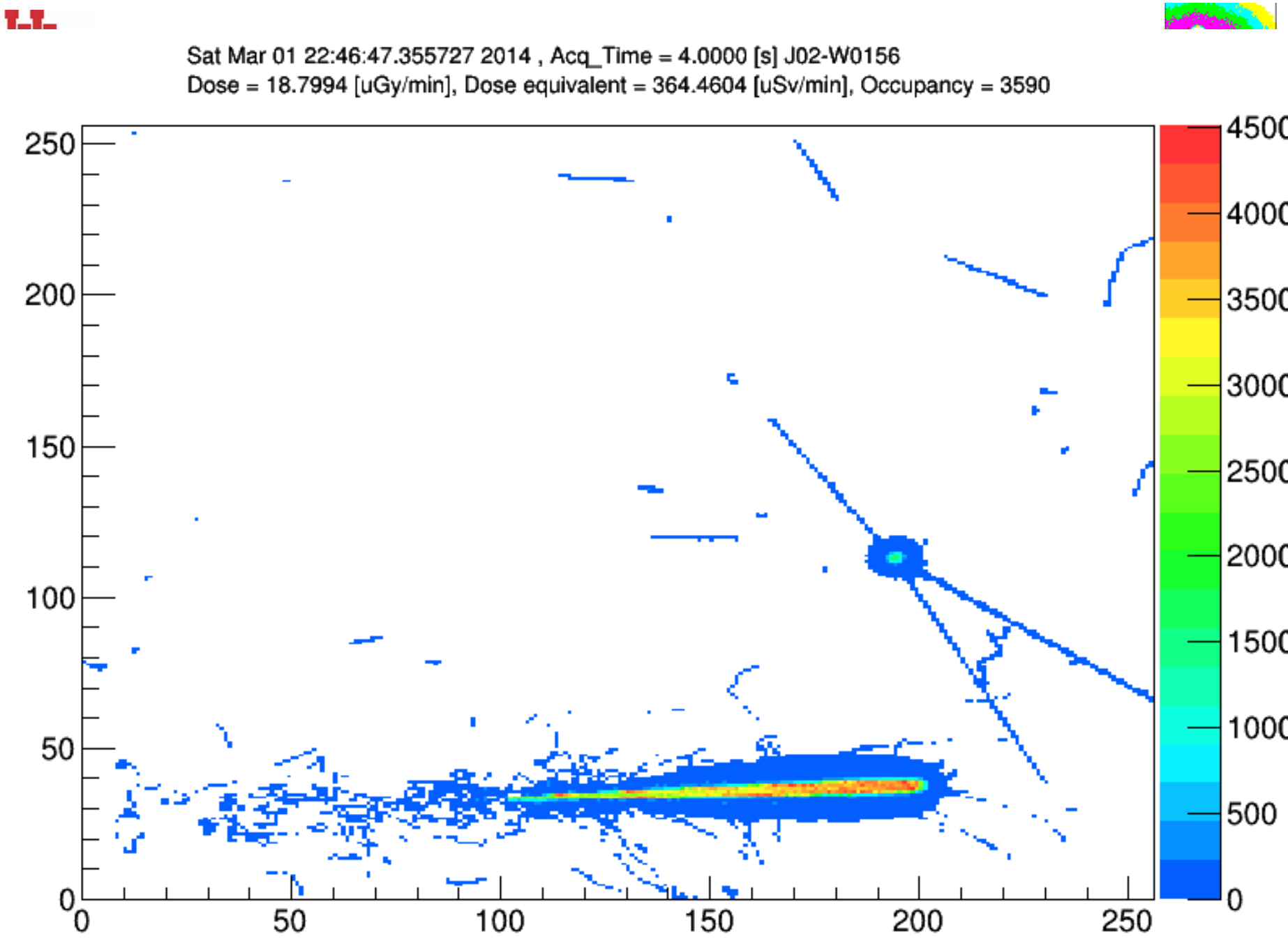
0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500
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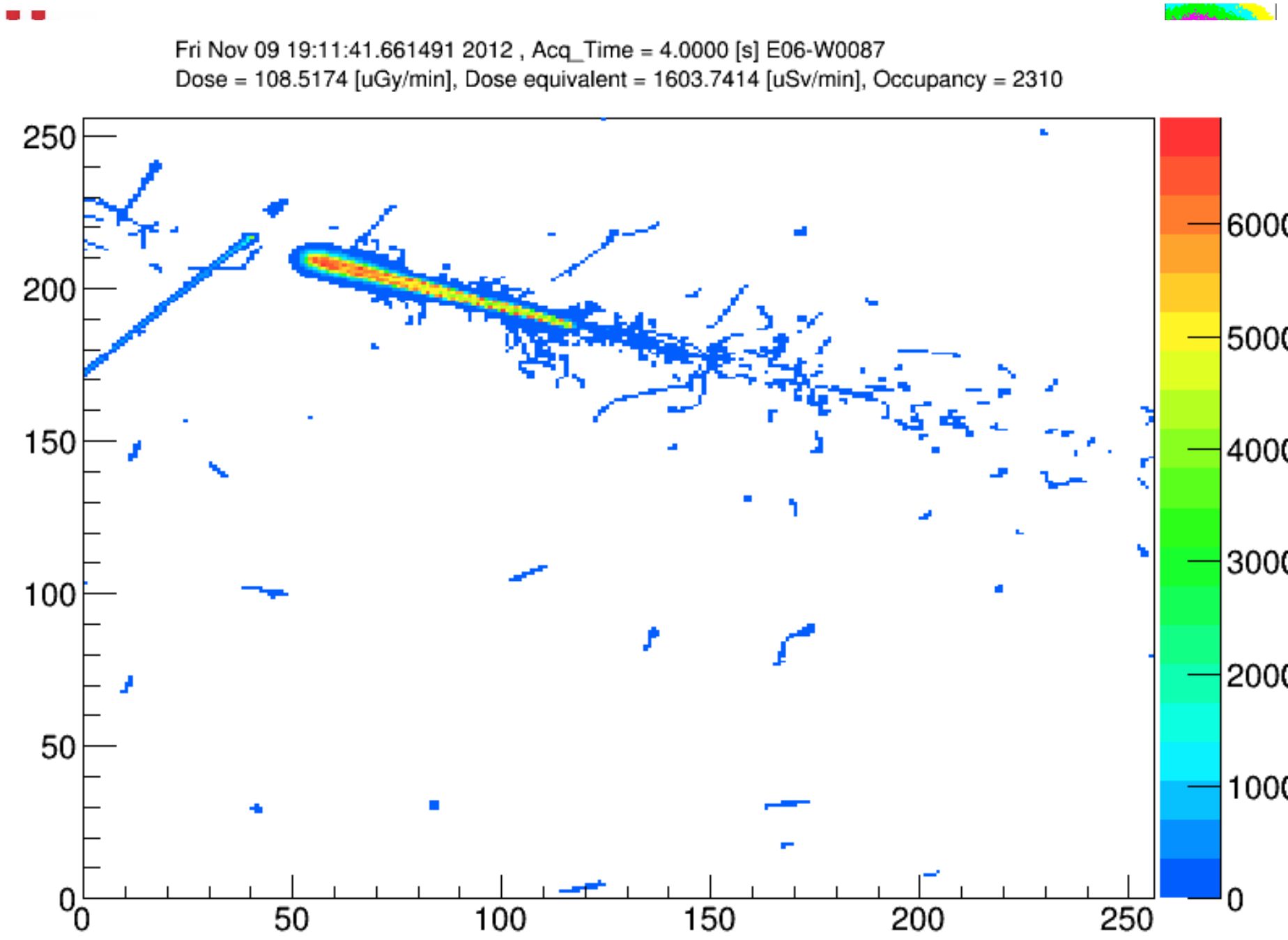
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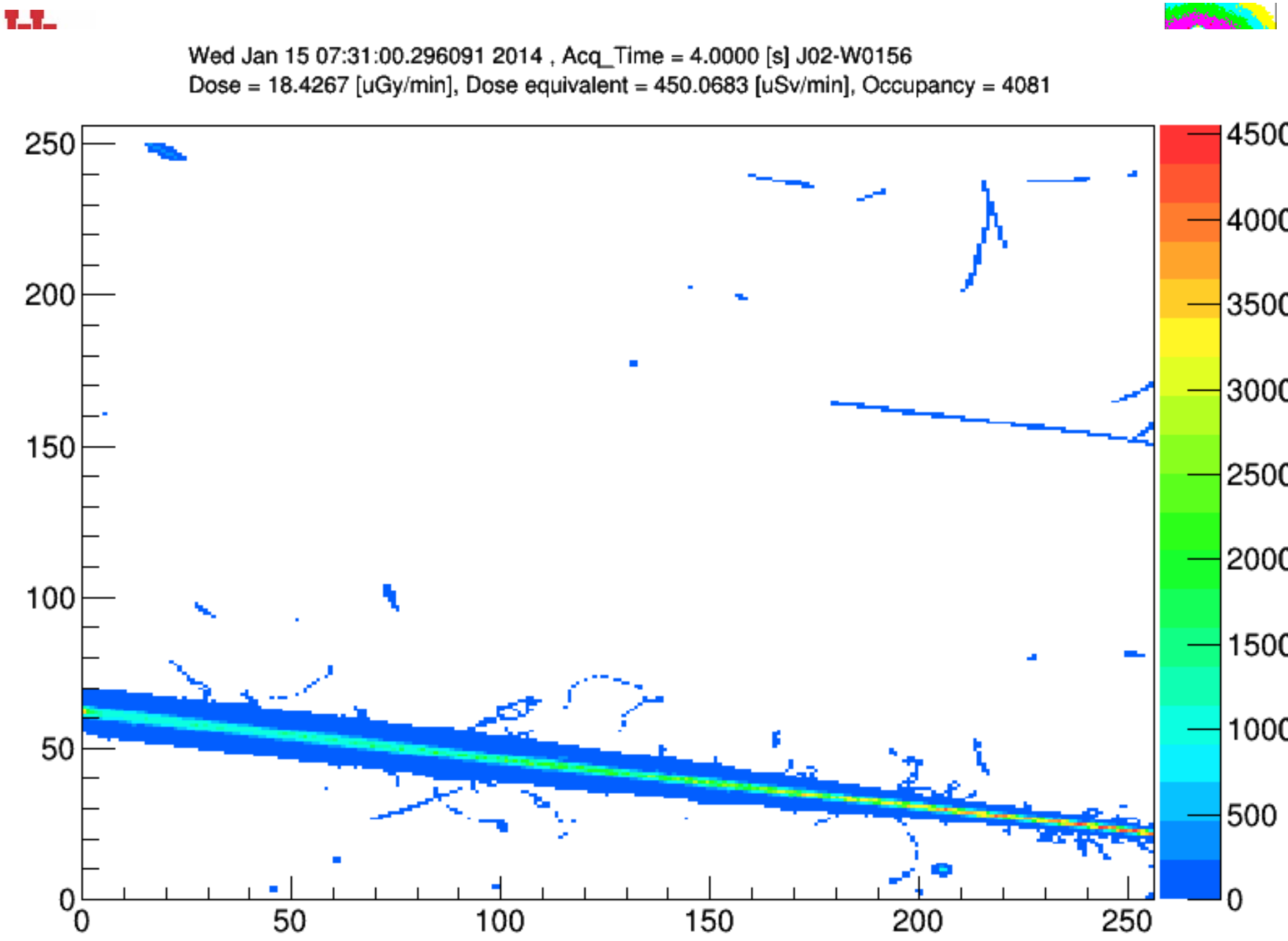
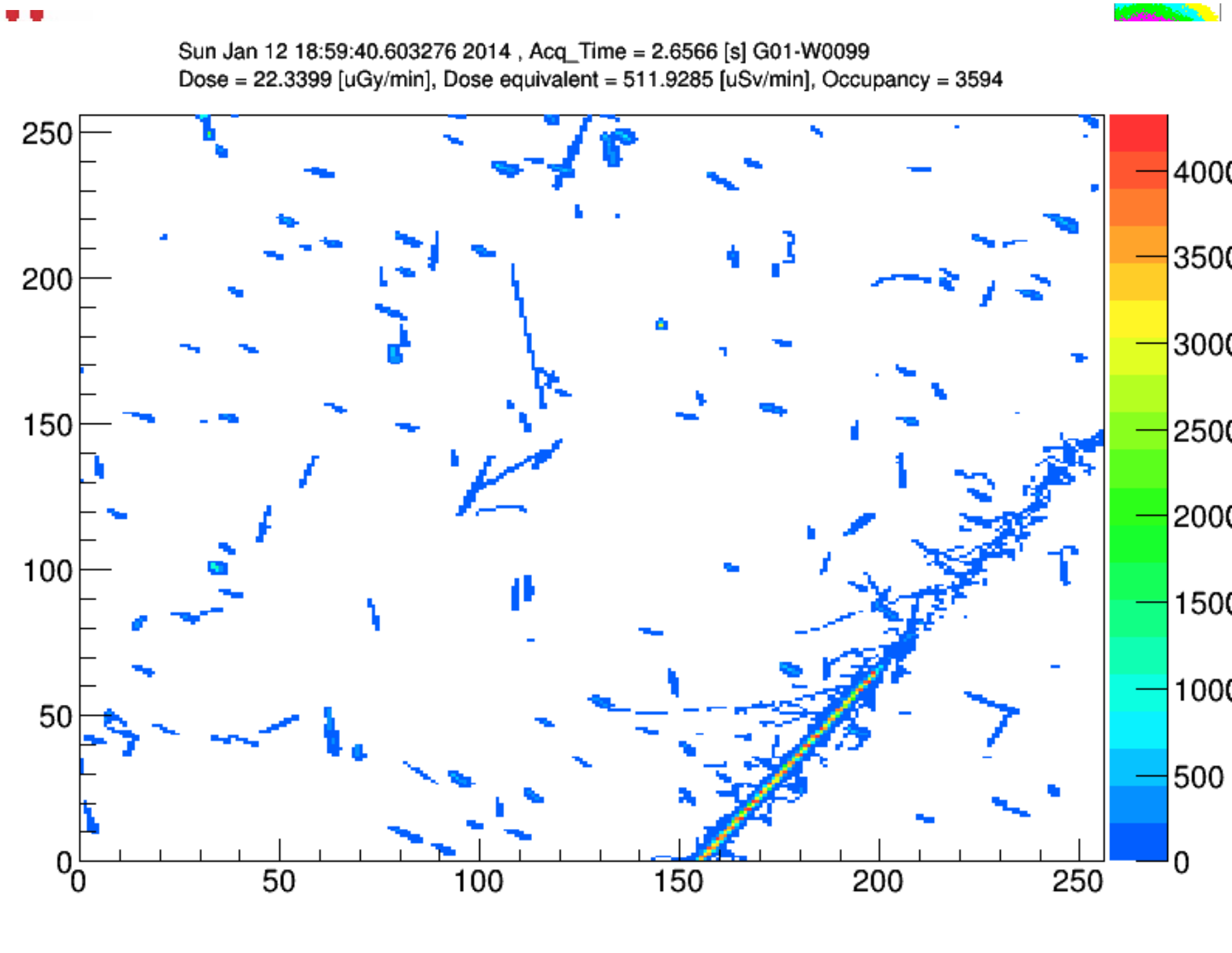
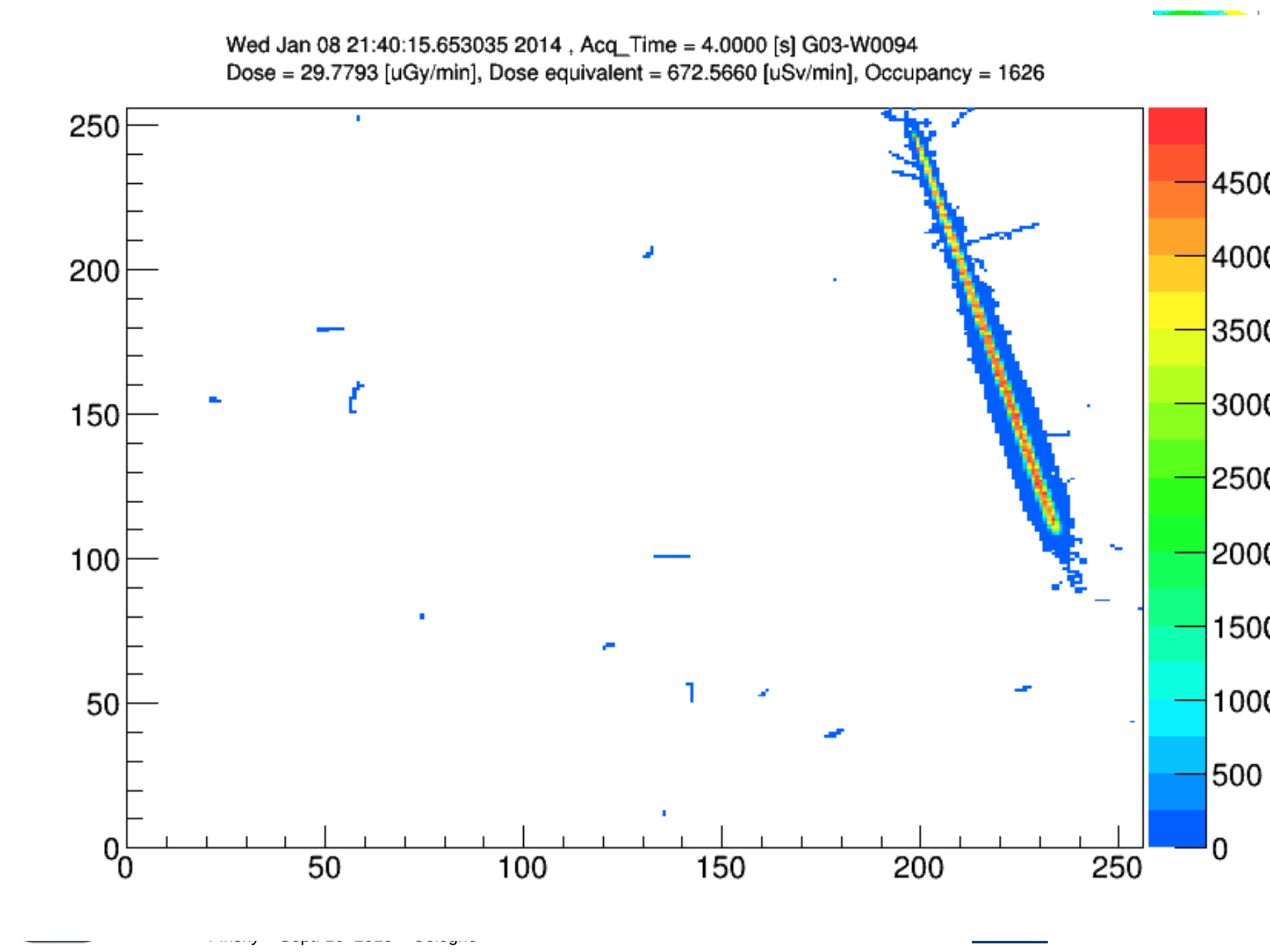
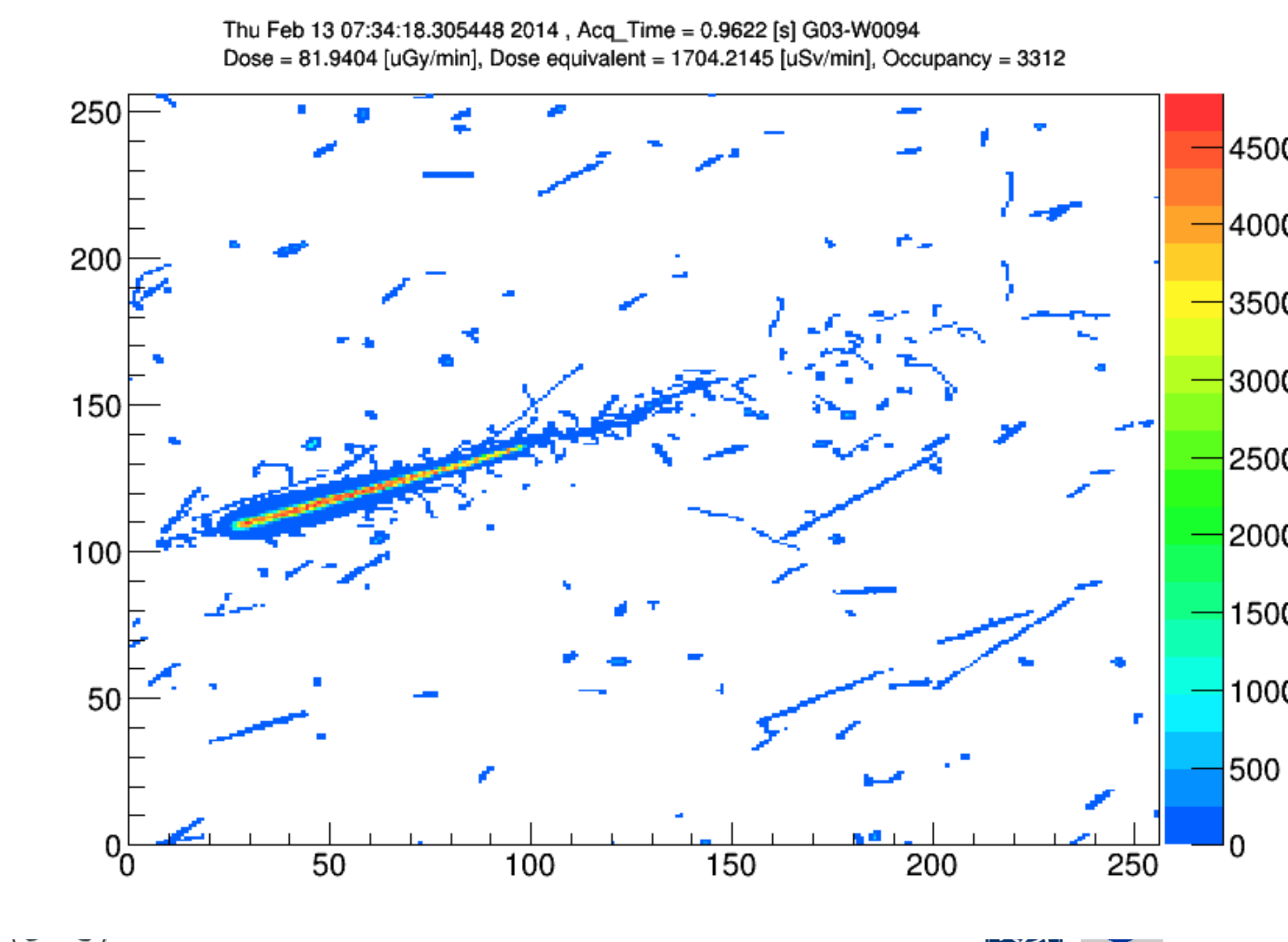
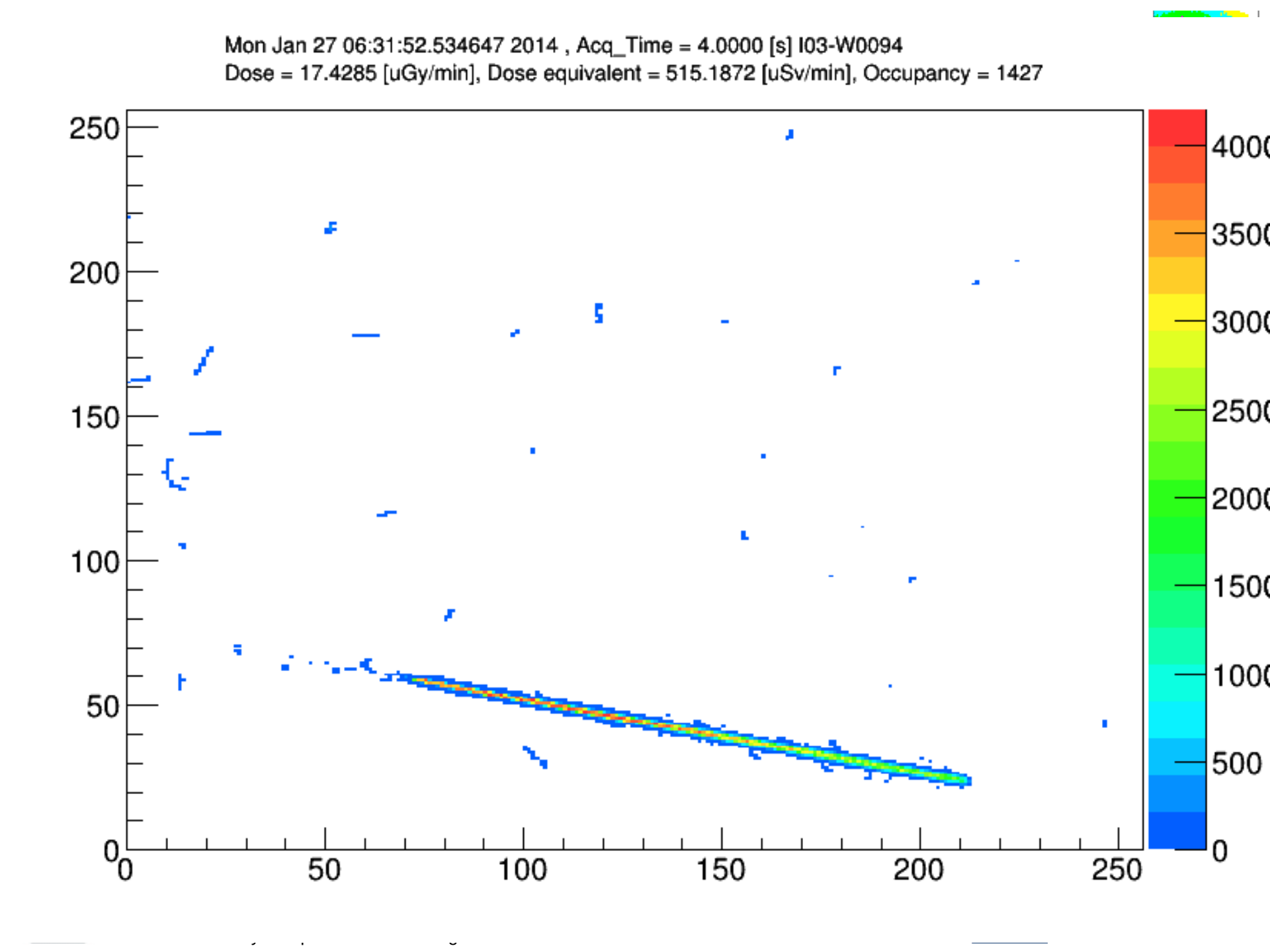
250
200
150
100
50
0
0
50
100
150
200
250
6000
5000
4000
3000
2000
1000
0

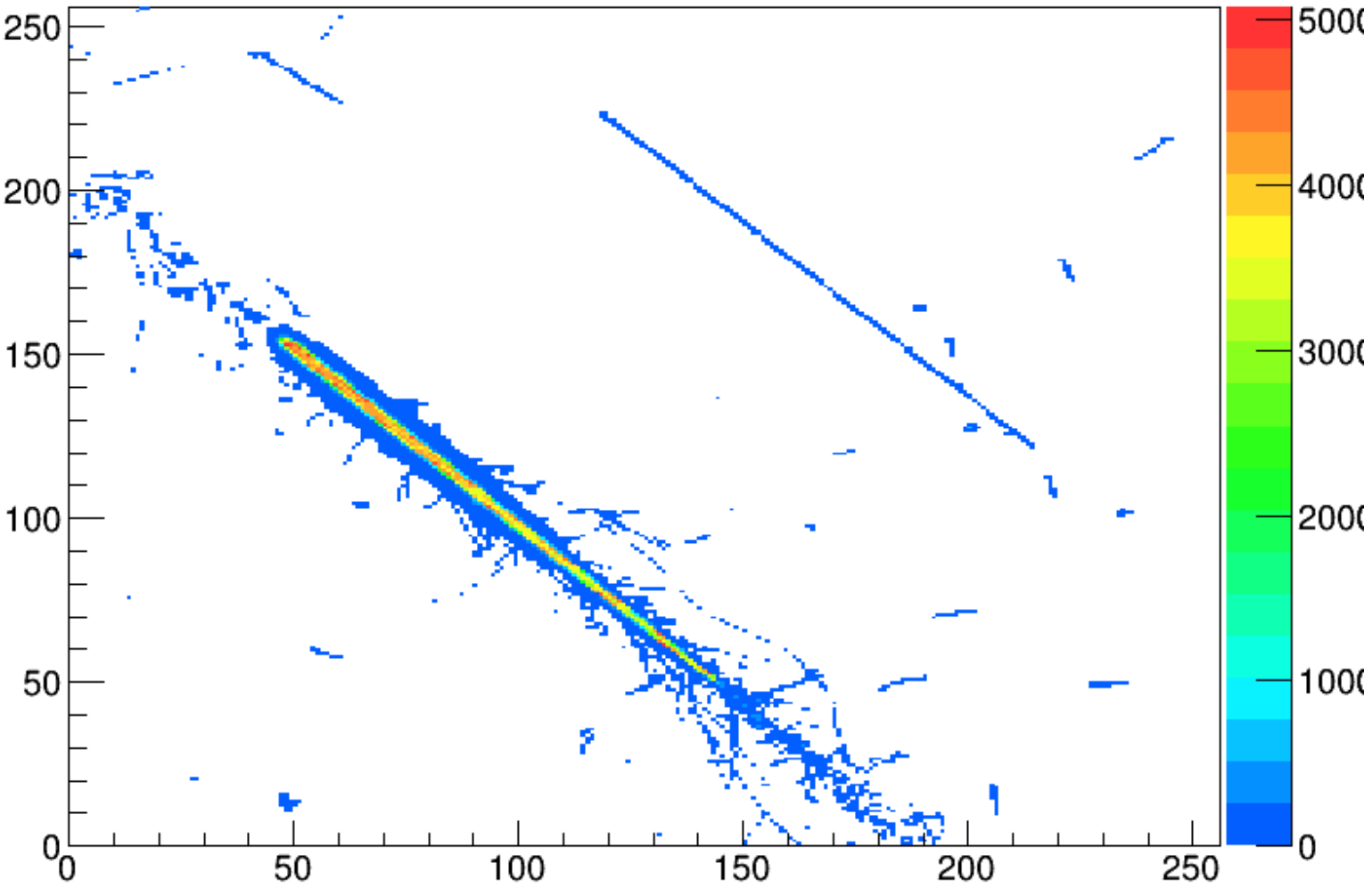

Wed Jan 15 07:31:00.296091 2014 , Acq_Time = 4.0000 [s] J02-W0156
Dose = 18.4267 [uGy/min], Dose equivalent = 450.0683 [uSv/min], Occupancy = 4081
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0

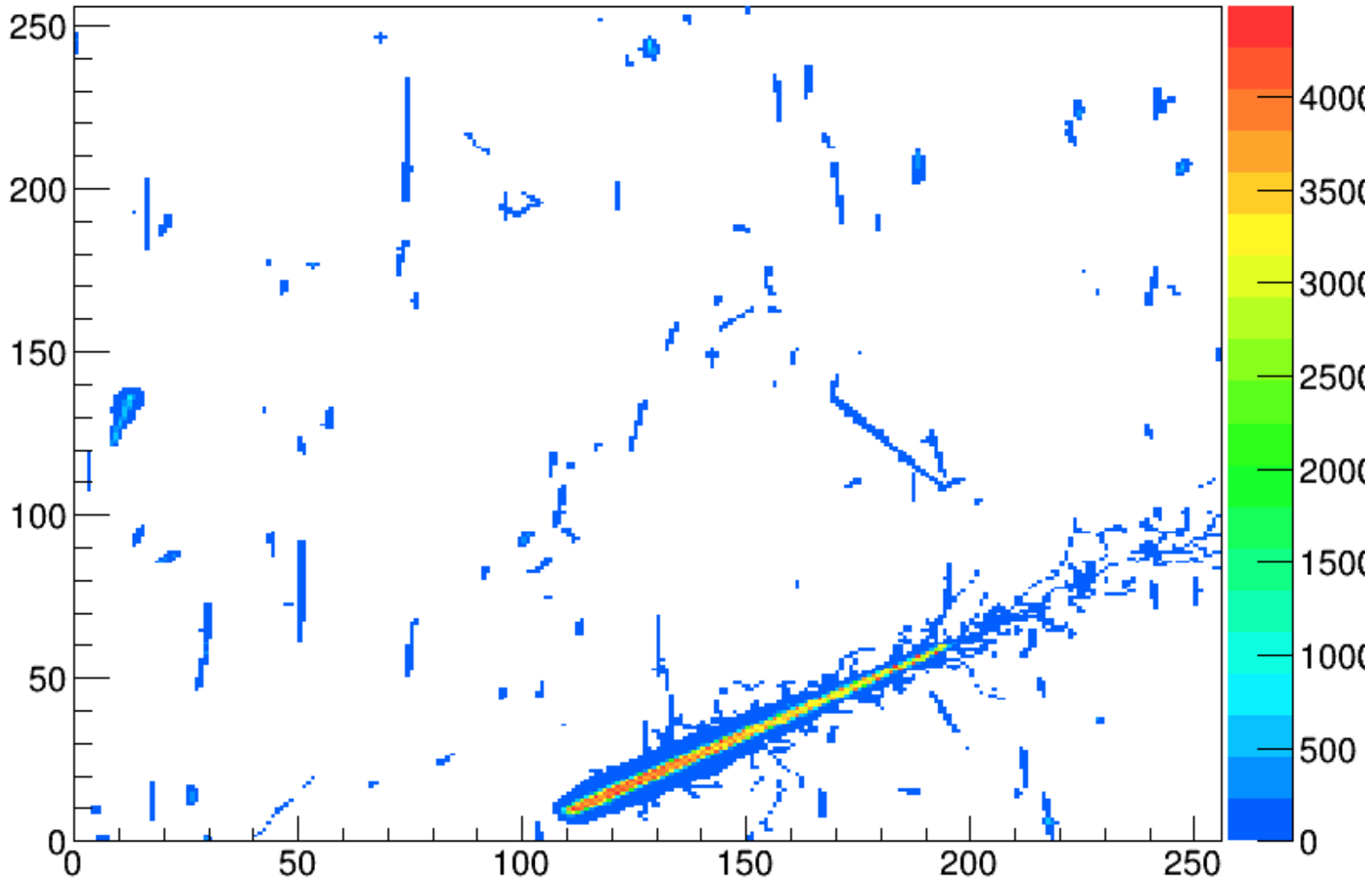

Sun Jan 12 18:59:40.603276 2014 , Acq_Time = 2.6566 [s] G01-W0099
Dose = 22.3399 [uGy/min], Dose equivalent = 511.9285 [uSv/min], Occupancy = 3594
250
200
150
100
50
0
0
50
100
150
200
250
4000
3500
3000
2500
2000
1500
1000
500
0


Wed Jan 08 21:40:15.653035 2014 , Acq_Time = 4.0000 [s] G03-W0094
Dose = 29.7793 [uGy/min], Dose equivalent = 672.5660 [uSv/min], Occupancy = 1626
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0


Thu Feb 13 07:34:18.305448 2014 , Acq_Time = 0.9622 [s] G03-W0094
Dose = 81.9404 [uGy/min], Dose equivalent = 1704.2145 [uSv/min], Occupancy = 3312
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0


Mon Jan 27 06:31:52.534647 2014 , Acq_Time = 4.0000 [s] I03-W0094
Dose = 17.4285 [uGy/min], Dose equivalent = 515.1872 [uSv/min], Occupancy = 1427
250
200
150
100
50
0
0
50
100
150
200
250
4000
3500
3000
2500
2000
1500
1000
500
0


Tue Feb 18 02:09:33.132259 2014 , Acq_Time = 4.0000 [s] G03-W0094
Dose = 38.2716 [uGy/min], Dose equivalent = 789.7881 [uSv/min], Occupancy = 3112
250
200
150
100
50
0
0
50
100
150
200
250
500
400
300
200
100
0


Fri Feb 14 15:01:36.526700 2014 , Acq_Time = 1.1816 [s] I04-W0094
Dose = 79.9586 [uGy/min], Dose equivalent = 1638.6990 [uSv/min], Occupancy = 3160
250
200
150
100
50
0
0
50
100
150
200
250
400
350
300
250
200
150
100
500
0

Thank You for Your Attention

Oh Yes! The DEMO