Timepix in LEO orbit on board VZLUSAT-1 nanosatellite: 1-year of Space Radiation dosimetry measurements

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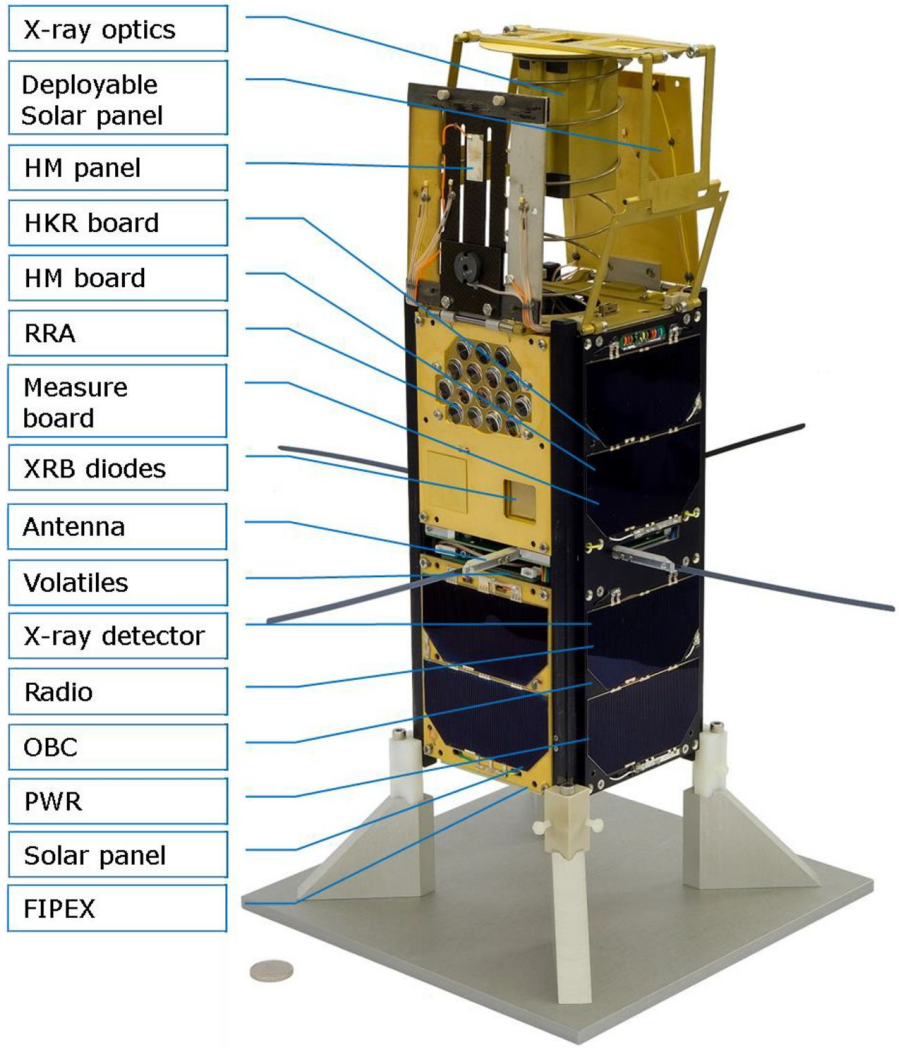
Overview

VZLUSAT-1 mission [Urban et al., 2017]

Mission parameters

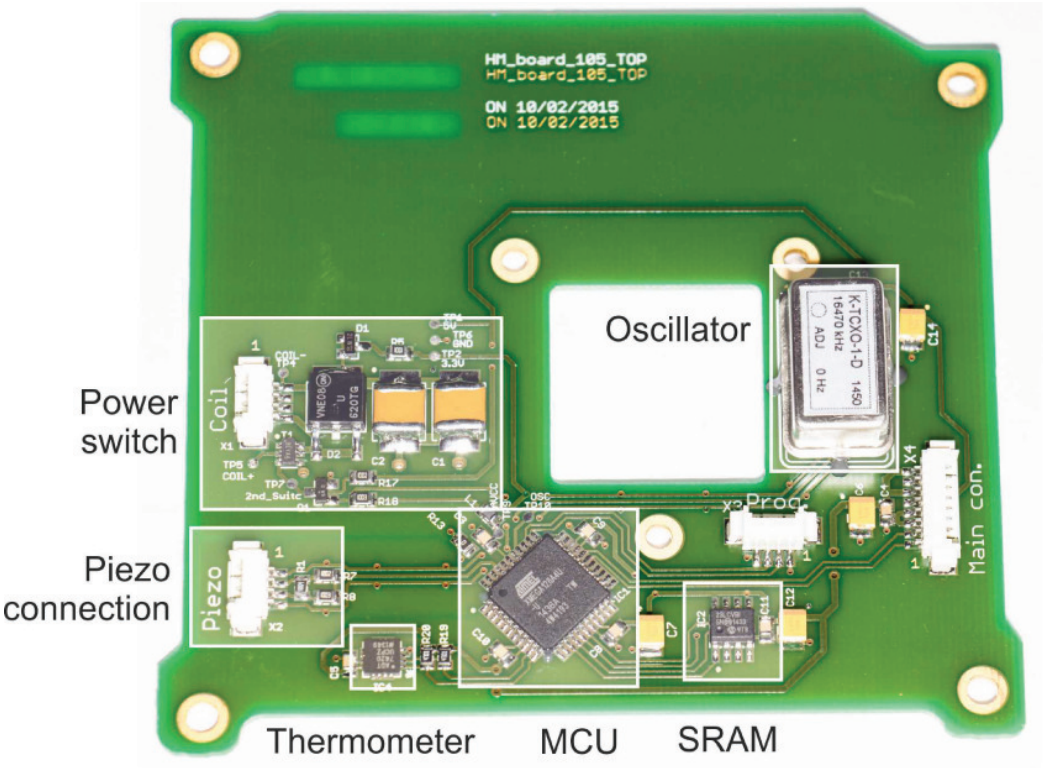
- 2-U cubesat (expands to 3-U)
- part of the QB50 mission
- approx. 510 km polar SSO
- technological demonstrator
  - material properties of RHCC
  - novel sensors for health monitoring: radiation, outgassing and temperature
  - custom-built solar panels
  - miniaturized X-Ray telescope
- the first Czech cubesat

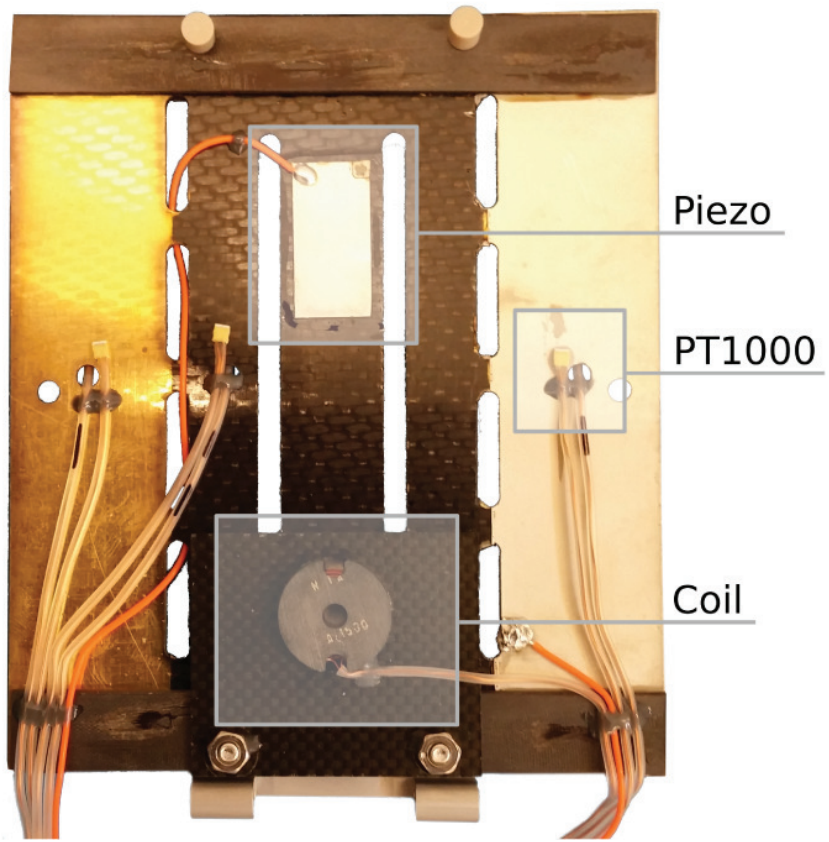


Aging properties of carbon composite [Urban et al., 2017]

Space material properties

- Radiation-hardened carbon composite counter leaver
- Measurement change eigenfrequencies of the material

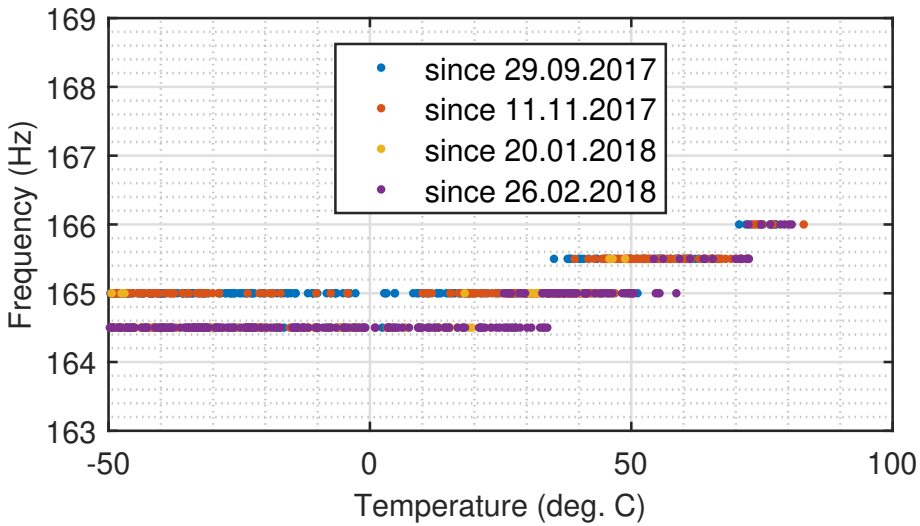




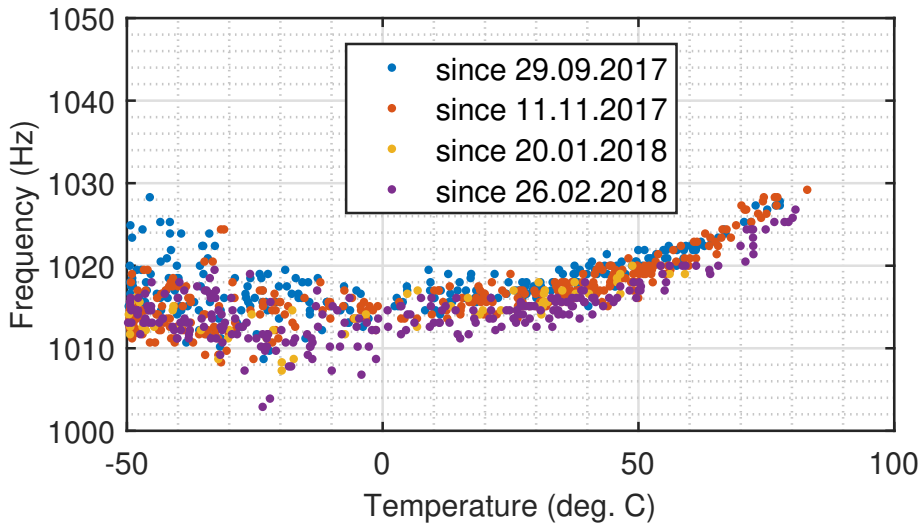
Aging properties of carbon composite [Urban et al., 2017]

Results

- Carbon fibre material degrades due to the space environment (mainly due to radiation).
- The eigenfrequencies decrease, data undergo analysis



(a) The first eigenfrequency

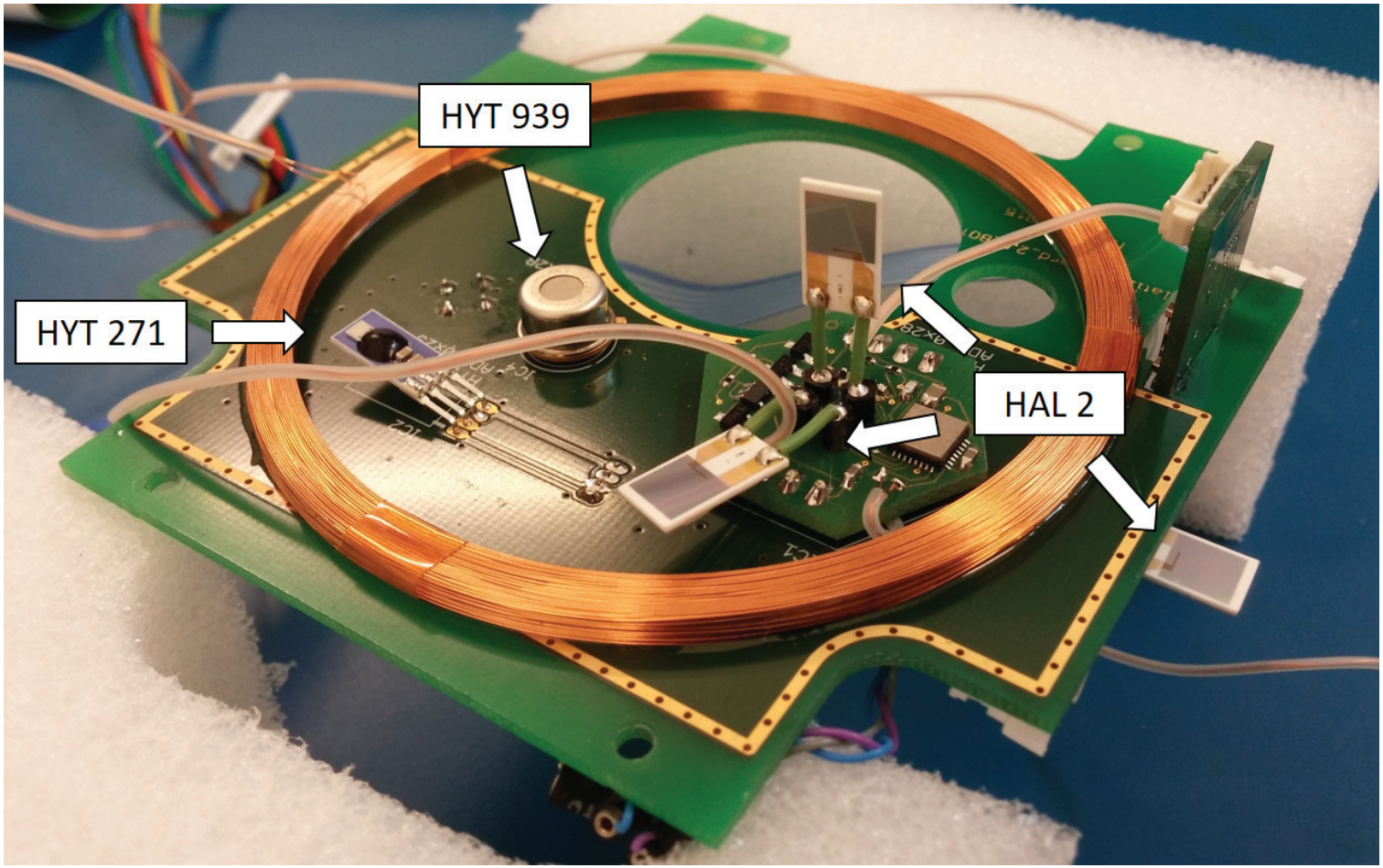


(b) The second eigenfrequency

Measurements of volatiles [Urban et al., 2017]

Outgassing monitoring

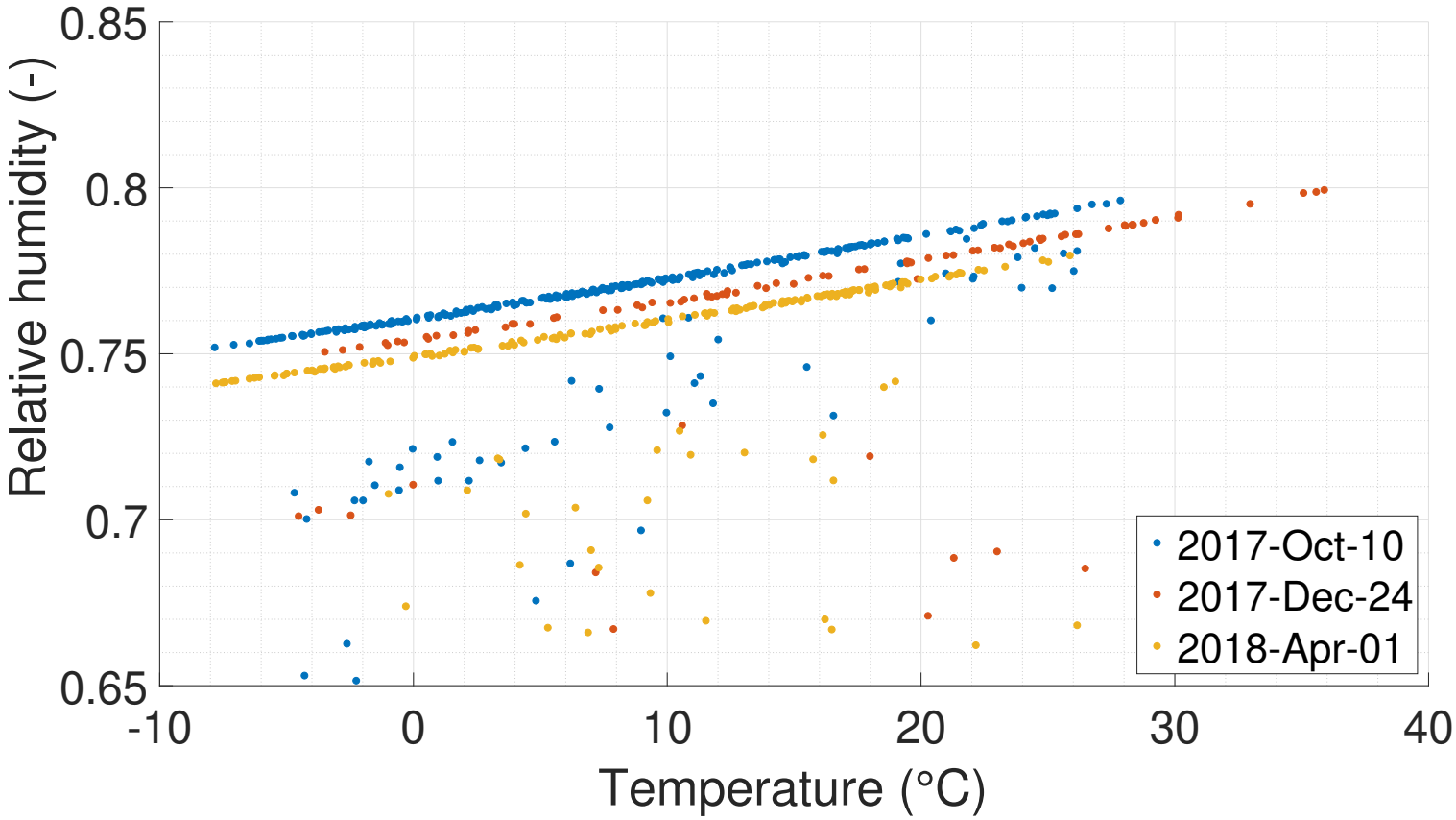
- Custom Czech-made outgassing sensors



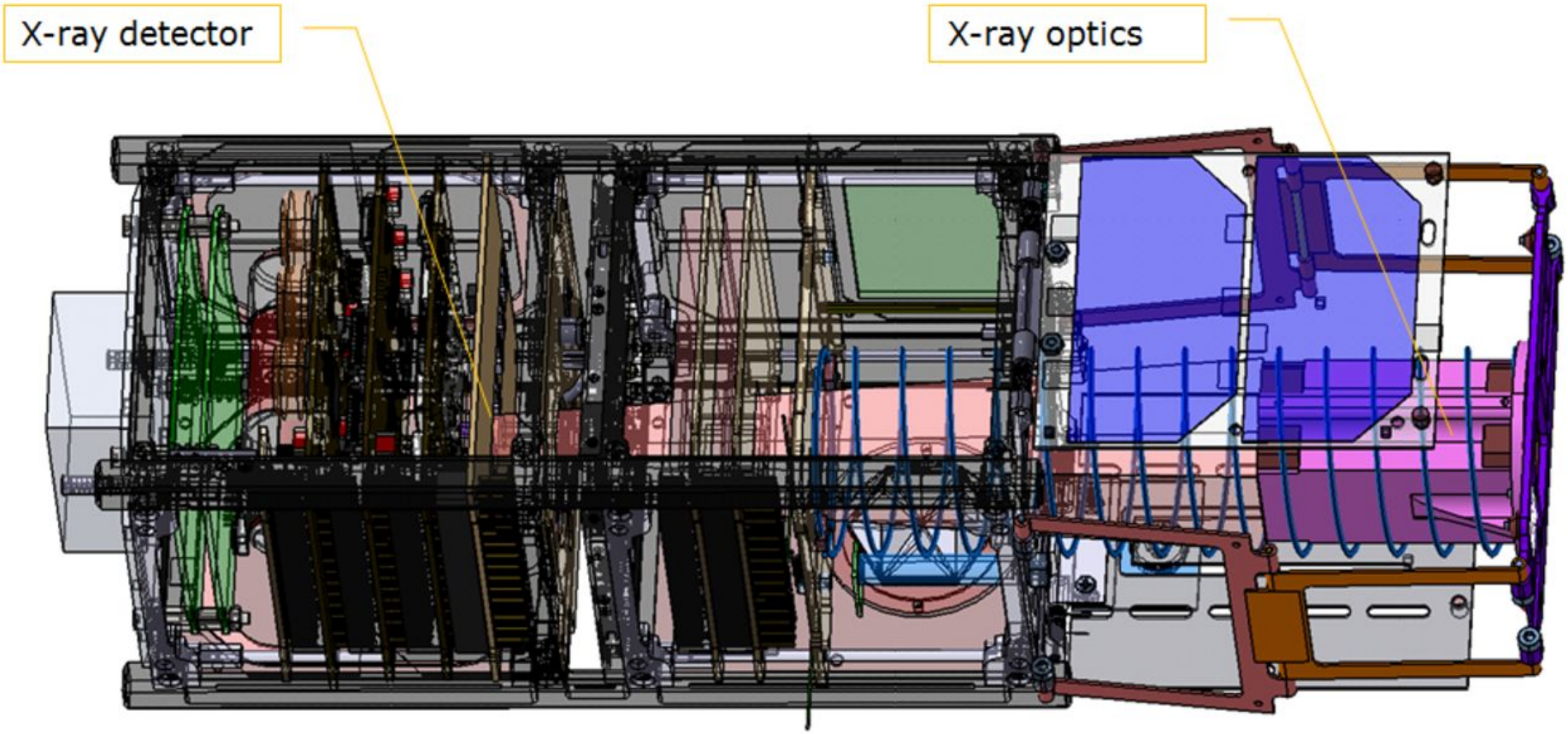
Measurements of volatiles [Urban et al., 2017]

Results

- Long-term monitoring is undergoing.
- Data are being analyzed.



X-Ray telescope

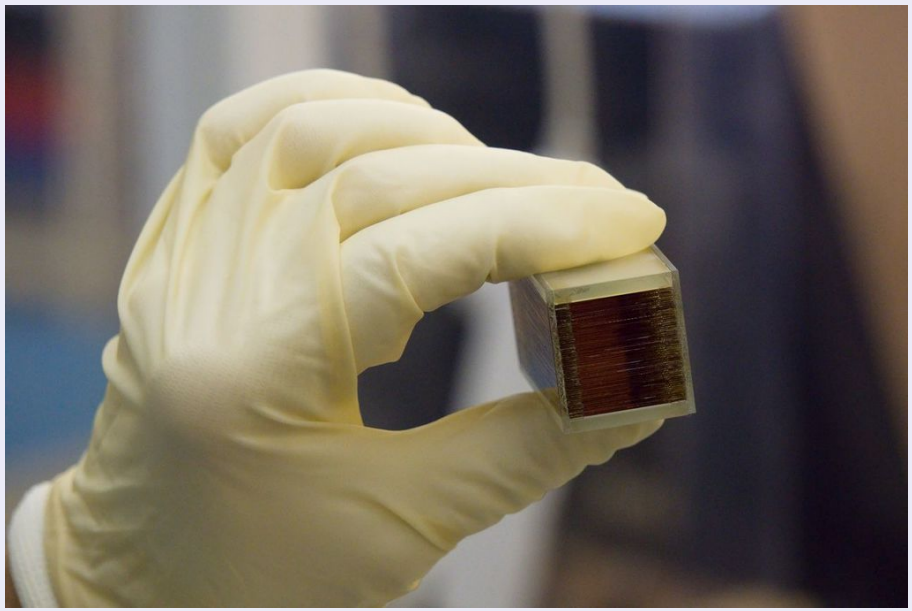


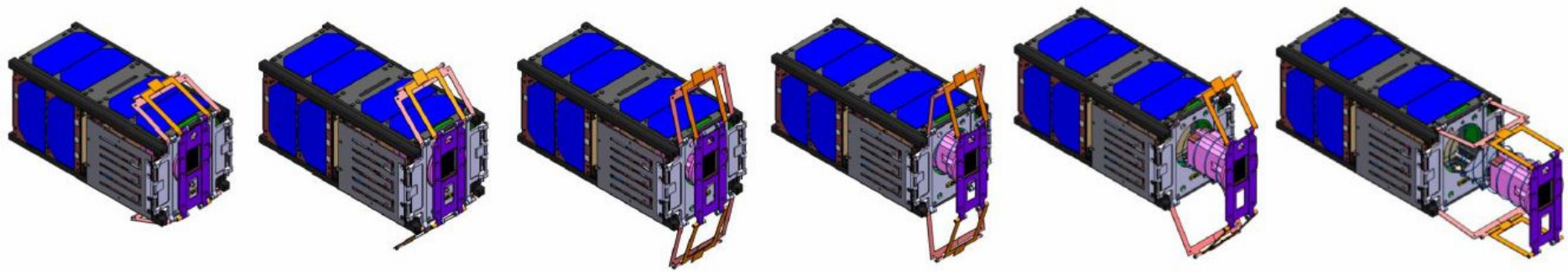
X-Ray optics [Pina et al., 2016]

The optics' parameters

- aperture 28 × 28 mm
- 250 mm focal length
- 4 – 20 keV energy range
- 56 glass foils
  - gold-coated
  - thickness 145 μm
  - spacing 300 μm

The optics module

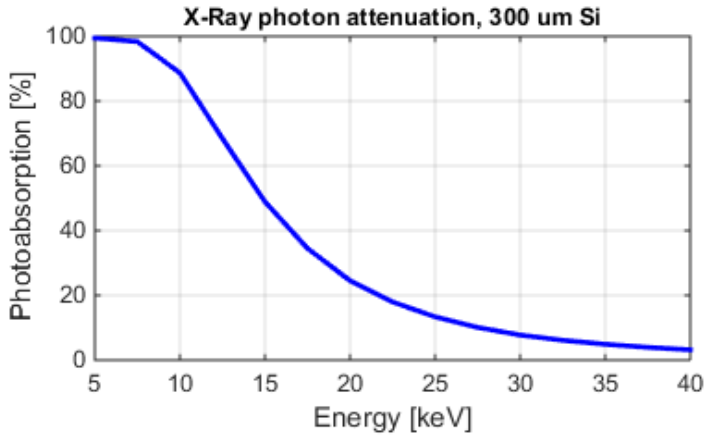


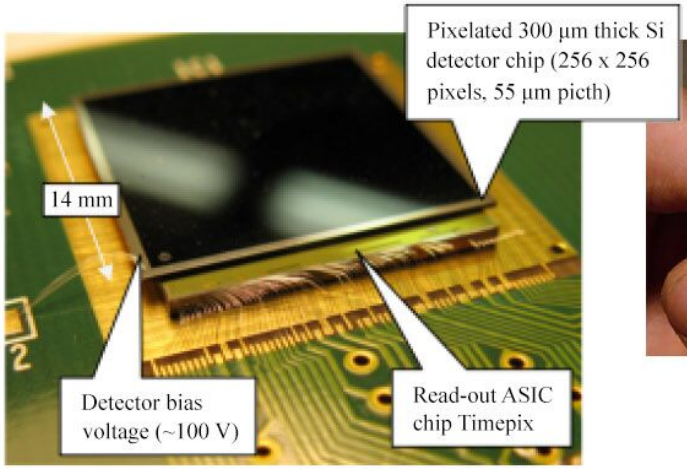


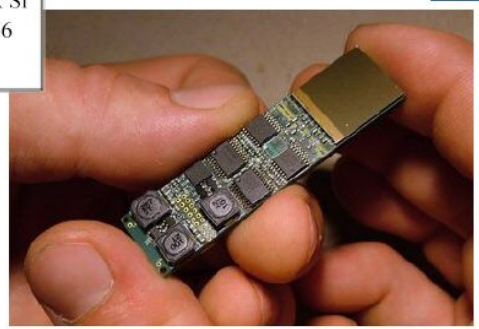
The sensor board [Baca et al. 2016, Llopart et al. 2007, Vykydal et al. 2011]

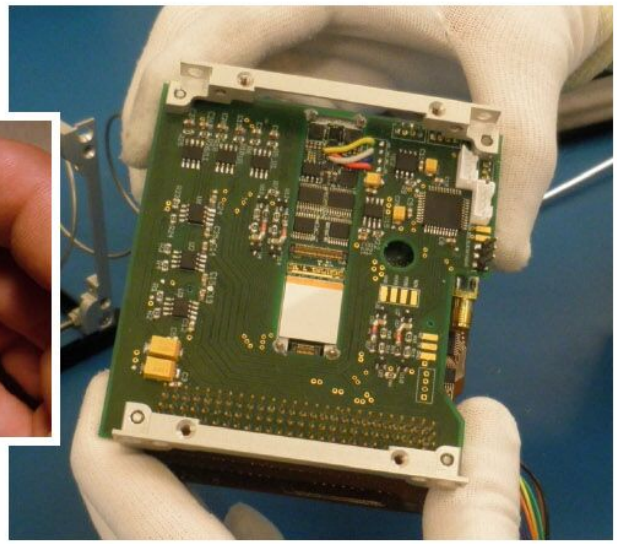
The Timepix sensor

- 300 μm Silicon detector
- 256 $\times$ 256 px, 55 μm pitch
- photon detection range: 2 – 50 keV
- passive cooling
- electronically suppressed noise

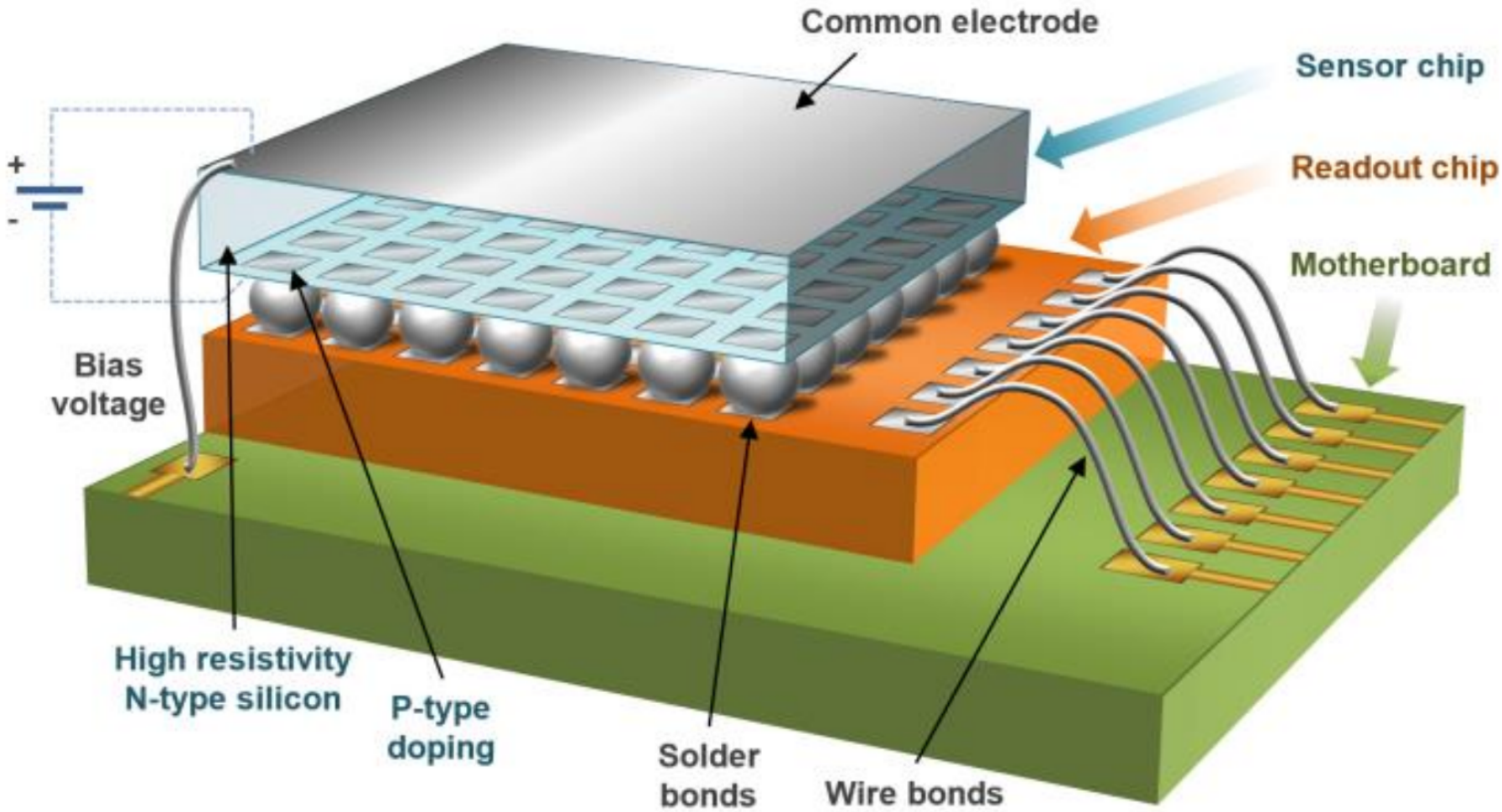




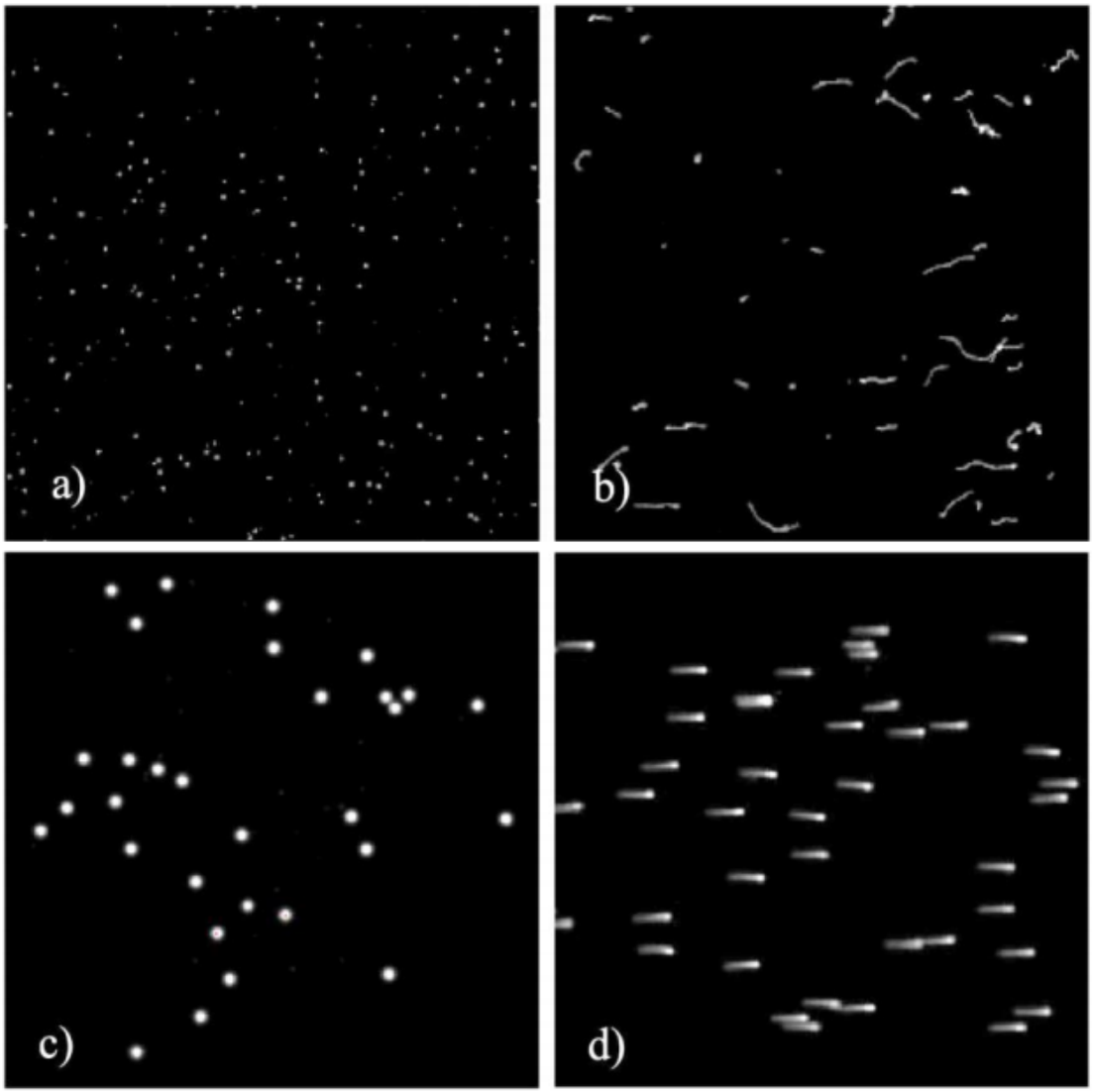




Timepix detector structure



Distinguishing Particle Types



4 particle types

a) photons

b) electron

c) light ions
He nuclei

d) heavy ions

Typical use of Timepix

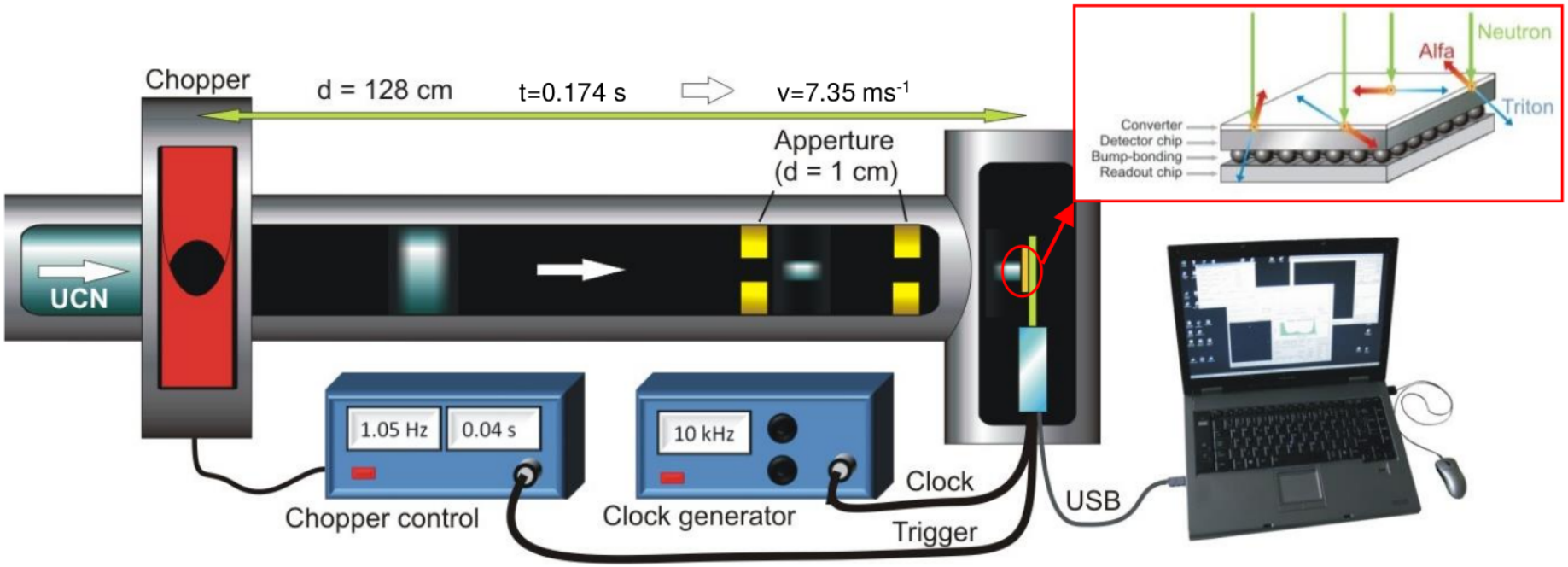


Figure: Timepix used with a personal computer

Assembly and testing

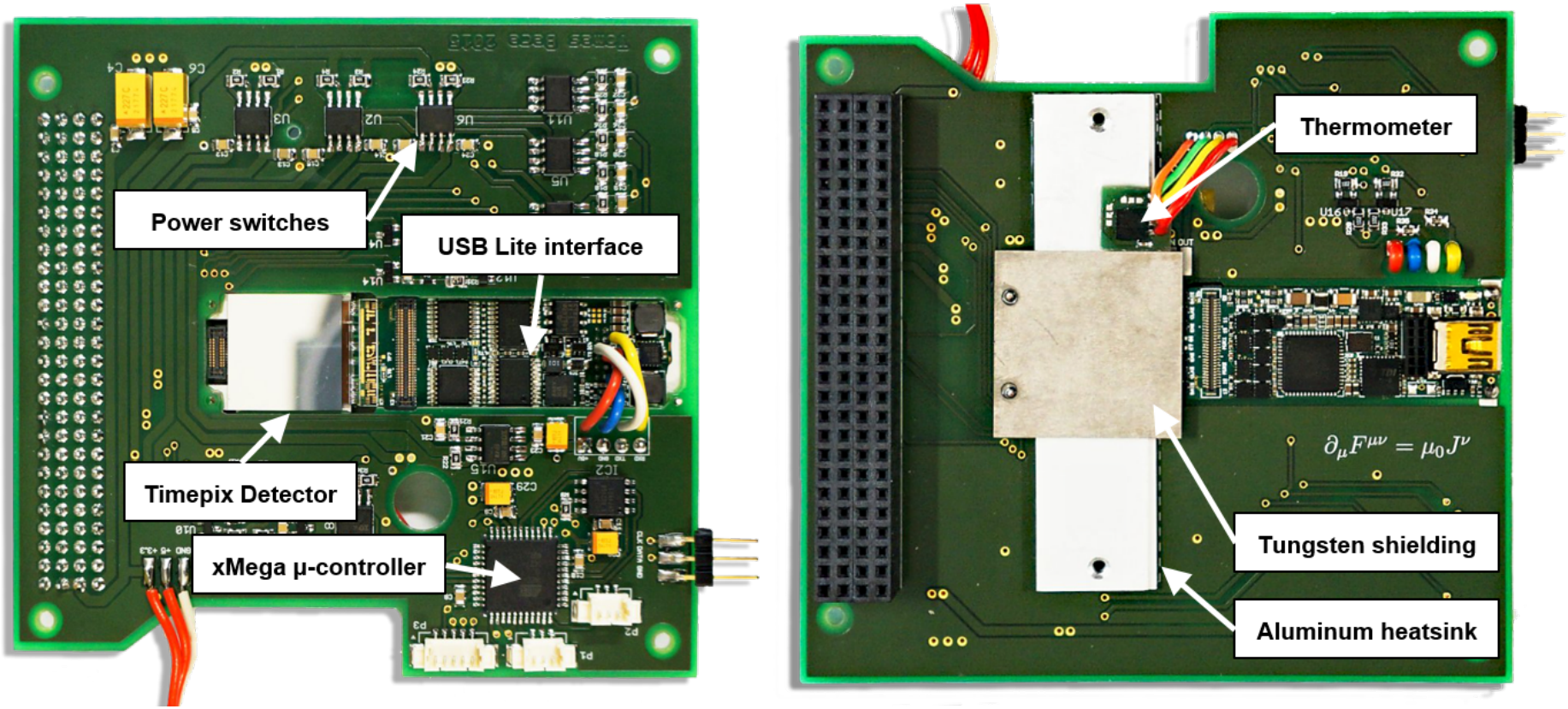


Figure: X-Ray sensor board

Assembly and testing

Figure: X-Ray optics

Assembly and testing

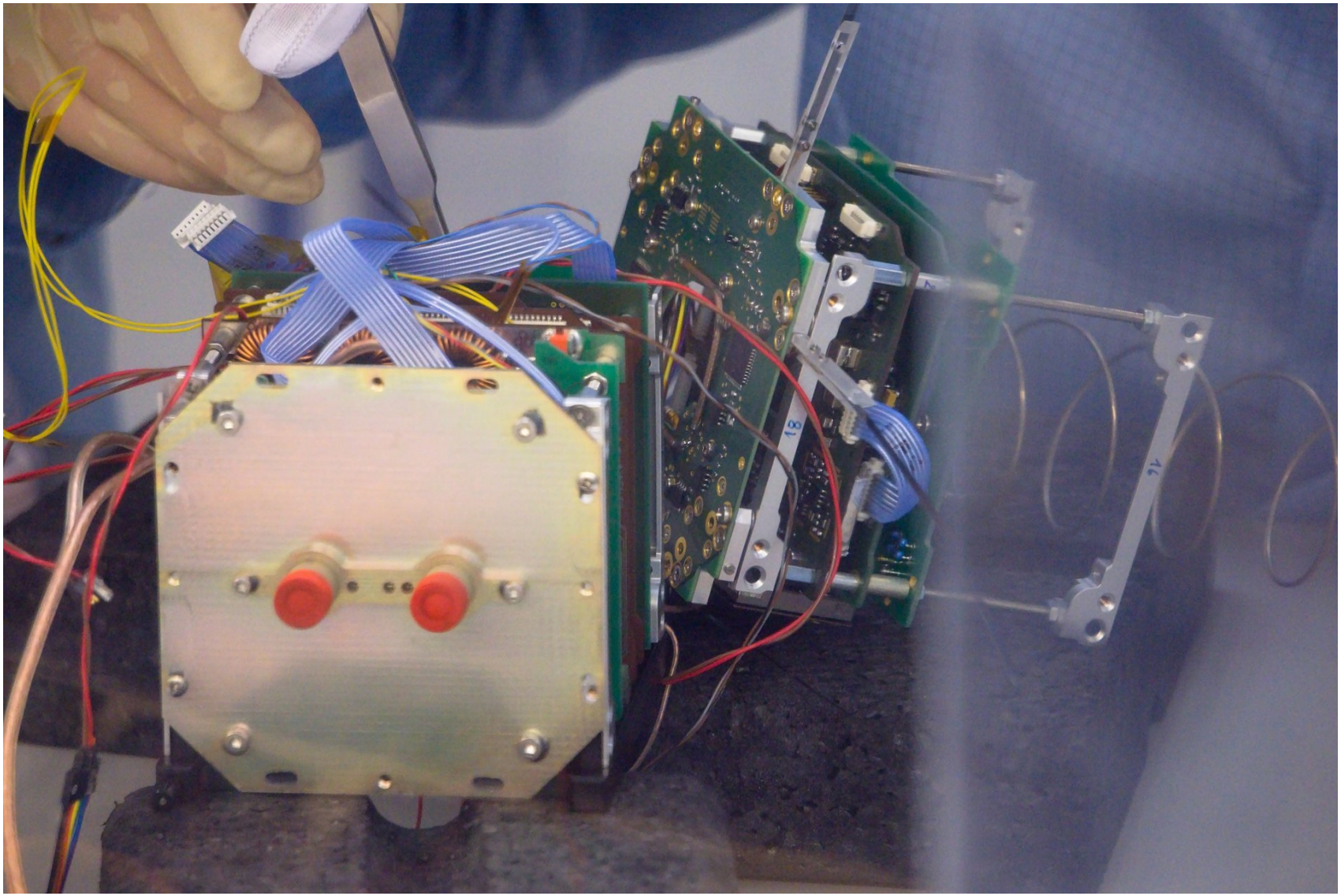
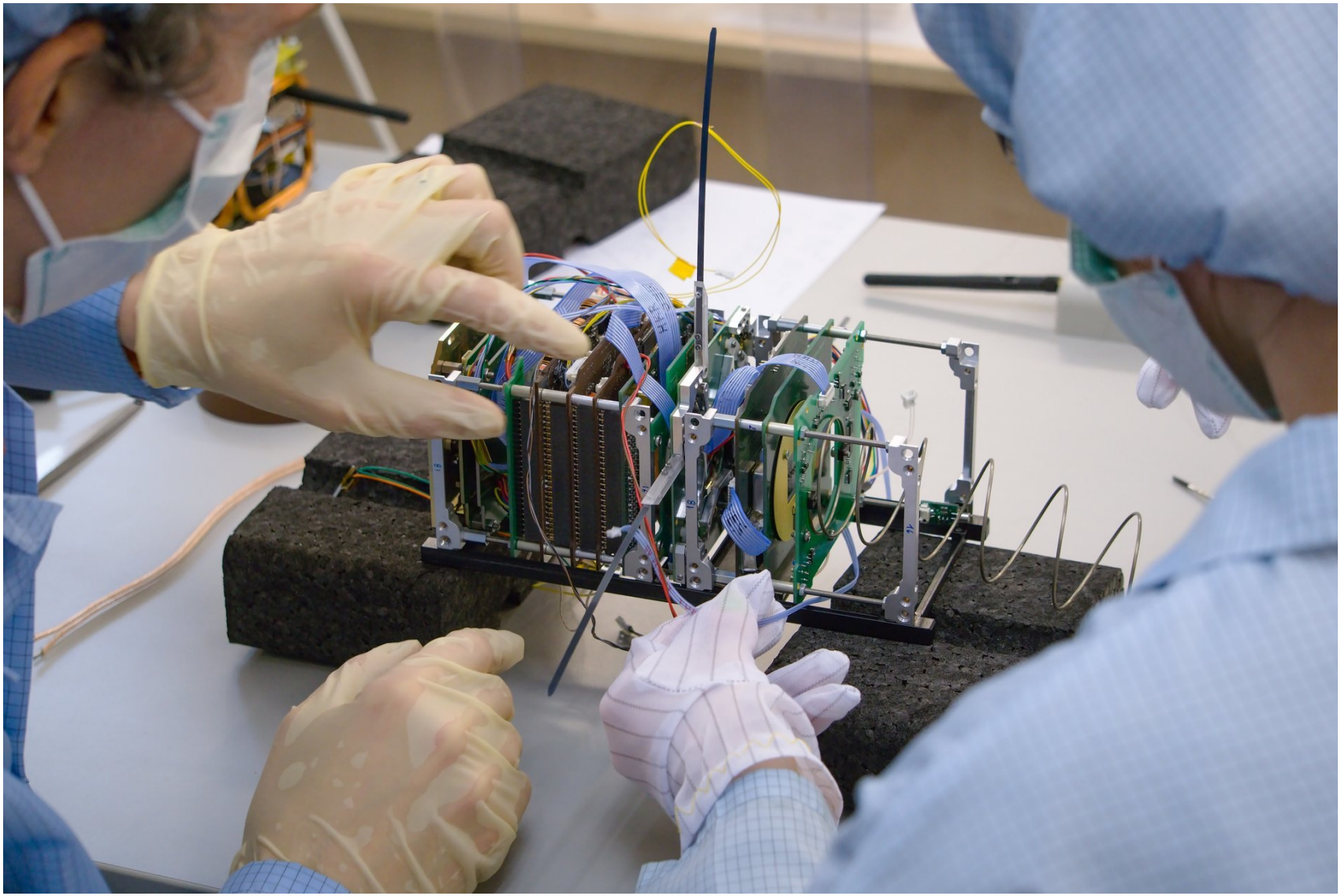


Figure: Assembly in VZLU clean rooms

Assembly and testing



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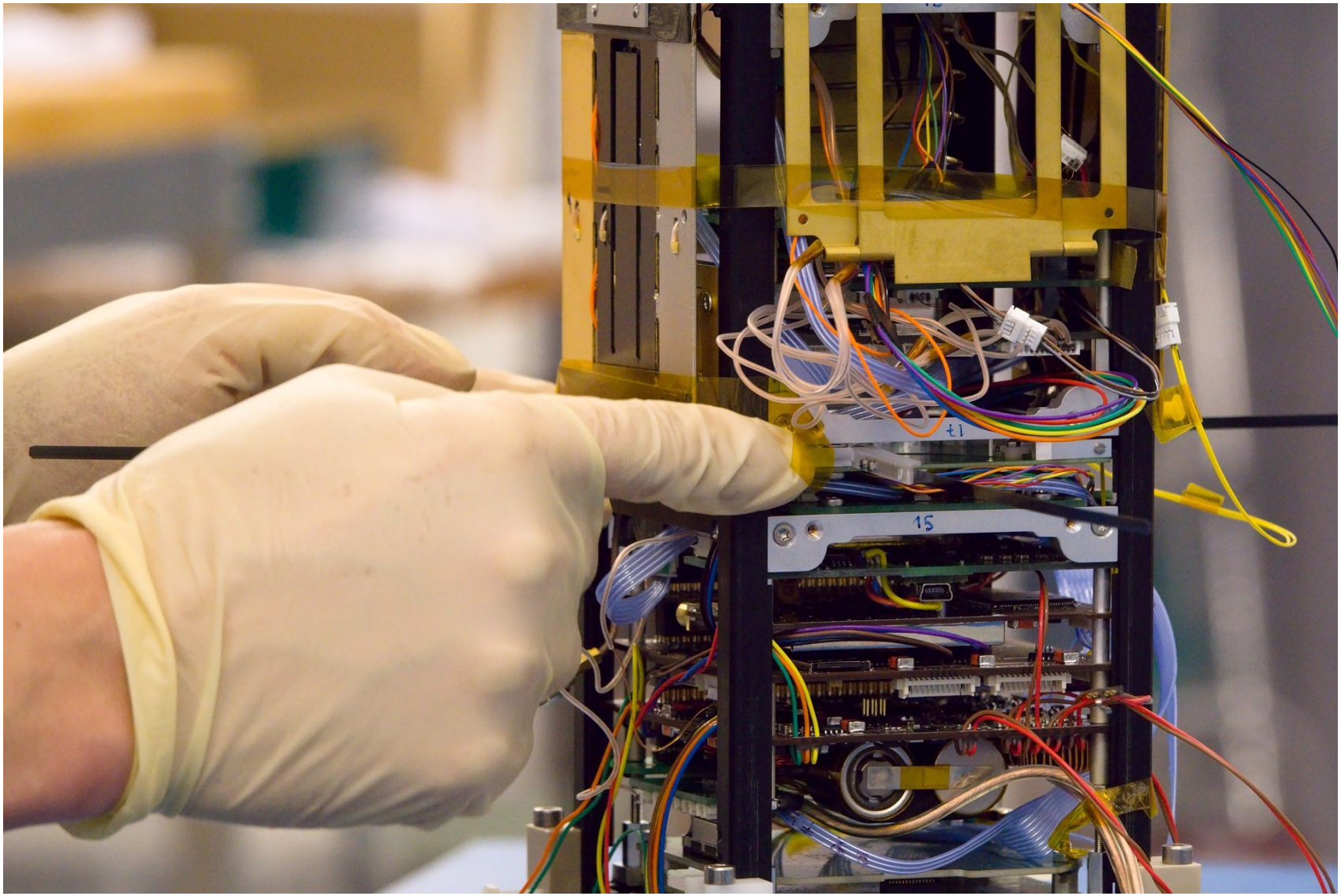

Figure: Assembly in VZLU clean rooms

The Launch

Launch dates... were delayed...

- ✗ ~~Late summer of 2016~~
- ✗ ~~April, 2017~~
- ✓ June 23rd, 2017

The launch from Sriharikota

PSLV rocket

The Launch

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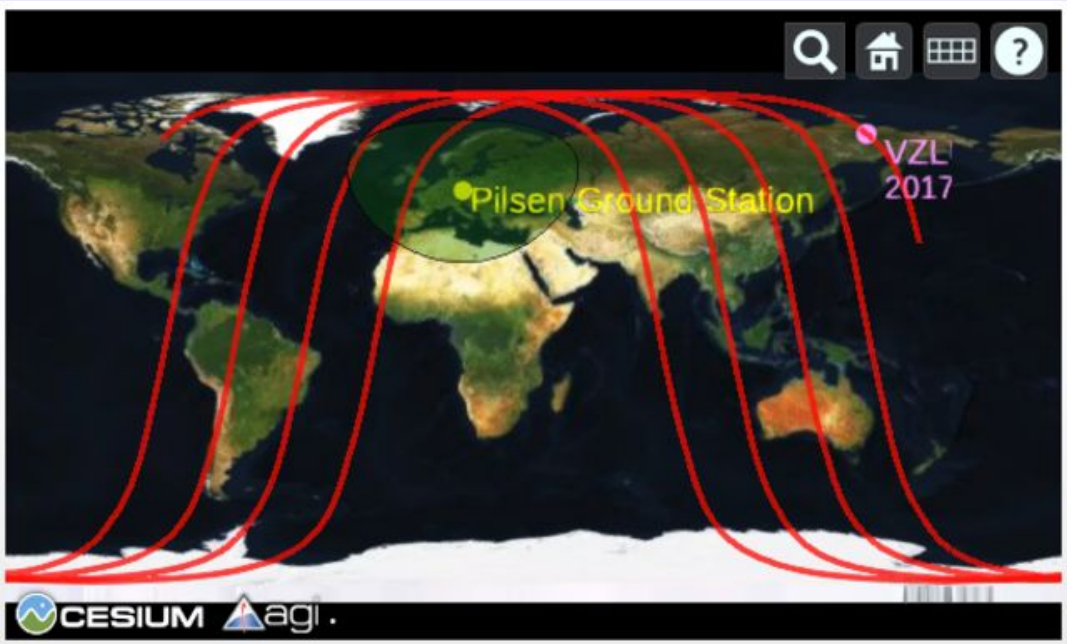
510 km SS LEO



PSLV rocket

Telescope operations - required factors

Remote control of the satellite

- Uploading measurement plans, automatic data acquisition

The sensor board inc. Timepix

- Real time Sun trigger

Attitude control

- Active orientation control system

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✗ Active orientation control system

UV-based Sun trigger

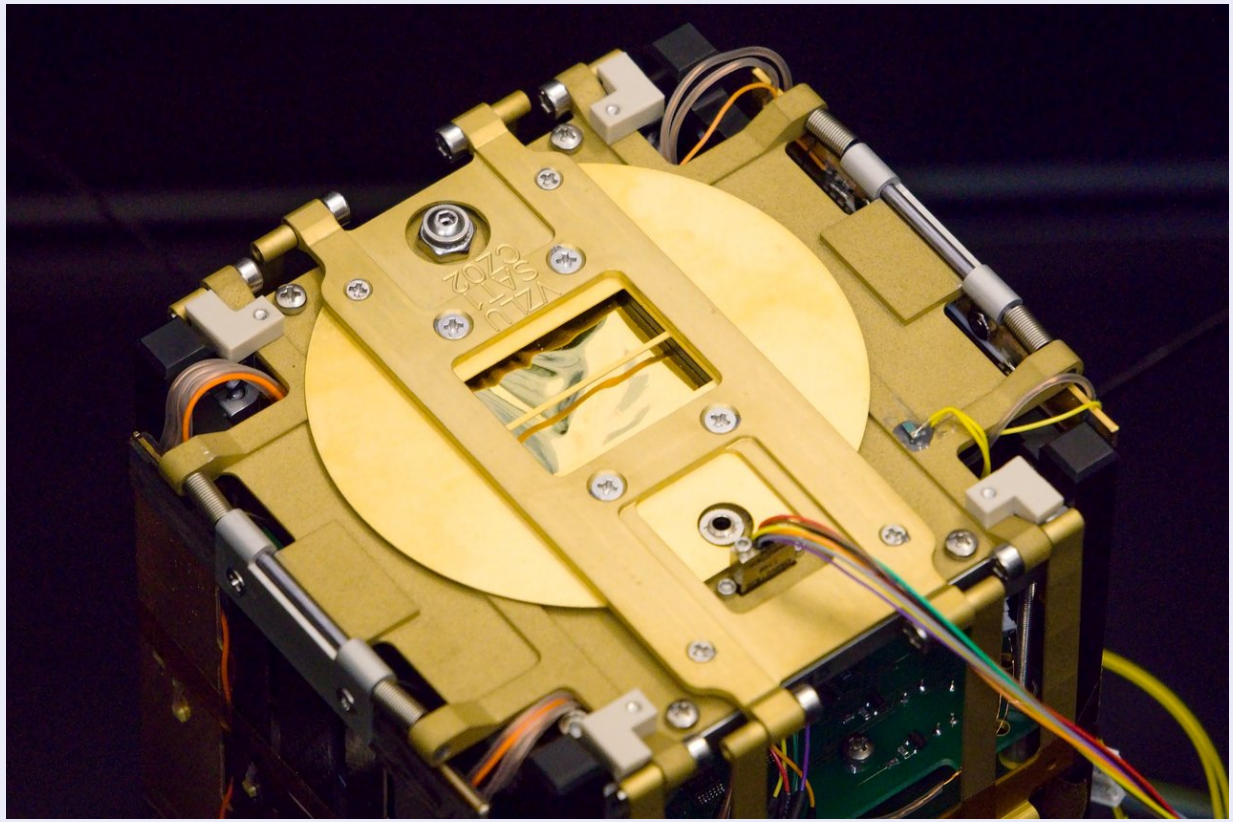
Automatic trigger

- UV sensor with 3° FOV
- pinhole aperture

Tumbelling

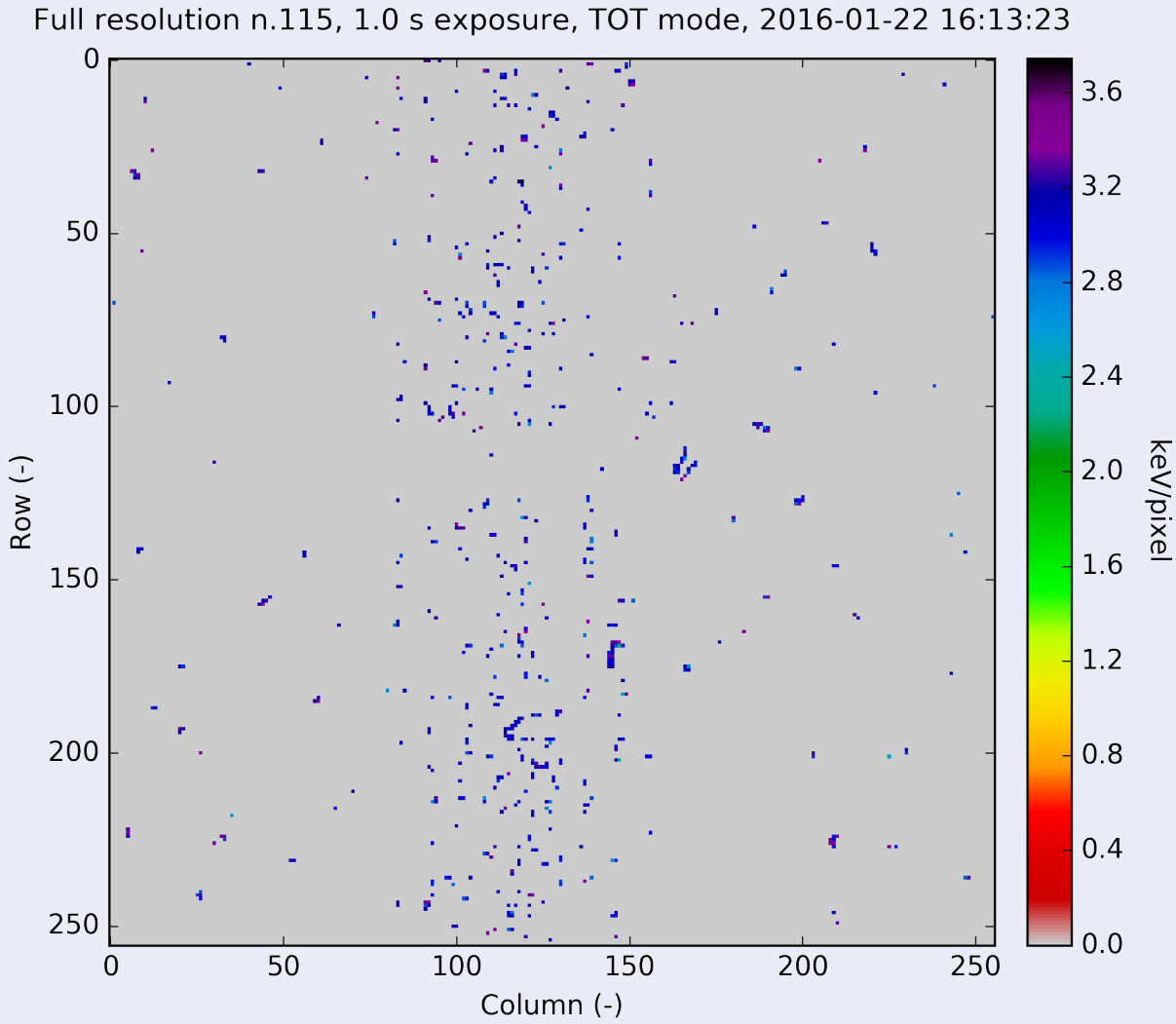
- 90 s period
- the Sun visible mostly above poles

UV Sensors' apertures



Expected Sun image

Simulated image: X-ray tube + radioactive decay source



Automated Solar exposures, optics not deployed

First UV triggered exposures

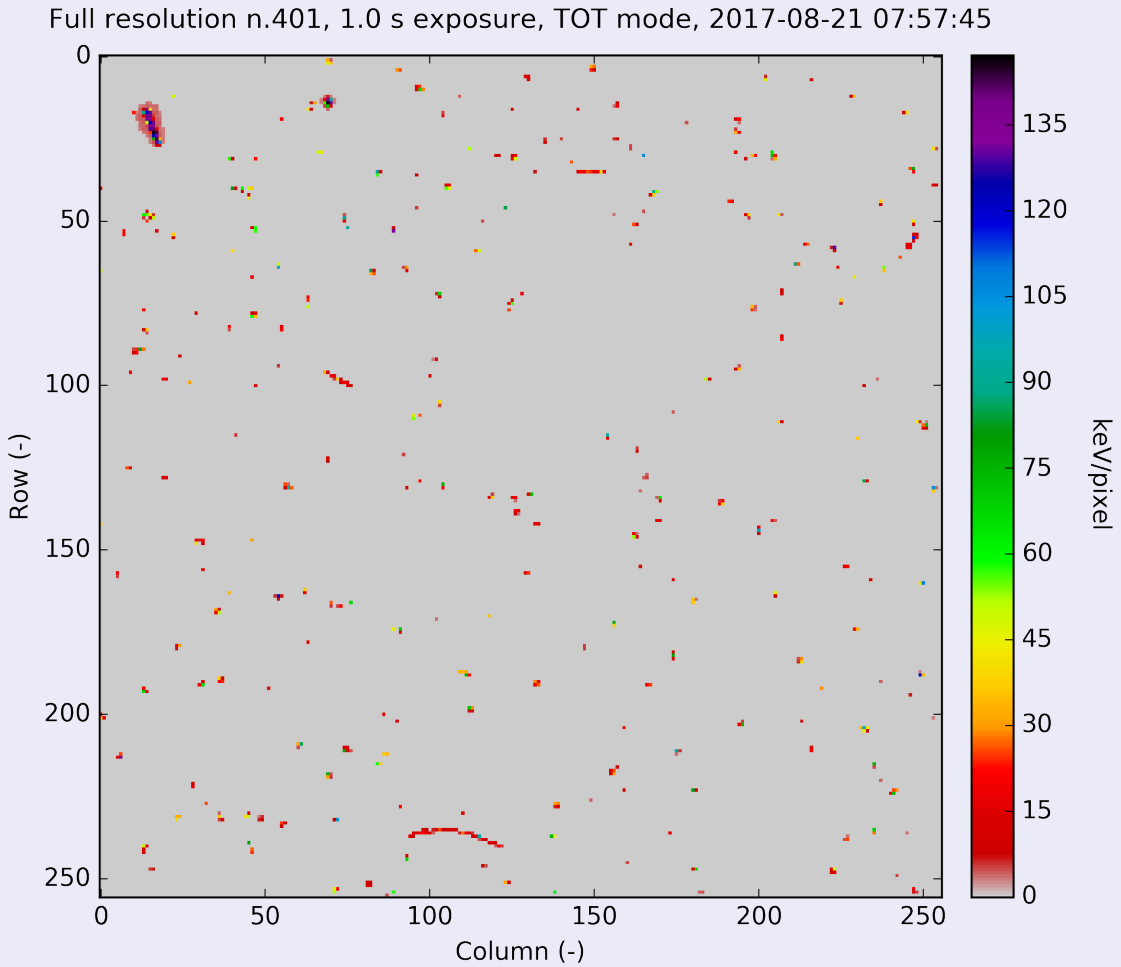
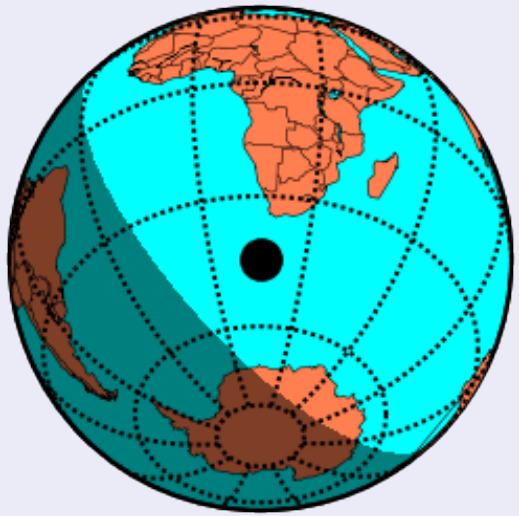


Image ID: 401
Acquisition: 1.0 s
Control: UV trigger



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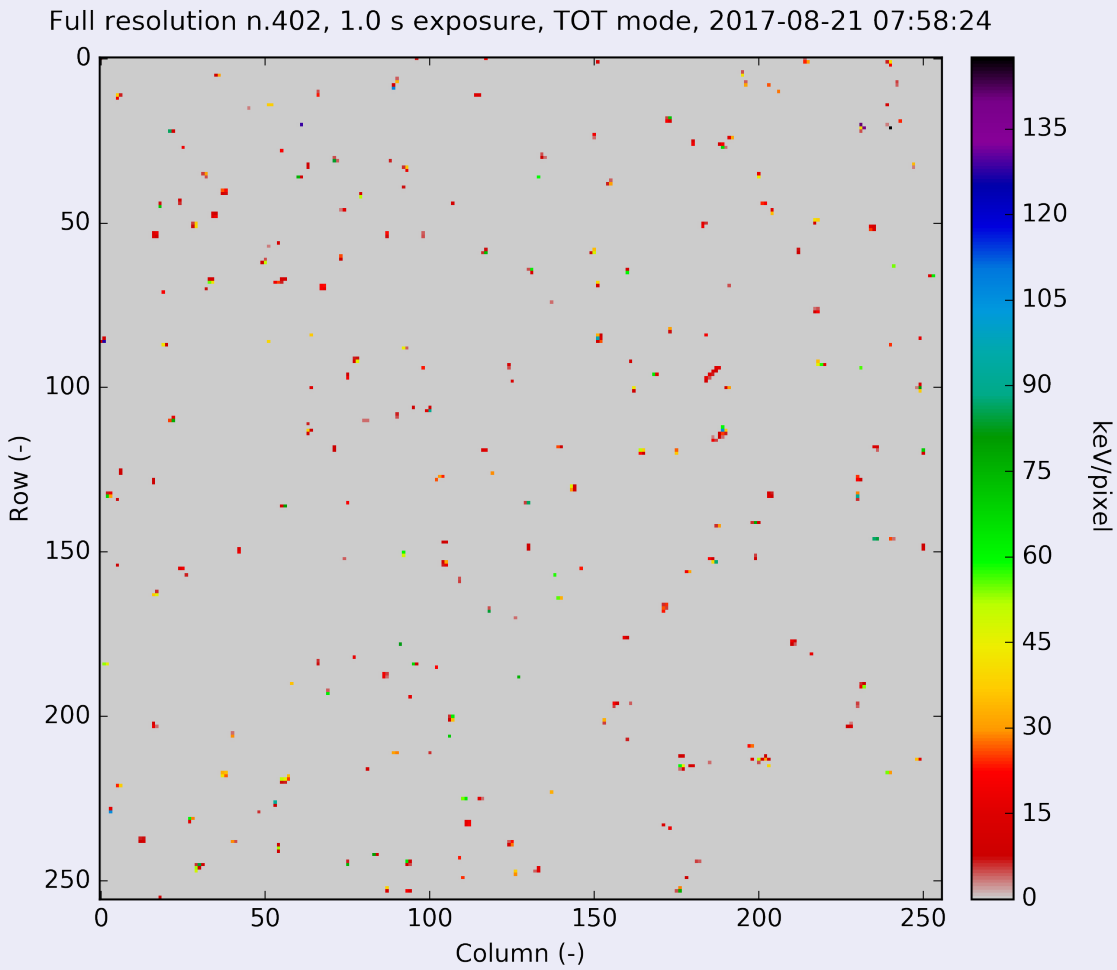

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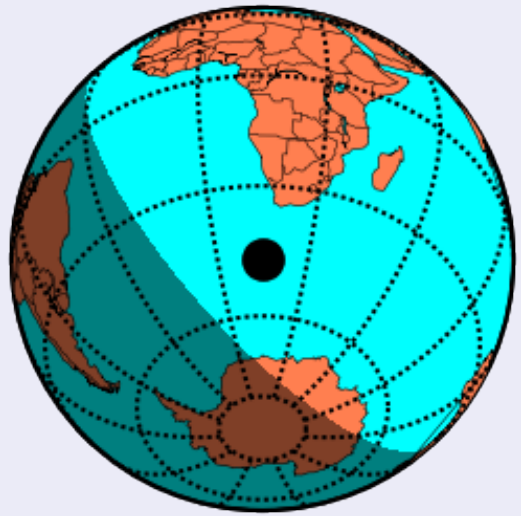

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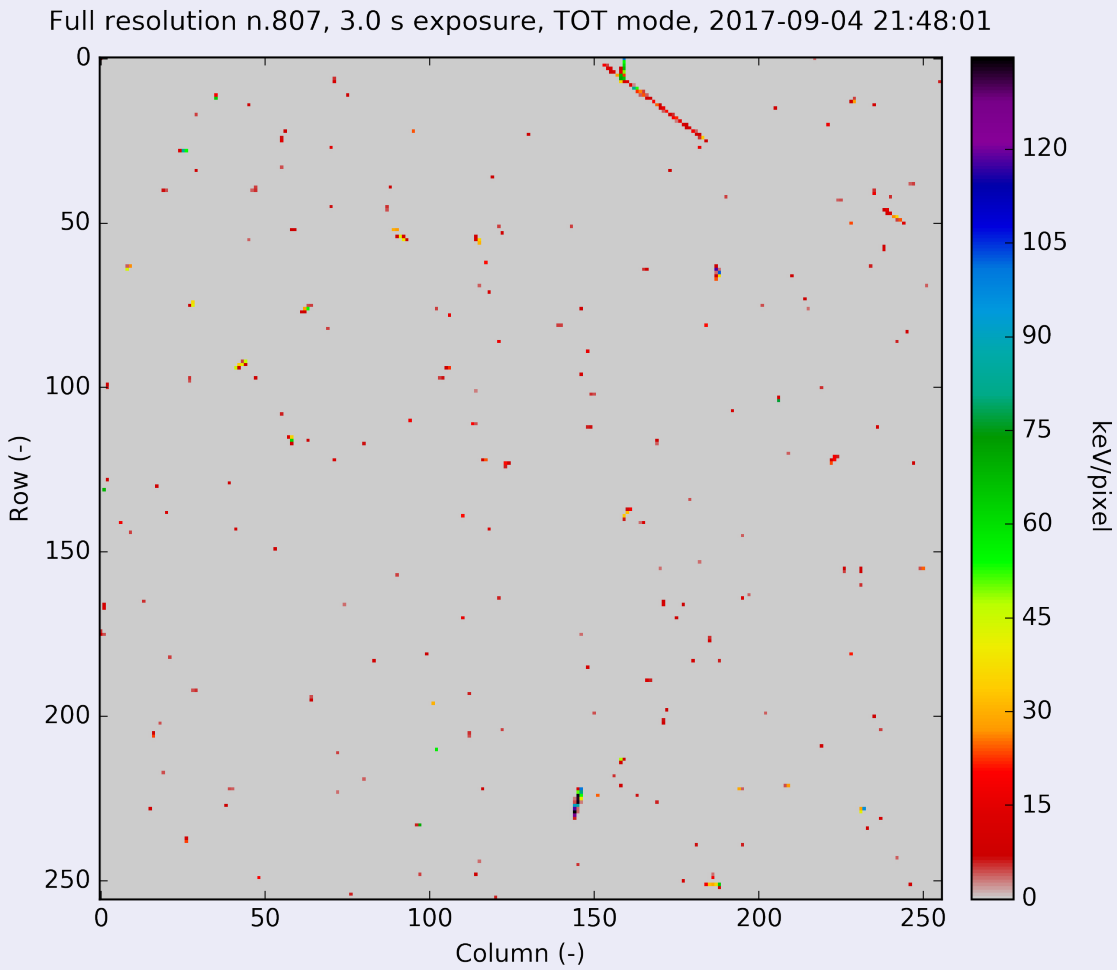

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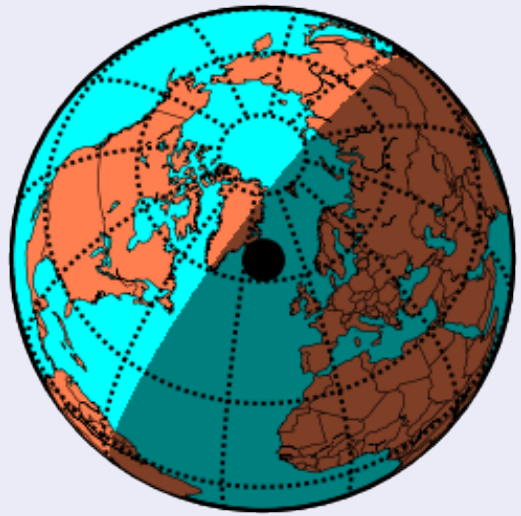
Control: UV trigger



Telescope operation summary

The X-Ray telescope payload results

- $>$ 100 frames captured with automatic UV trigger
- no evidence of direct solar X-ray observation
- images blurred by motion the satellite's motion
- ambient radiation levels are too high for photon isolation

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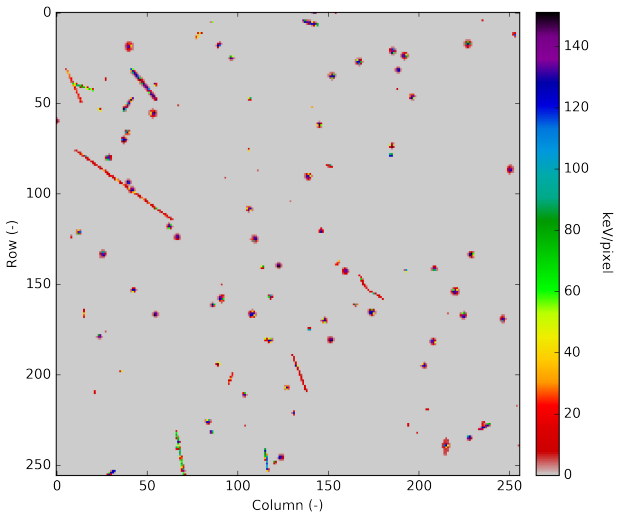
Alternative plan

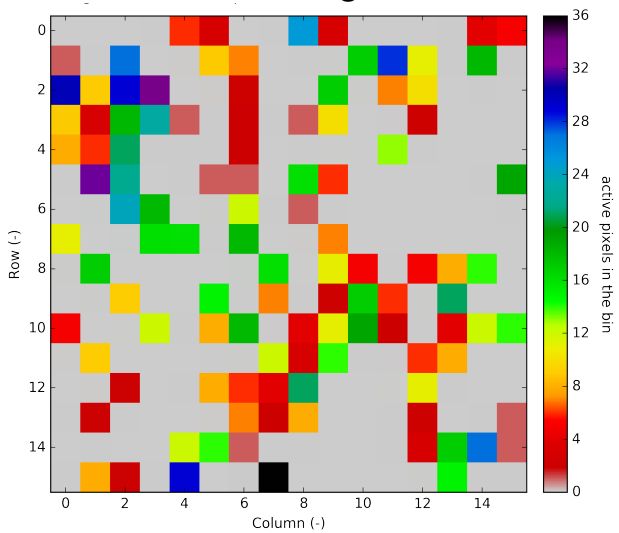
- background radiation scanning and dosimetry using the Timepix sensor

Onboard data processing – available data outputs

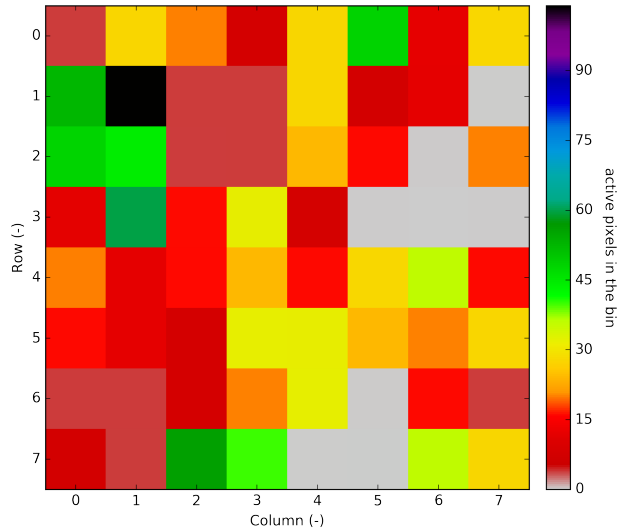
Full resolution



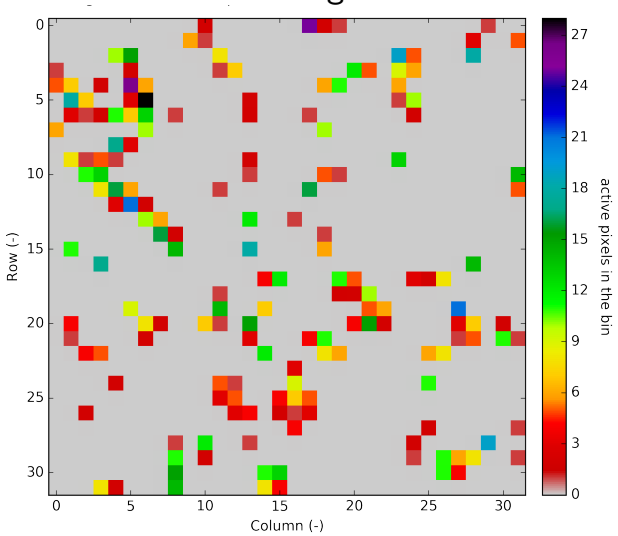
Binning 16



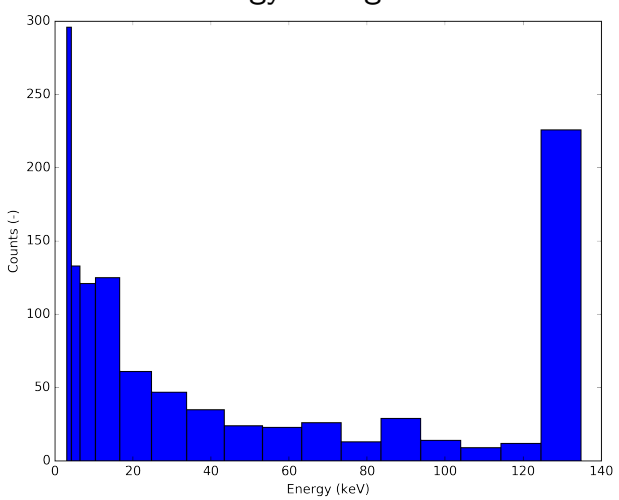
Binning 32



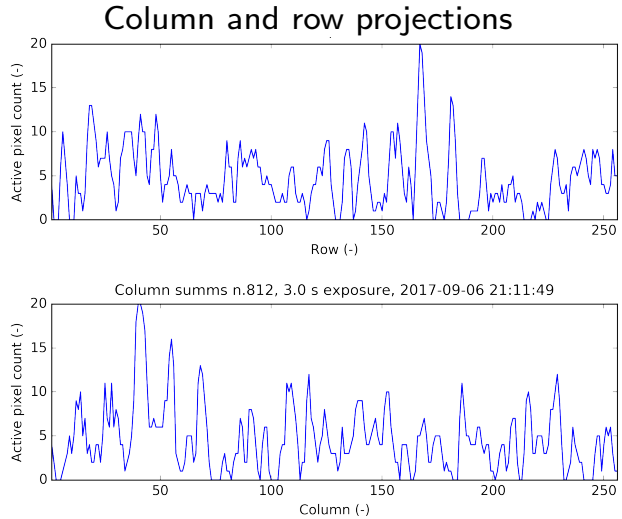
Binning 8



Energy histogram



Column and row projections



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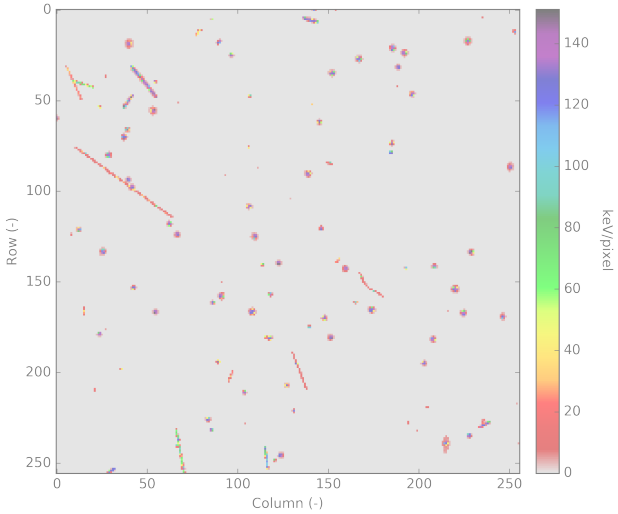

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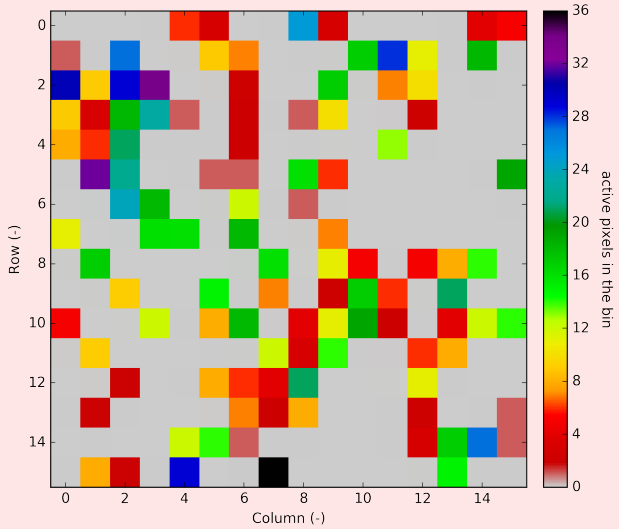

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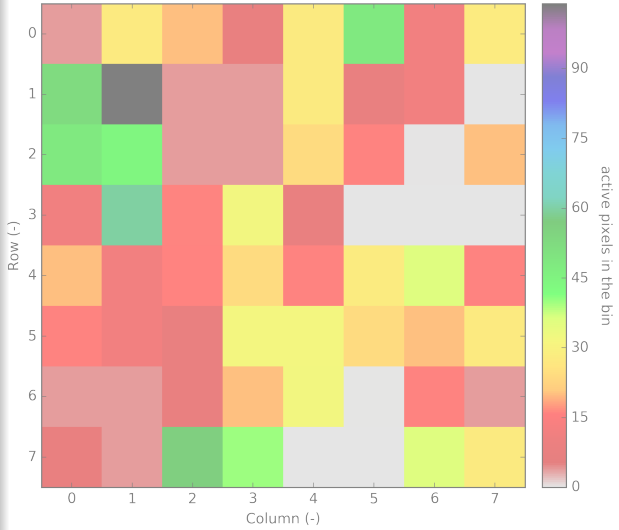

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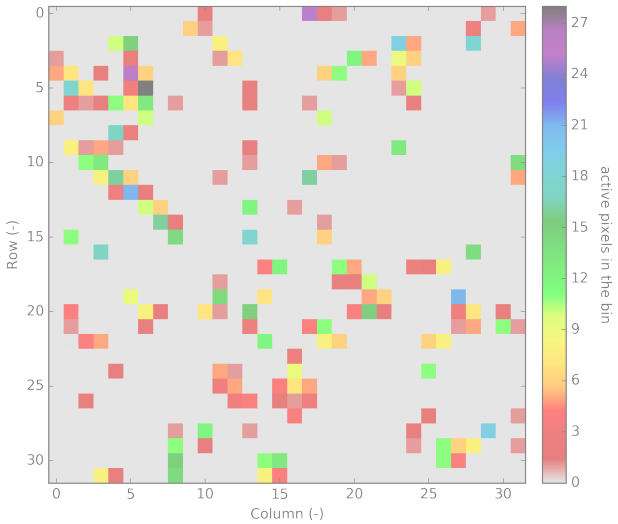

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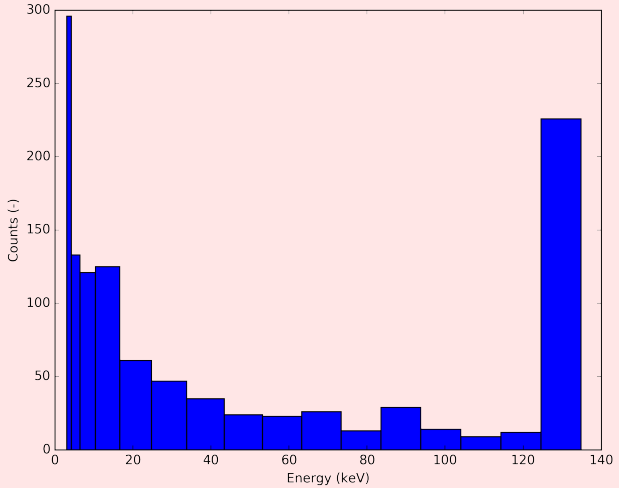

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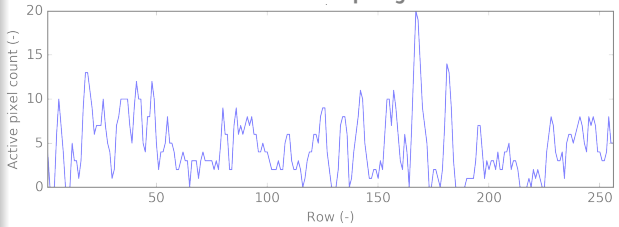
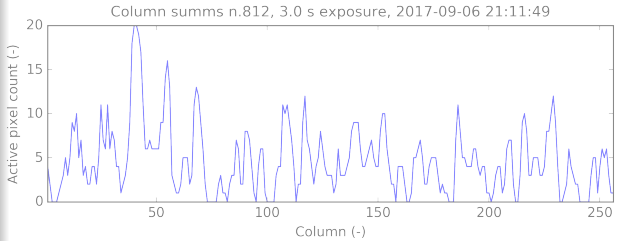
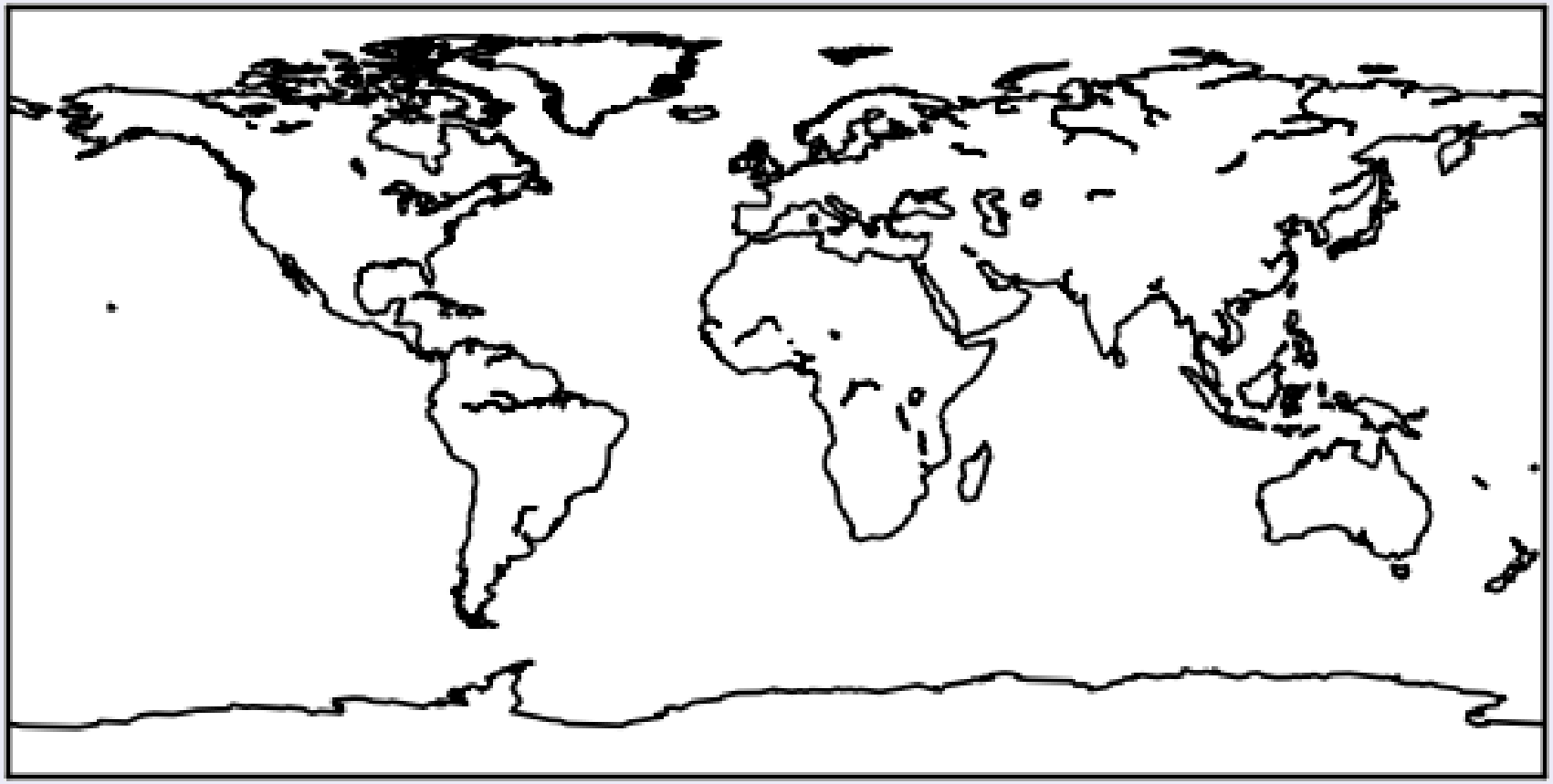




Planetary Dosimetry

Earth



Planetary Dosimetry

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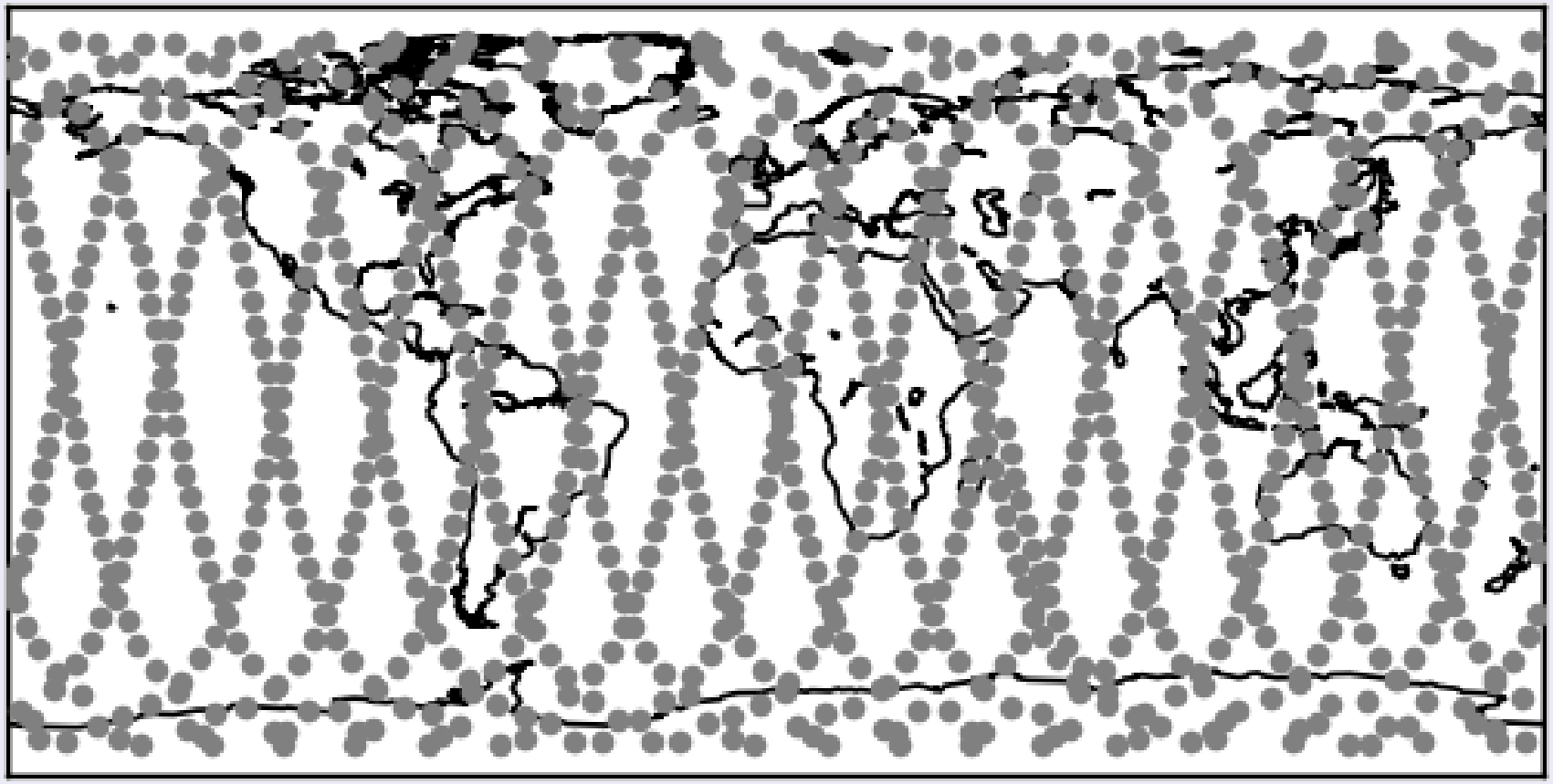

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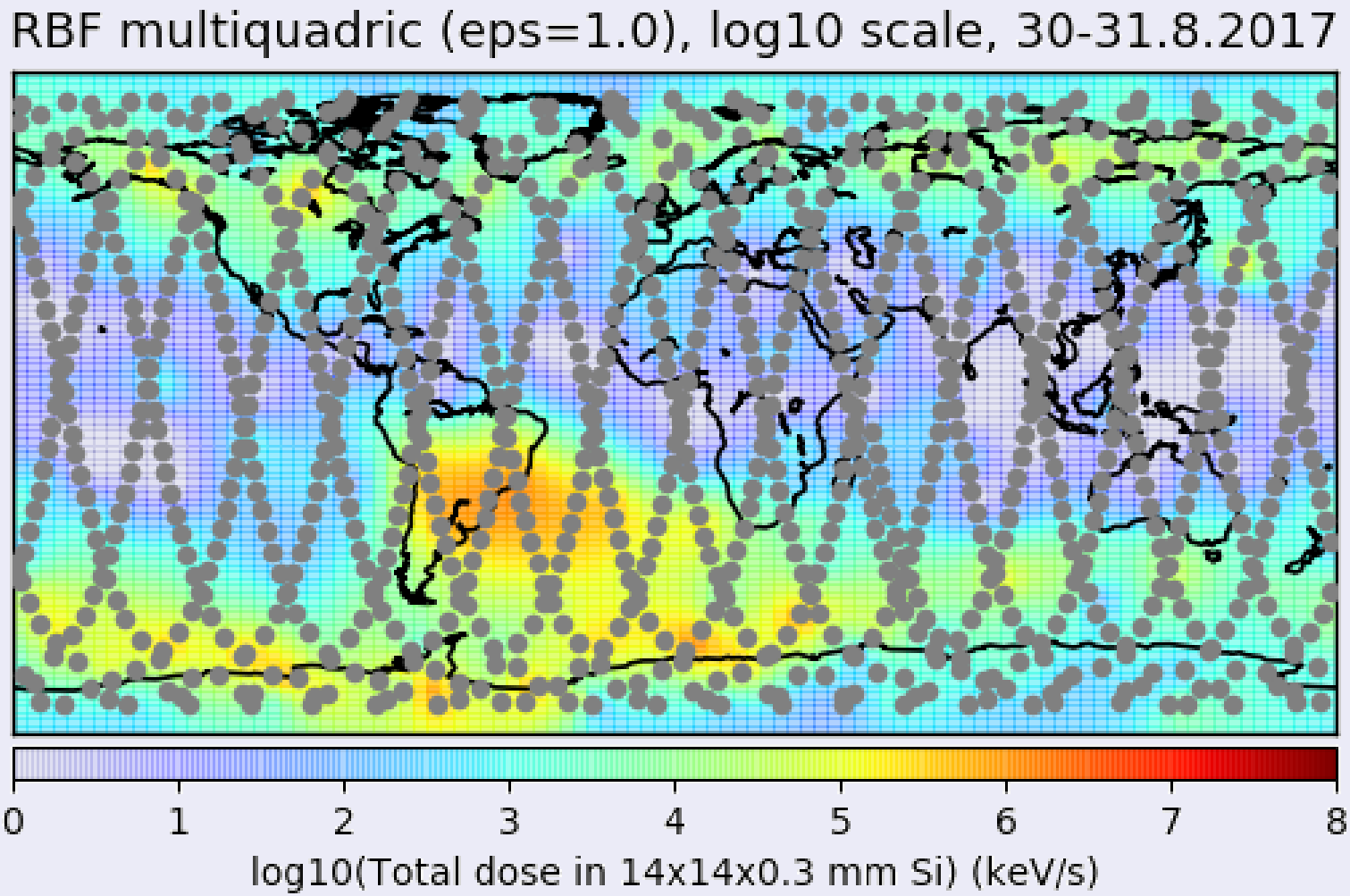
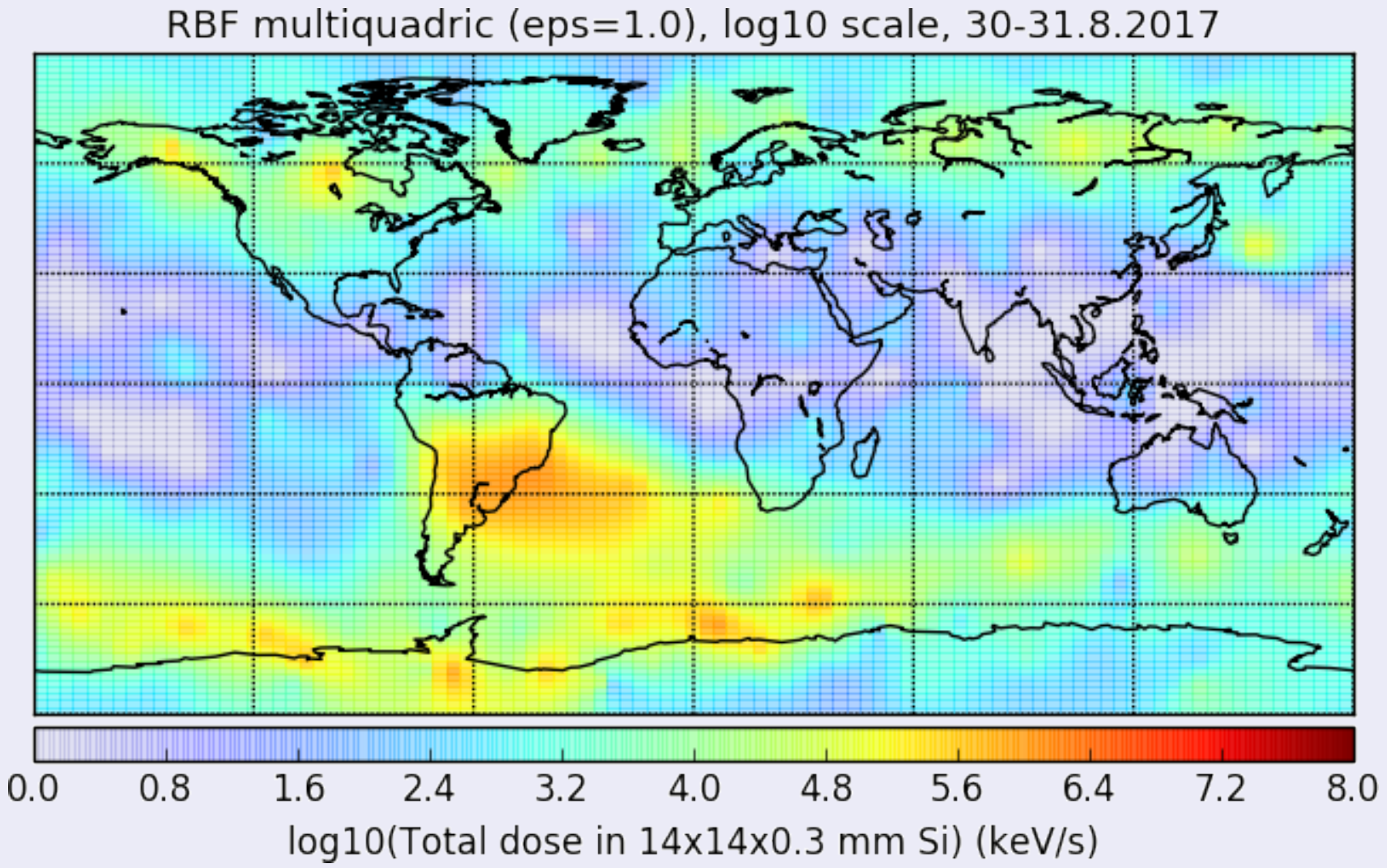
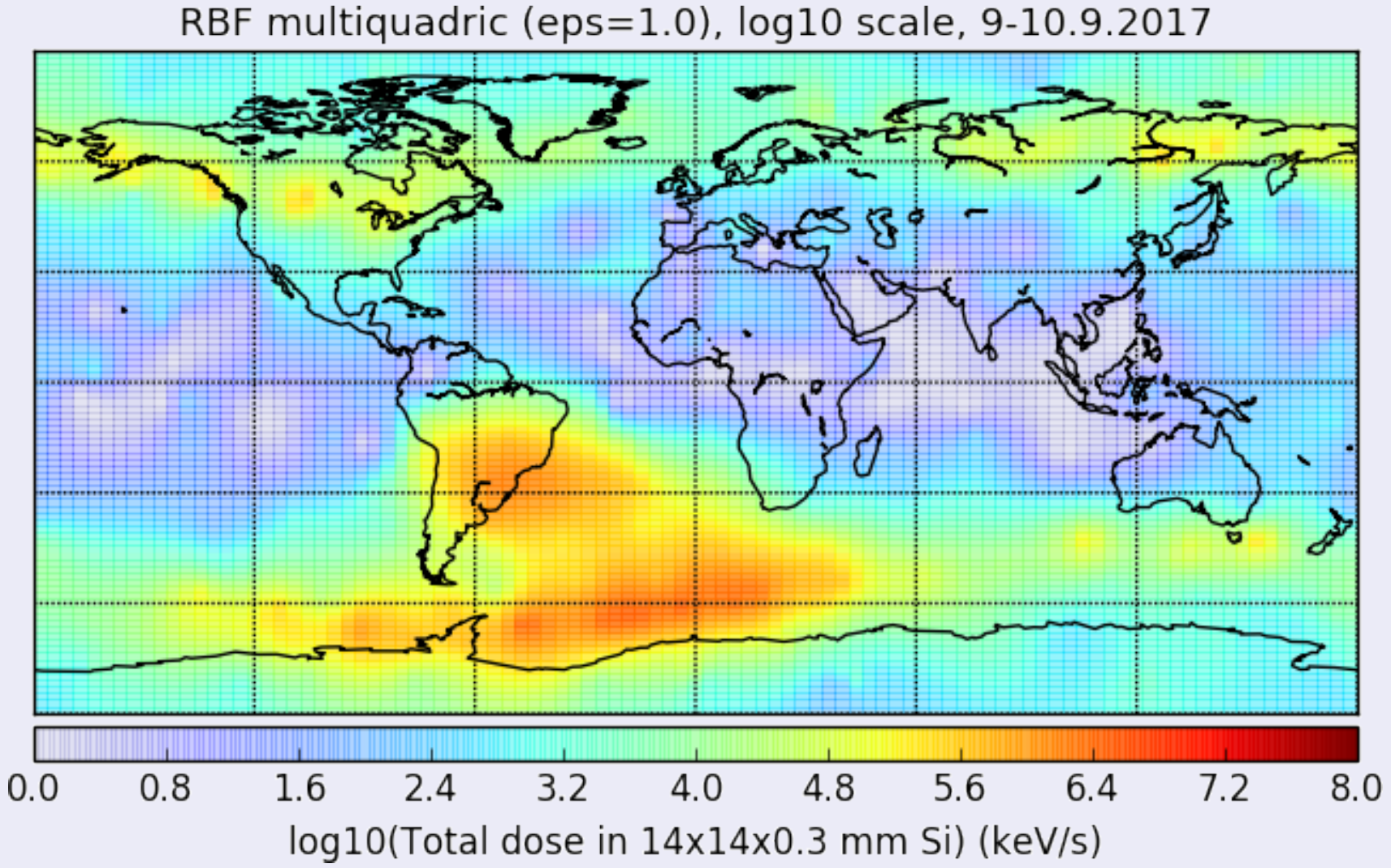


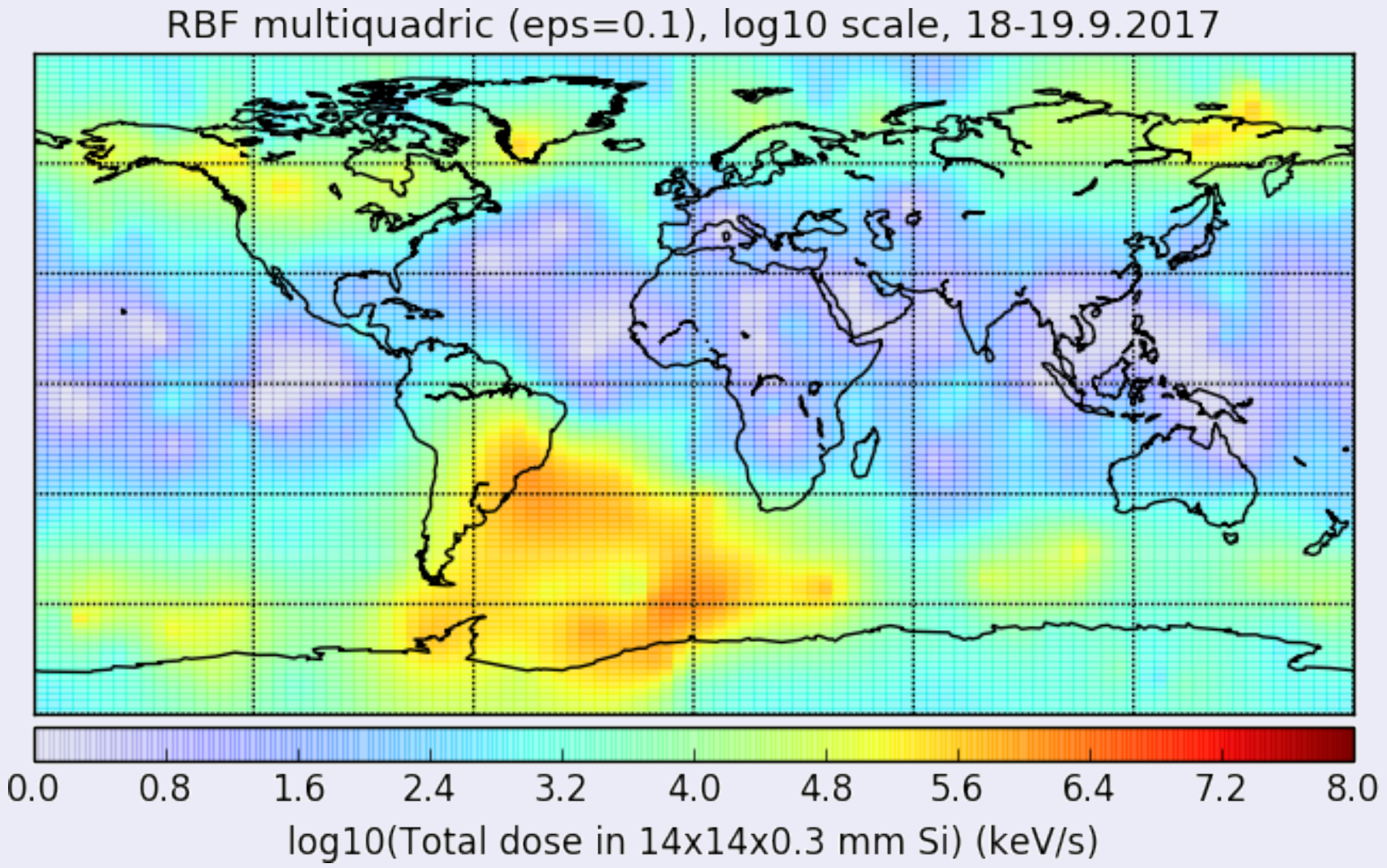
Earth dosimetry (1/5)



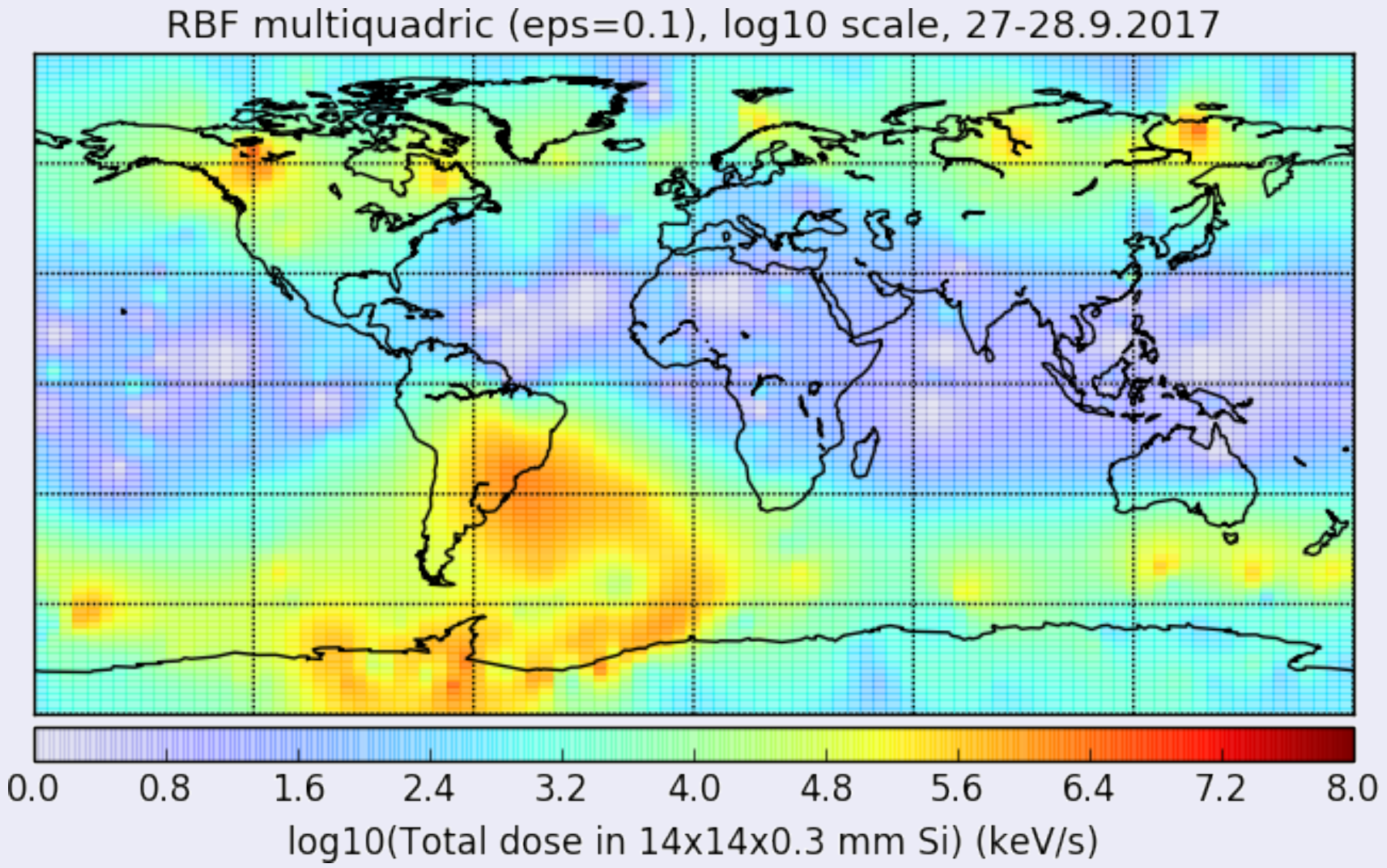
Earth dosimetry (2/5)



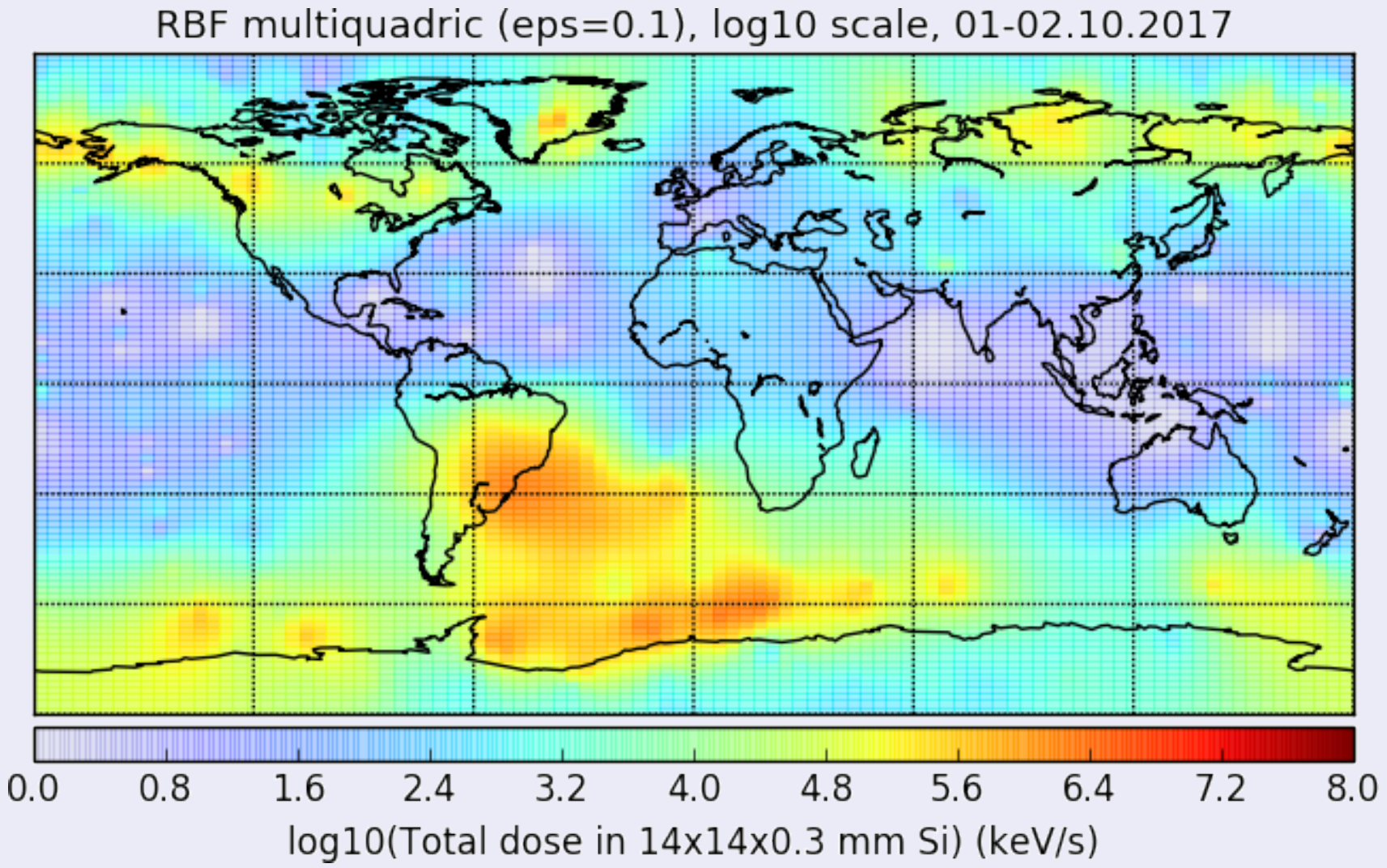
Earth dosimetry (3/5)



Earth dosimetry (4/5)

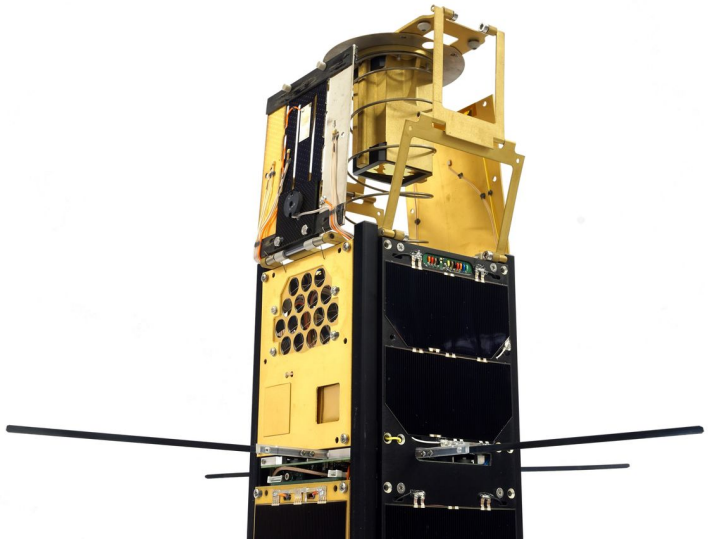


Earth dosimetry (5/5)

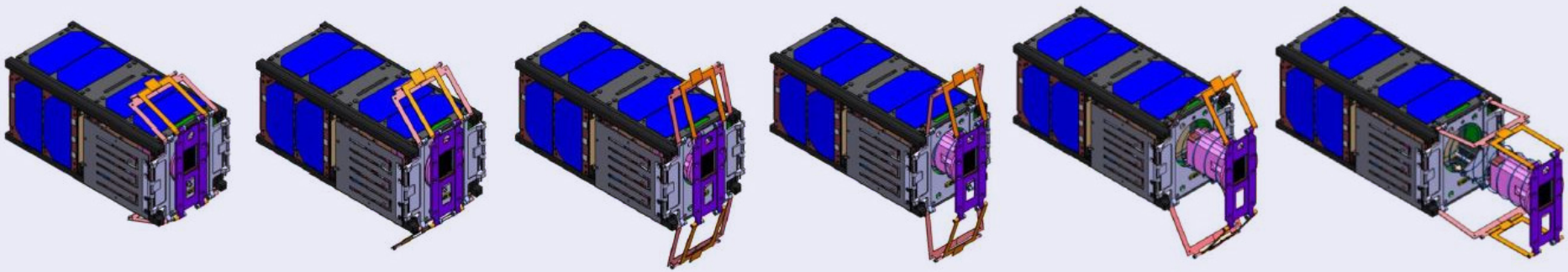


Deploying X-ray optics

Optic deployed on October 4th, 2017

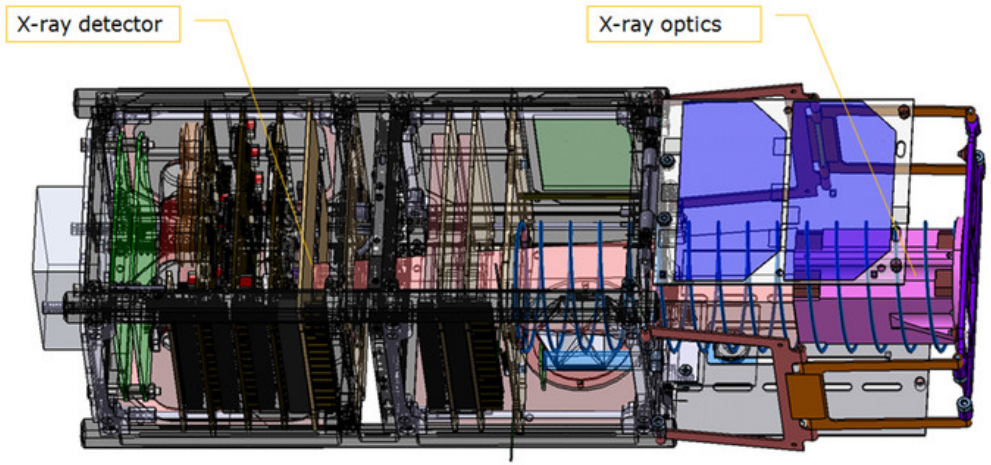


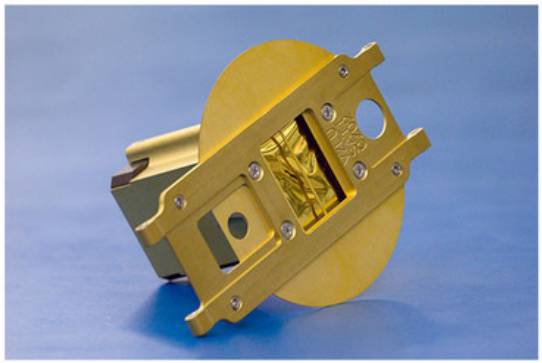
Optics deployment animation

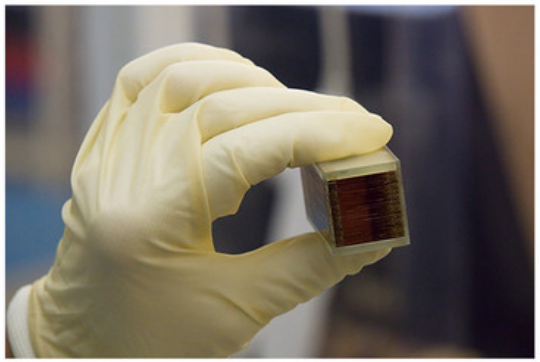


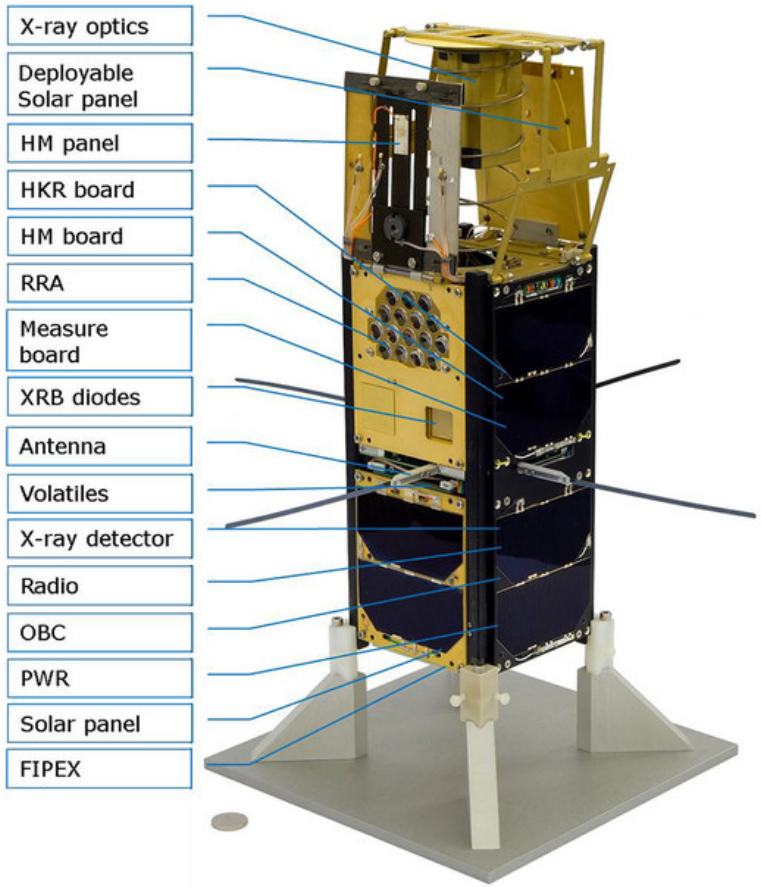
Deploying X-Ray optics

The telescope is missing a buffle $\Longrightarrow$ Timepix is exposed to space









Direct exposure to the Sun

Visible light exciting the Timepix sensor

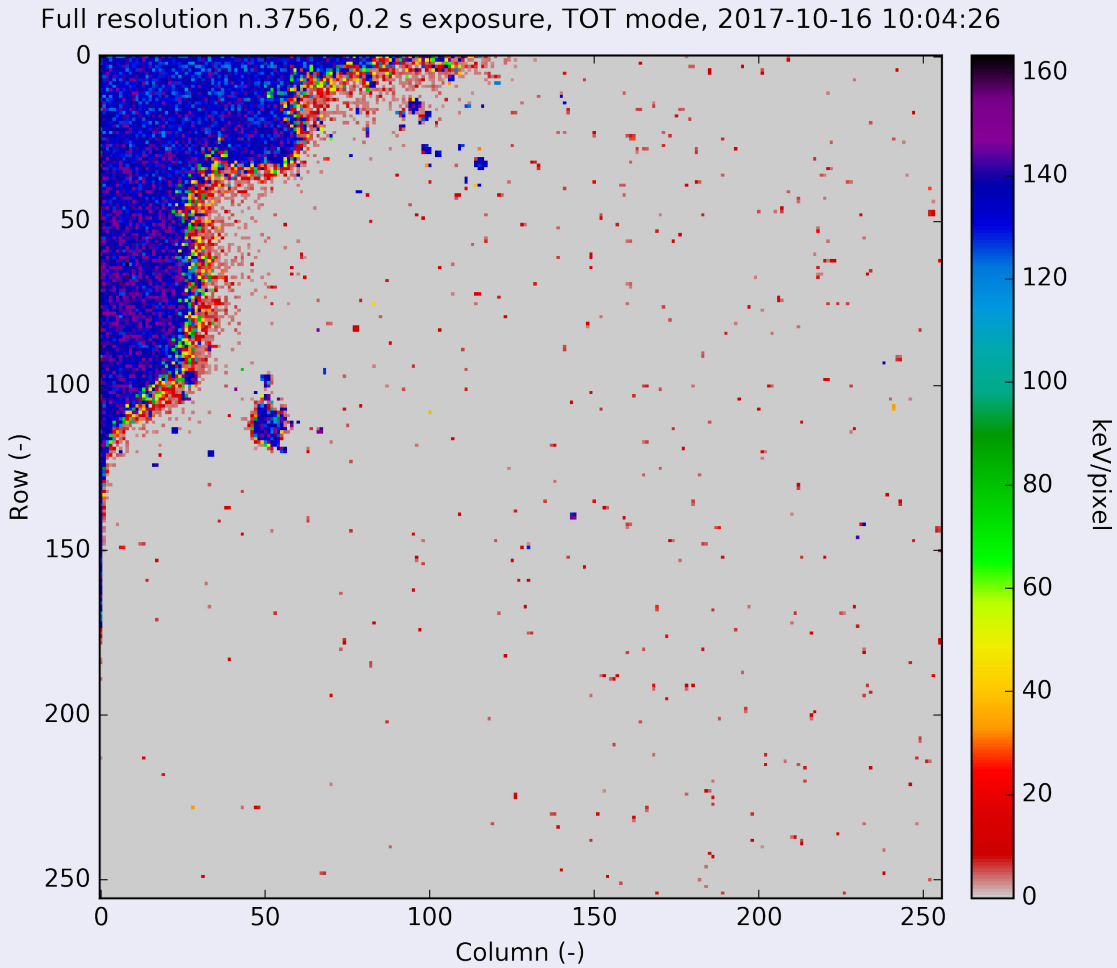
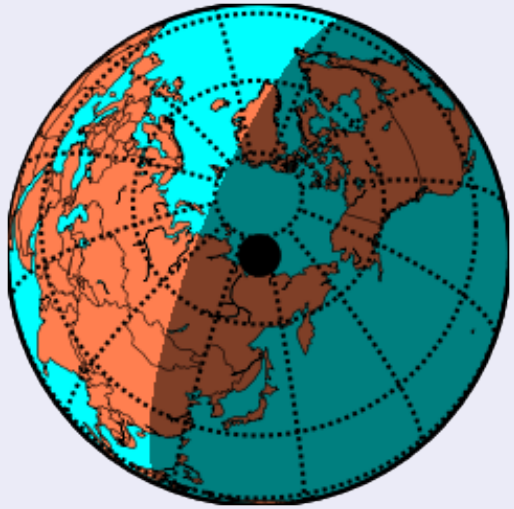


Image ID: 3756
Acquisition: 0.1 s
Control: UV trigger



Direct exposure to the Sun

Visible light exciting the Timepix sensor

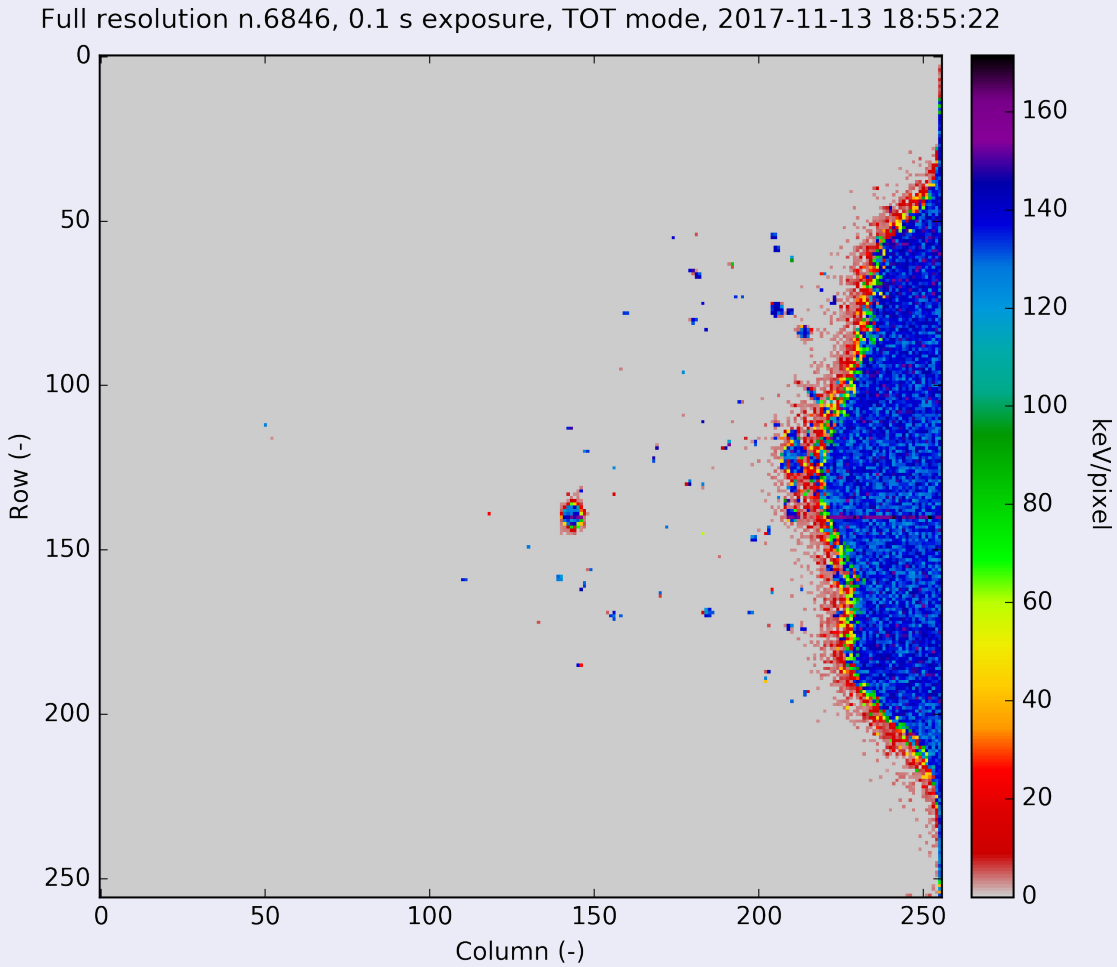


Image ID: 6846
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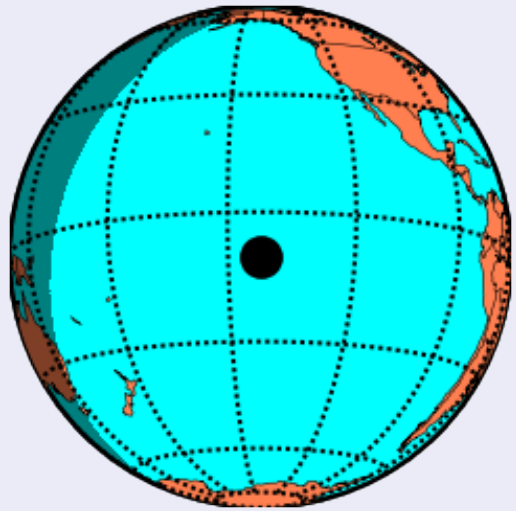


Direct exposure to the Sun

Visible light exciting the Timepix sensor

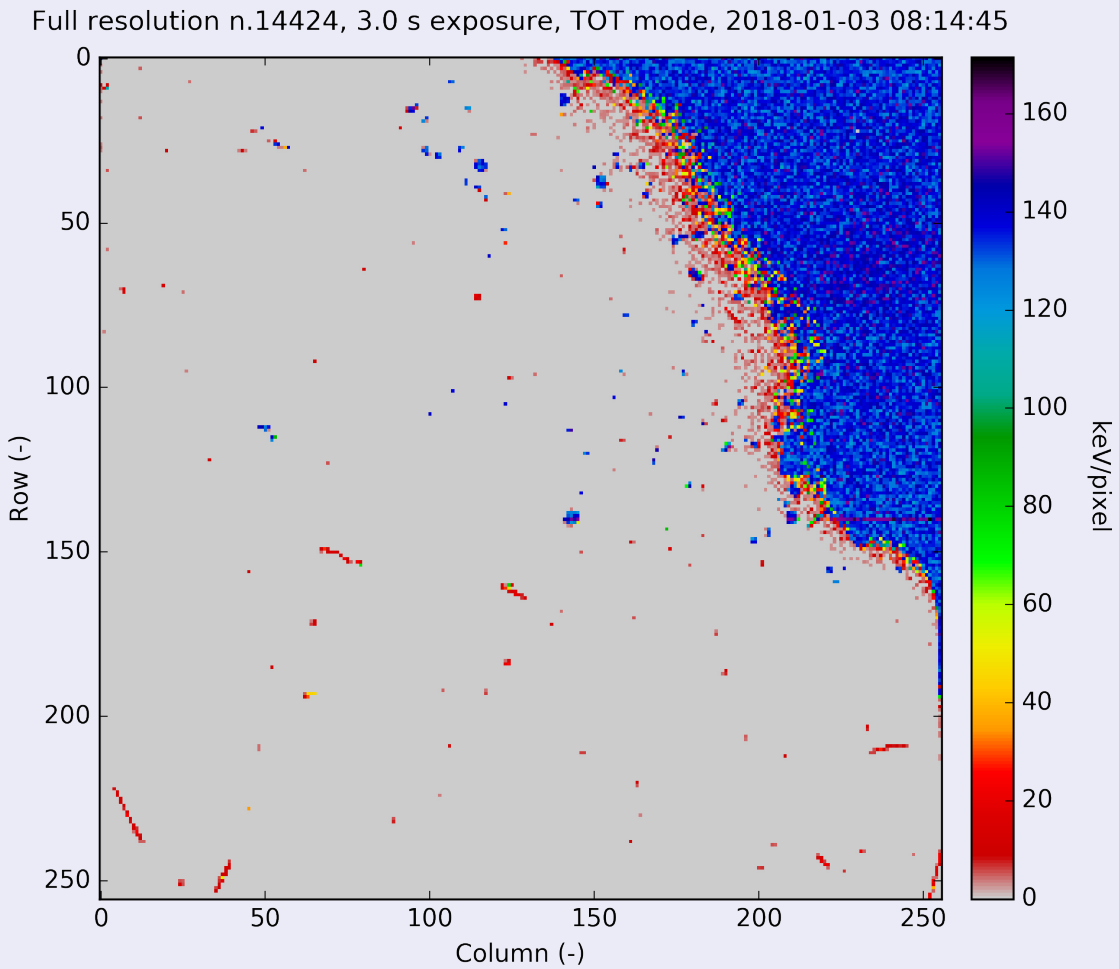
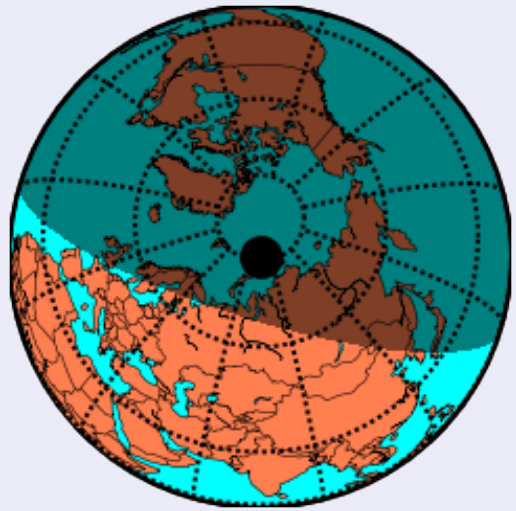
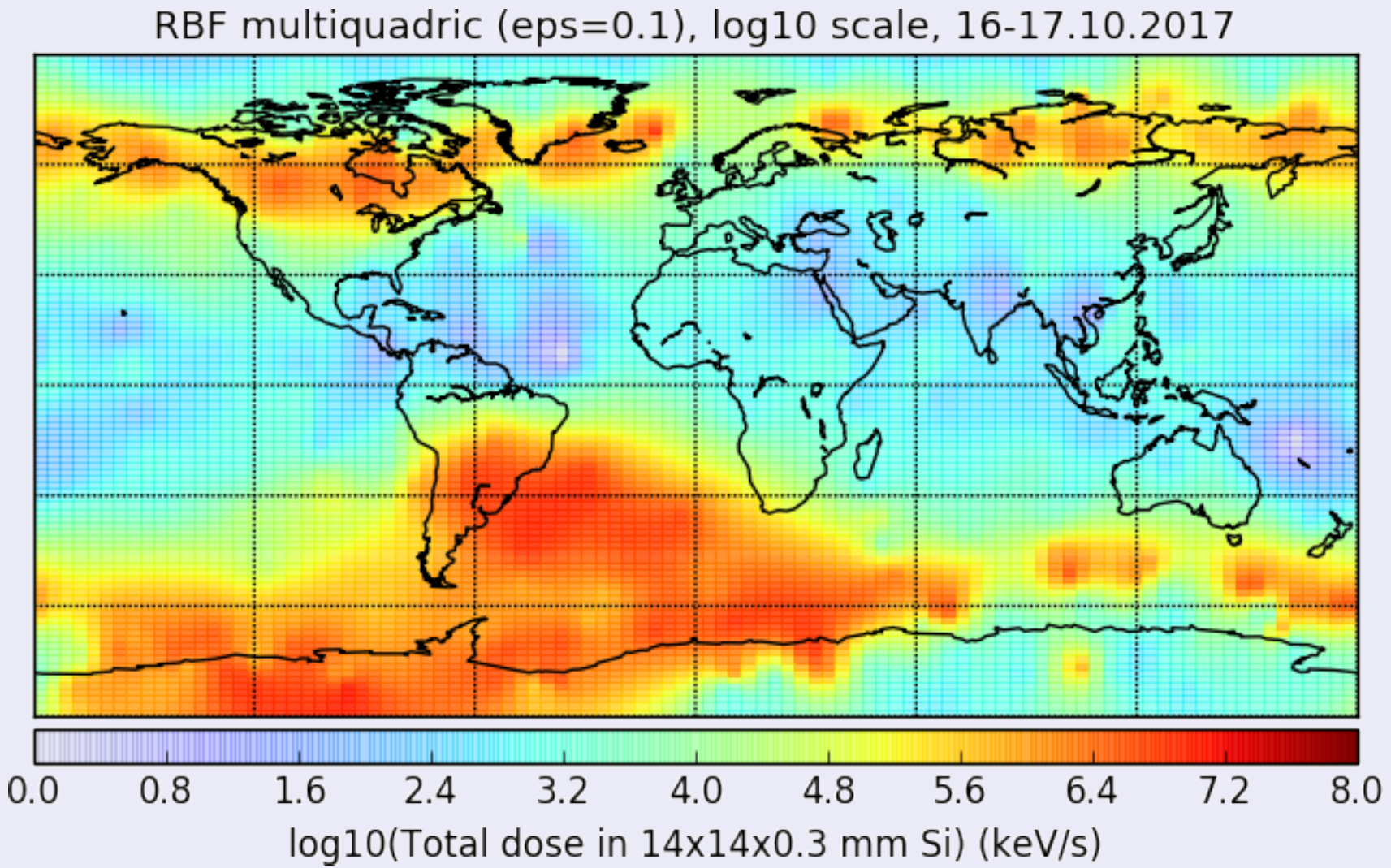


Image ID: 14424
Acquisition: 3.0 s
Control: UV trigger



Planetary dosimetry after deploying the optics

9th Earth dosimetry

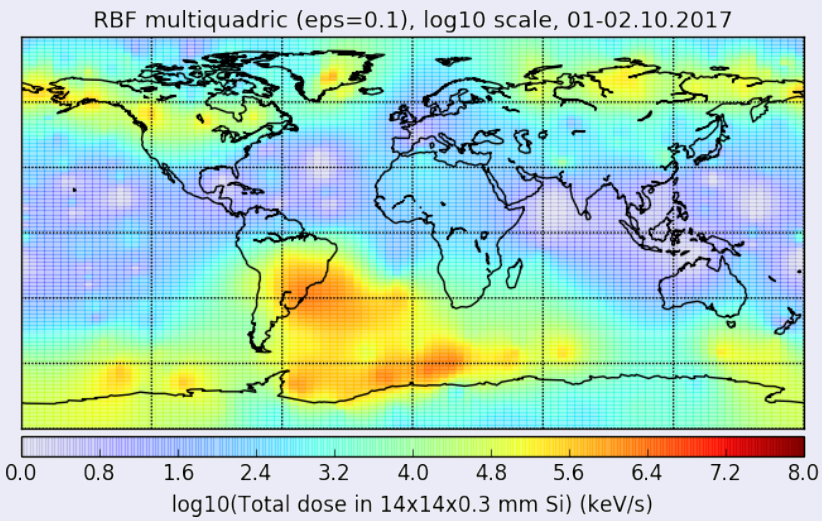


Planetary dosimetry after deploying the optics

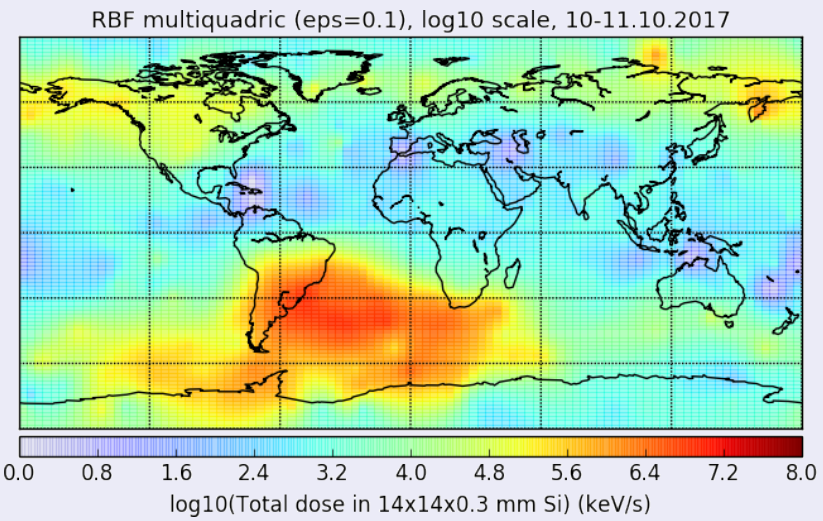
Additional ambient radiation

- measured dose increased by 2 orders of magnitude
- invariant on satellite location above the Earth
- mostly low-energy electron radiation; $\approx$ 100 keV

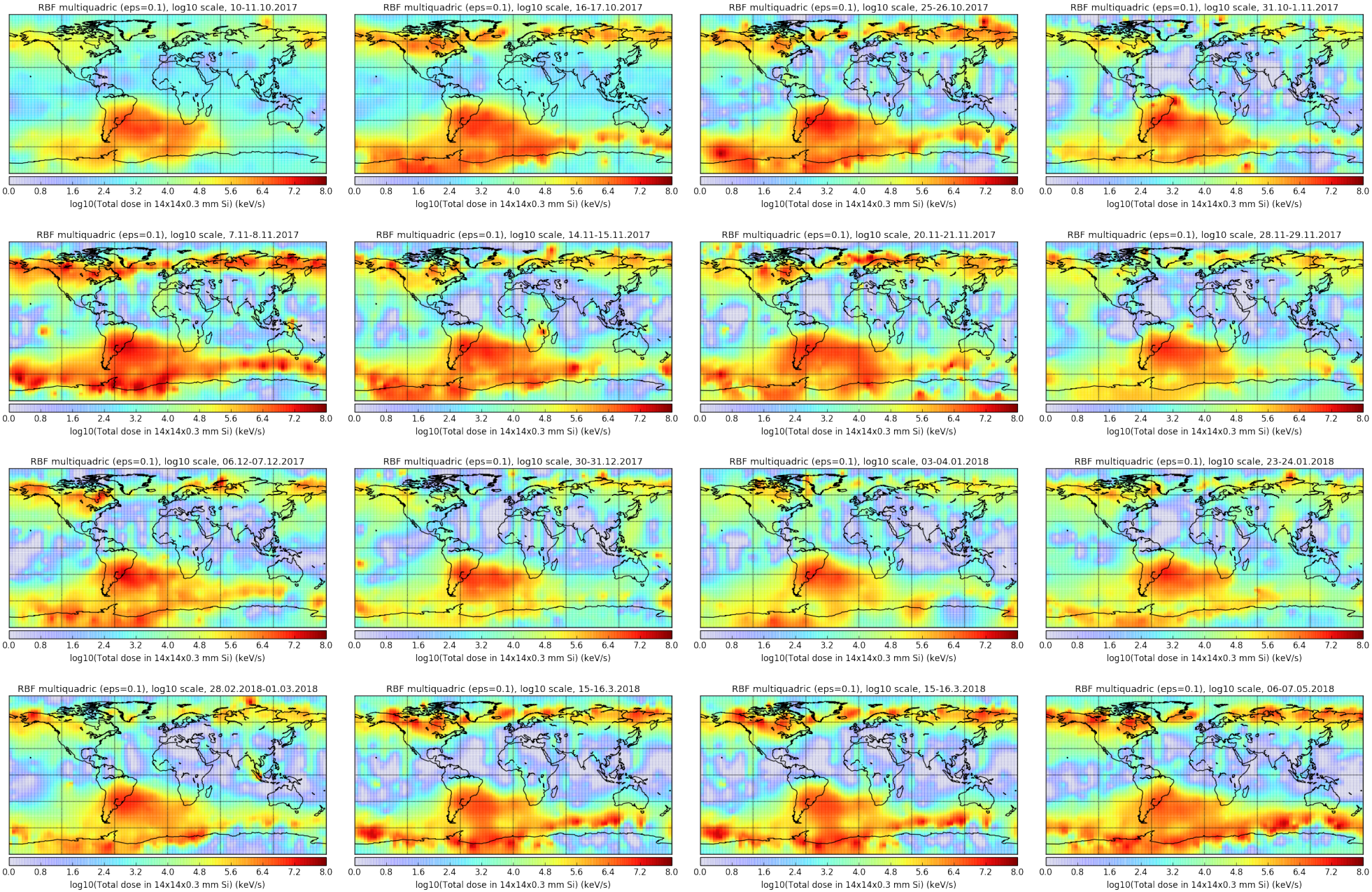
7th Earth dosimetry



8th Earth dosimetry

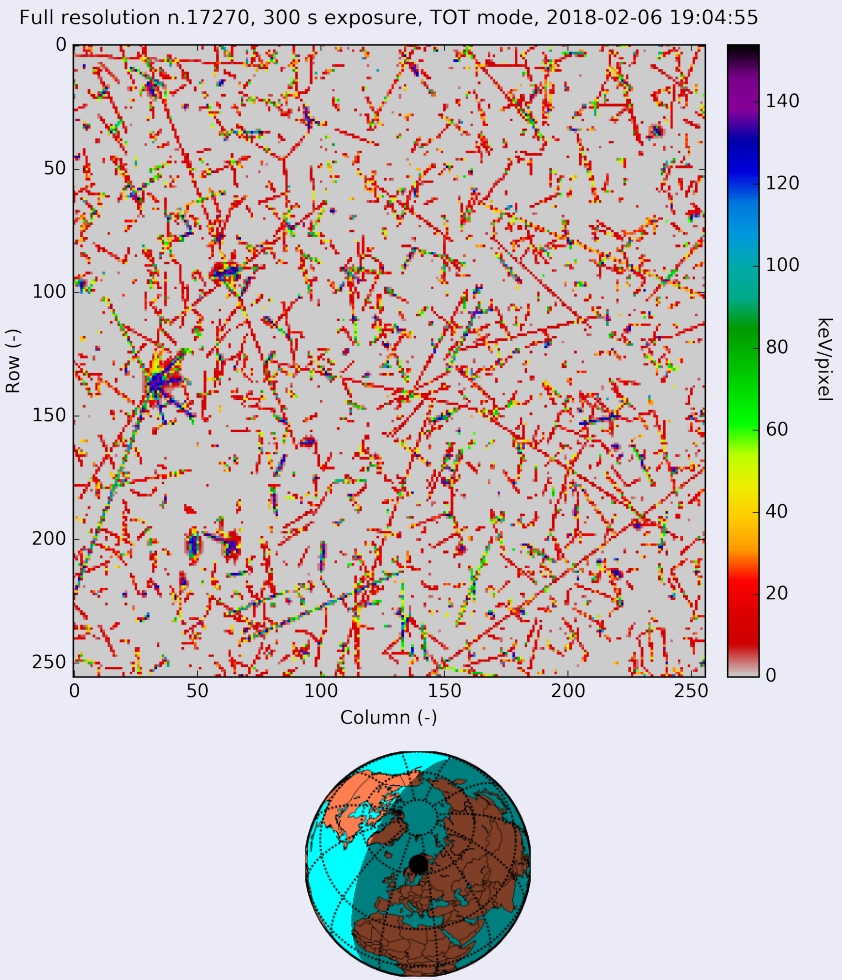


Dosimetry maps after the optics deployment

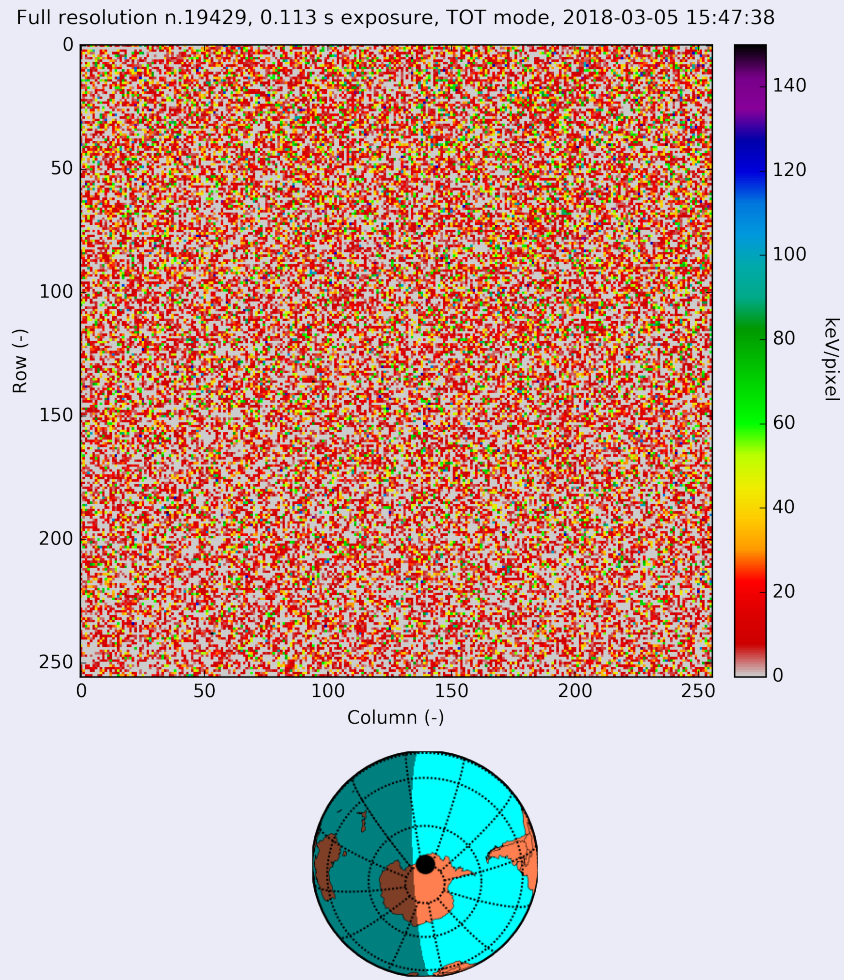


Comparison of radiation intensities in LEO

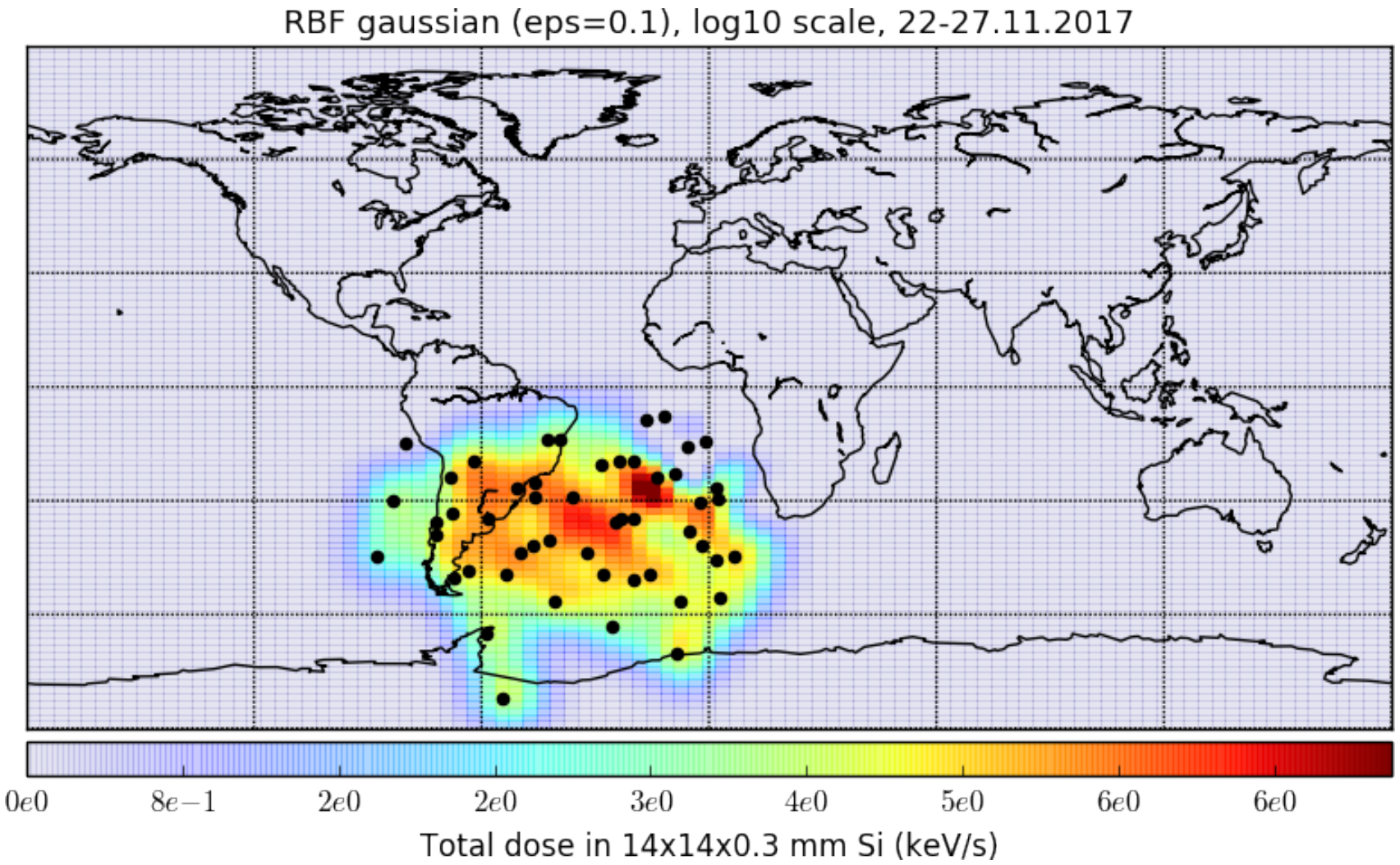
300 s acquisition



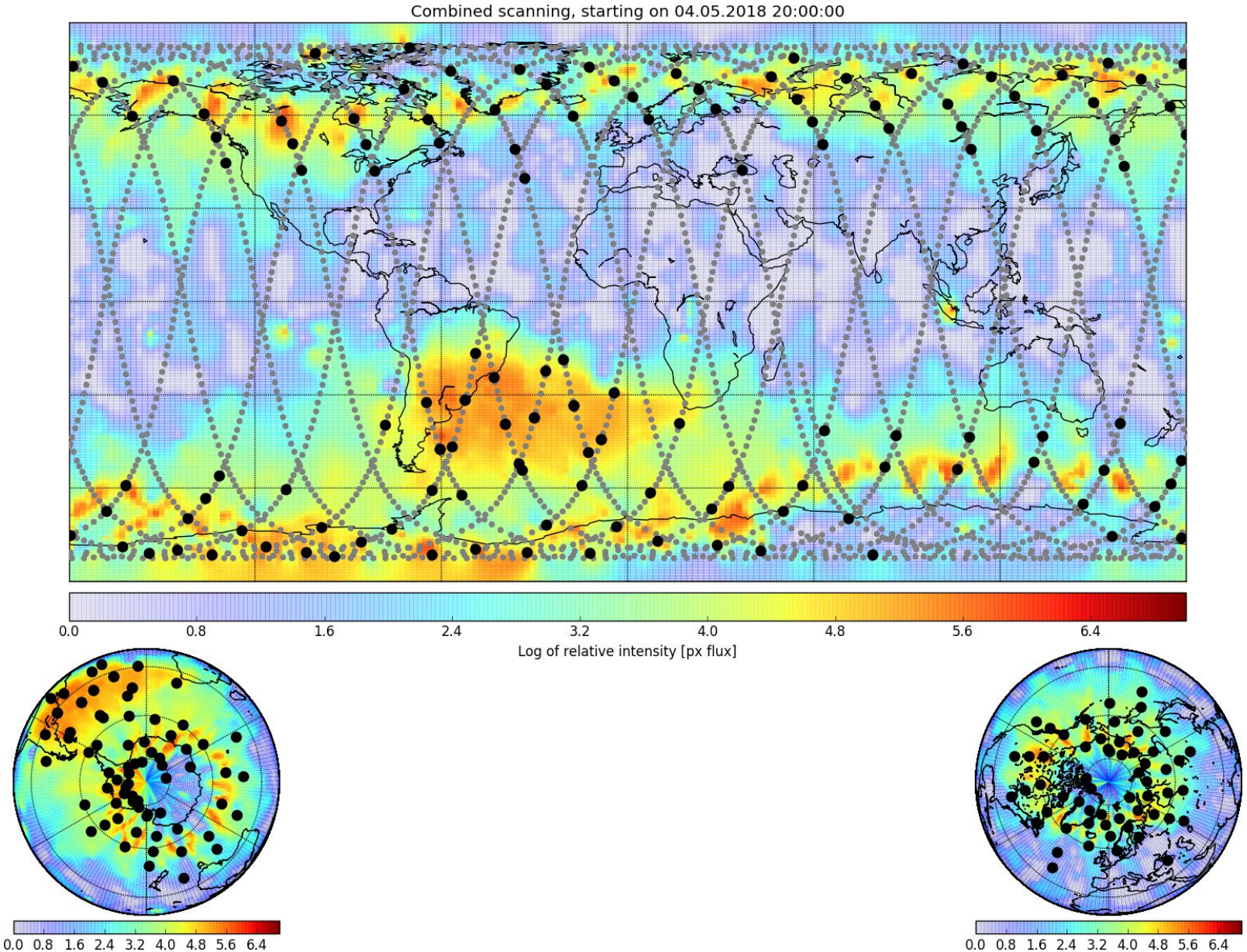
0.1 s acquisition



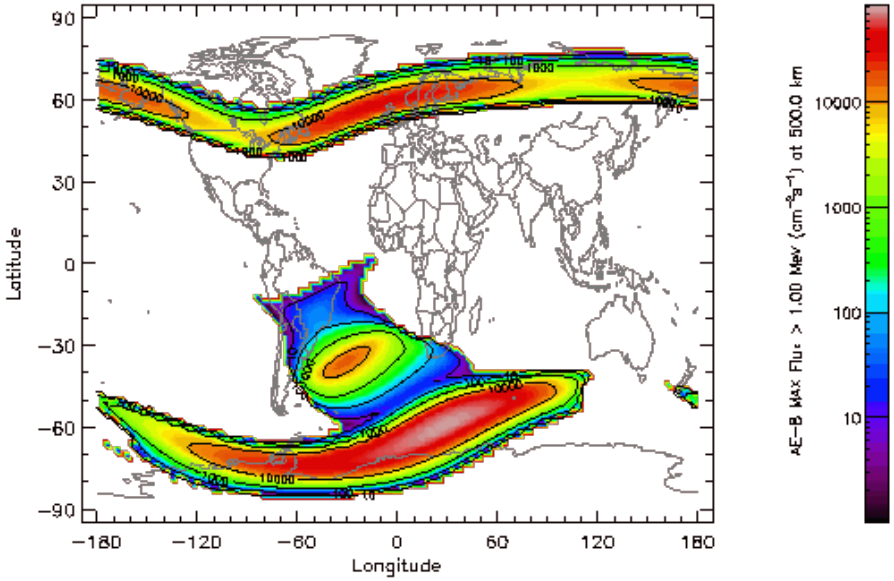
South-Atlantic Anomaly Scanning



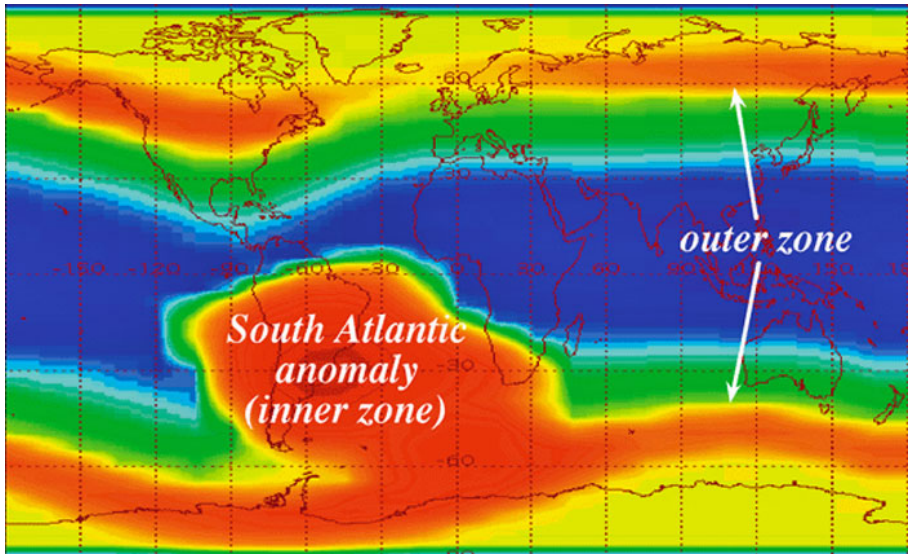
Combined scanning: SAA + Polar belts



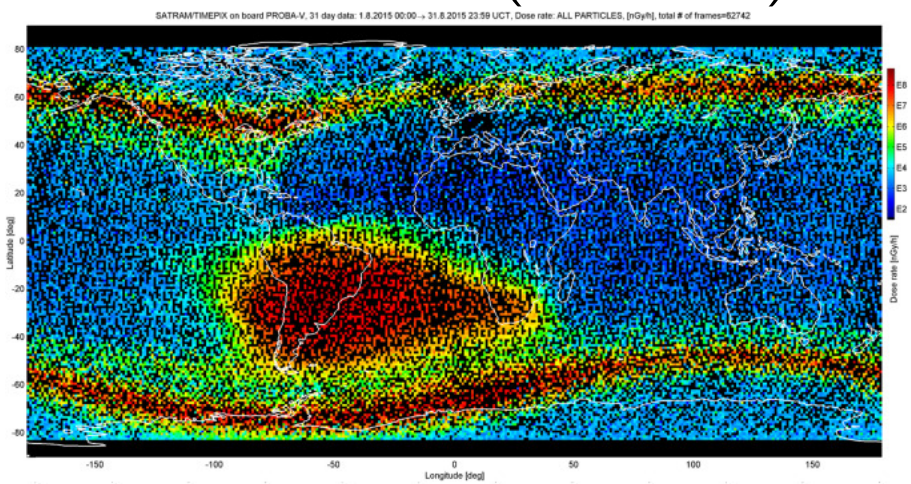
Comparing with state-of-the art



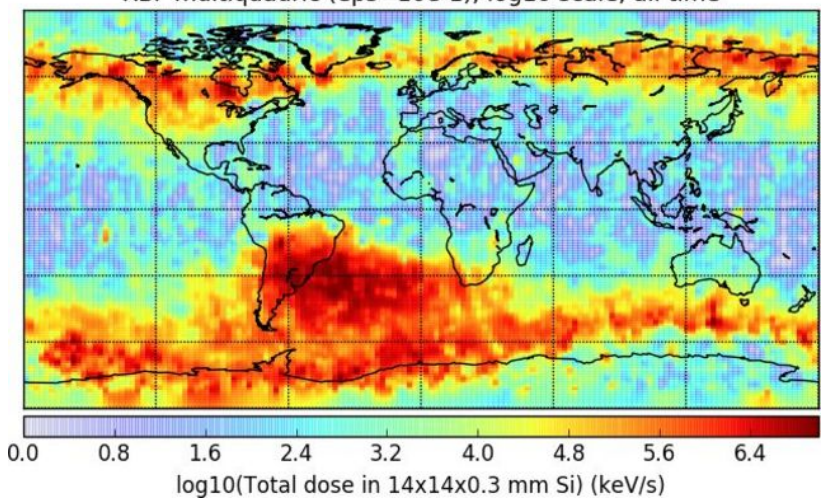
source: NASA (SPENVIS)



source: NASA (SAMPEX)

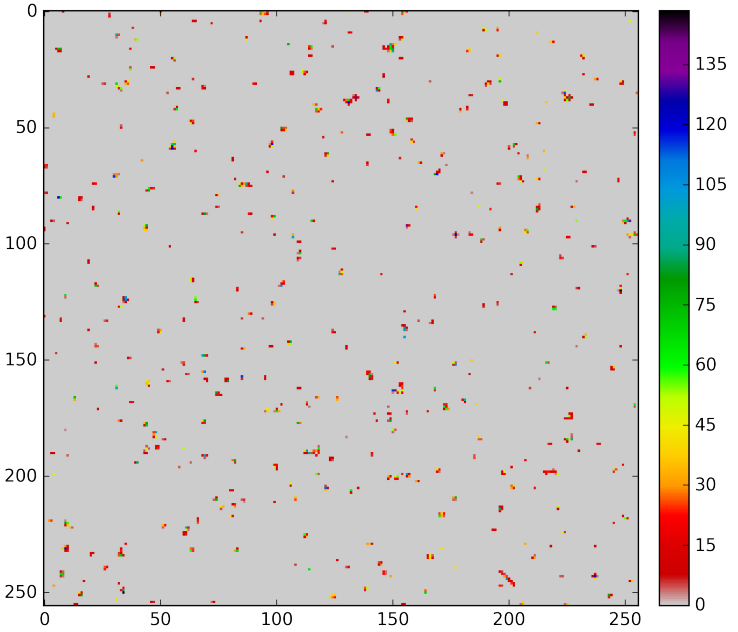


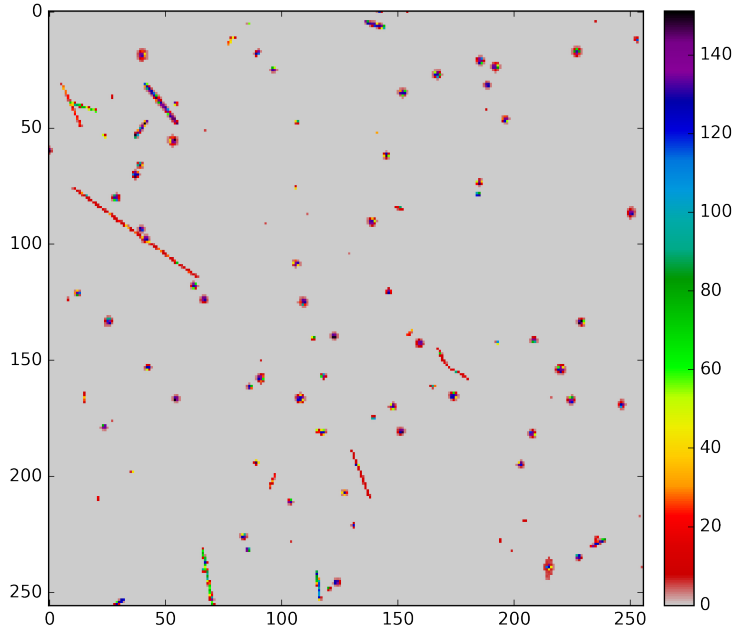
source: ESA (SATRAM)

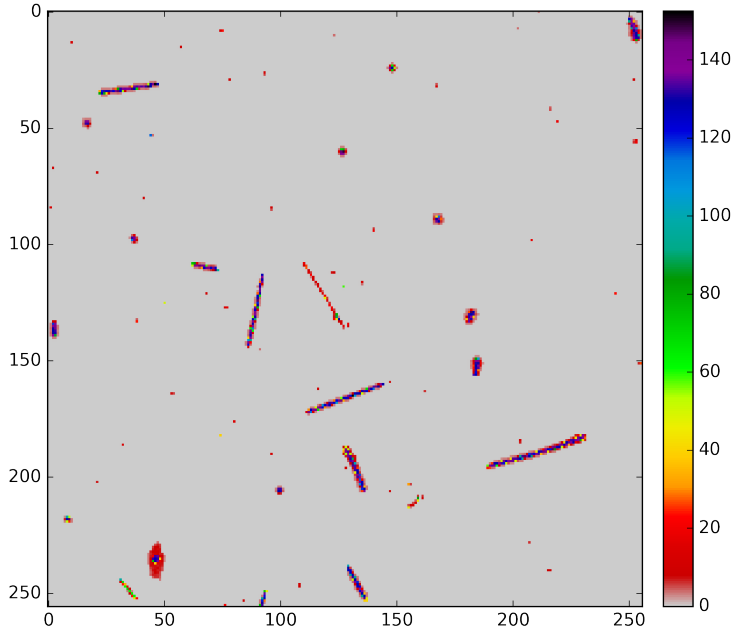


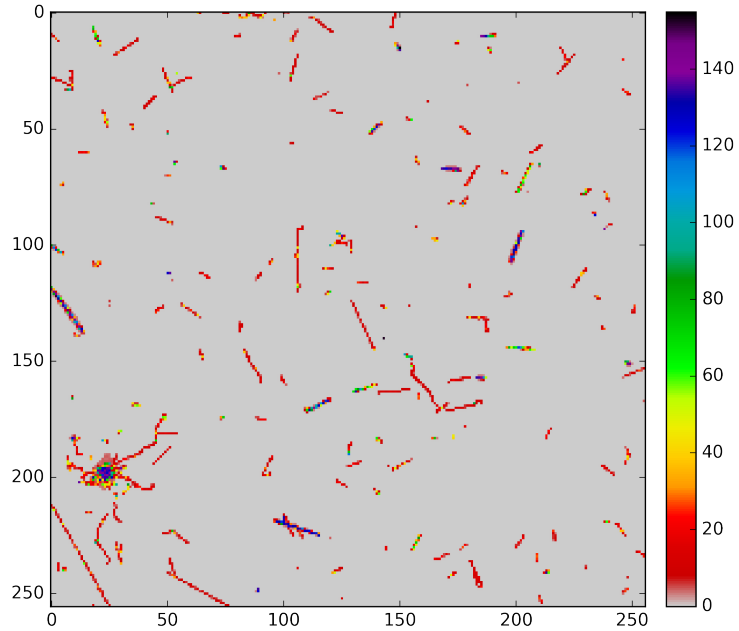
source: VZLUSAT-1

Variations in the track types









Track type density maps - full resolution ($\approx$ 1000 images), [Baca et al. 2018]

Figure: X-Ray/High-energy electrons

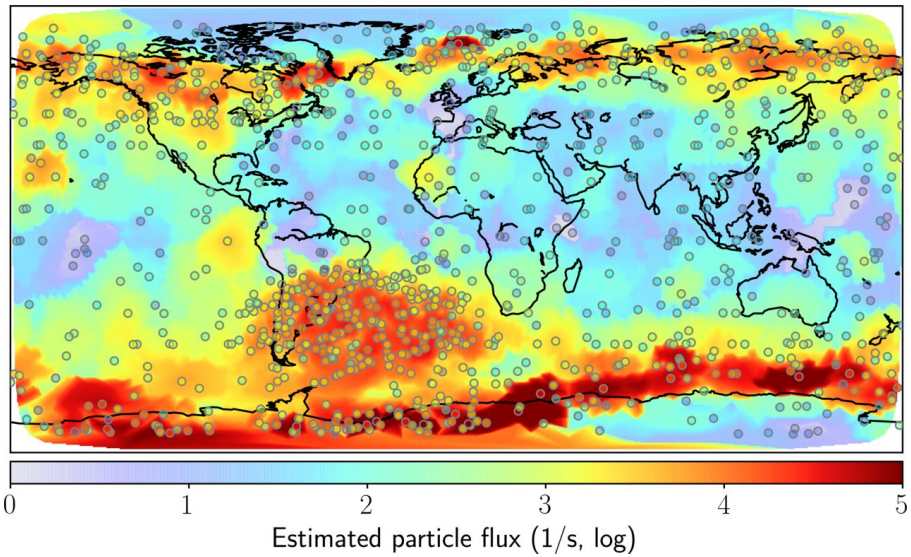


Figure: Ions

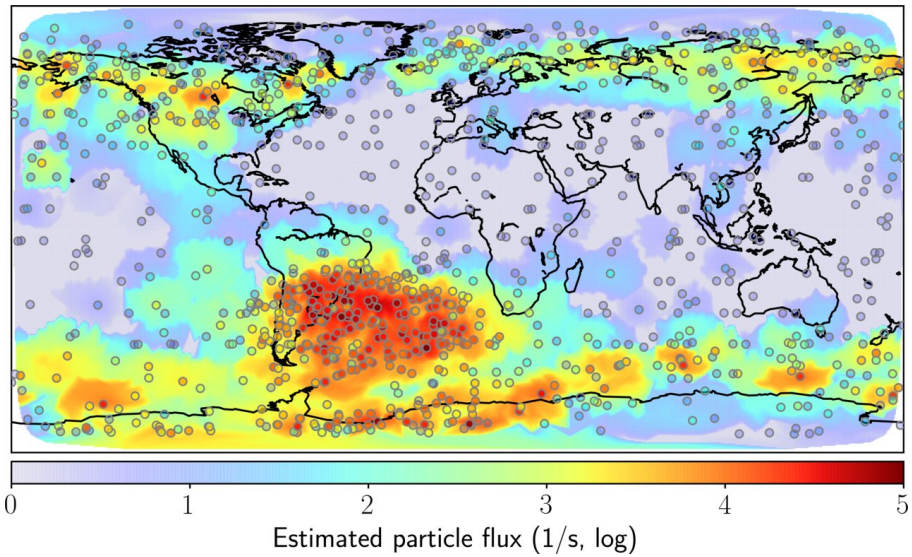


Figure: Muons

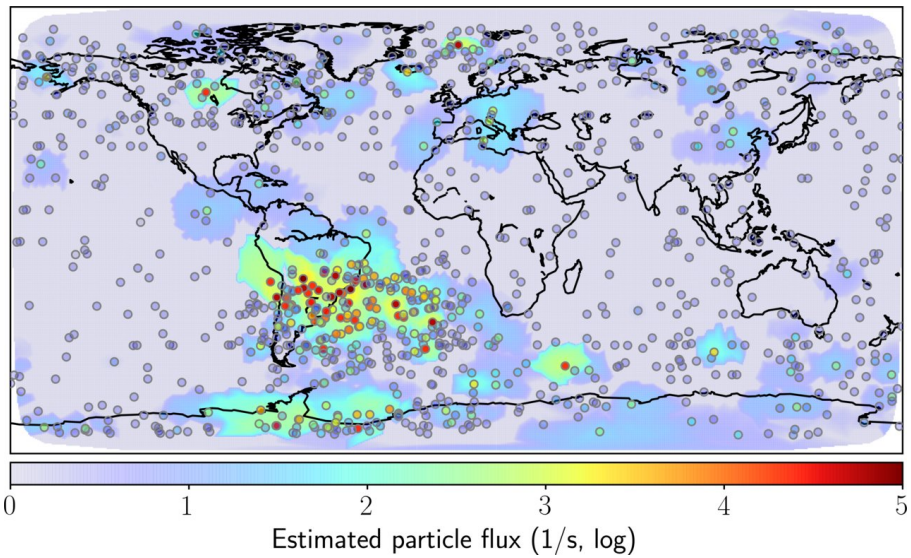
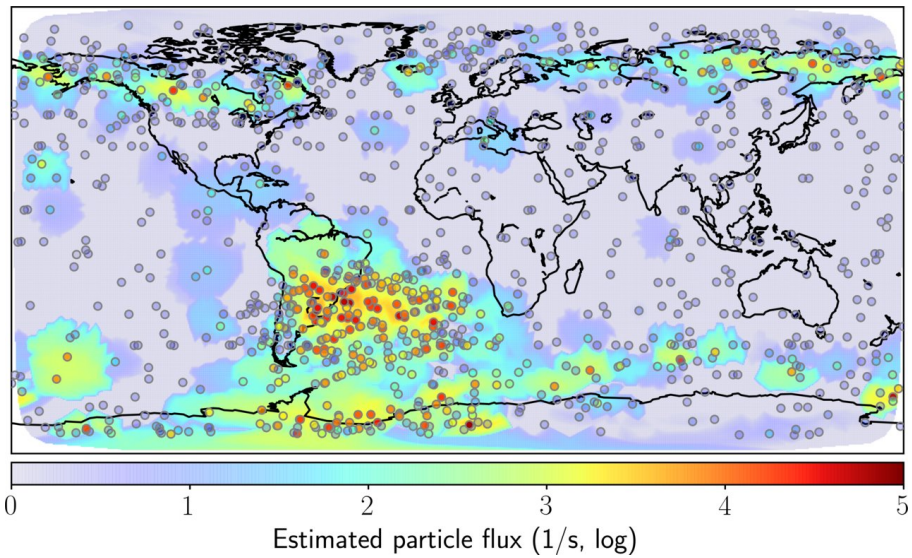


Figure: Electrons



Post-processed reconstruction ($\approx$ 20 000 images), [Baca et al. 2018]

Figure: X-Ray/High-energy electrons

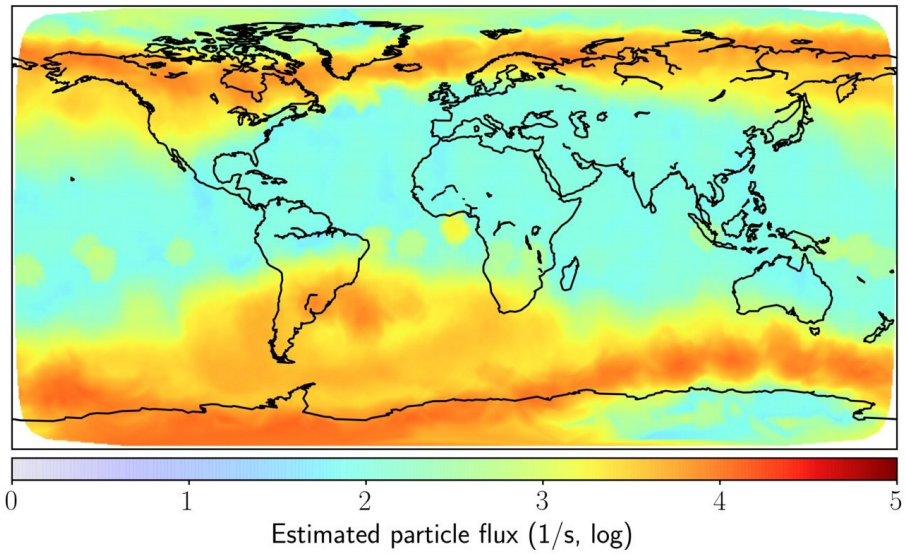


Figure: Ions

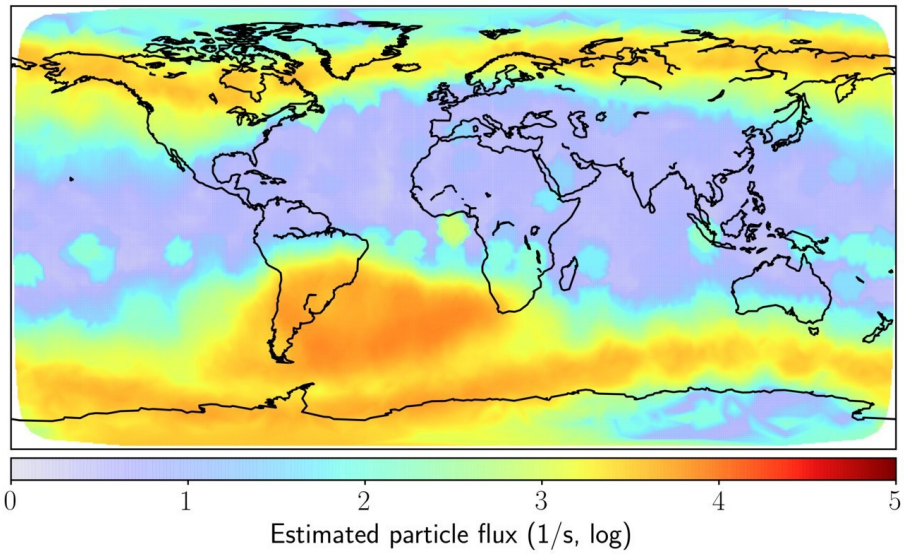


Figure: Muons

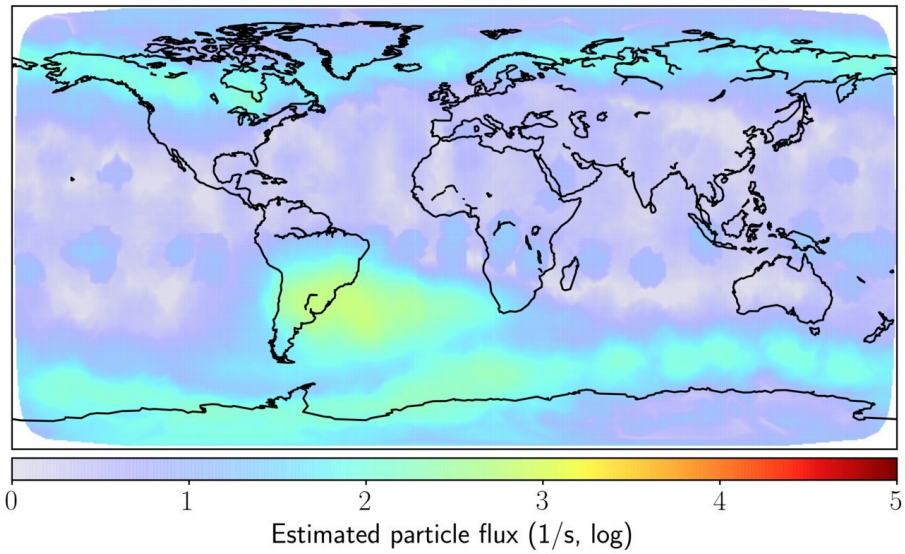
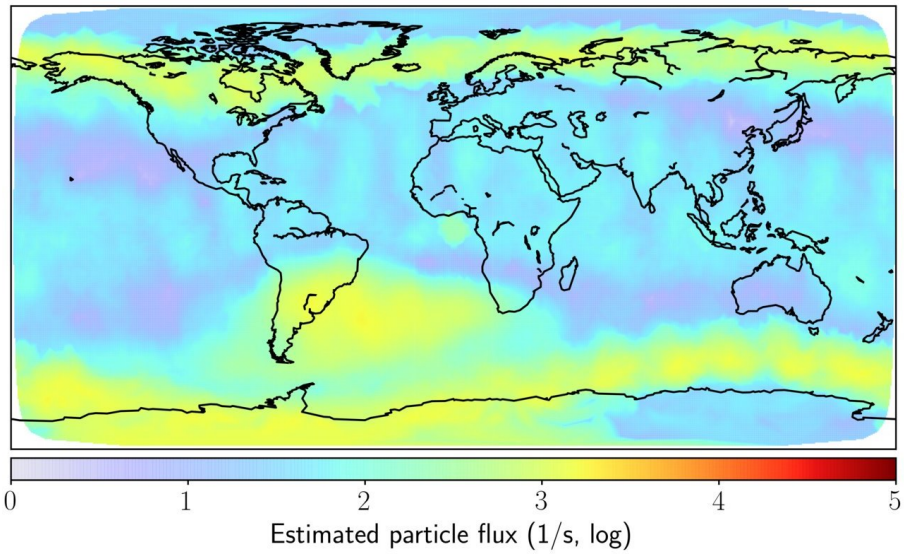


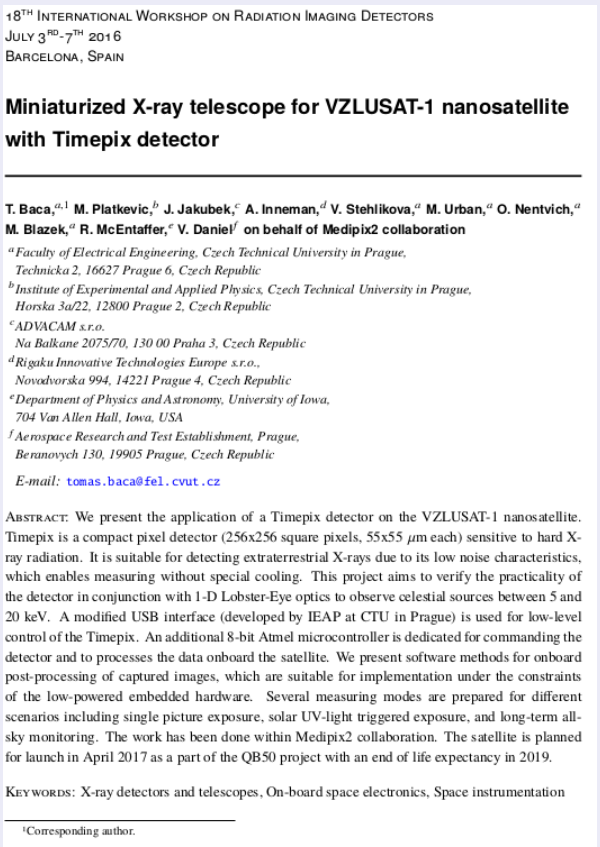
Figure: Electrons



Publications

[Baca et al. 2016]

Miniaturized X-ray telescope for VZLUSAT-1 nanosatellite with Timepix detector



18TH INTERNATIONAL WORKSHOP ON RADIATION IMAGING DETECTORS
JULY 3RD-7TH 2016
BARCELONA, SPAIN

Miniaturized X-ray telescope for VZLUSAT-1 nanosatellite with Timepix detector

T. Baca,[a,1] M. Platkevic,[b] J. Jakubek,[c] A. Inneman,[d] V. Stehlikova,[a] M. Urban,[a] O. Nentvich,[a] M. Blazek,[a] R. McEntaffer,[e] V. Daniel[f] on behalf of Medipix2 collaboration

[a] *Faculty of Electrical Engineering, Czech Technical University in Prague, Technicka 2, 16627 Prague 6, Czech Republic*
[b] *Institute of Experimental and Applied Physics, Czech Technical University in Prague, Horska 3a/22, 12800 Prague 2, Czech Republic*
[c] *ADVACAM s.r.o. Na Balkane 2075/70, 130 00 Praha 3, Czech Republic*
[d] *Rigaku Innovative Technologies Europe s.r.o., Novodvorska 994, 14221 Prague 4, Czech Republic*
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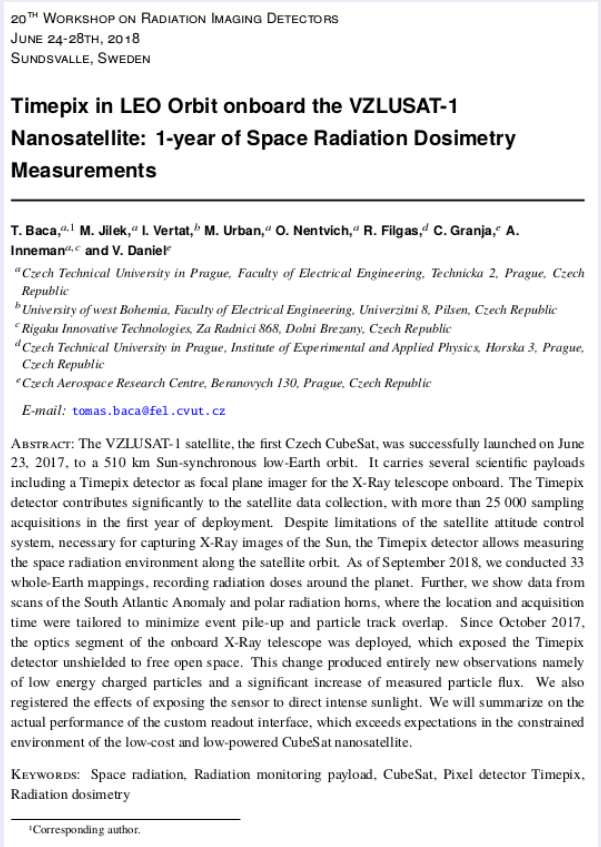
ABSTRACT: We present the application of a Timepix detector on the VZLUSAT-1 nanosatellite. Timepix is a compact pixel detector (256x256 square pixels, 55x55 μm each) sensitive to hard X-ray radiation. It is suitable for detecting extraterrestrial X-rays due to its low noise characteristics, which enables measuring without special cooling. This project aims to verify the practicality of the detector in conjunction with 1-D Lobster-Eye optics to observe celestial sources between 5 and 20 keV. A modified USB interface (developed by IEAP at CTU in Prague) is used for low-level control of the Timepix. An additional 8-bit Atmel microcontroller is dedicated for commanding the detector and to processes the data onboard the satellite. We present software methods for onboard post-processing of captured images, which are suitable for implementation under the constraints of the low-powered embedded hardware. Several measuring modes are prepared for different scenarios including single picture exposure, solar UV-light triggered exposure, and long-term all-sky monitoring. The work has been done within Medipix2 collaboration. The satellite is planned for launch in April 2017 as a part of the QB50 project with an end of life expectancy in 2019.

KEYWORDS: X-ray detectors and telescopes, On-board space electronics, Space instrumentation

[1]Corresponding author.

[Baca et al. 2018]

Timepix in LEO Orbit onboard the VZLUSAT-1 Nanosatellite: 1-year of Space Radiation Dosimetry Measurements



20TH WORKSHOP ON RADIATION IMAGING DETECTORS
JUNE 24-28TH, 2018
SUNDSVALLE, SWEDEN

Timepix in LEO Orbit onboard the VZLUSAT-1 Nanosatellite: 1-year of Space Radiation Dosimetry Measurements

T. Baca,[a,1] M. Jilek,[a] I. Vertat,[b] M. Urban,[a] O. Nentvich,[a] R. Filgas,[d] C. Granja,[e] A. Inneman[a,c] and V. Daniel[e]

[a] *Czech Technical University in Prague, Faculty of Electrical Engineering, Technicka 2, Prague, Czech Republic*
[b] *University of west Bohemia, Faculty of Electrical Engineering, Univerzitni 8, Pilsen, Czech Republic*
[c] *Rigaku Innovative Technologies, Za Radnici 868, Dolni Brezany, Czech Republic*
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ABSTRACT: The VZLUSAT-1 satellite, the first Czech CubeSat, was successfully launched on June 23, 2017, to a 510 km Sun-synchronous low-Earth orbit. It carries several scientific payloads including a Timepix detector as focal plane imager for the X-Ray telescope onboard. The Timepix detector contributes significantly to the satellite data collection, with more than 25 000 sampling acquisitions in the first year of deployment. Despite limitations of the satellite attitude control system, necessary for capturing X-Ray images of the Sun, the Timepix detector allows measuring the space radiation environment along the satellite orbit. As of September 2018, we conducted 33 whole-Earth mappings, recording radiation doses around the planet. Further, we show data from scans of the South Atlantic Anomaly and polar radiation horns, where the location and acquisition time were tailored to minimize event pile-up and particle track overlap. Since October 2017, the optics segment of the onboard X-Ray telescope was deployed, which exposed the Timepix detector unshielded to free open space. This change produced entirely new observations namely of low energy charged particles and a significant increase of measured particle flux. We also registered the effects of exposing the sensor to direct intense sunlight. We will summarize on the actual performance of the custom readout interface, which exceeds expectations in the constrained environment of the low-cost and low-powered CubeSat nanosatellite.

KEYWORDS: Space radiation, Radiation monitoring payload, CubeSat, Pixel detector Timepix, Radiation dosimetry

[1]Corresponding author.

Summary (as of June 28th, 2018)

- 1.5 years in orbit
- low cost: under $2M
- day-to-day operation from Pilsen, the Czech Republic
- most of the onboard systems are operational
- $>$ 1 year life expectancy ✓

Timepix payload statistics

- $>$ 26 000 images taken
- 32$\times$ 24-hour whole-Earth dosimetries
- 100 exposures triggered by the UV trigger
- $\approx$ 1000 images downloaded in full resolution (the rest post-processed)
- $>$ 70 hours of onboard data processing
- data compression: 2800 MB (raw data) $\rightarrow$ 30 MB (downloaded)

References

T. Baca, M. Jilek, I. Vertat, M. Urban, O. Nentvich, R. Filgas, C. Granja, A. Inneman and V. Daniel

Timepix in LEO Orbit onboard the VZLUSAT-1 Nanosatellite: 1-year of Space Radiation Dosimetry Measurements

Journal of Instrumentation 13(11), C11010, 2018

T. Baca, M. Platkevic, J. Jakubek, A. Inneman, V. Stehlikova, M. Urban, O. Nentvich, M. Blazek, R. McEntaffer, and V. Daniel

Miniaturized X-ray telescope for VZLUSAT-1 nanosatellite with Timepix detector

Journal of Instrumentation 11(10), C10007, 2016

X. Llopart, R. Ballabriga, M. Campbell, L. Tlustos, and W. Wong

Timepix, a 65k programmable pixel readout chip for arrival time, energy and/or photon counting measurements

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 581.1-2 (2007): 485-494.

Z. Vykydal, and J. Jakubek.

USB Lite – Miniaturized readout interface for Medipix2 detector

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 633 (2011): S48-S49.

M. Urban, O. Nentvich, V. Stehlikova, T Baca, V. Daniel, and R. Hudec

Miniaturized X-ray telescope for VZLUSAT-1 nanosatellite with Timepix detector

Acta Astronautica 140, p. 96 – 104, 2017

L. Pina, R. Hudec, A. Inneman, T. Baca, M. Blazek, M. Platkevic, L. Sieger, D. Doubravova, R. McEntaffer, T. Schultz, and V. Daniel

Miniaturized X-ray telescope for VZLUSAT-1 nanosatellite with Timepix detector

SPIE: Advances in Laboratory-based X-Ray Sources, Optics, and Applications, 2016

Thank you for your attention

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Acknowledgments

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