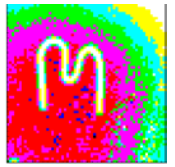
Update on Medipix Developments

Lawrence Pinsky
Physics Department
University of Houston

The Principal Acknowlegments…



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

AND the Medipix2, Medipix3 and Medipix4 Collaborations,

As Well As

The NASA HERA & BIRD Engineering and Management Teams

[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

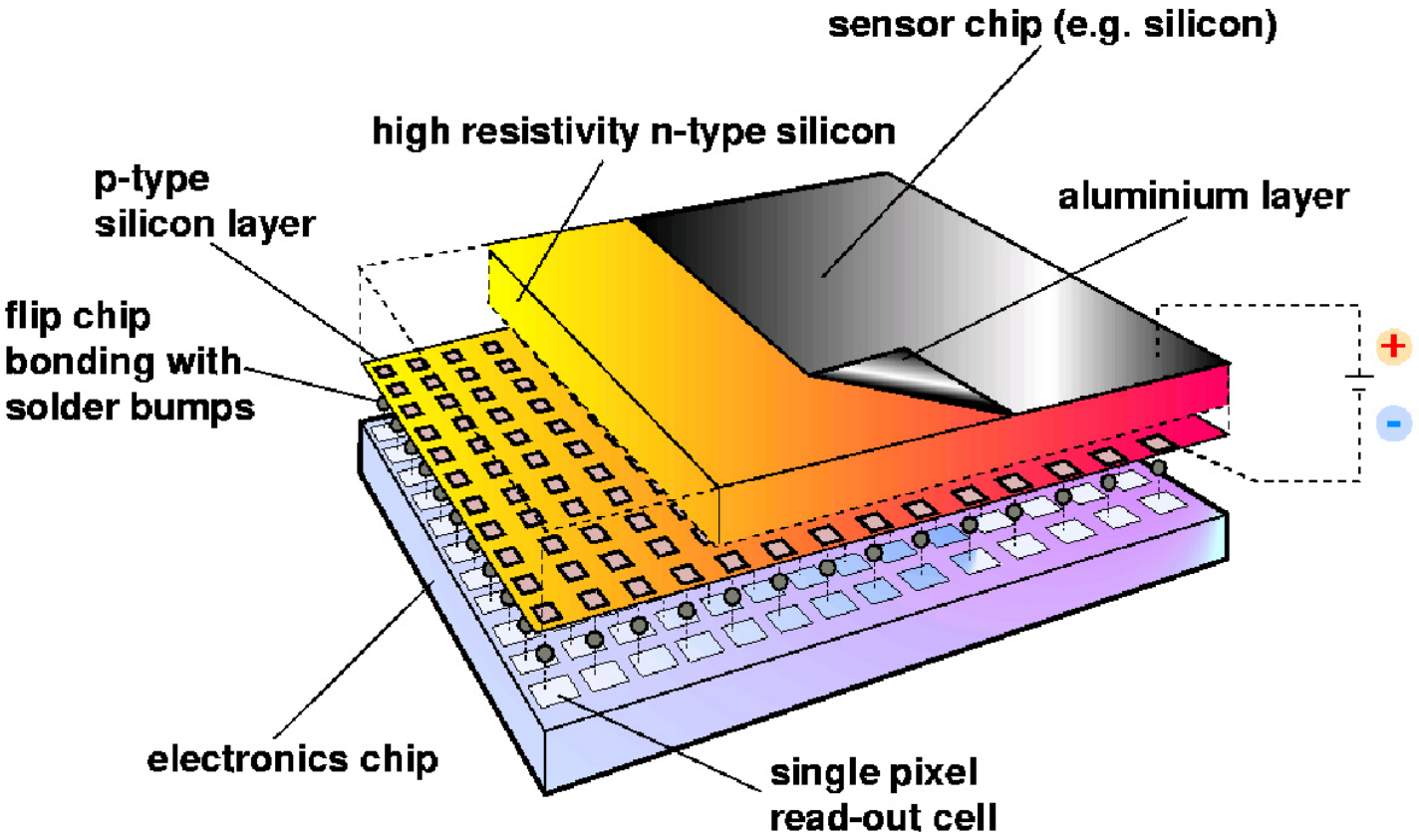
[4] University of Houston-Downtown, Houston, TX, USA

[5] Institute of Experimental and Applied Physics, Czech Technical University in Prague, Czech Republic

[6] National Institute for Radiological Sciences, Inage, Japan

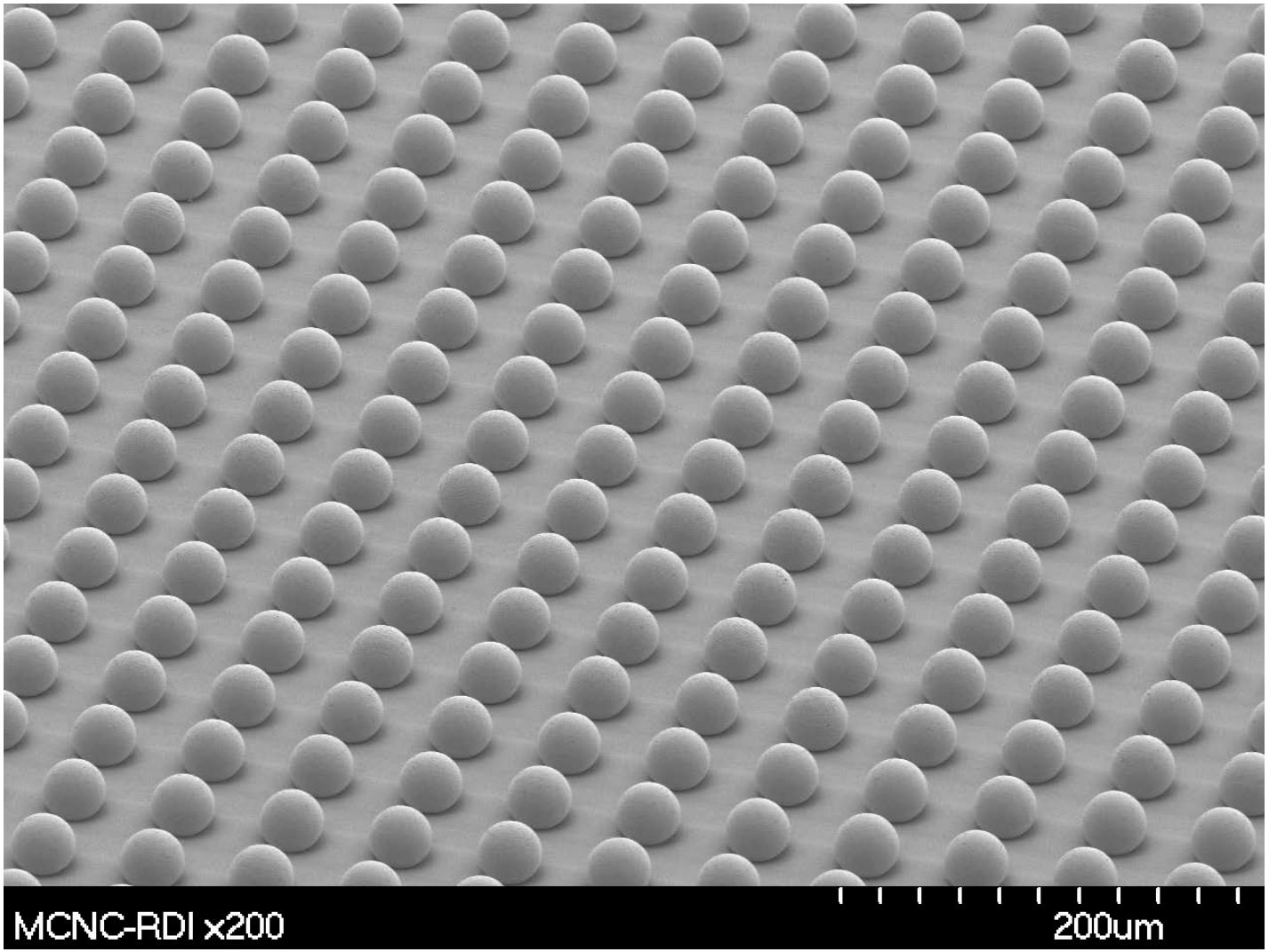
[7] Kansas State University

Hybrid Pixel Detectors

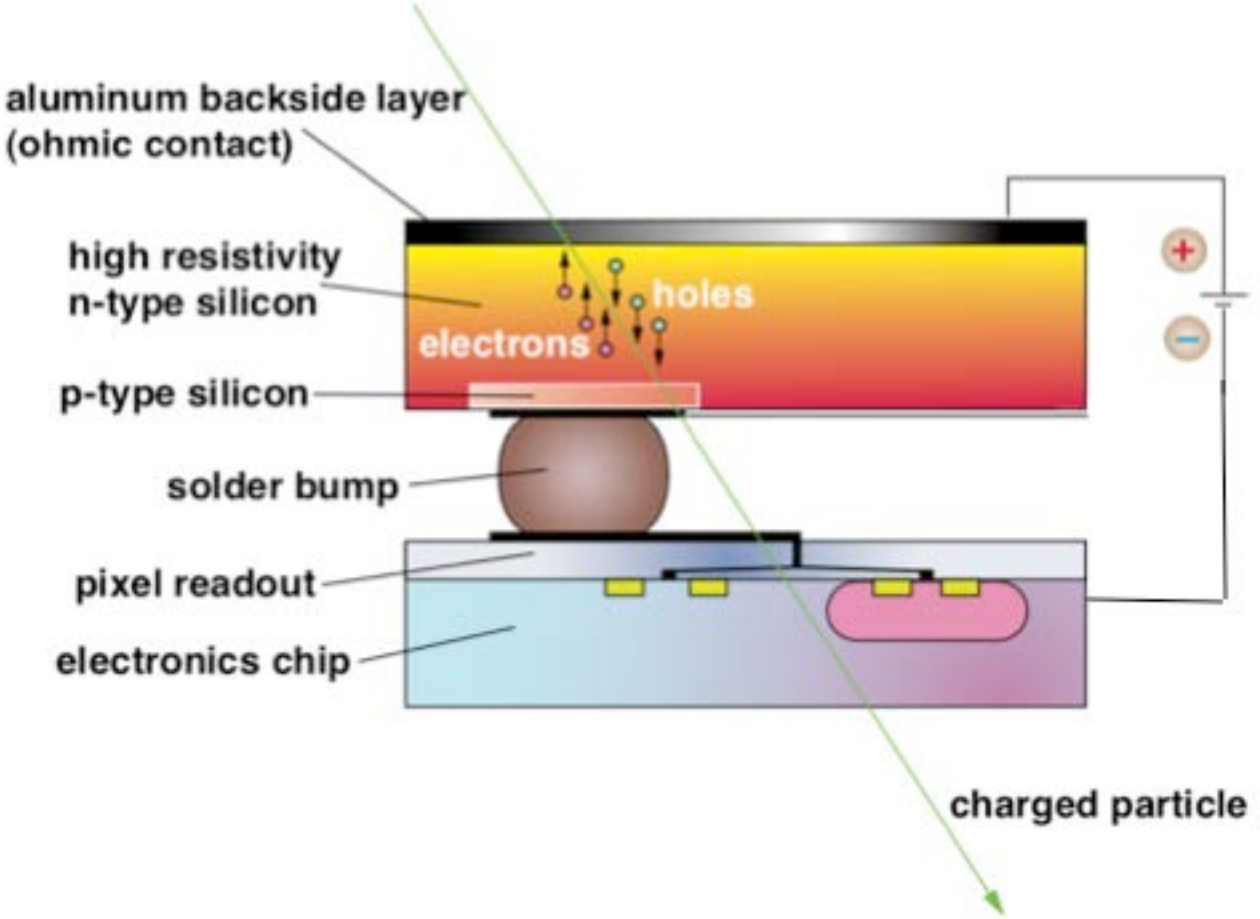


Detector and electronics readout are optimized separately

Bumps on BOTH the Chip and Sensor

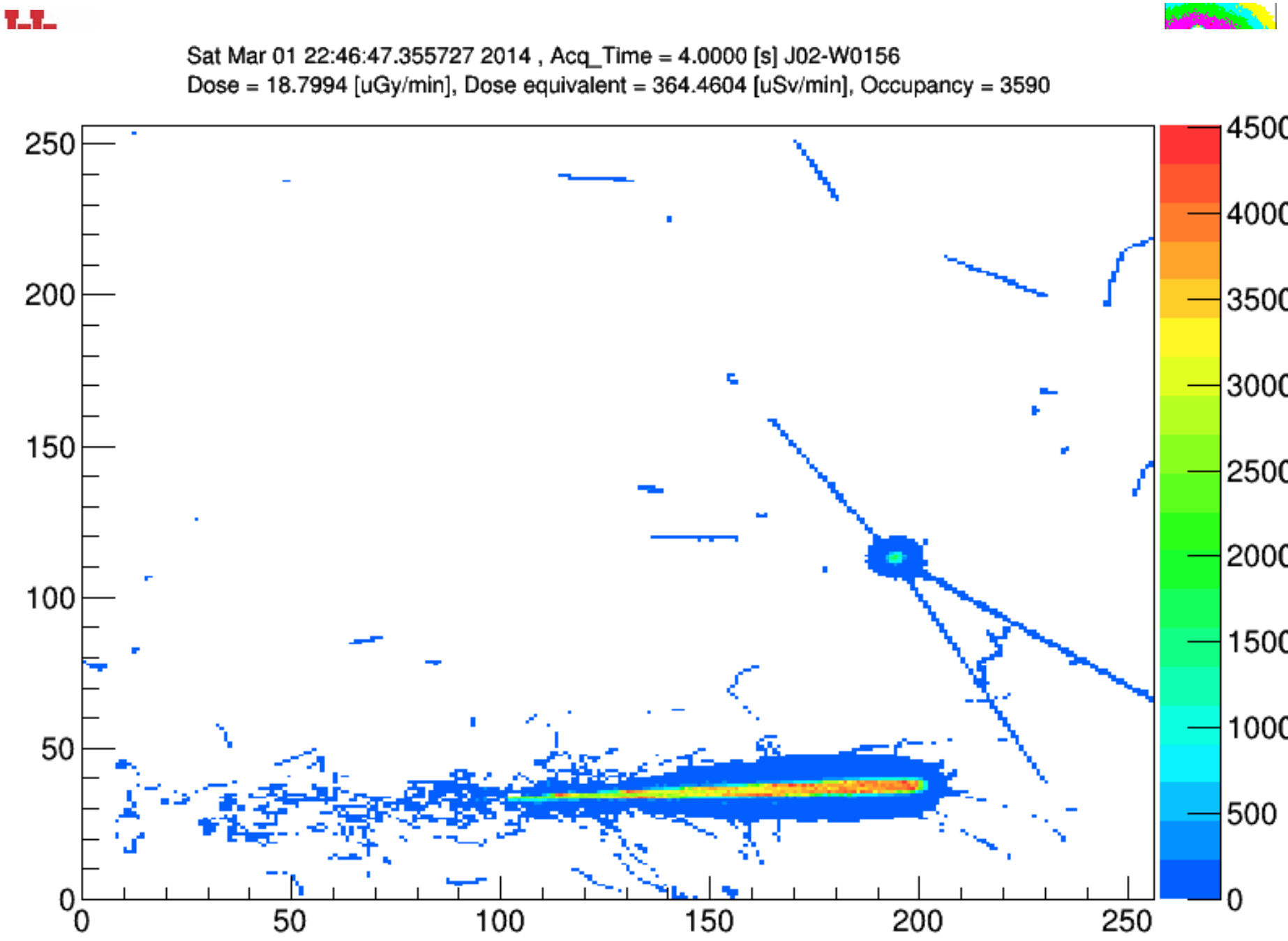


Hybrid Pixel Detector - Cross Section



Radiation Environment Monitor ("REM")
NASA ISS Flight Hardware!

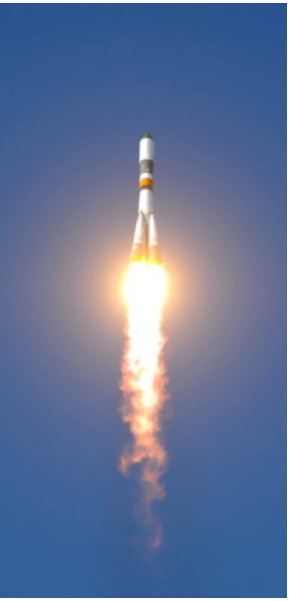
Based on the First-Generation "USB-Lite" Interfaces from IEAP


Sat Mar 01 22:46:47.355727 2014 , Acq_Time = 4.0000 [s] J02-W0156
Dose = 18.7994 [uGy/min], Dose equivalent = 364.4604 [uSv/min], Occupancy = 3590
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0

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…
- 2 are currently in the BEAM facility being compared with simultaneous inside the ISS measurements.
- (Two have been returned for evaluation, but as yet no Timepix chips have failed in space… Failures due to support electronics)

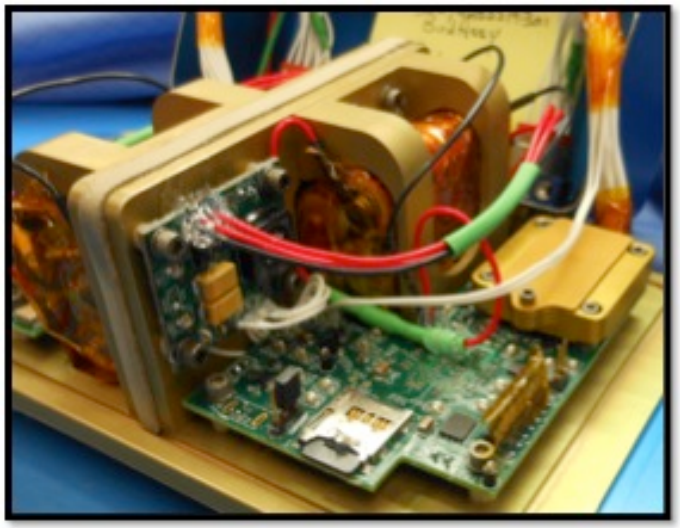


S114E7221

Medipix Devices in Space On Orion (EFT-1), Dec. 2014

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

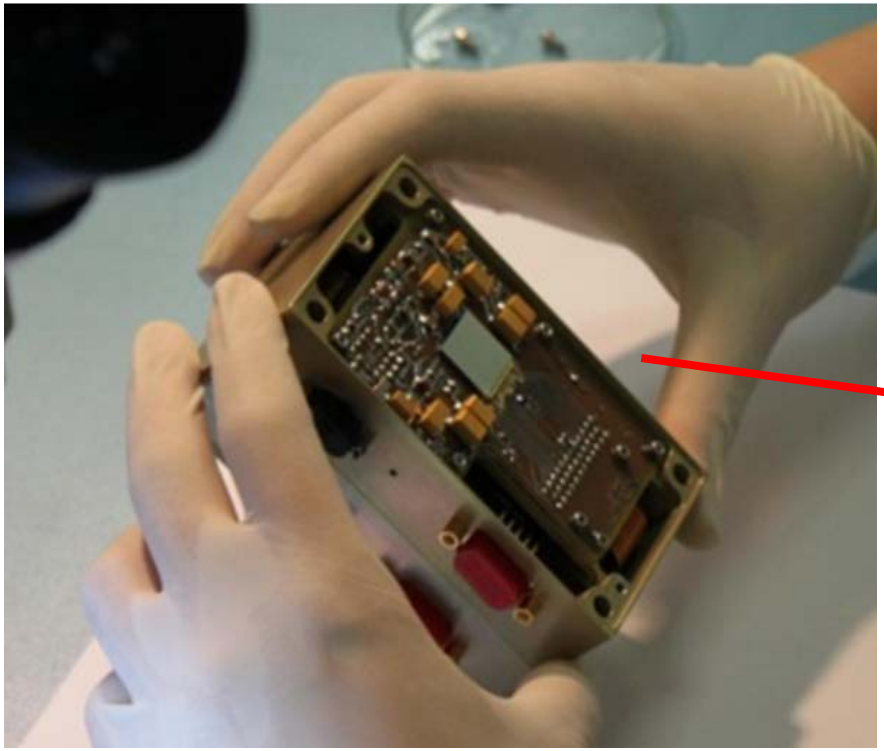
BIRD @ NASA Space Rad. Lab @ Brookhaven Nat. Lab in NY

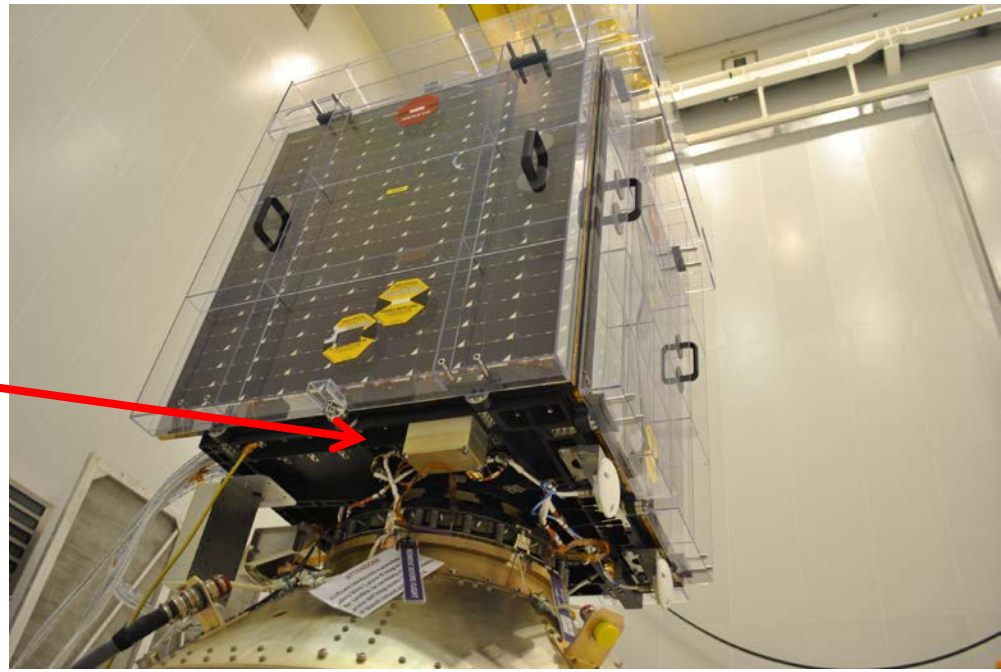


BIRD with the cover off…

Medipix Devices in Space Already and Very Soon…

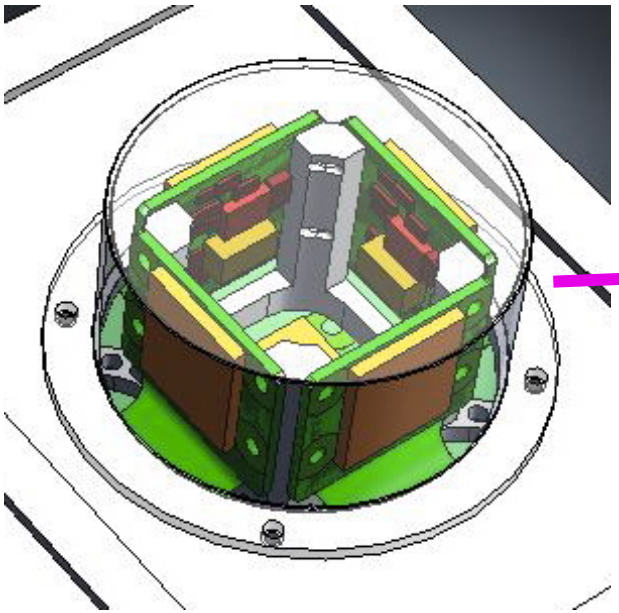
- **ESA—Proba-V (IEAP—CTU Prague)**
  - **1 Timepix device (SATRAM) in Polar orbit satellite at 820 Km with minimal shielding since May 2013…**

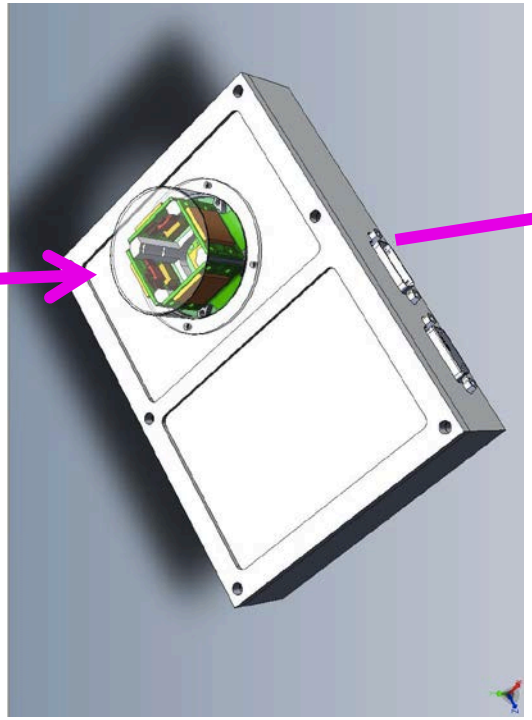


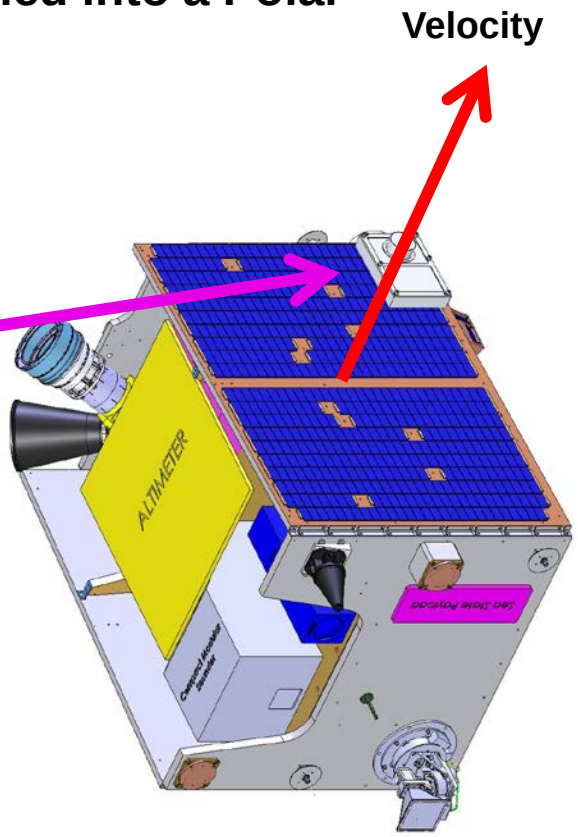


Medipix Devices in Space Already and Very Soon…

- **UK—TechDemoSat**
  - **5 Timepix devices (LUCID) in one detector head unit with 0.5 mm Al shielding to be launched into a Polar orbit at ~620 Km July 8, 2014**

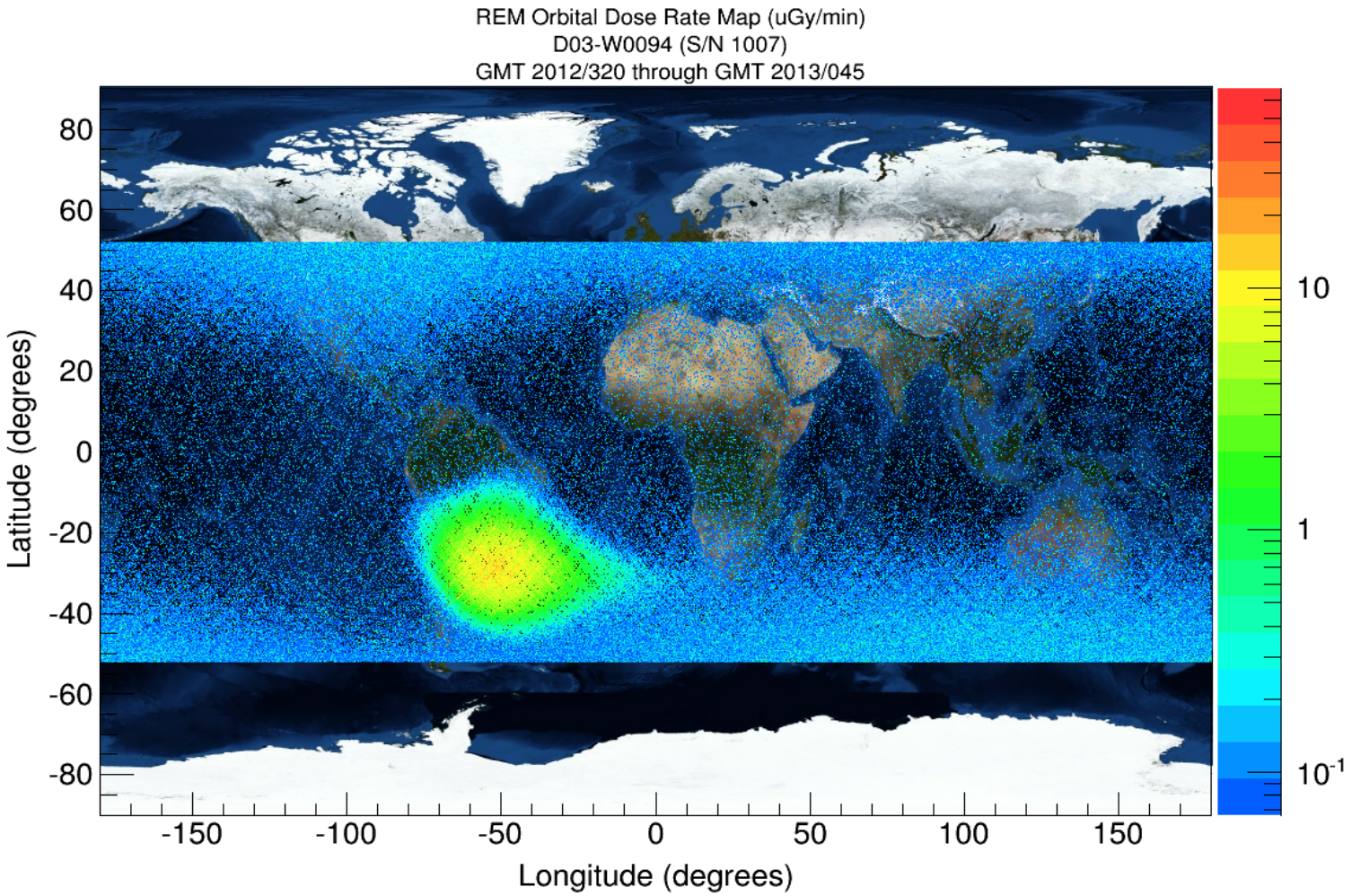




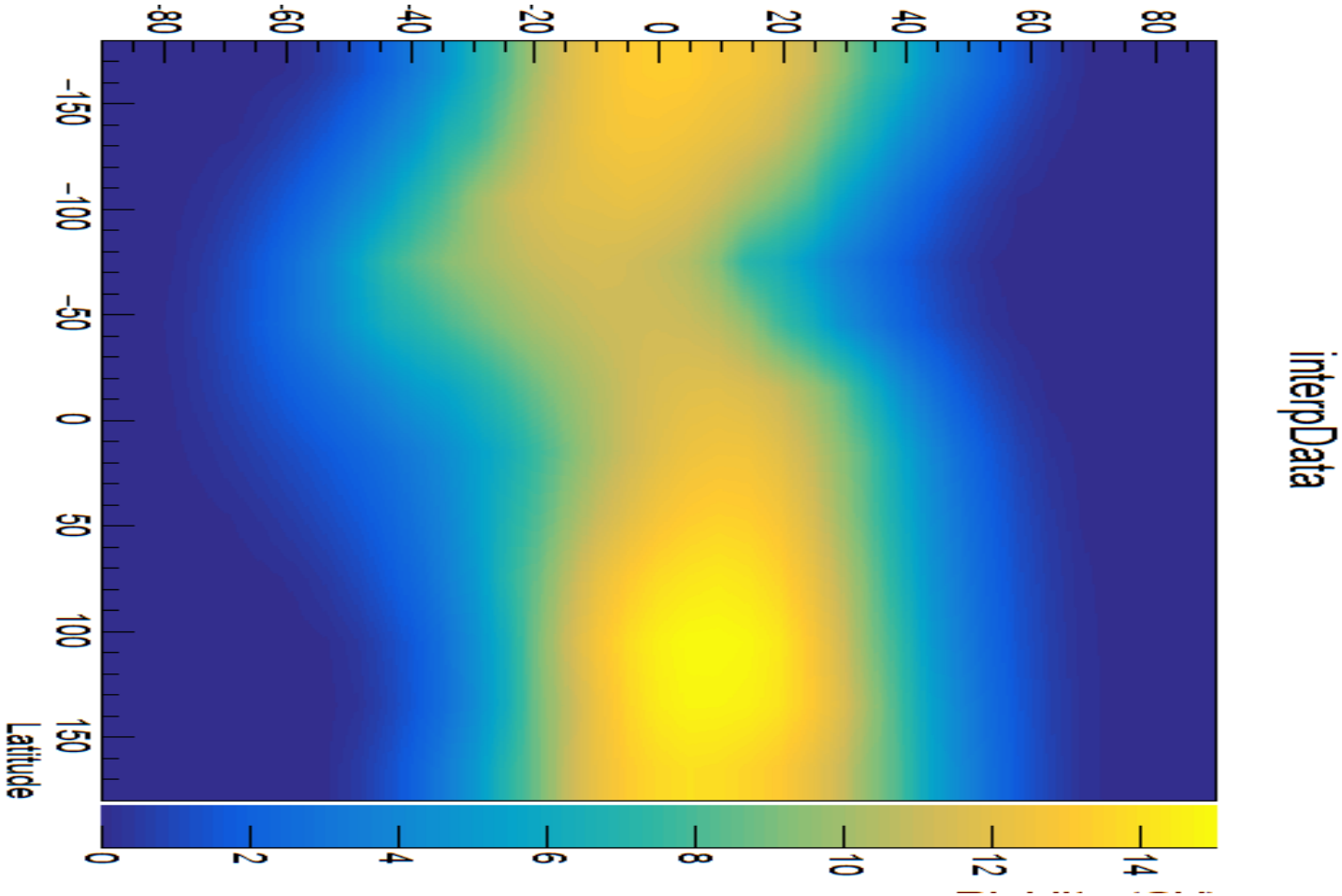


~4 Years Onboard ISS

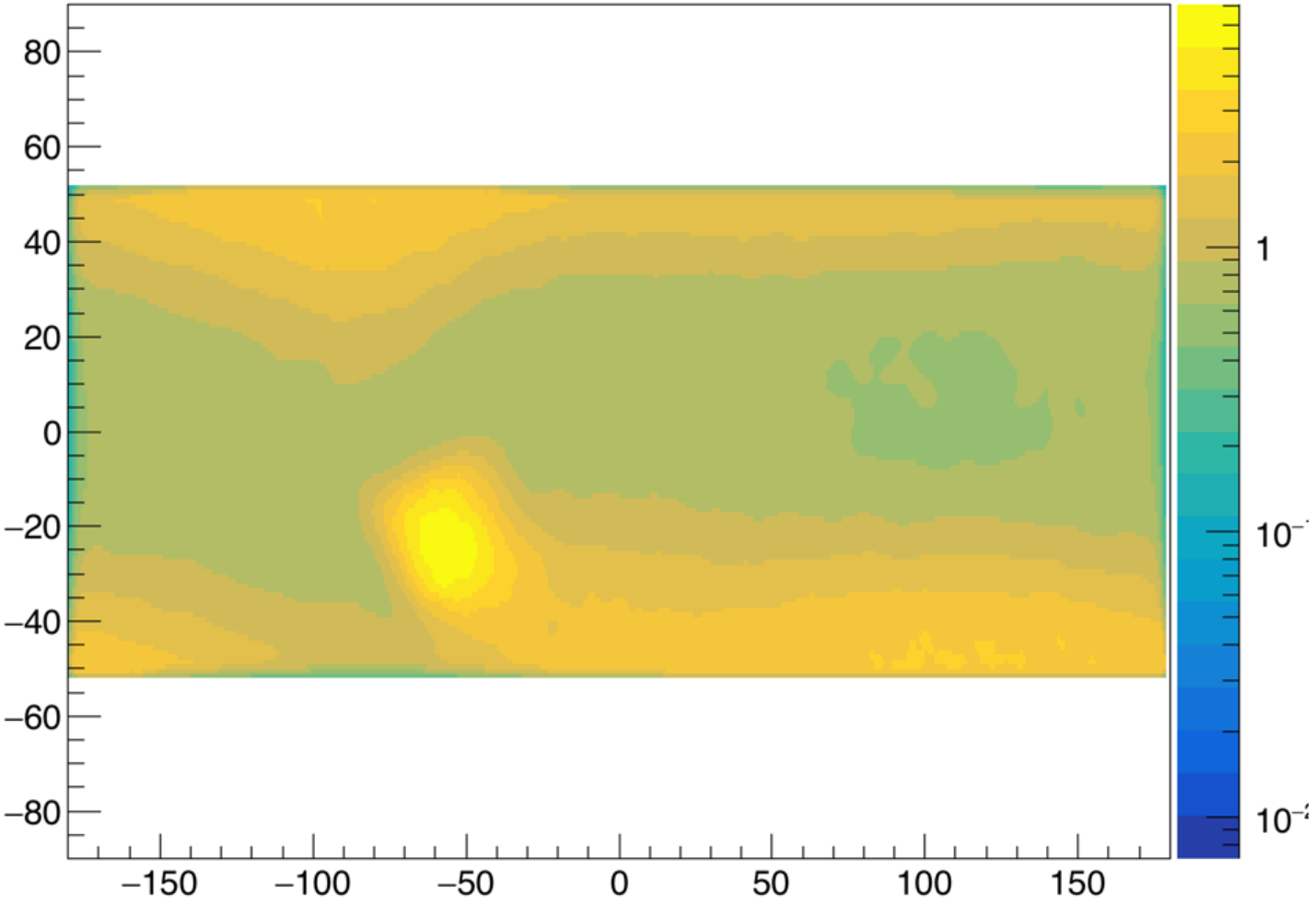
REM Absorbed Dose Rate Data (μG/min)



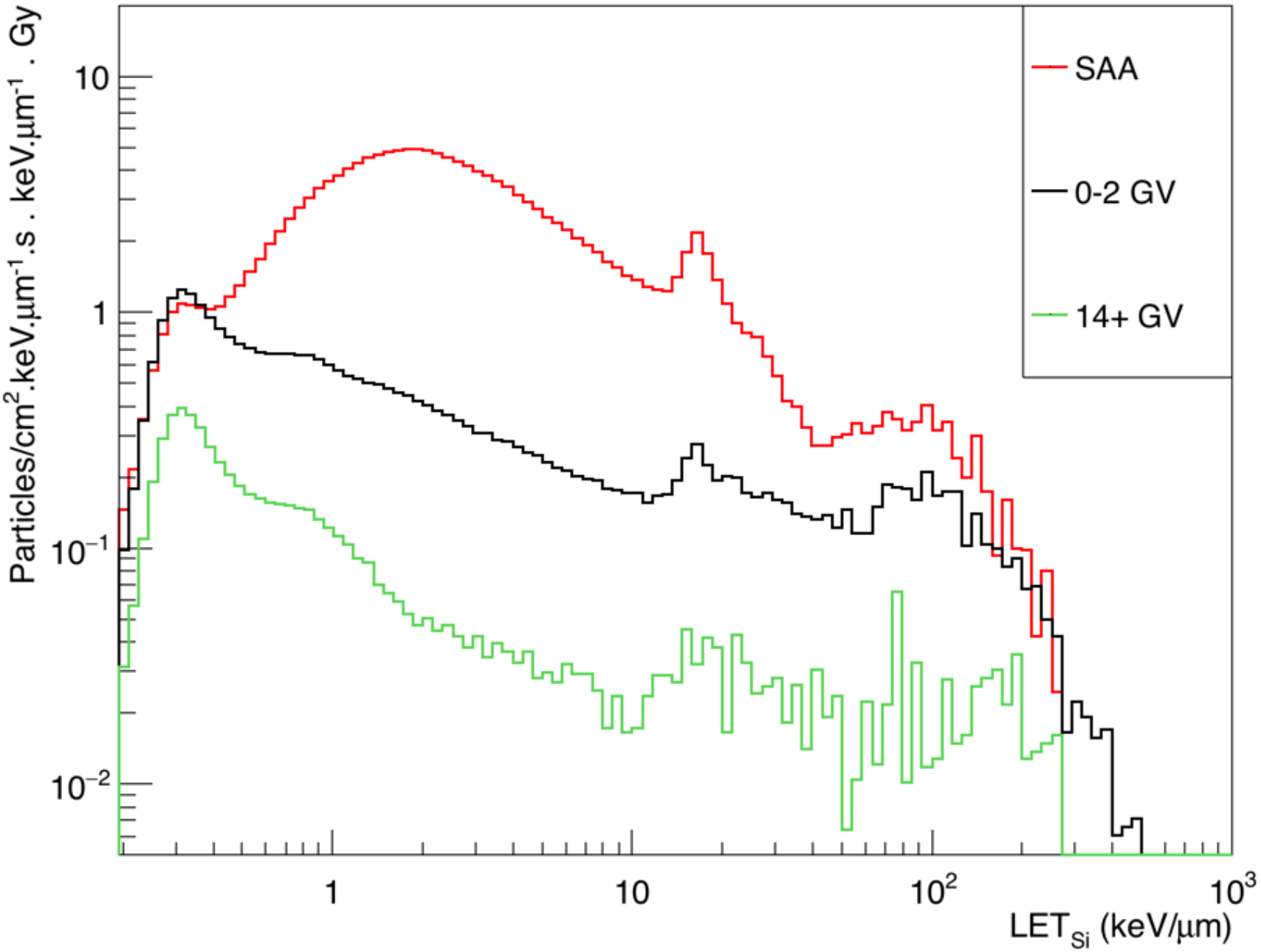
Vertical Cutoff (GV)



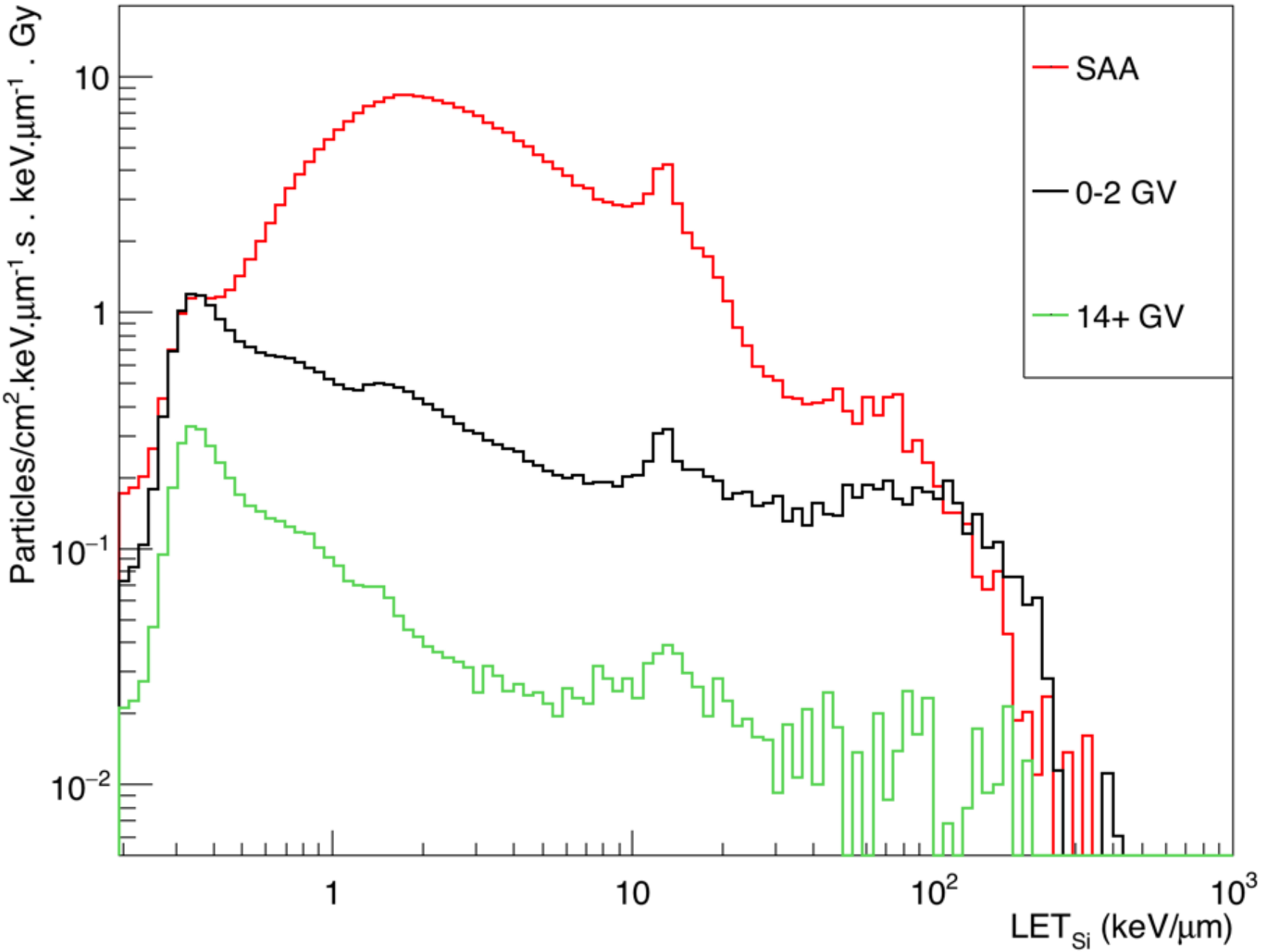
MIPs As A Function of Cutoff



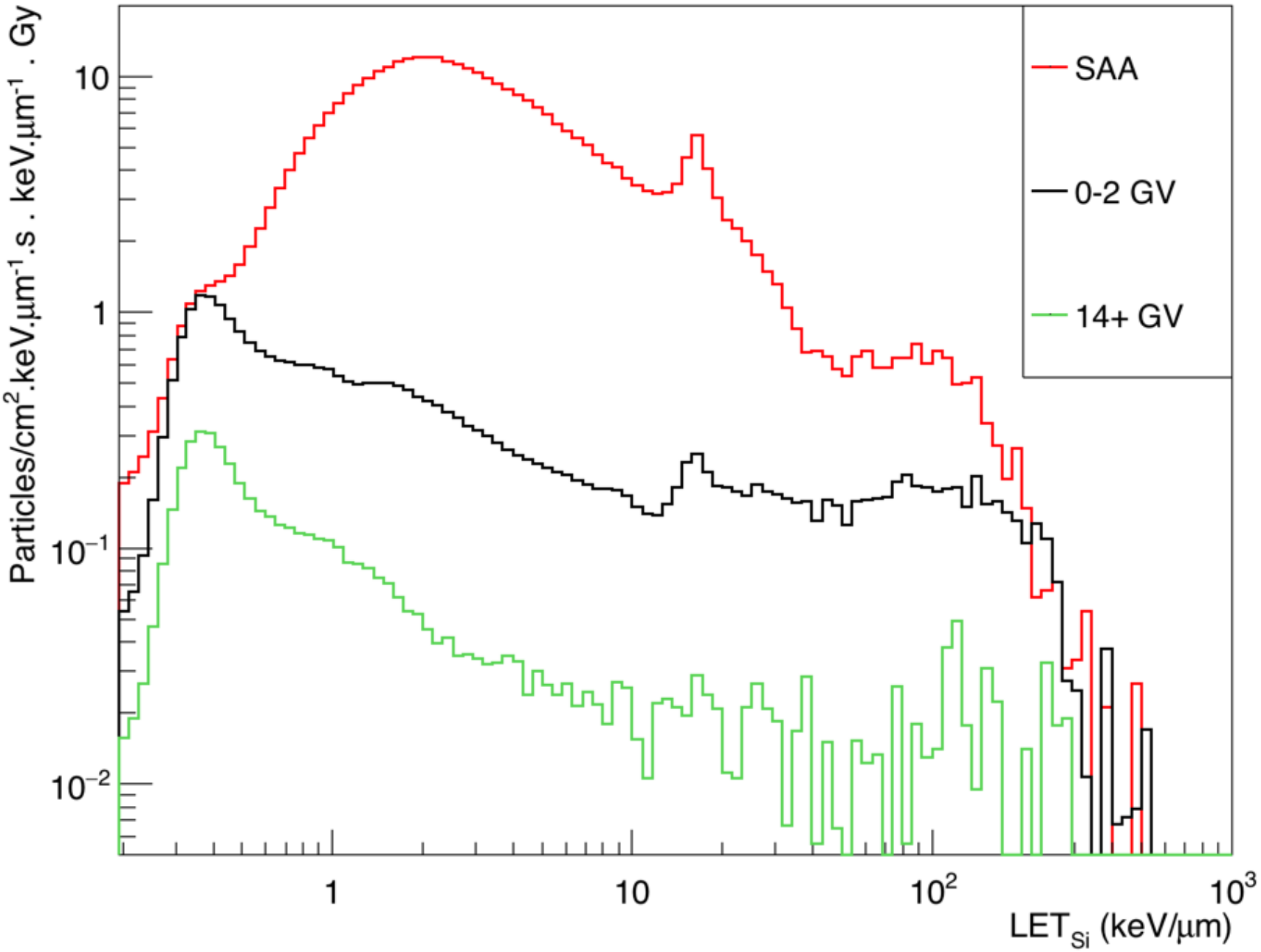
Inner SAA LET Spectrum D03-W0094

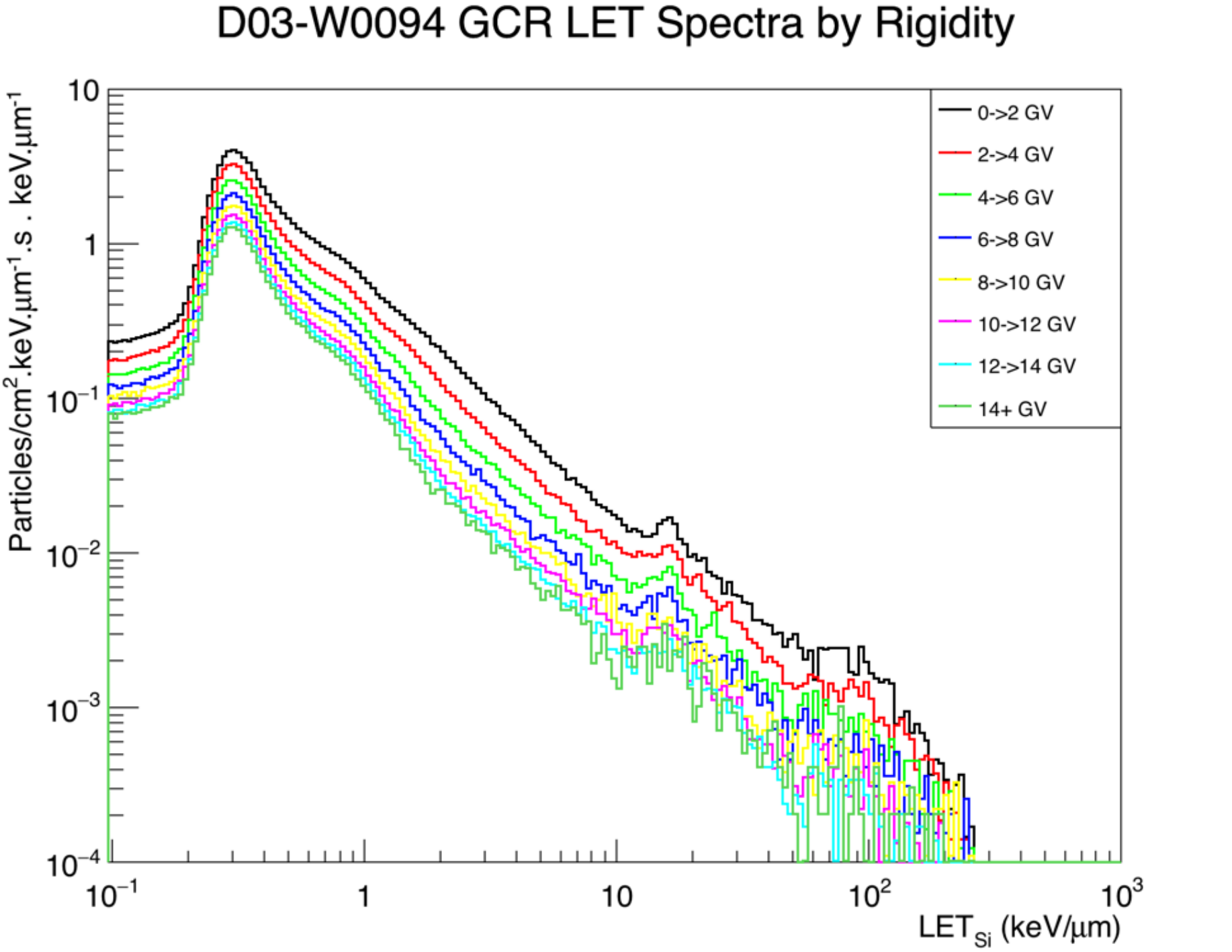


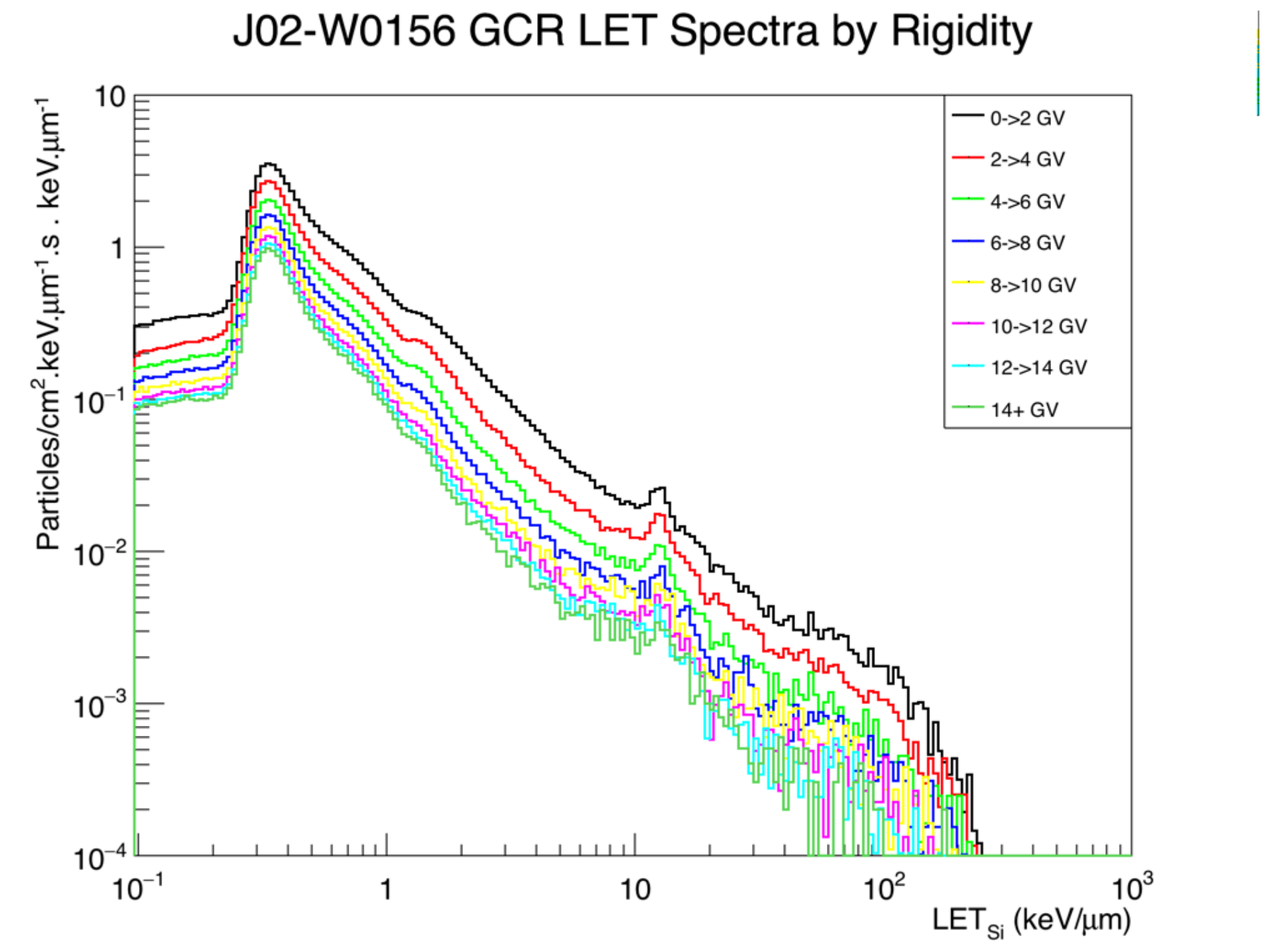
Inner SAA LET Spectrum J02-W0156

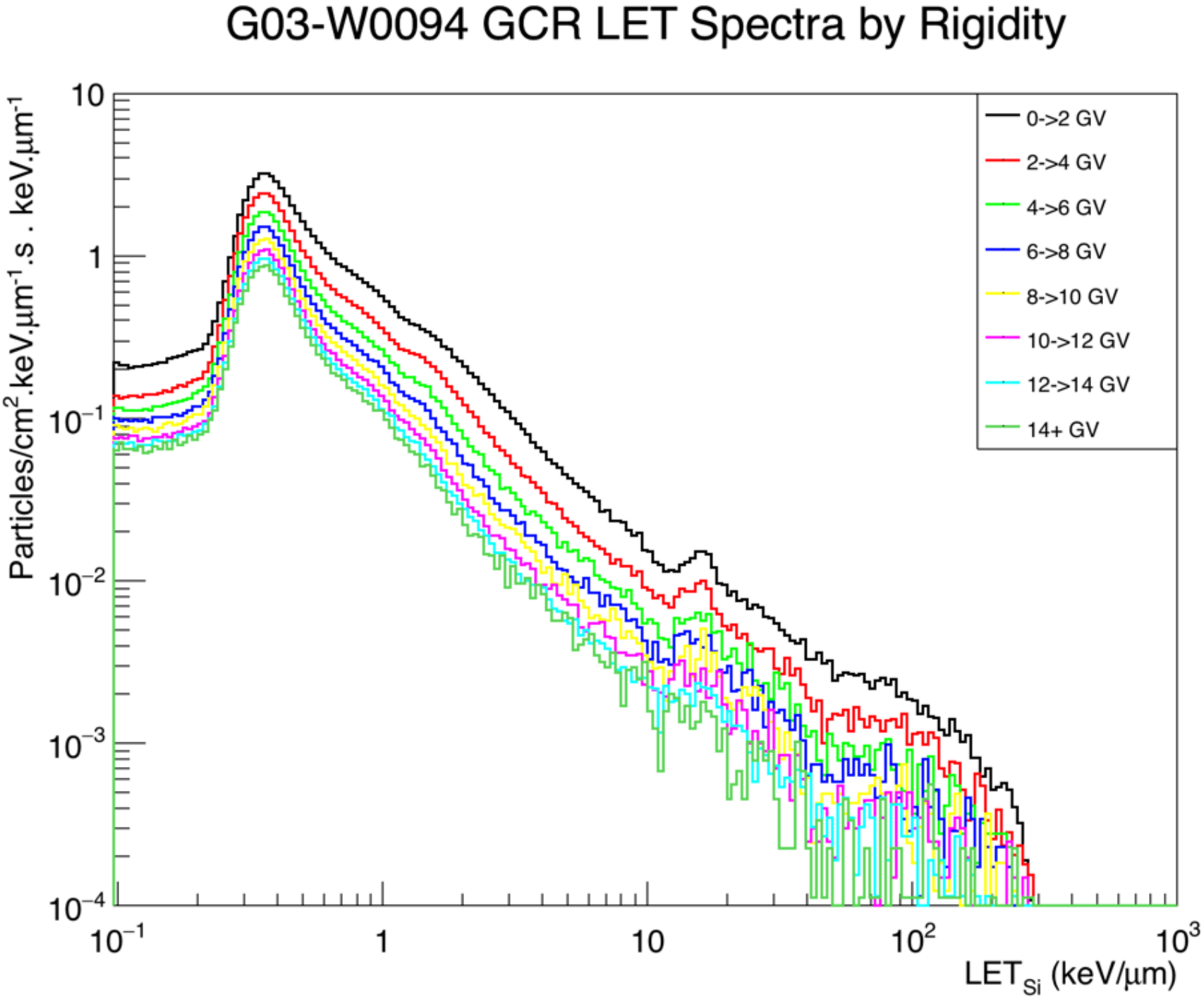


Inner SAA LET Spectrum G03-W0094

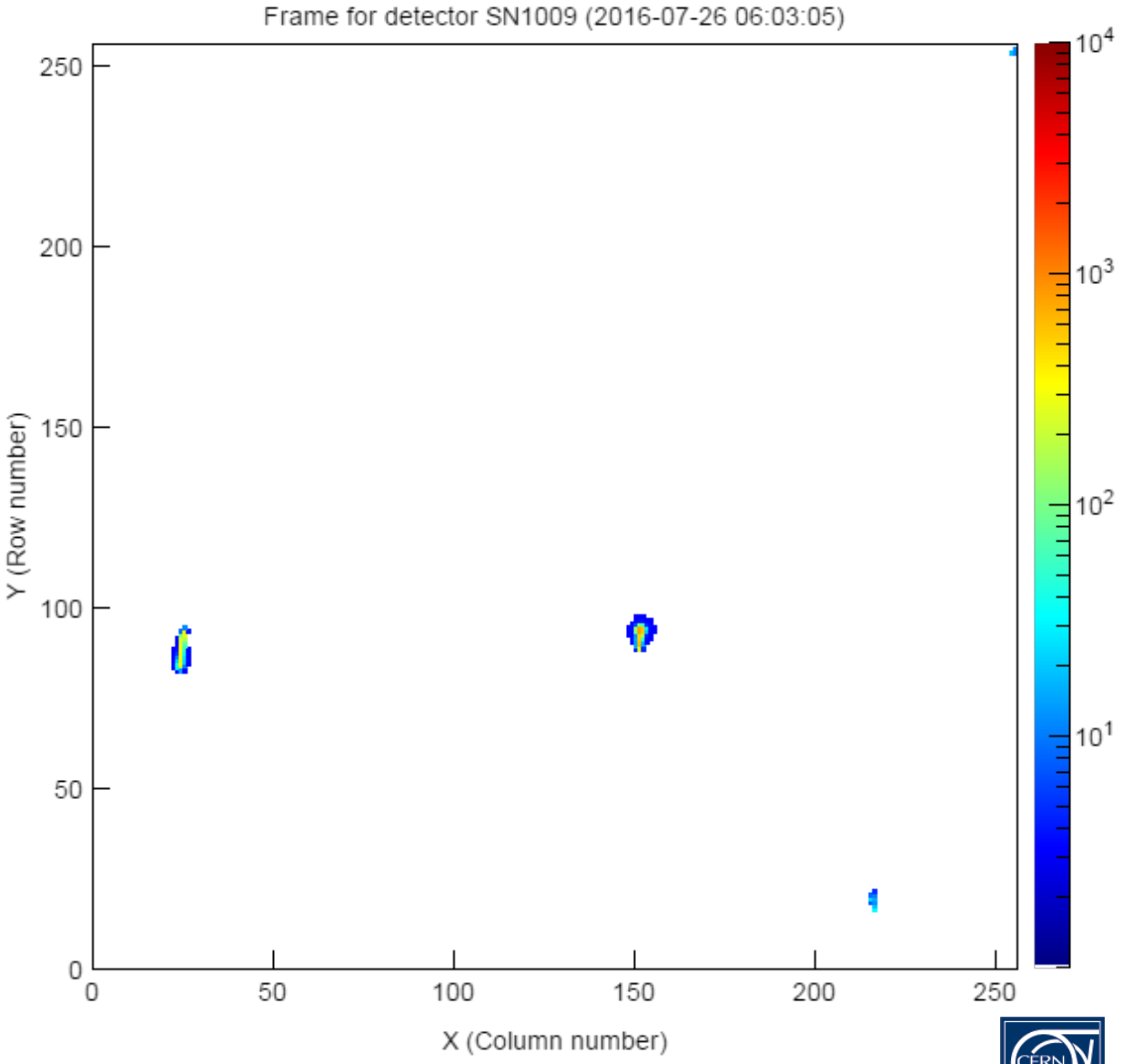



D03-W0094 GCR LET Spectra by Rigidity
Particles/cm^2.keV.μm^{-1}.s . keV.μm^{-1}
LET$_{Si}$ (keV/μm)
0->2 GV
2->4 GV
4->6 GV
6->8 GV
8->10 GV
10->12 GV
12->14 GV
14+ GV
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-1}
1
10
10^2
10^3


J02-W0156 GCR LET Spectra by Rigidity
Particles/cm^2.keV.μm^{-1}.s . keV.μm^{-1}
LET$_{Si}$ (keV/μm)
0->2 GV
2->4 GV
4->6 GV
6->8 GV
8->10 GV
10->12 GV
12->14 GV
14+ GV
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-1}
1
10
10^2
10^3

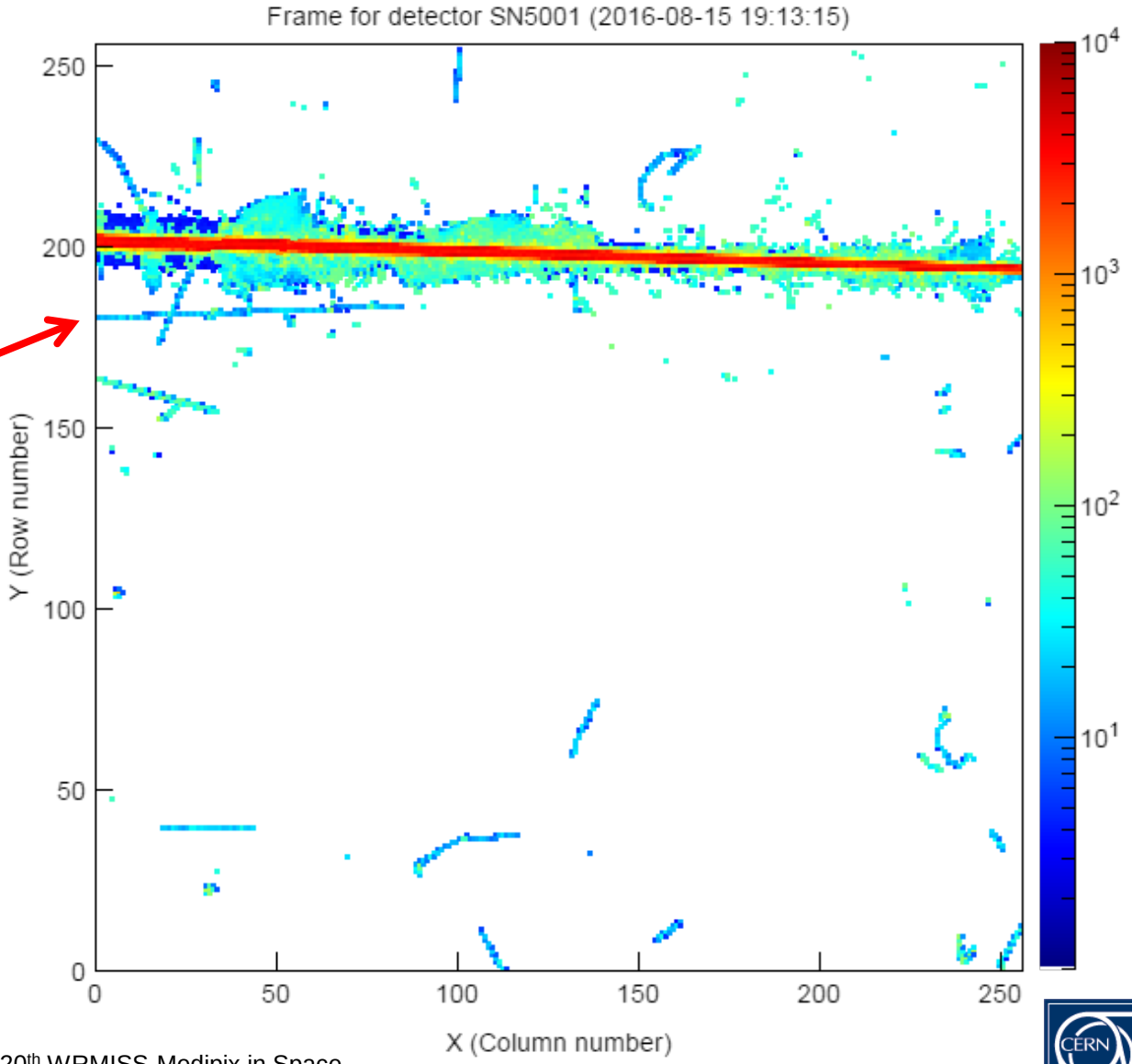

G03-W0094 GCR LET Spectra by Rigidity
Particles/cm^2.keV.μm^{-1}.s . keV.μm^{-1}
LET$_{Si}$ (keV/μm)
0->2 GV
2->4 GV
4->6 GV
6->8 GV
8->10 GV
10->12 GV
12->14 GV
14+ GV
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-1}
1
10
10^2
10^3

Parallel Pairs of Tracks
Downward Secondary Fragments?

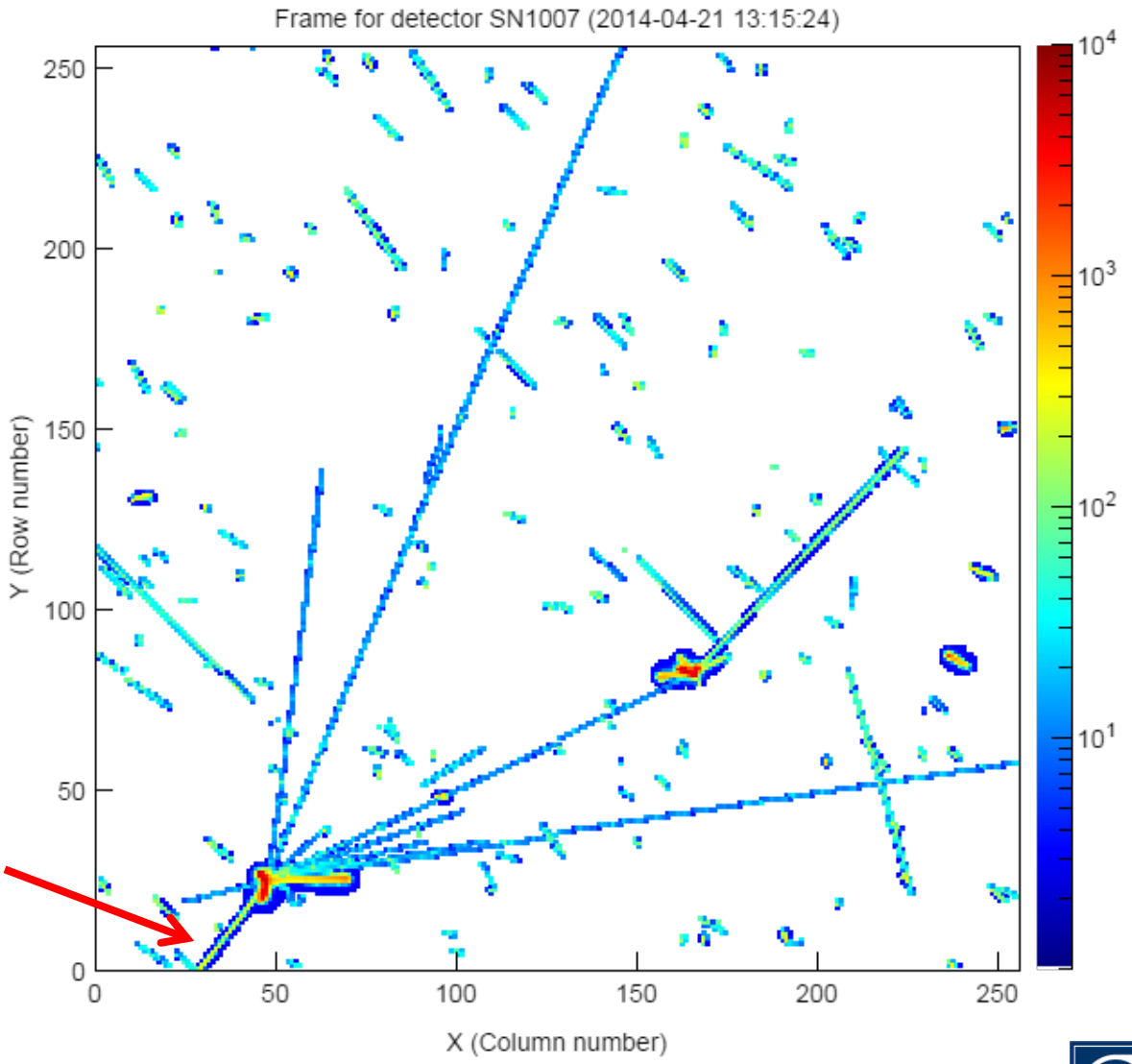


Nuclear Interactions ?

Note

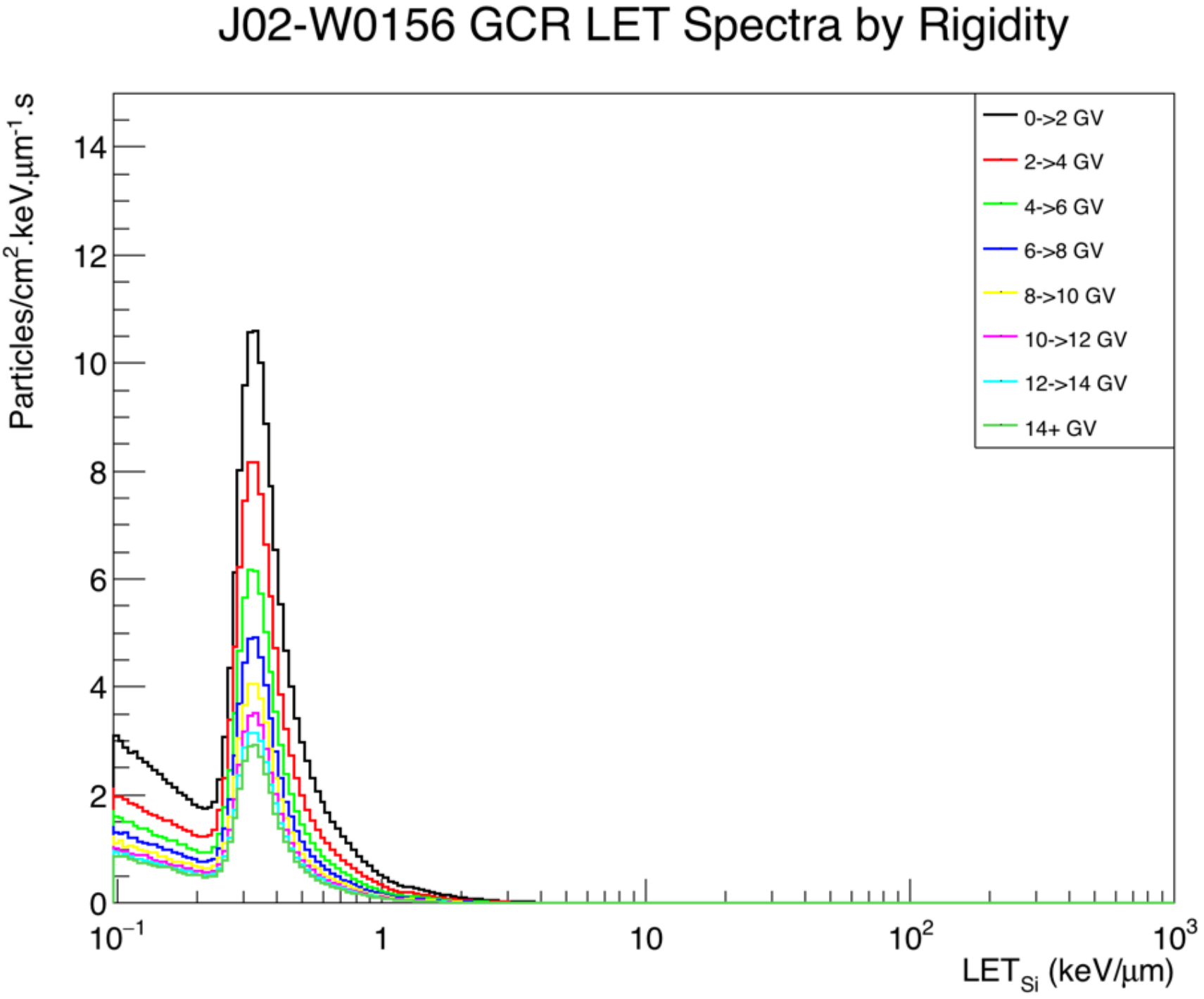


Nuclear Interactions
What We Want Is The Primary

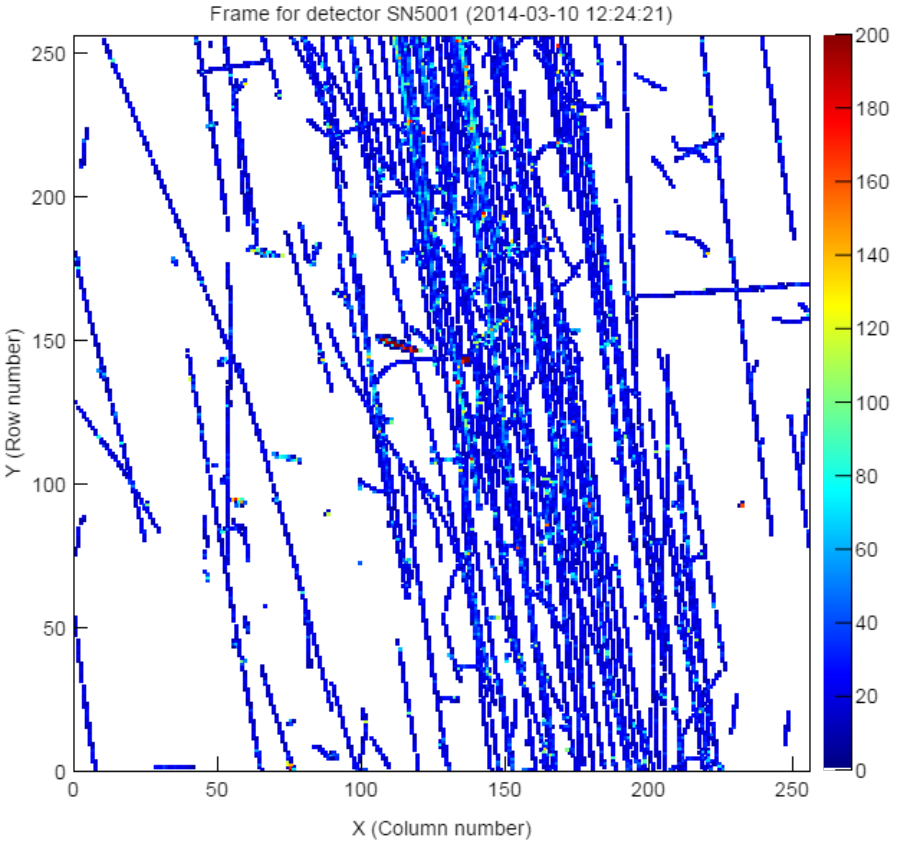


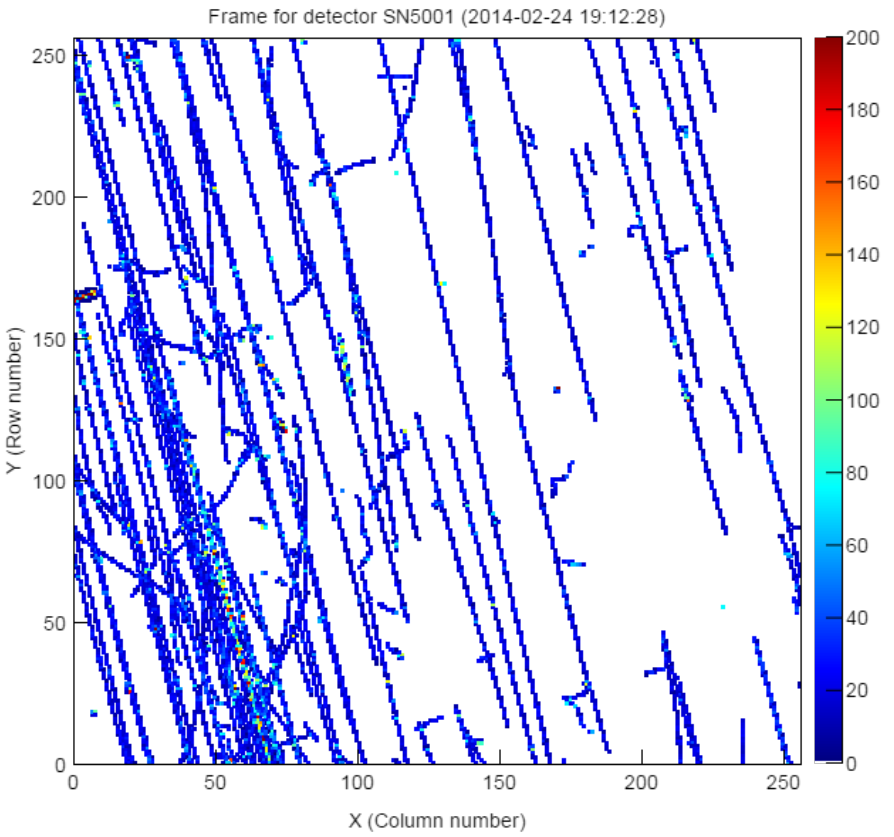
The Primary

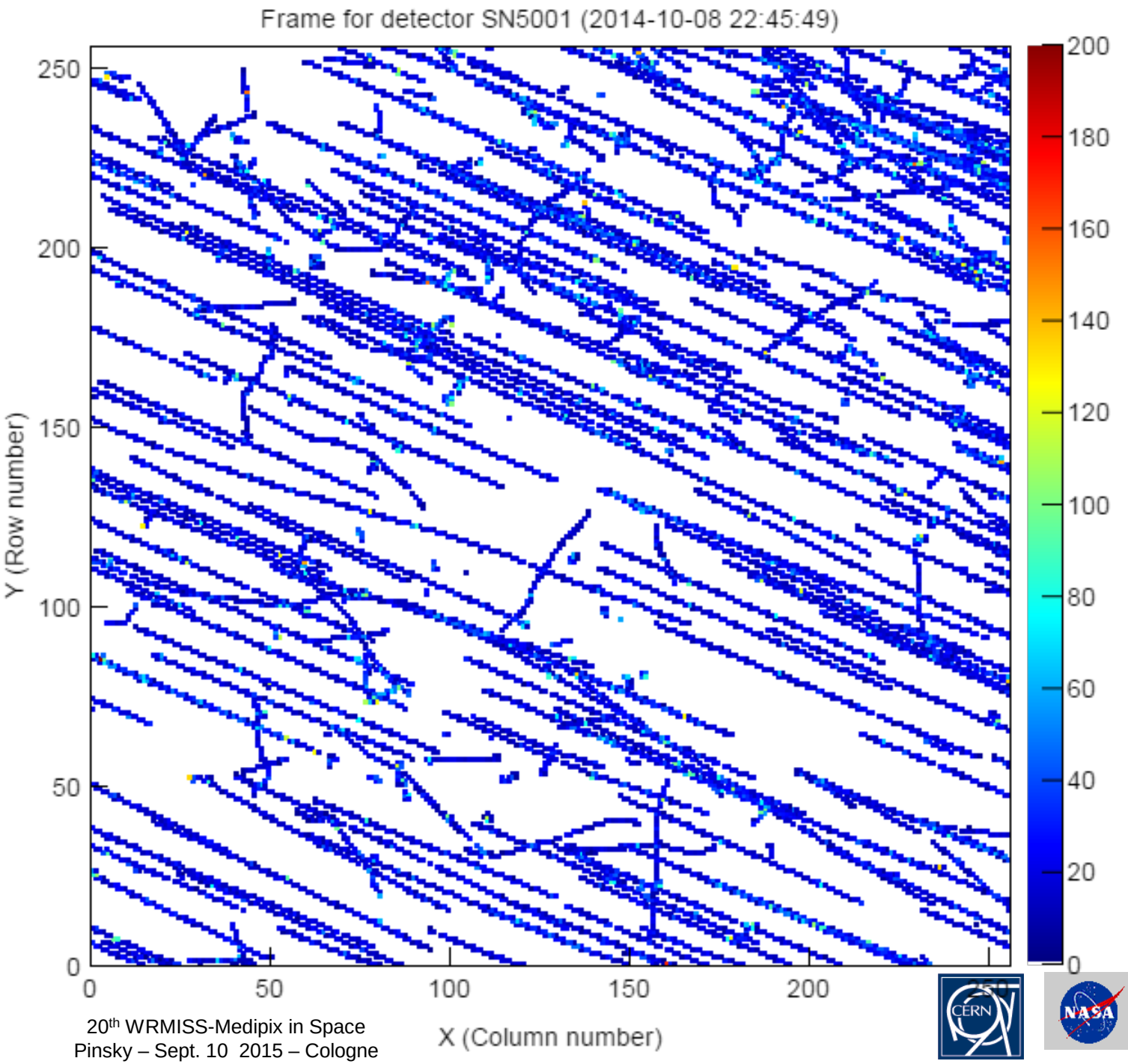
Note that this occurred during an SAA Pass

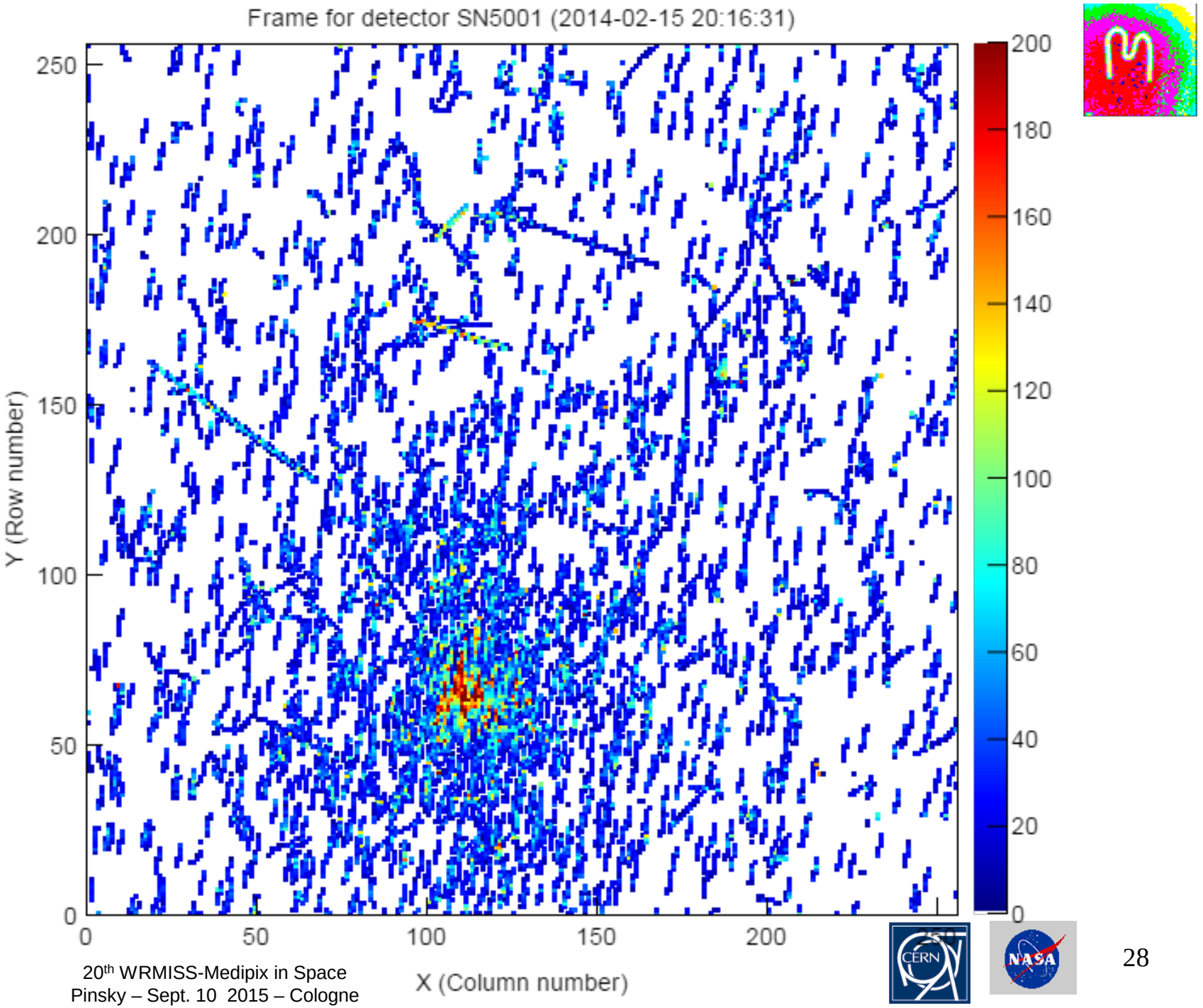

J02-W0156 GCR LET Spectra by Rigidity
Particles/cm^2.keV.μm^{-1}.s
0
2
4
6
8
10
12
14
10^{-1}
1
10
10^2
10^3
LET$_{Si}$ (keV/μm)
0->2 GV
2->4 GV
4->6 GV
6->8 GV
8->10 GV
10->12 GV
12->14 GV
14+ GV

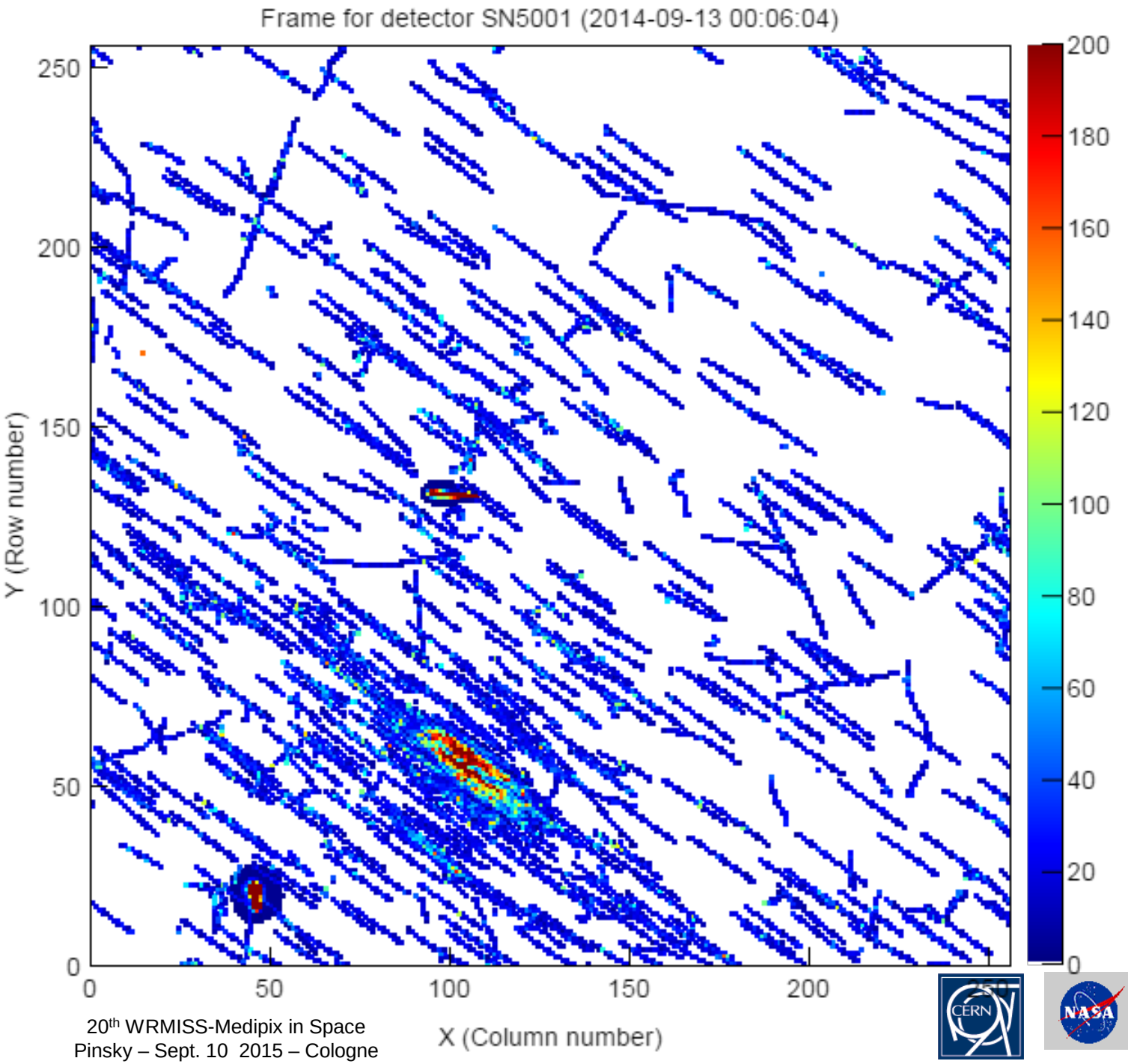
Showers

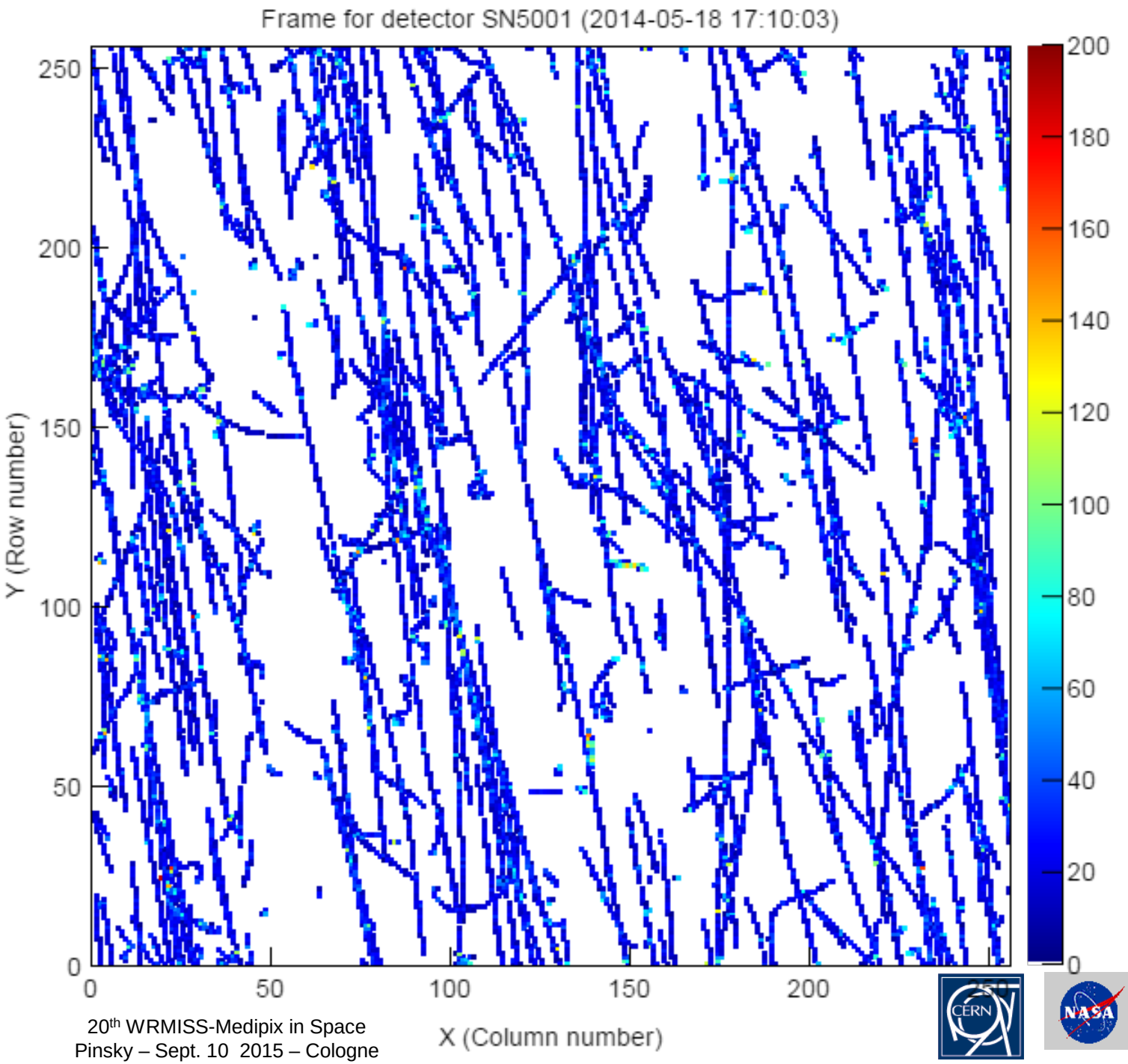

Frame for detector SN5001 (2014-03-10 12:24:21)
Y (Row number)
X (Column number)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200

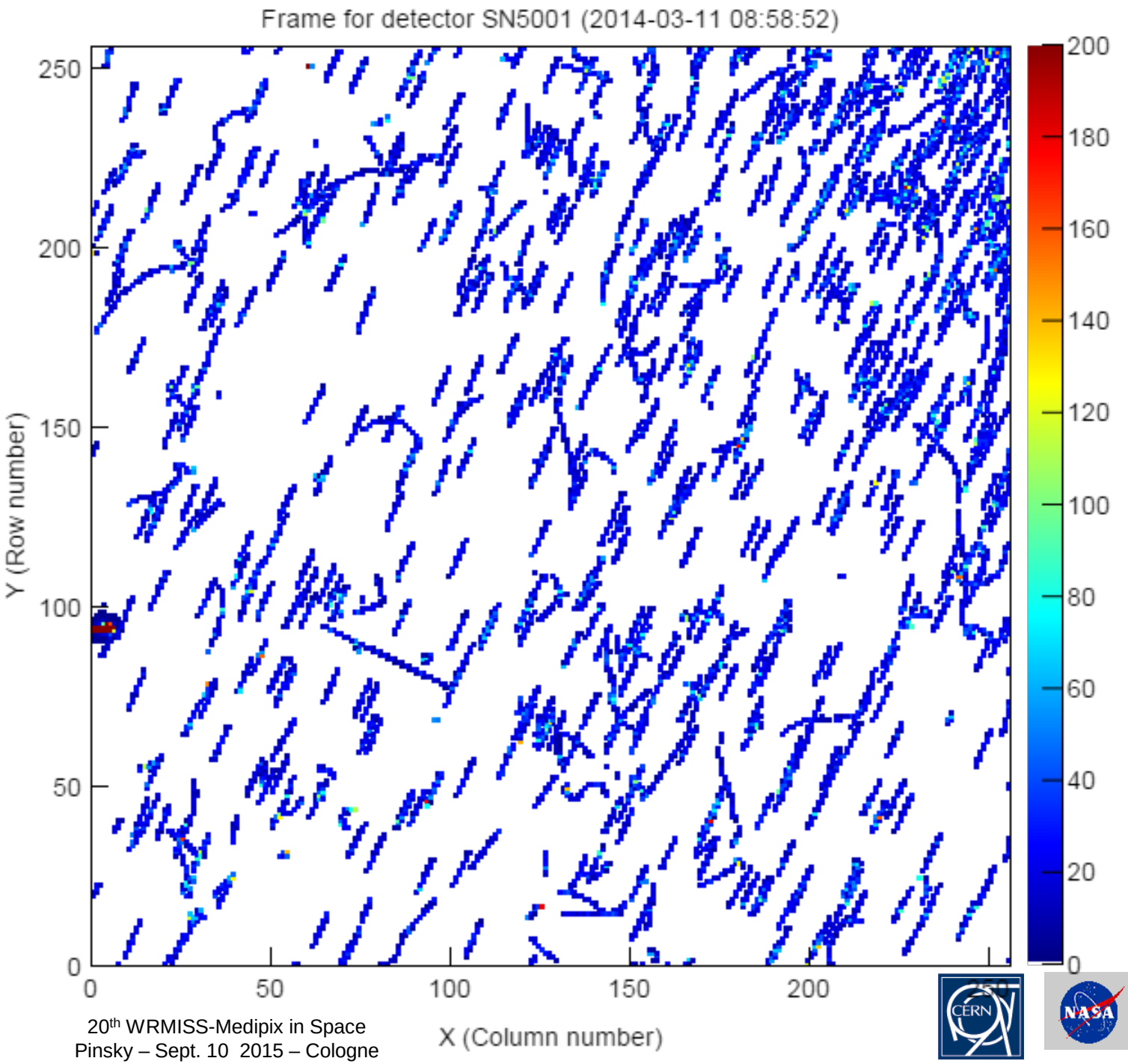

Frame for detector SN5001 (2014-02-24 19:12:28)
Y (Row number)
X (Column number)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200


Frame for detector SN5001 (2014-10-08 22:45:49)
Y (Row number)
X (Column number)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200

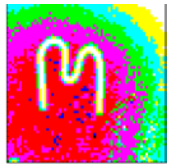

Frame for detector SN5001 (2014-02-15 20:16:31)
Y (Row number)
X (Column number)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200


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

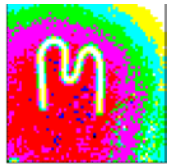

Frame for detector SN5001 (2014-03-11 08:58:52)
Y (Row number)
X (Column number)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200

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.

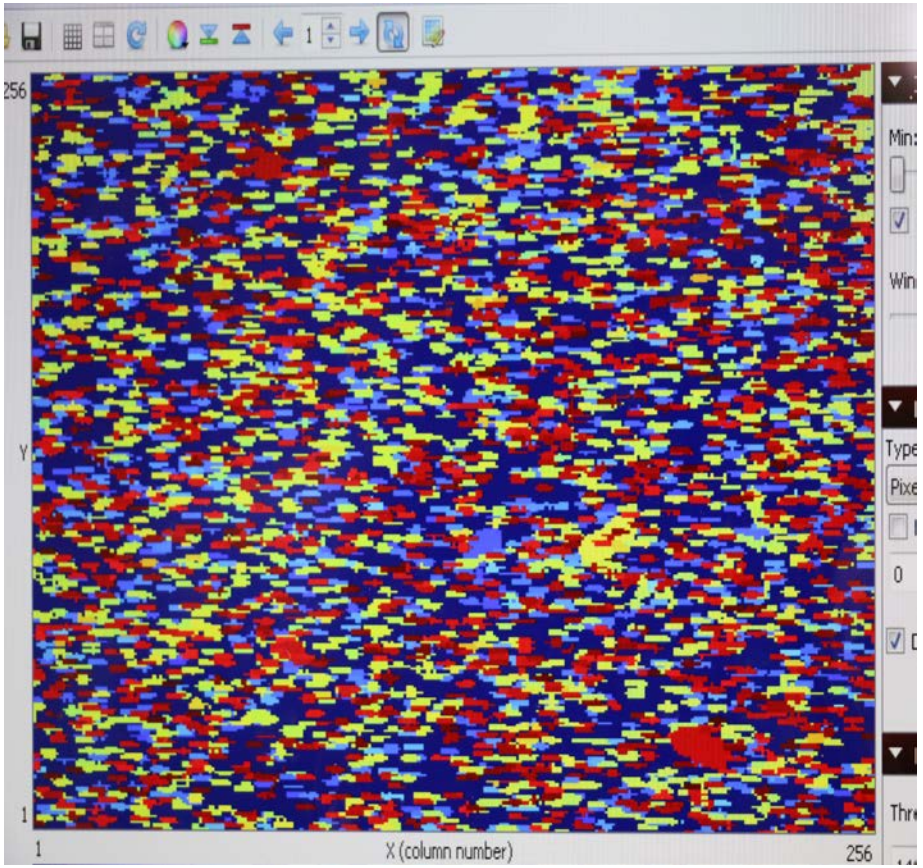
Timepix v. Timepix3 v. Timepix3



- **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…**

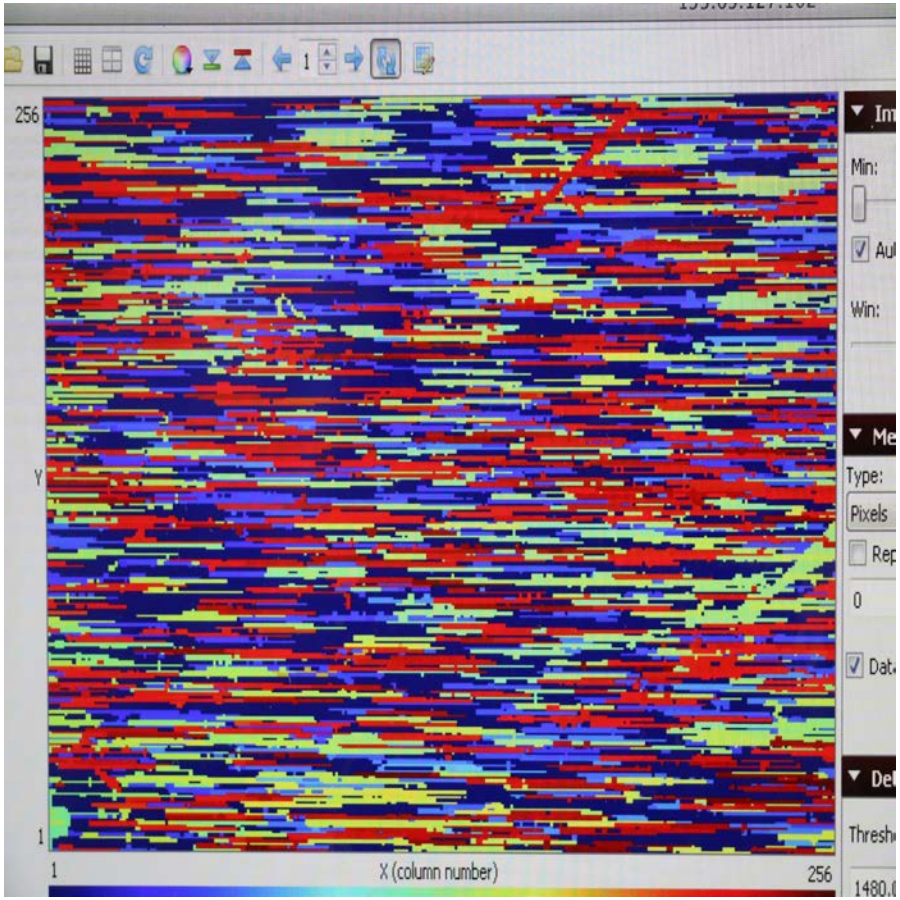
Timepix3 Proton Flux "Olympics"

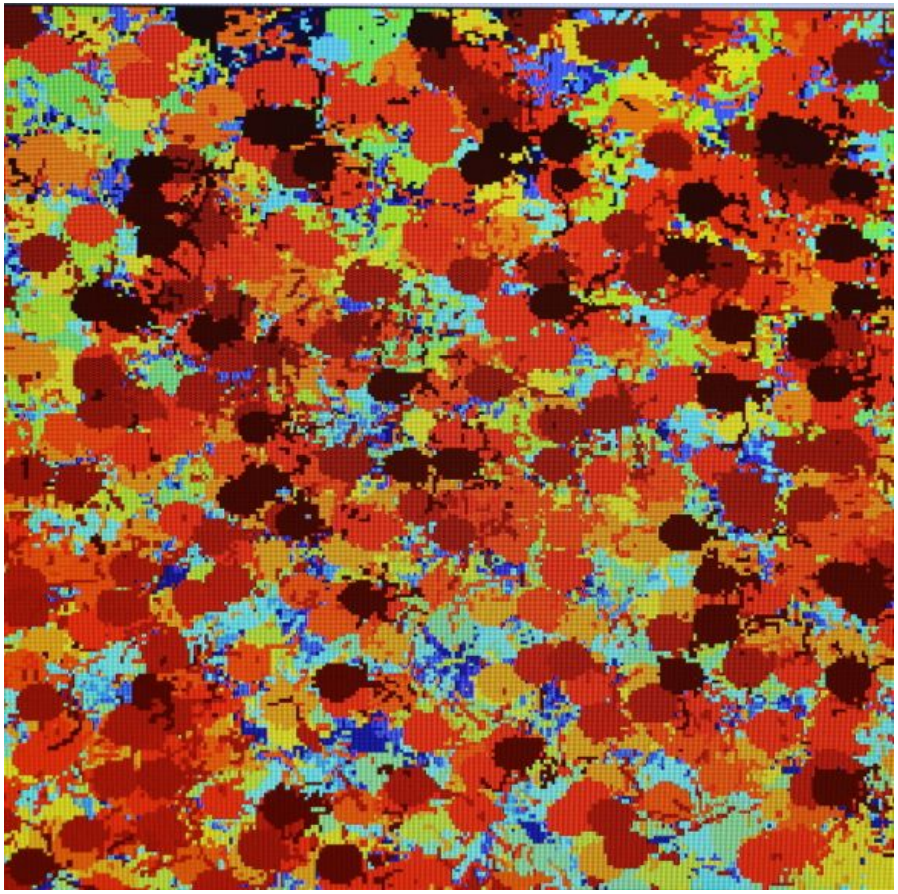
- A proton flux test of the Timepix3 was conducted in the HIMAC proton beam @ 180 MeV.
- We achieved a rate of ~10^7/cm^{2}s in "normal" TOT + TOA mode with no loss of data!
- In the "counting" mode, we achieved a rate of ~10^9/cm^{2}s with no loss of data!
- Note that this was done with a new USB 3 interface, which achieves ~ 50% of the Timepix3's ultimate capability….



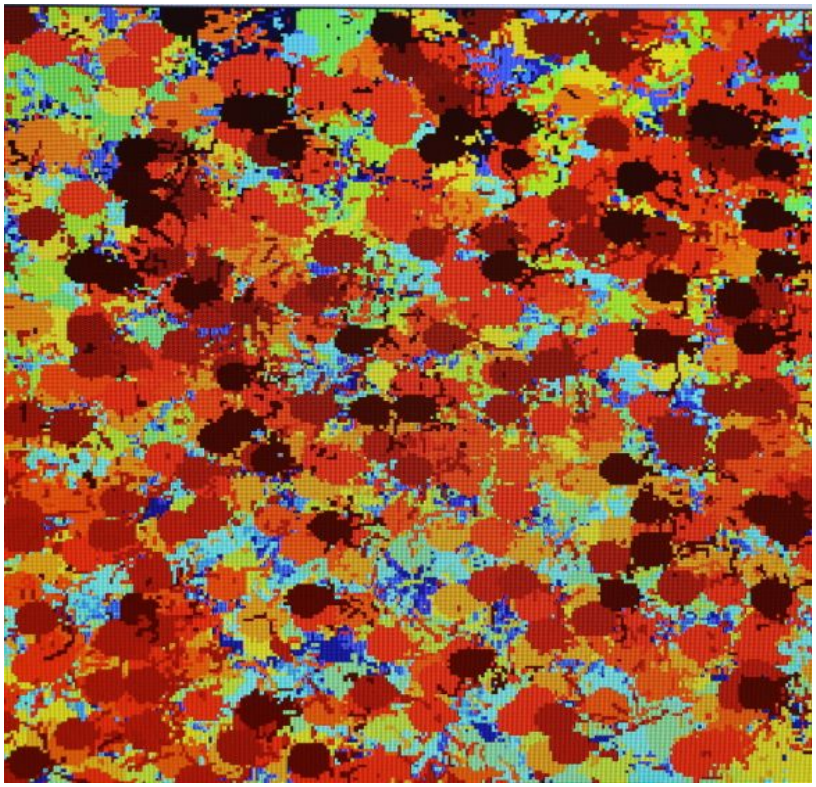
Time Of Arrival (pseudo-frame)

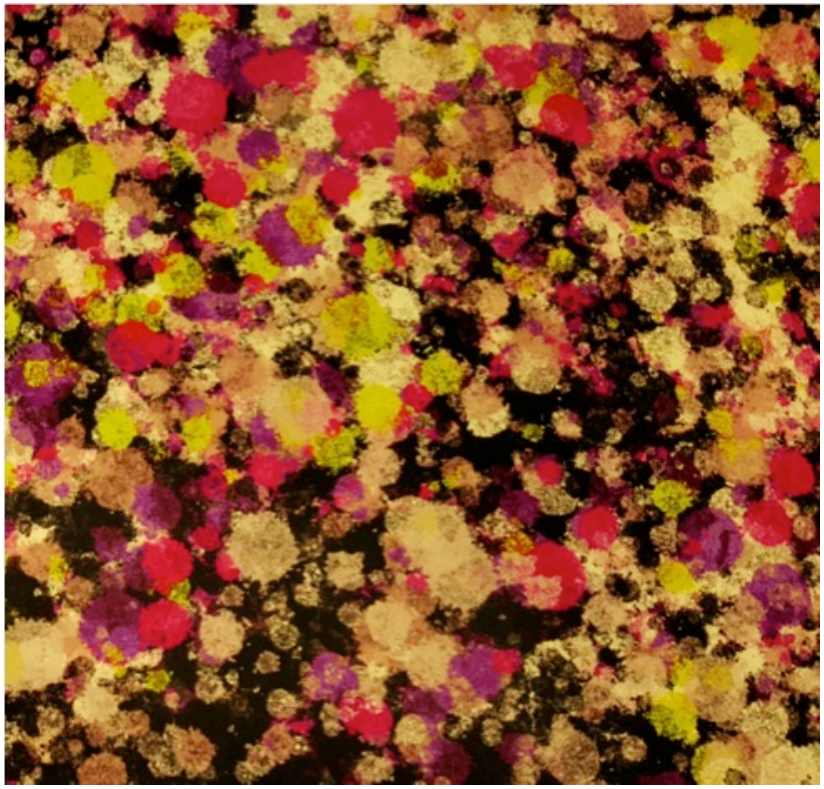
TOArt



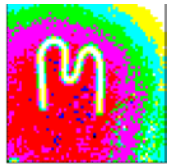


TOArt v. “Real” Art





AND… Medipix4 HAS FORMED

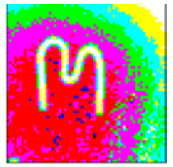


- Unlike the previous Medipix Collaborations, Medipix4 will simultaneously design the Medipix4 (counting chip) and the Timepix4.
- It will employ the latest CMOS technology… (With Power Control Options…)
- The Chips will be much larger than the current ones and the Timepix4 will have smaller pixels..
- 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…

Towards Timepix4

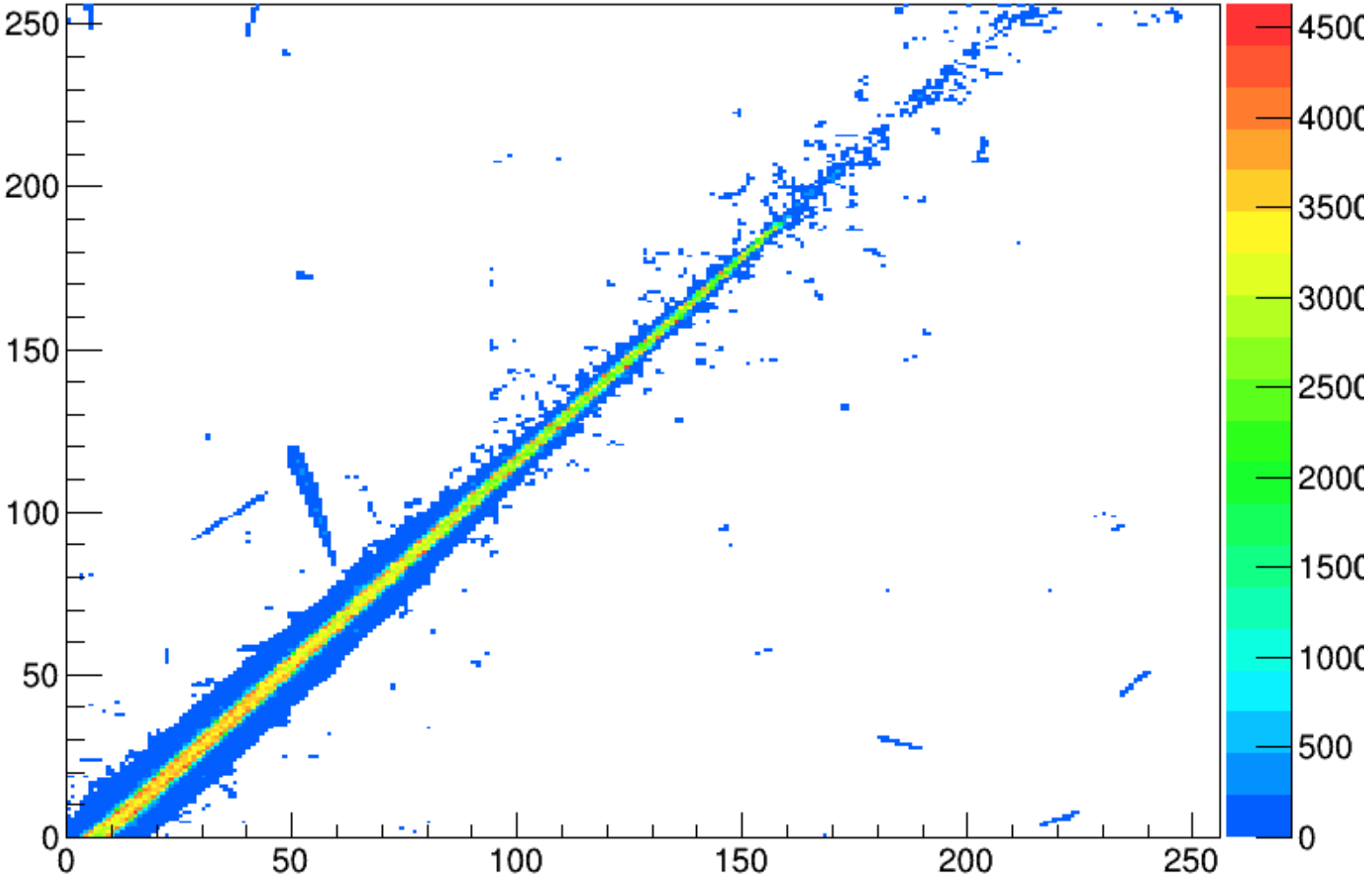
- **Improve energy resolution (TOT) and time resolution (TOA):**
  - **TOT resolution limited by ENC only:**
    - **Minimize the quantization error**
    - **Target < 1 KeV**
    - **> 5 MeV *per pixel* in sensor sensitivity**
  - **TOA resolution limited by front-end bandwidth, pixel noise and VCO 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.**

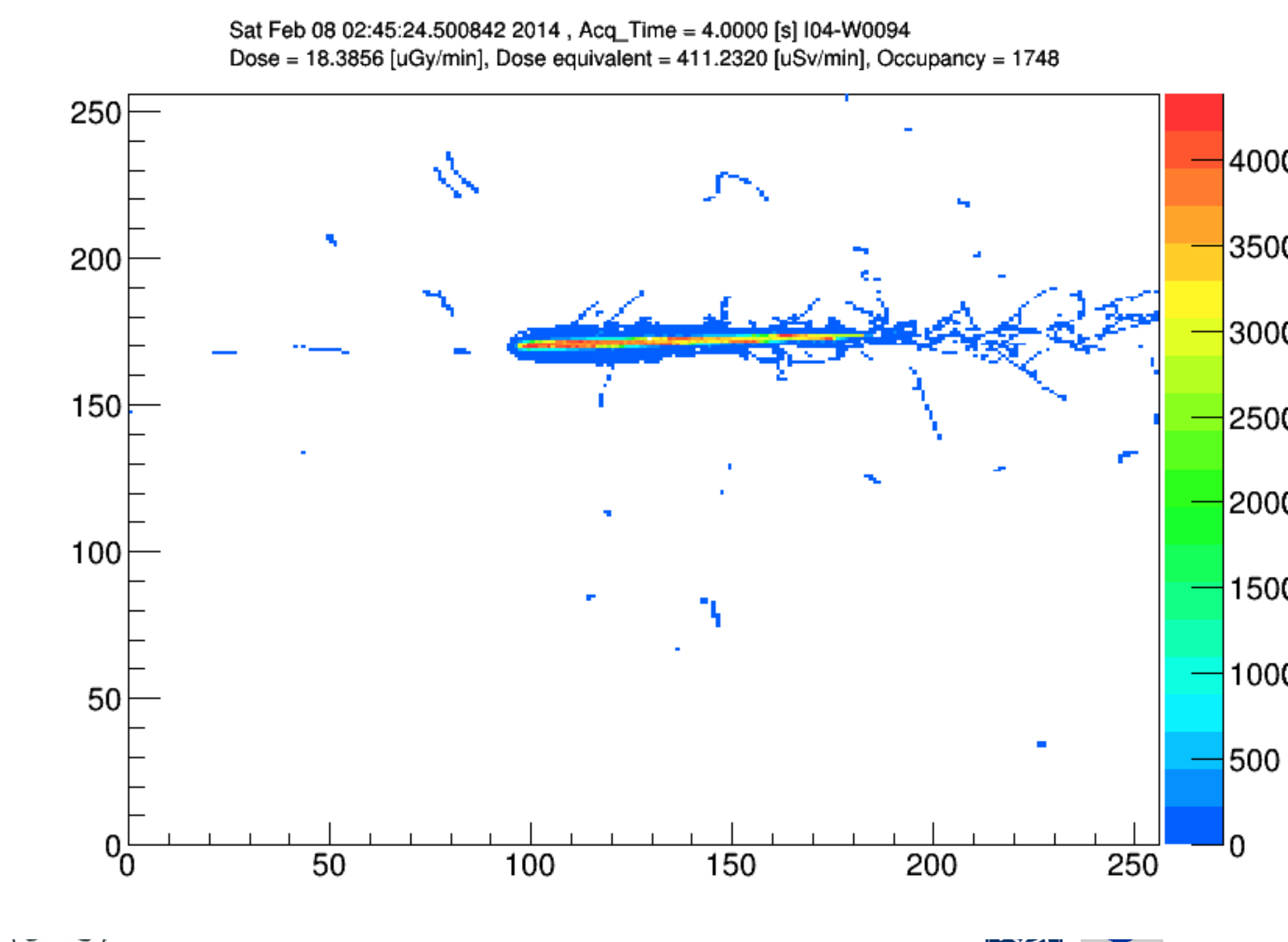
Future (Potential) Devices

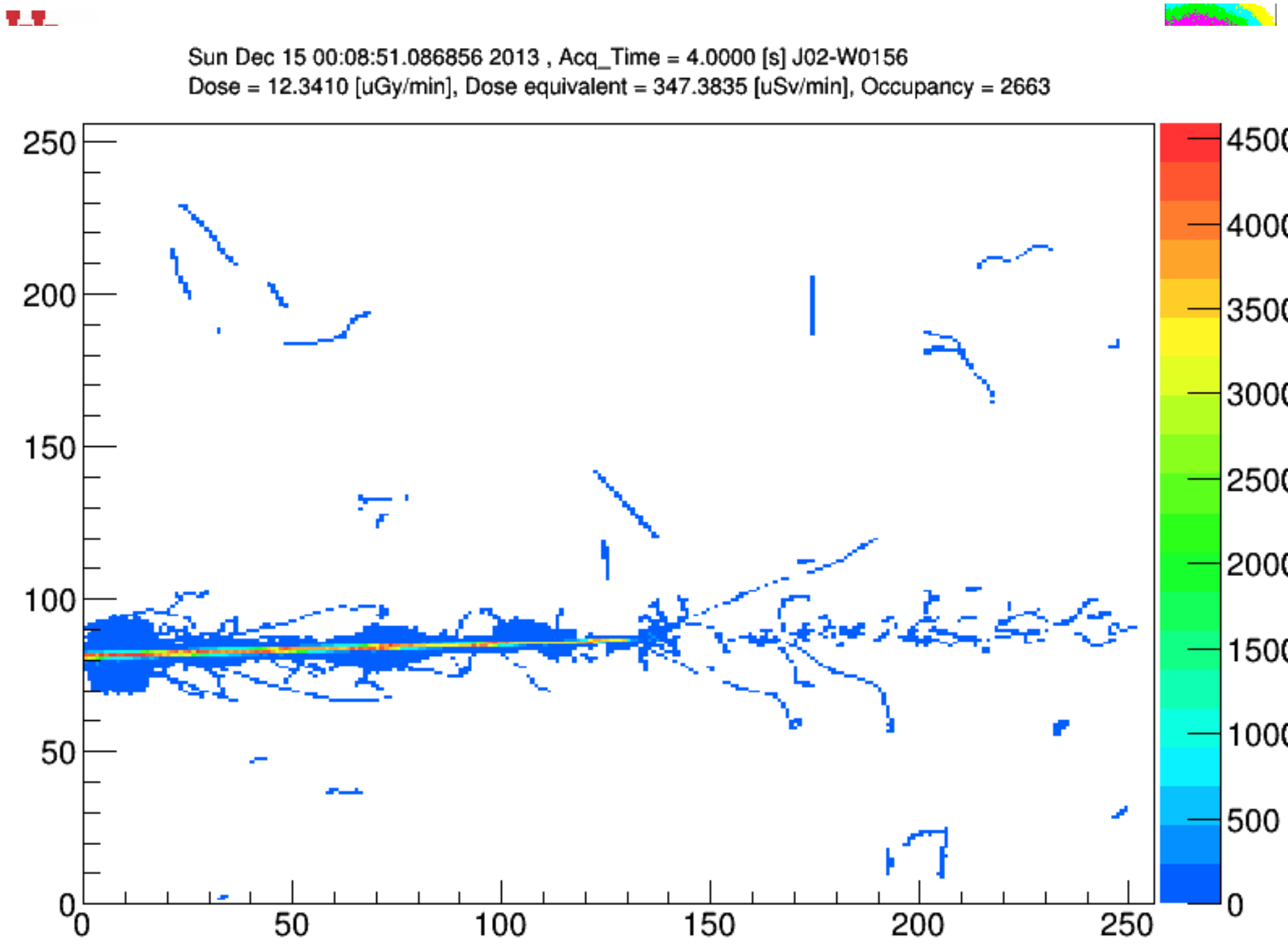


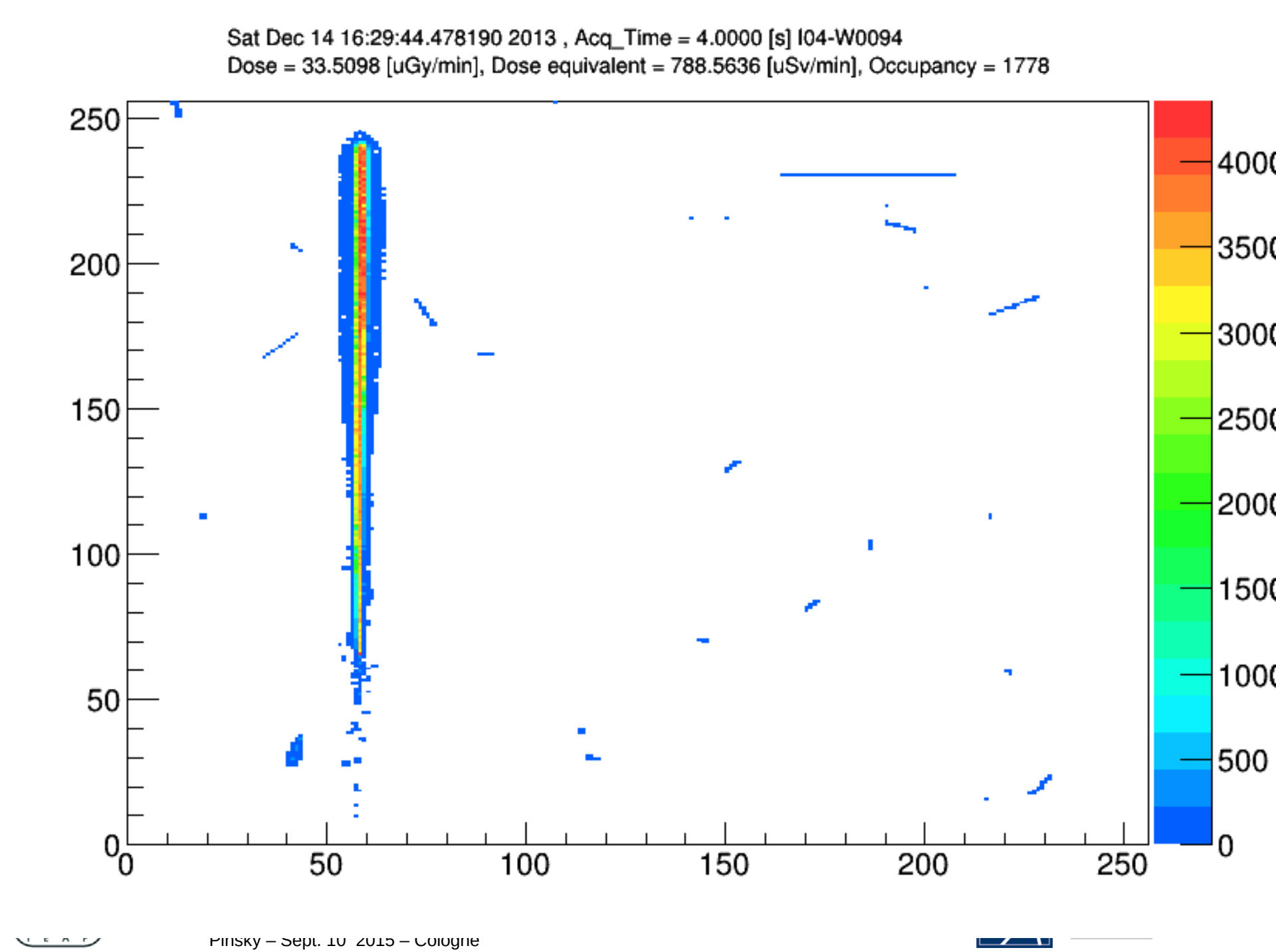
- **Omni-directional "Spectrometer" Cube**
  - 6-sided "hermetic" cube of Timepix4 devices
  - Embedded Scintillator
  - Single Synced (via Medipix) DAQ
- **Timepix4-based Neutron detector**
  - Based on current LHC (ATLAS) neutron monitors
  - Both Thermal and Fast Neutrons
- **Timepix2 & Timepix4 Characterization**
  - New Pseudo-Logarithmic response…
  - Timepix Particle Spectrometer Stacks
- **ALTEA Collaboration…**
- **Light Fragment Nuclear Interaction Cross Section Measurements**

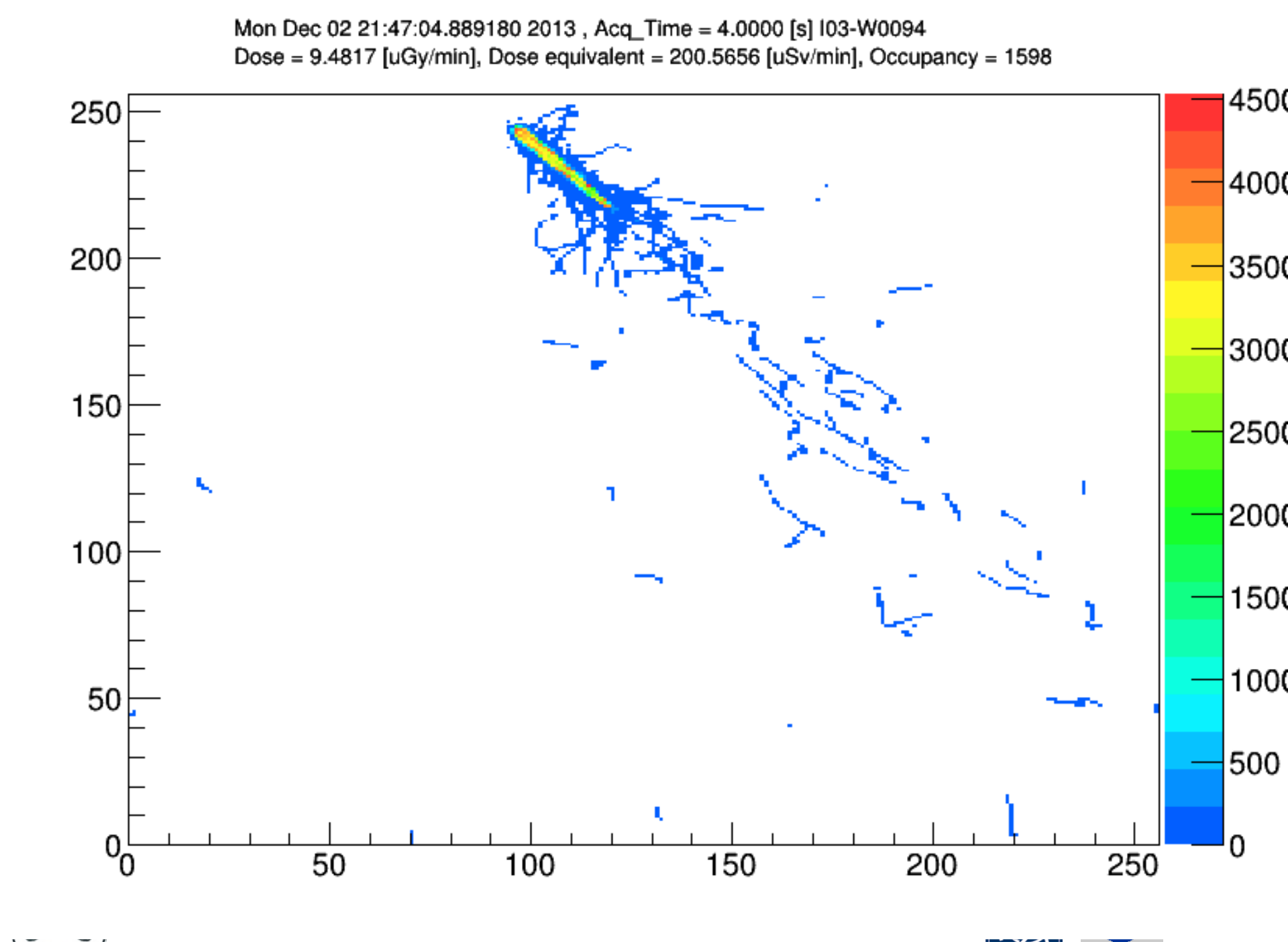

Thank you for your attention…

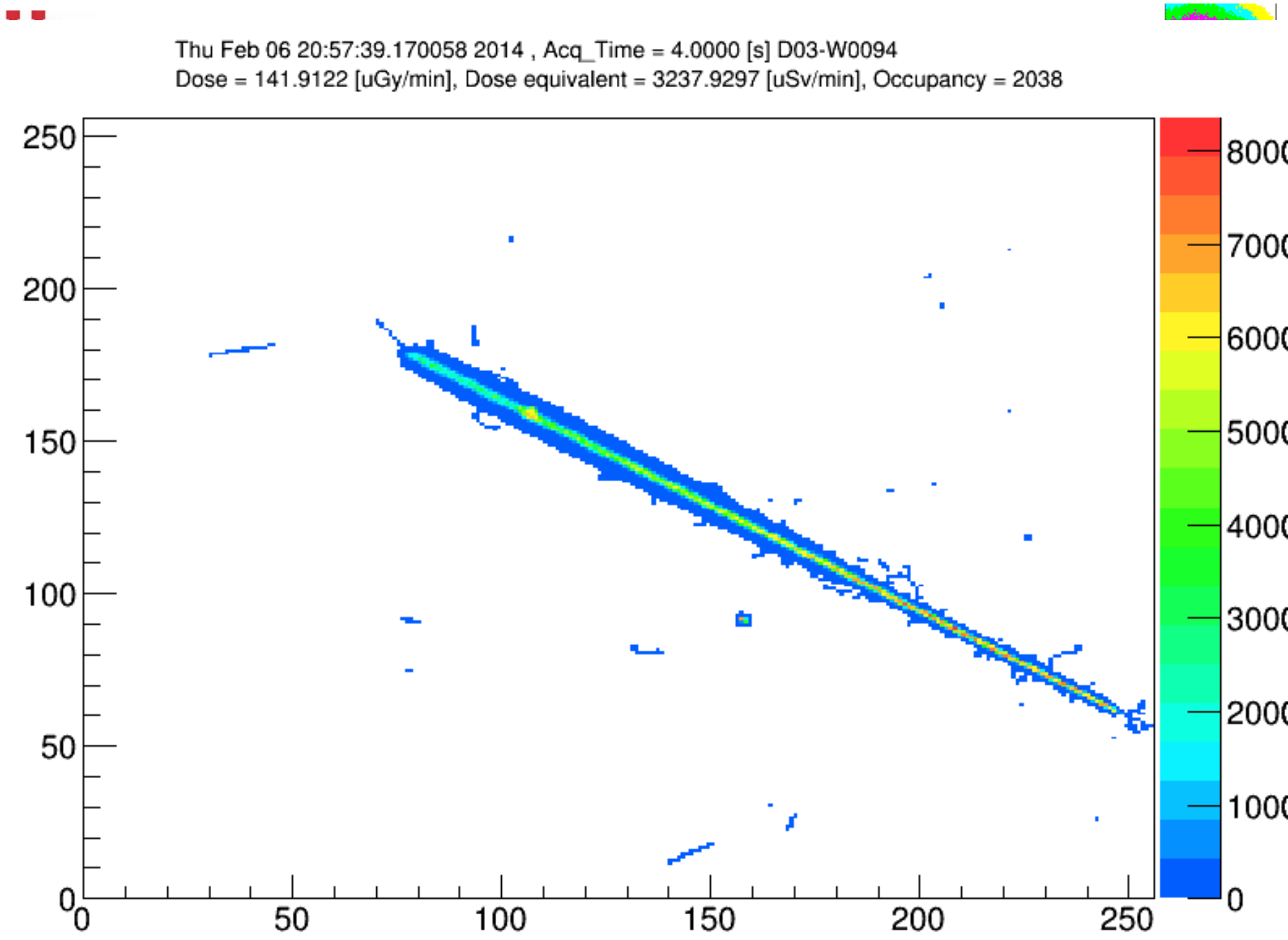

Sat Feb 15 00:40:52.242498 2014 , Acq_Time = 4.0000 [s] J02-W0156
Dose = 42.2278 [uGy/min], Dose equivalent = 853.9796 [uSv/min], Occupancy = 4197
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0

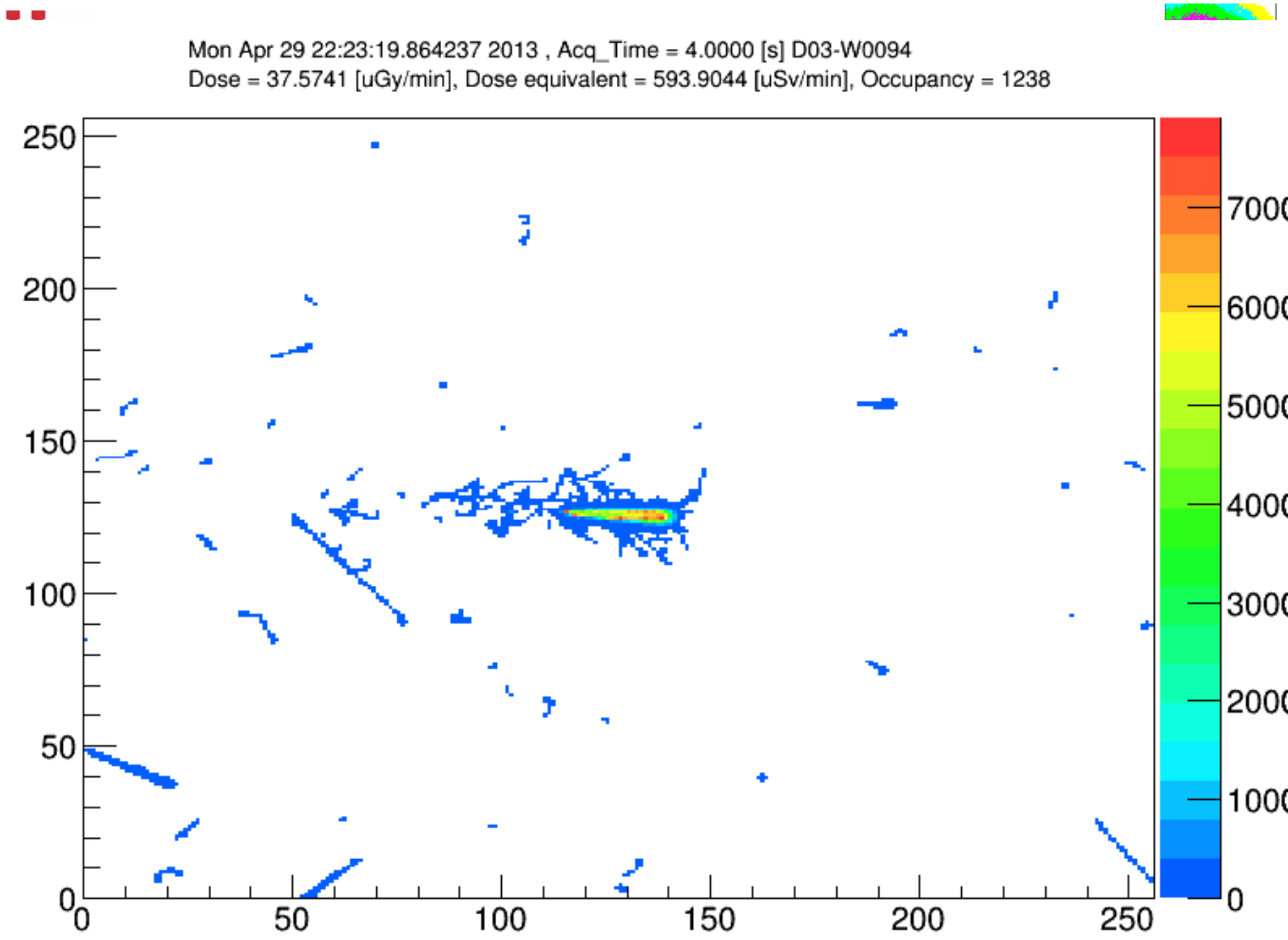

Sat Feb 08 02:45:24.500842 2014 , Acq_Time = 4.0000 [s] I04-W0094
Dose = 18.3856 [uGy/min], Dose equivalent = 411.2320 [uSv/min], Occupancy = 1748
250
200
150
100
50
0
0
50
100
150
200
250
4000
3500
3000
2500
2000
1500
1000
500
0

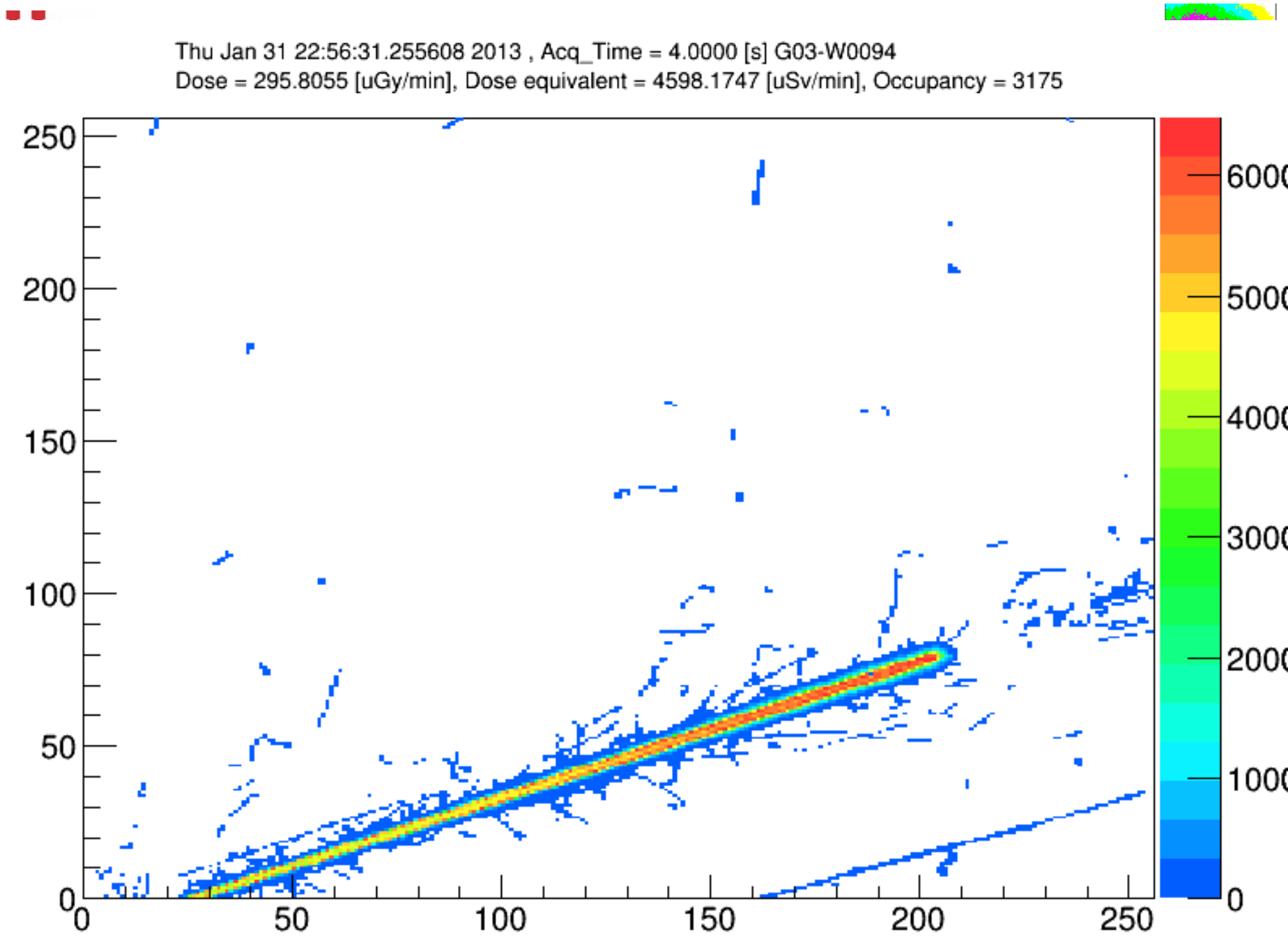

Sun Dec 15 00:08:51.086856 2013 , Acq_Time = 4.0000 [s] J02-W0156
Dose = 12.3410 [uGy/min], Dose equivalent = 347.3835 [uSv/min], Occupancy = 2663
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0

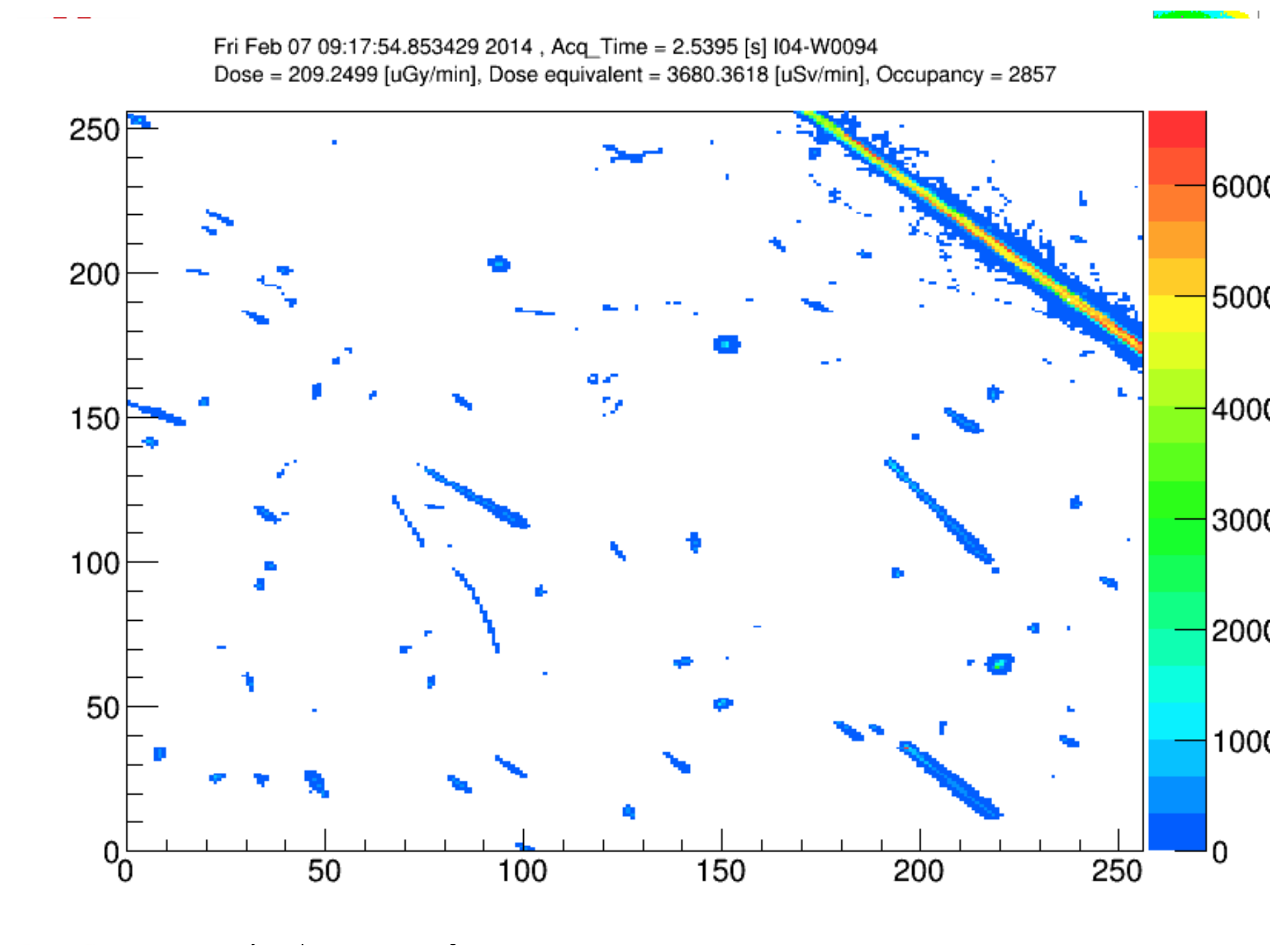

Sat Dec 14 16:29:44.478190 2013 , Acq_Time = 4.0000 [s] I04-W0094
Dose = 33.5098 [uGy/min], Dose equivalent = 788.5636 [uSv/min], Occupancy = 1778
250
200
150
100
50
0
0
50
100
150
200
250
4000
3500
3000
2500
2000
1500
1000
500
0

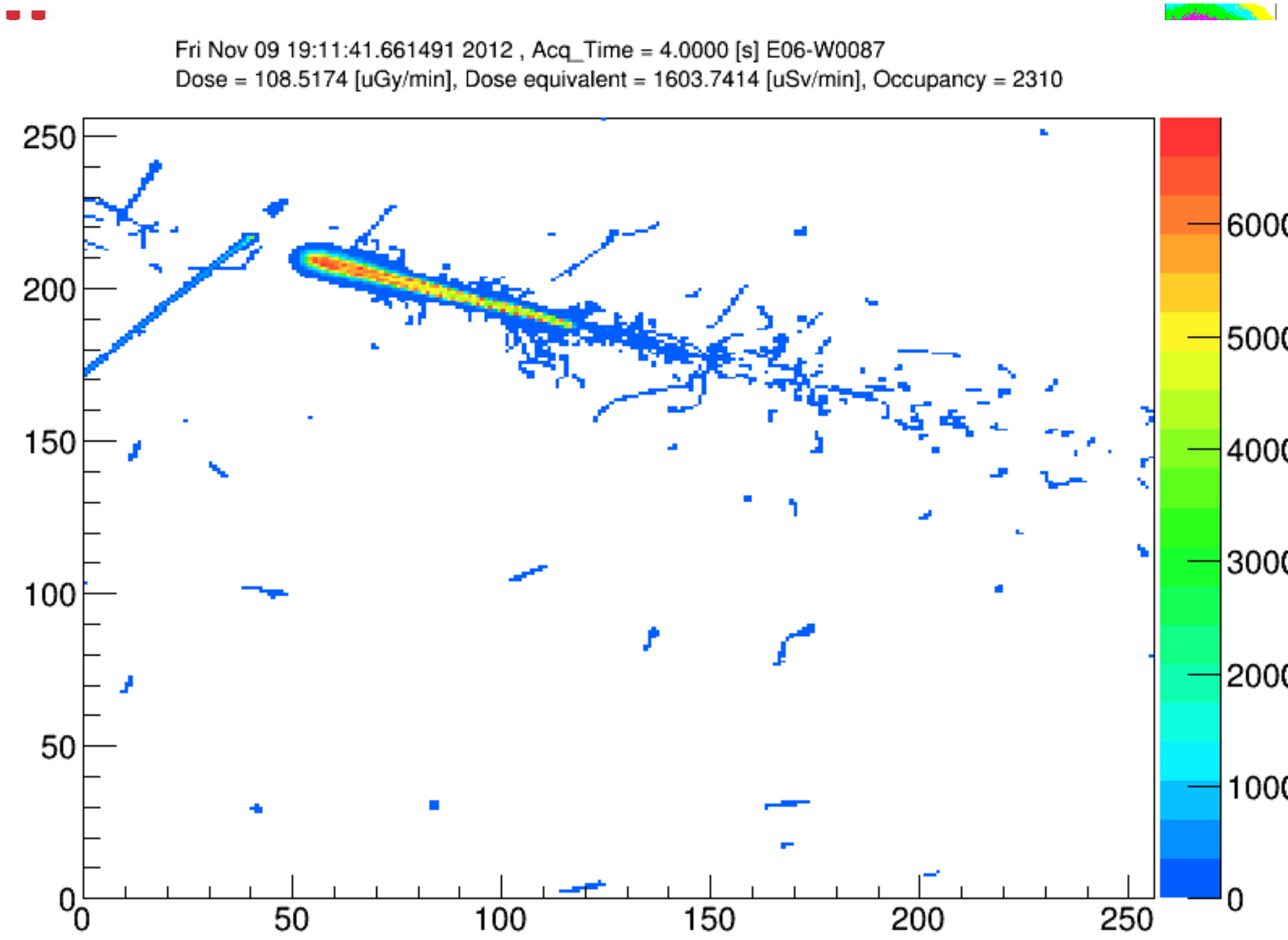

Mon Dec 02 21:47:04.889180 2013 , Acq_Time = 4.0000 [s] I03-W0094
Dose = 9.4817 [uGy/min], Dose equivalent = 200.5656 [uSv/min], Occupancy = 1598
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0

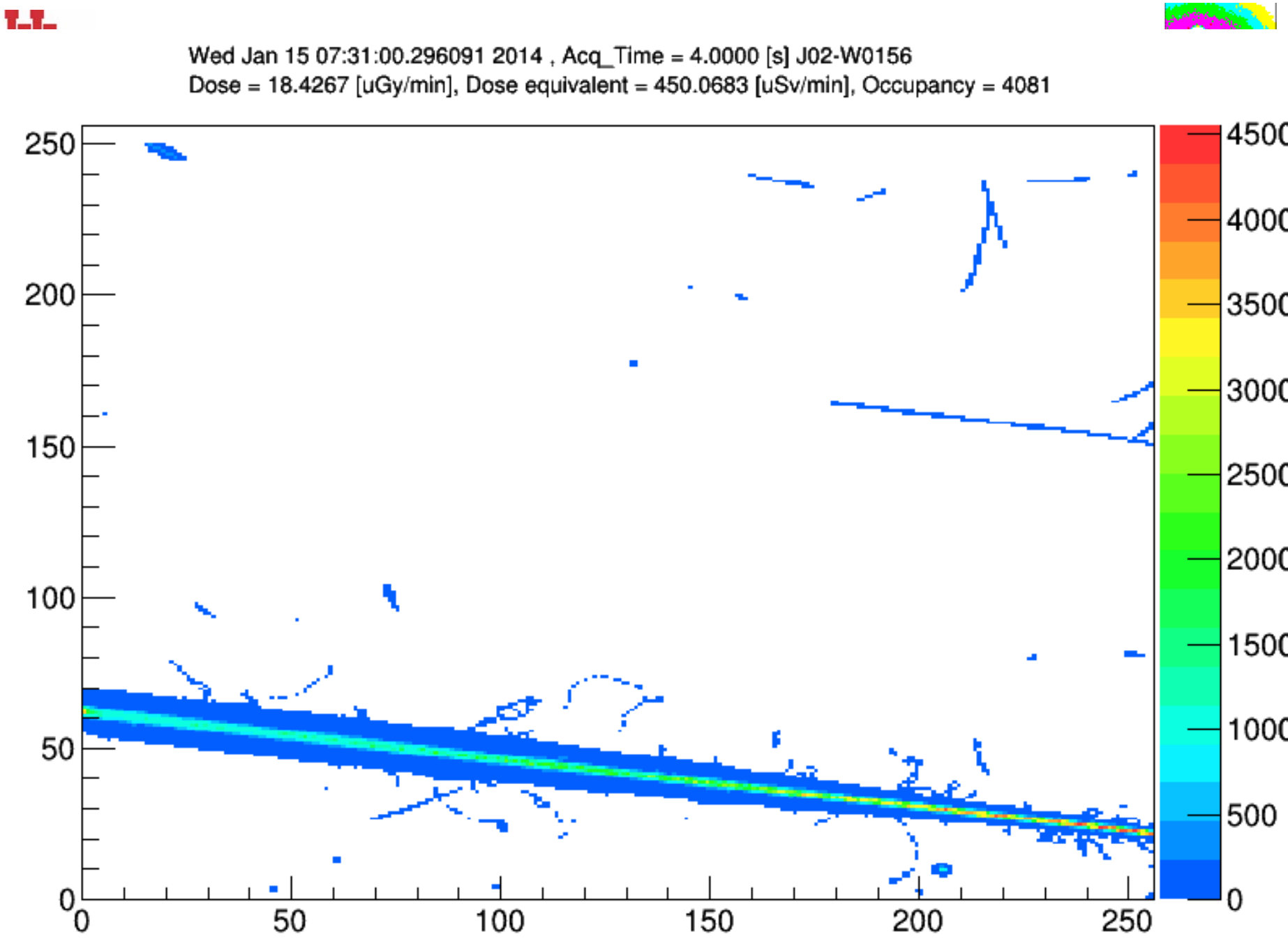

Thu Feb 06 20:57:39.170058 2014 , Acq_Time = 4.0000 [s] D03-W0094
Dose = 141.9122 [uGy/min], Dose equivalent = 3237.9297 [uSv/min], Occupancy = 2038
250
200
150
100
50
0
0
50
100
150
200
250
8000
7000
6000
5000
4000
3000
2000
1000
0

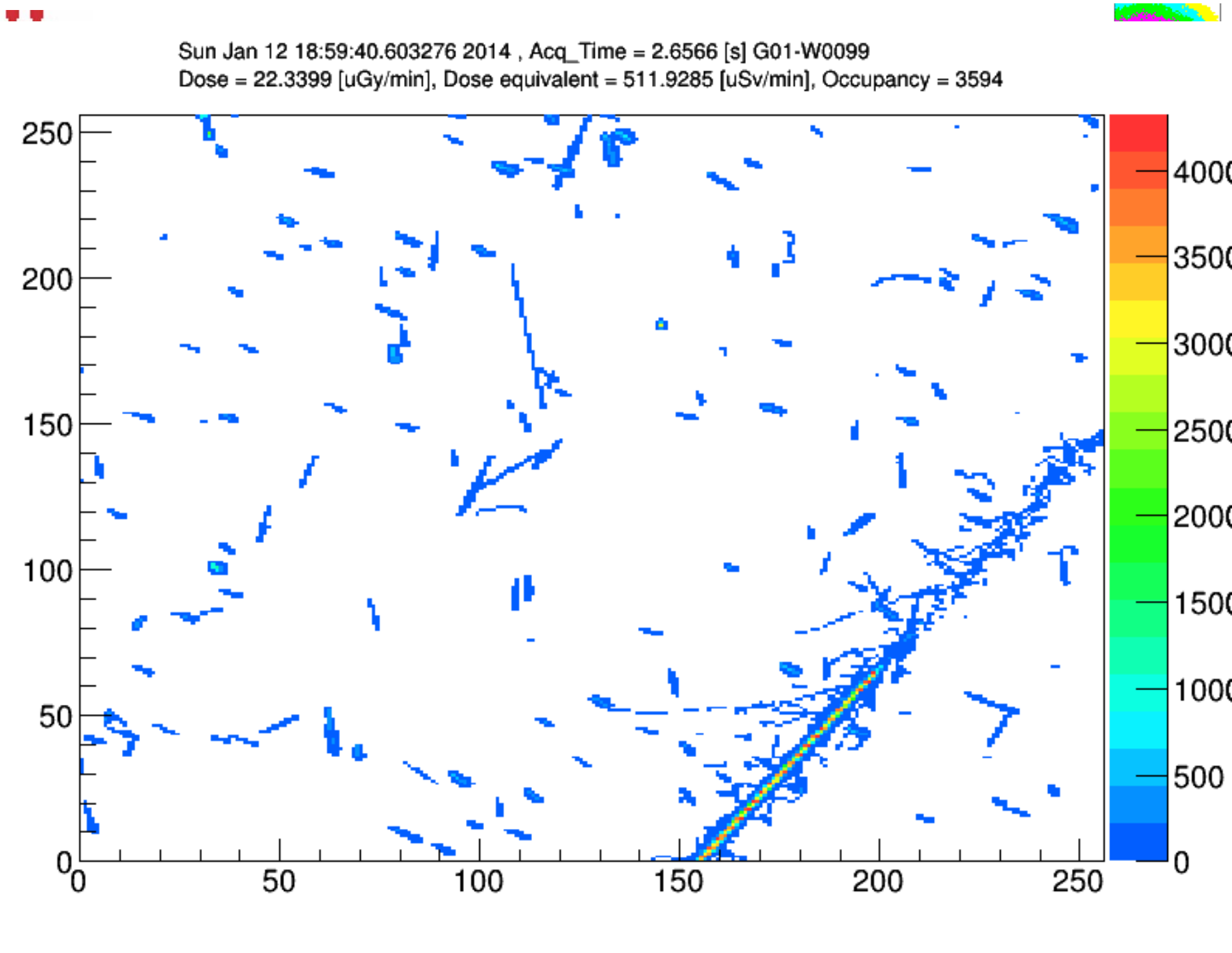

Mon Apr 29 22:23:19.864237 2013 , Acq_Time = 4.0000 [s] D03-W0094
Dose = 37.5741 [uGy/min], Dose equivalent = 593.9044 [uSv/min], Occupancy = 1238
250
200
150
100
50
0
0
50
100
150
200
250
7000
6000
5000
4000
3000
2000
1000
0

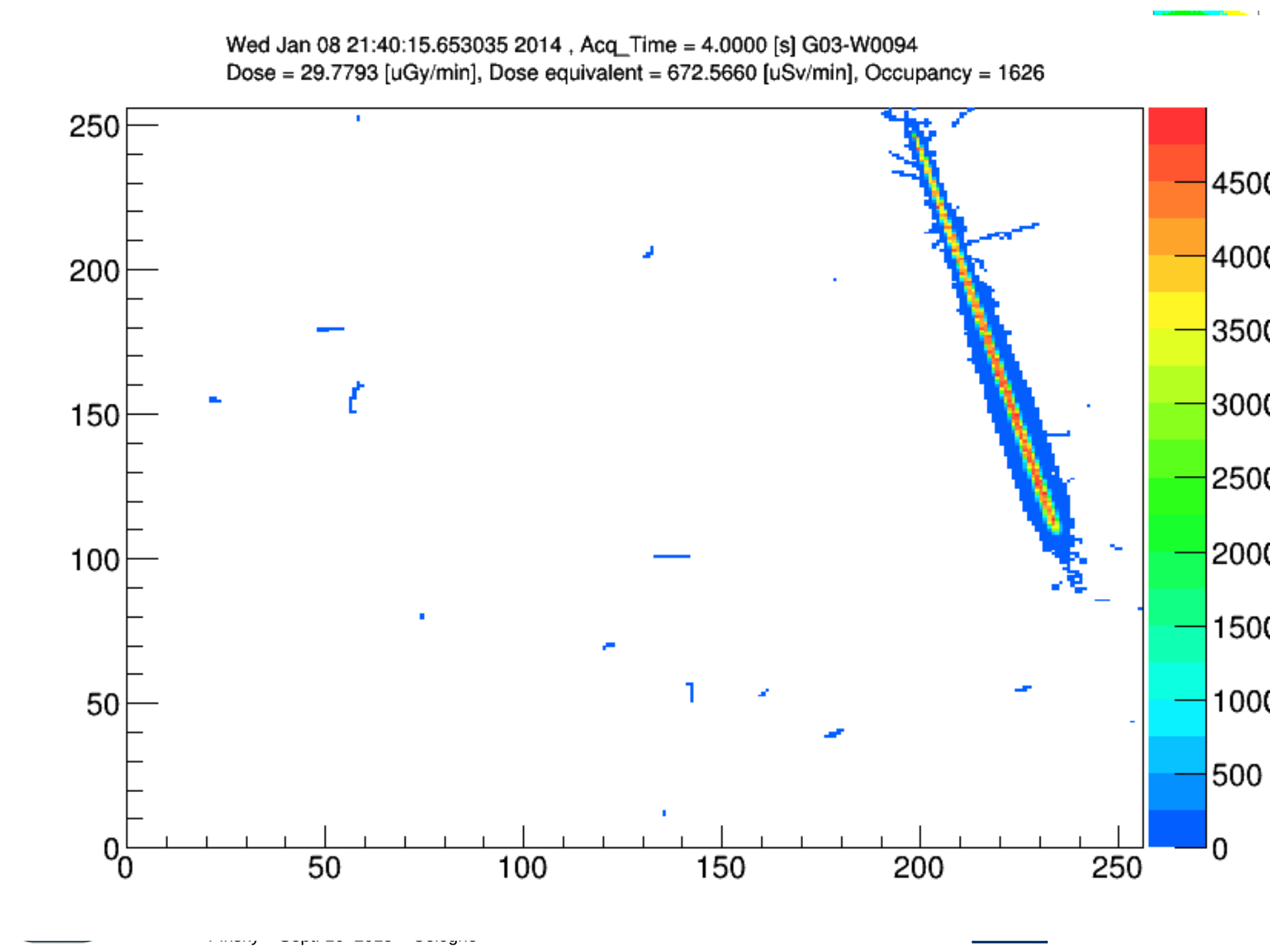

Thu Jan 31 22:56:31.255608 2013 , Acq_Time = 4.0000 [s] G03-W0094
Dose = 295.8055 [uGy/min], Dose equivalent = 4598.1747 [uSv/min], Occupancy = 3175
250
200
150
100
50
0
0
50
100
150
200
250
6000
5000
4000
3000
2000
1000
0

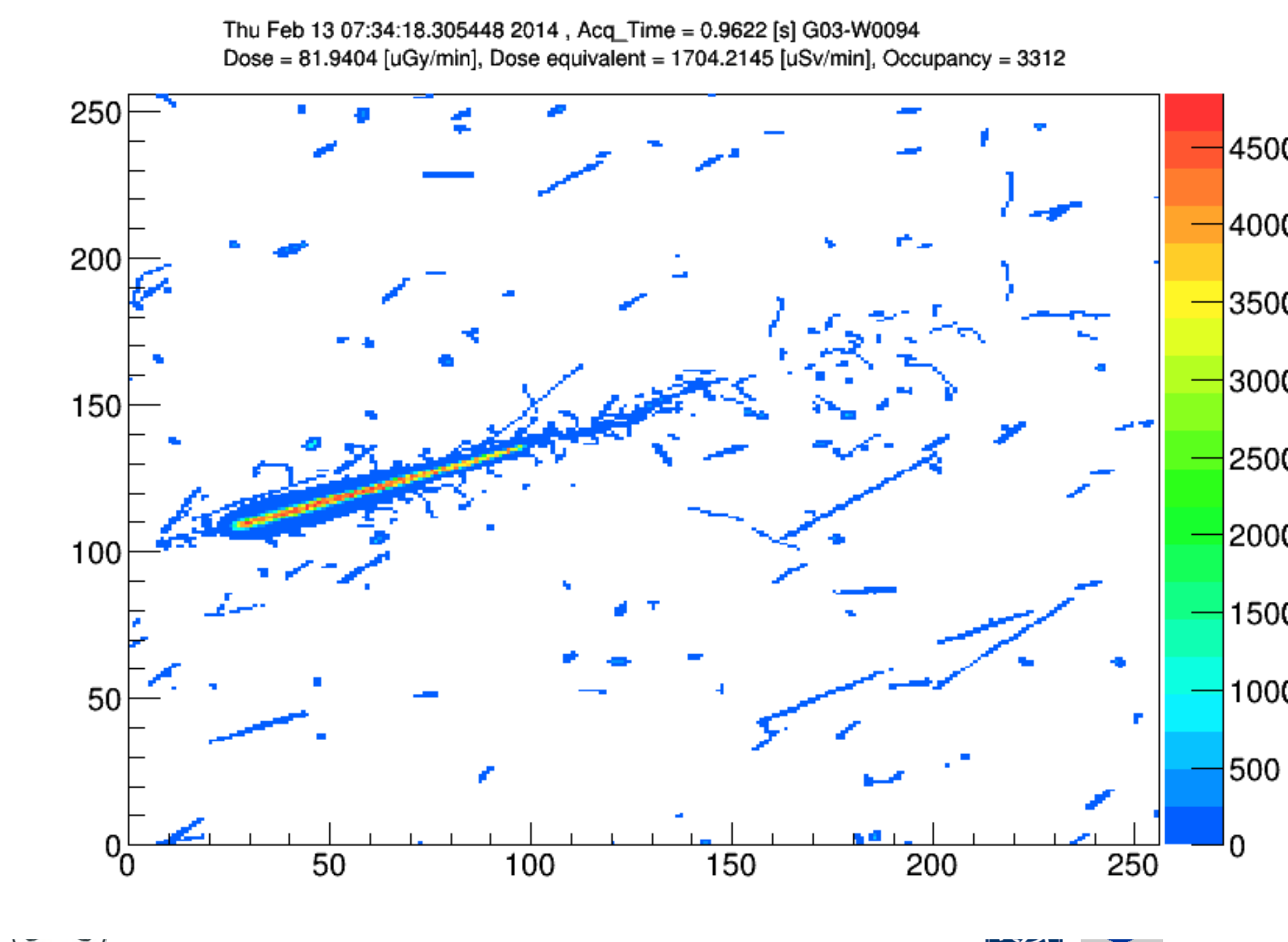

Fri Feb 07 09:17:54.853429 2014 , Acq_Time = 2.5395 [s] I04-W0094
Dose = 209.2499 [uGy/min], Dose equivalent = 3680.3618 [uSv/min], Occupancy = 2857
250
200
150
100
50
0
0
50
100
150
200
250
6000
5000
4000
3000
2000
1000
0

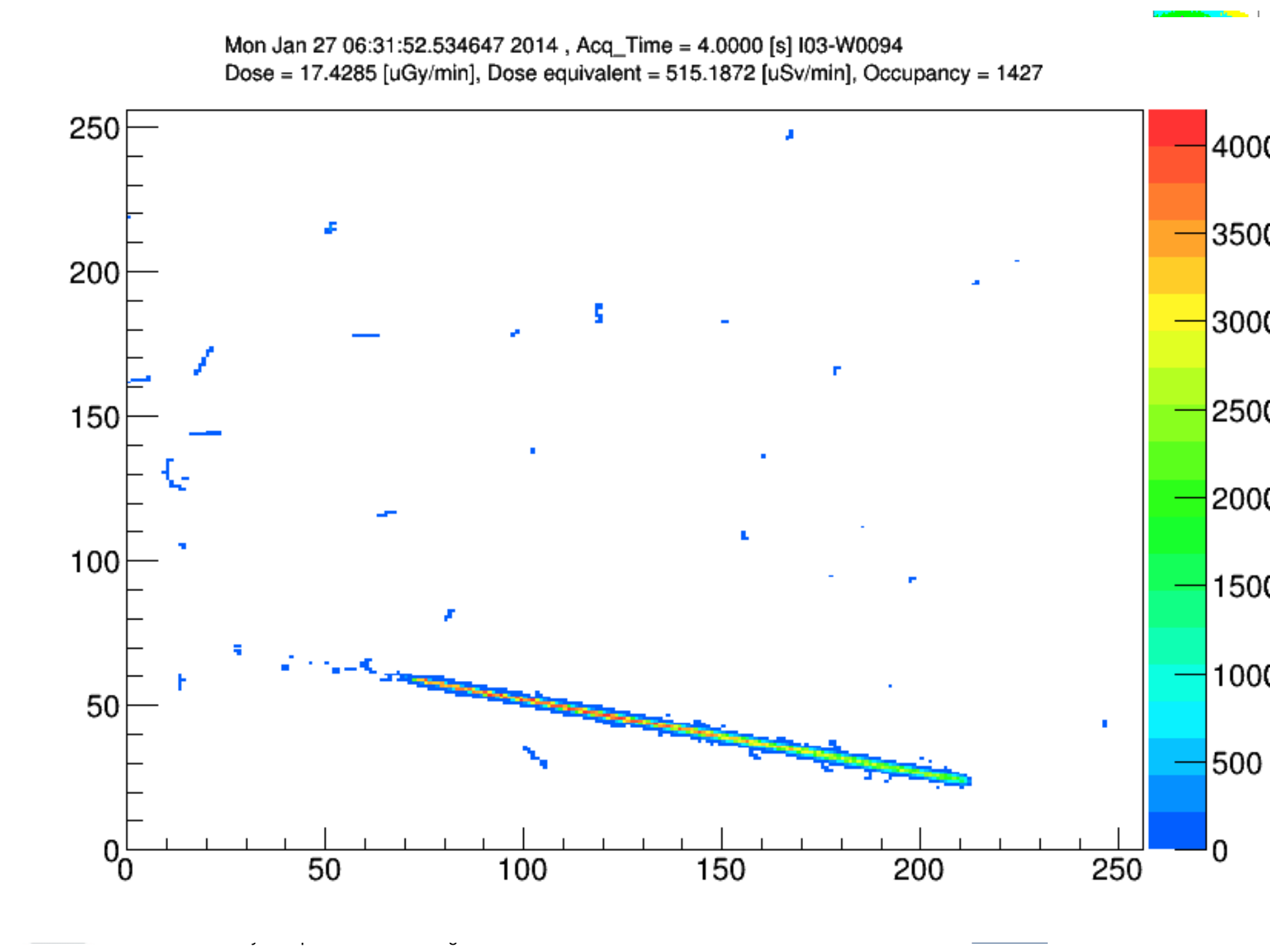

Fri Nov 09 19:11:41.661491 2012 , Acq_Time = 4.0000 [s] E06-W0087
Dose = 108.5174 [uGy/min], Dose equivalent = 1603.7414 [uSv/min], Occupancy = 2310
250
200
150
100
50
0
0
50
100
150
200
250
6000
5000
4000
3000
2000
1000
0

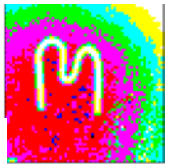

Wed Jan 15 07:31:00.296091 2014 , Acq_Time = 4.0000 [s] J02-W0156
Dose = 18.4267 [uGy/min], Dose equivalent = 450.0683 [uSv/min], Occupancy = 4081
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0


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

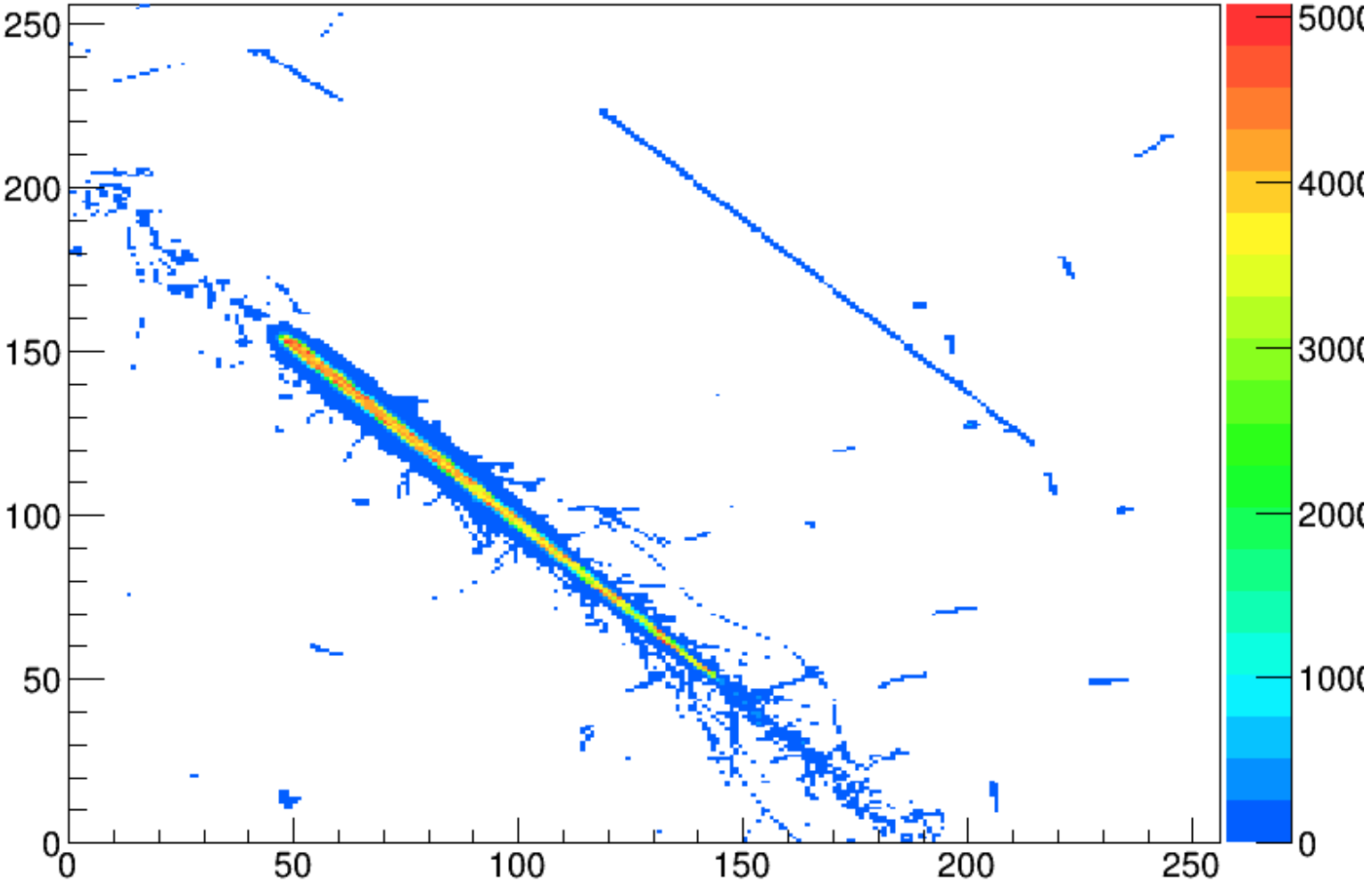

Wed Jan 08 21:40:15.653035 2014 , Acq_Time = 4.0000 [s] G03-W0094
Dose = 29.7793 [uGy/min], Dose equivalent = 672.5660 [uSv/min], Occupancy = 1626
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0

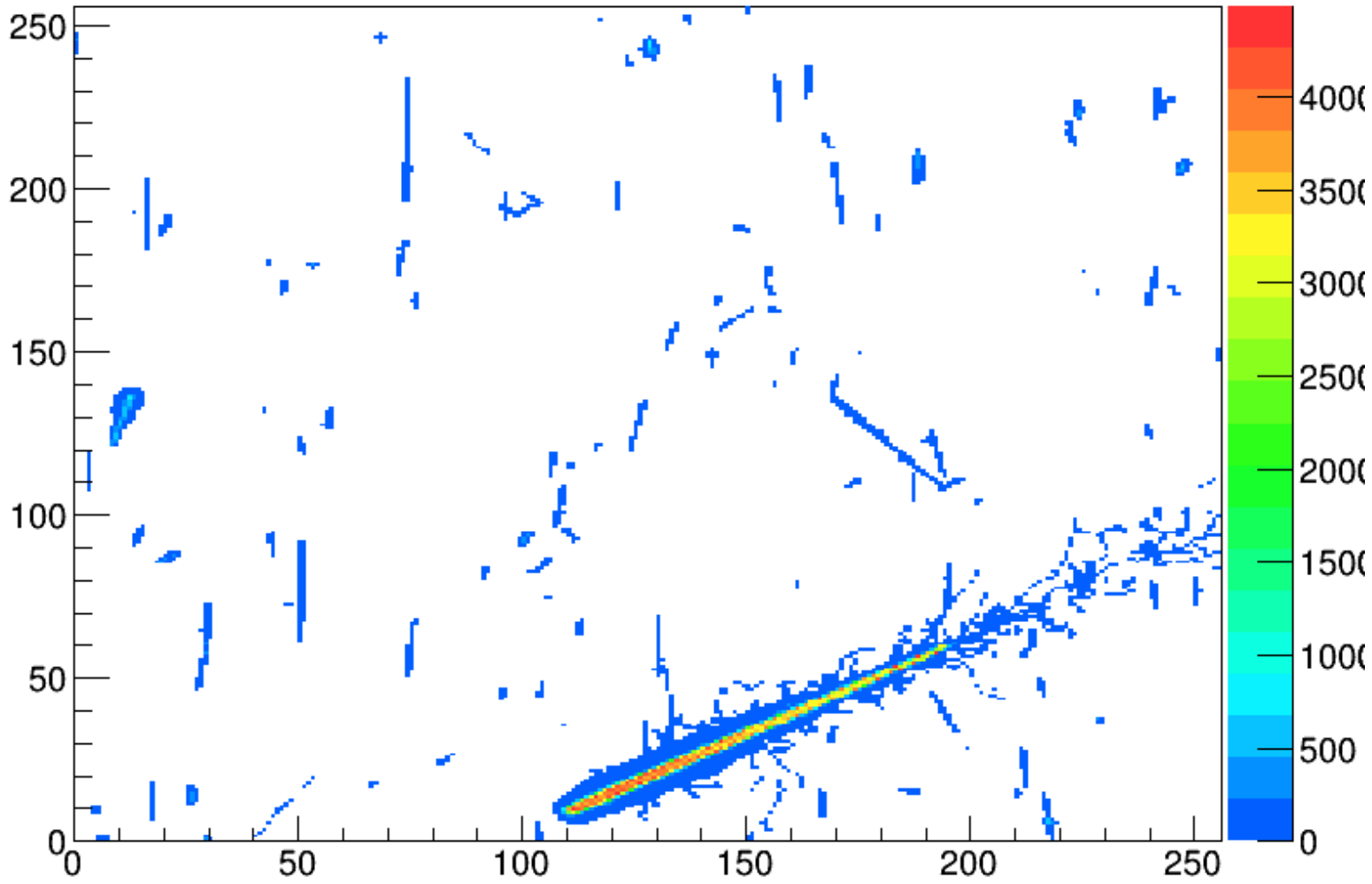

Thu Feb 13 07:34:18.305448 2014 , Acq_Time = 0.9622 [s] G03-W0094
Dose = 81.9404 [uGy/min], Dose equivalent = 1704.2145 [uSv/min], Occupancy = 3312
250
200
150
100
50
0
0
50
100
150
200
250
4500
4000
3500
3000
2500
2000
1500
1000
500
0


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




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