Space Radiation and Plasma Monitoring Workshop 2014

13-14 May 2014
European Space Research and Technology Centre (ESTEC)

Compact payload SATRAM on-board Proba-V satellite for radiation monitoring in open space with quantum and directional sensitivity based on the pixel detector Timepix

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Research performed in frame of the CERN Medipix Collaboration

Project funded by the European Space Agency

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Czech Technical University in Prague

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Basic Research

Astroparticle & non-accelerator physics
- Neutrino physics (NEMO3/SuperNEMO, TGV)
- Cosmic rays (CZELTA)
- Dark matter (PICASSO)

ATLAS at LHC
- SCT detection modules
- Neutron shielding
- Medipix radiation monitoring
- Higgs boson physics

Nuclear spectroscopy
- Fission fragment spectroscopy
- Laser induced nuclear excitation
- Ultra cold neutrons

Applied Research

Radiation imaging
- Medipix pixel detectors: SW, HW
- X-ray radiography and tomography
- Charged particle & neutron imaging
- Biomedical imaging
- Material science and defectoscopy

R&D of semiconductor detectors
- 3D and semi-3D detectors
- Thermal neutron detectors
- Room-temperature detectors
- Instrumentation for detector testing

Applied spectrometry
- Material analysis (CINAA, XRF, Radon)
- Particle tracking and spectroscopy
- Space: (gamma, neutron,micro-sensor,SATRAM payload)

Fundamental Experiments in the Physics of the Microworld

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Recent events

IEEE NPSS — NSS MIC IEEE Conference
Seattle, USA
8-15 Nov 2014

NSS MIC IEEE Conference
Seoul, Korea
27 Oct - 2 Nov 2013

15th IWORID
Paris
23-27 June 2013

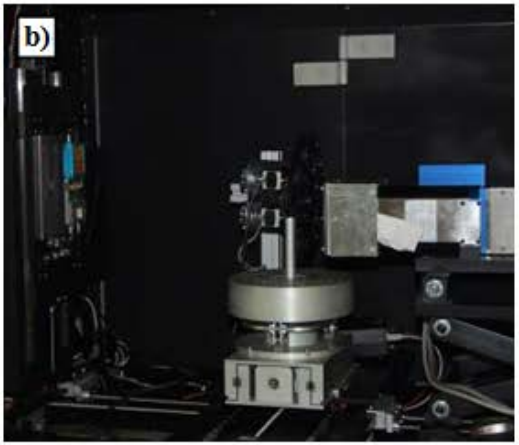
All.

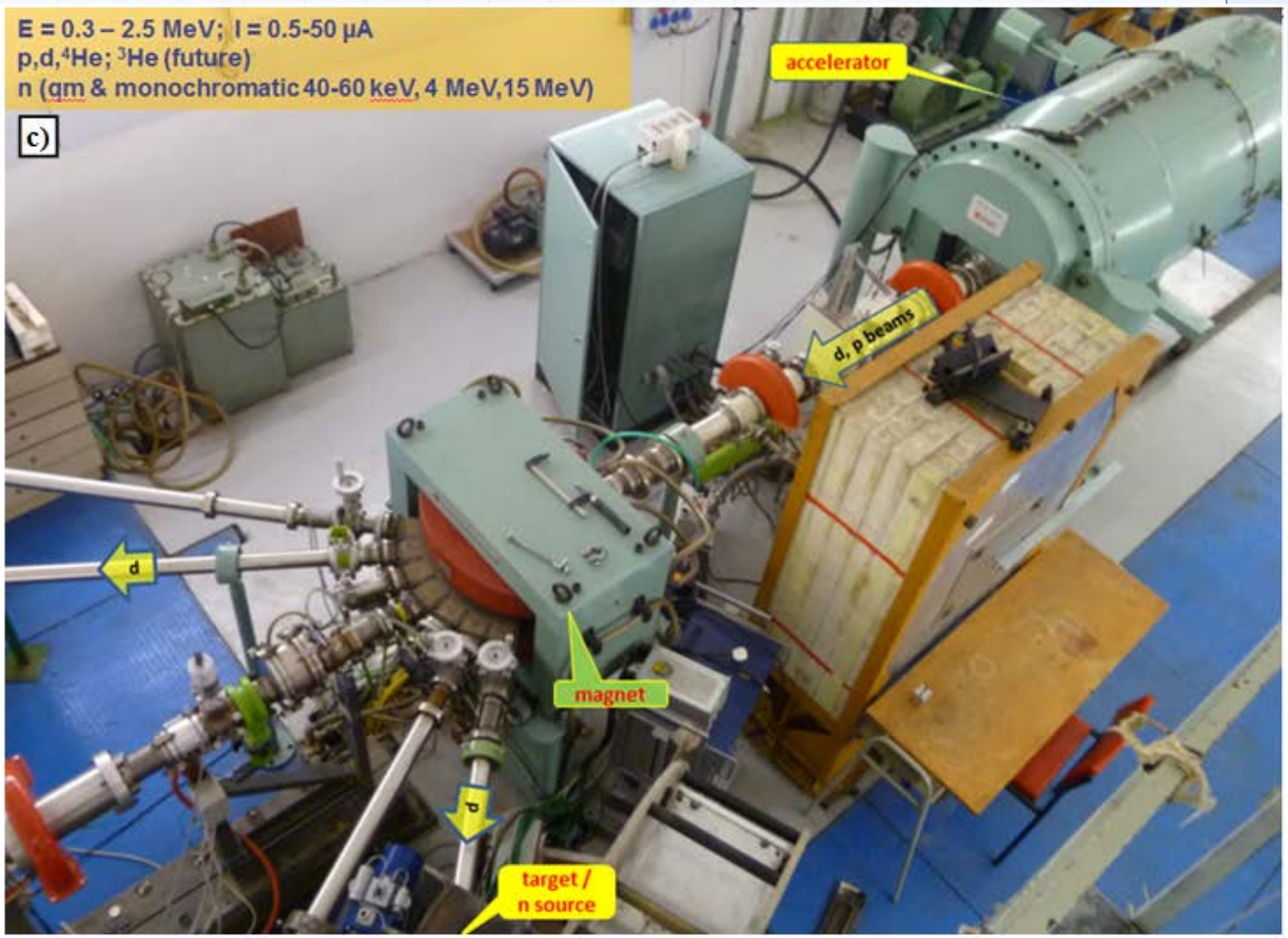
IEAP, Horská 3a/22, 128 00 Praha 2, Tel: (+420) 22435 9290

Designed by Marte

IEAP CTU in Prague

R&D Radiation Detectors / Instrumentation / Spectroscopy, VdG ion accelerator

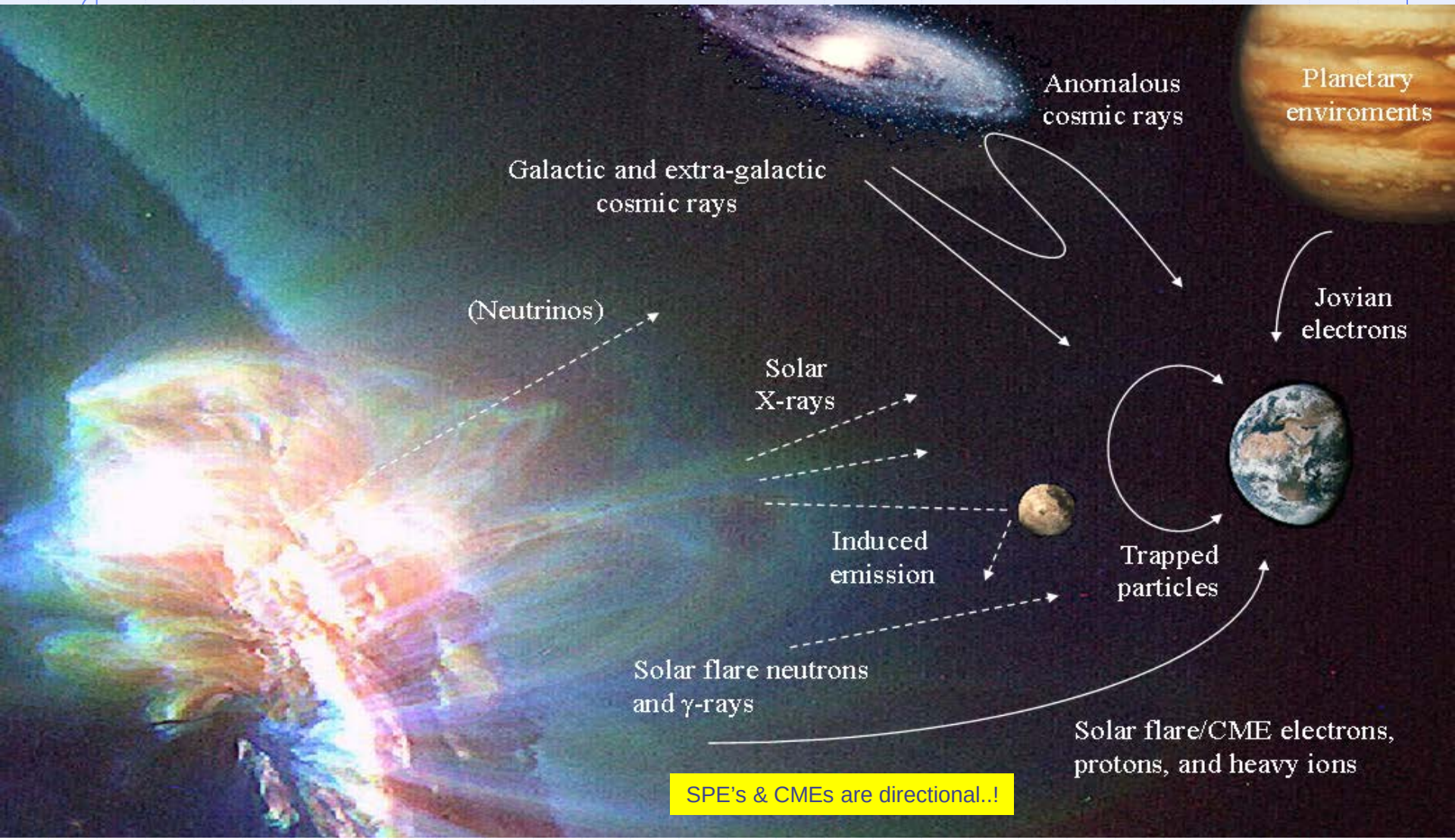




Clean room (a), X-ray μ-imaging & μ-tomography unit, X-ray pencil beam test bench (b), Van de Graaff accelerator, beam guides (c).

Space Radiation Environment

Mixed radiation field + broad E spectra + high flux gradients + directionality

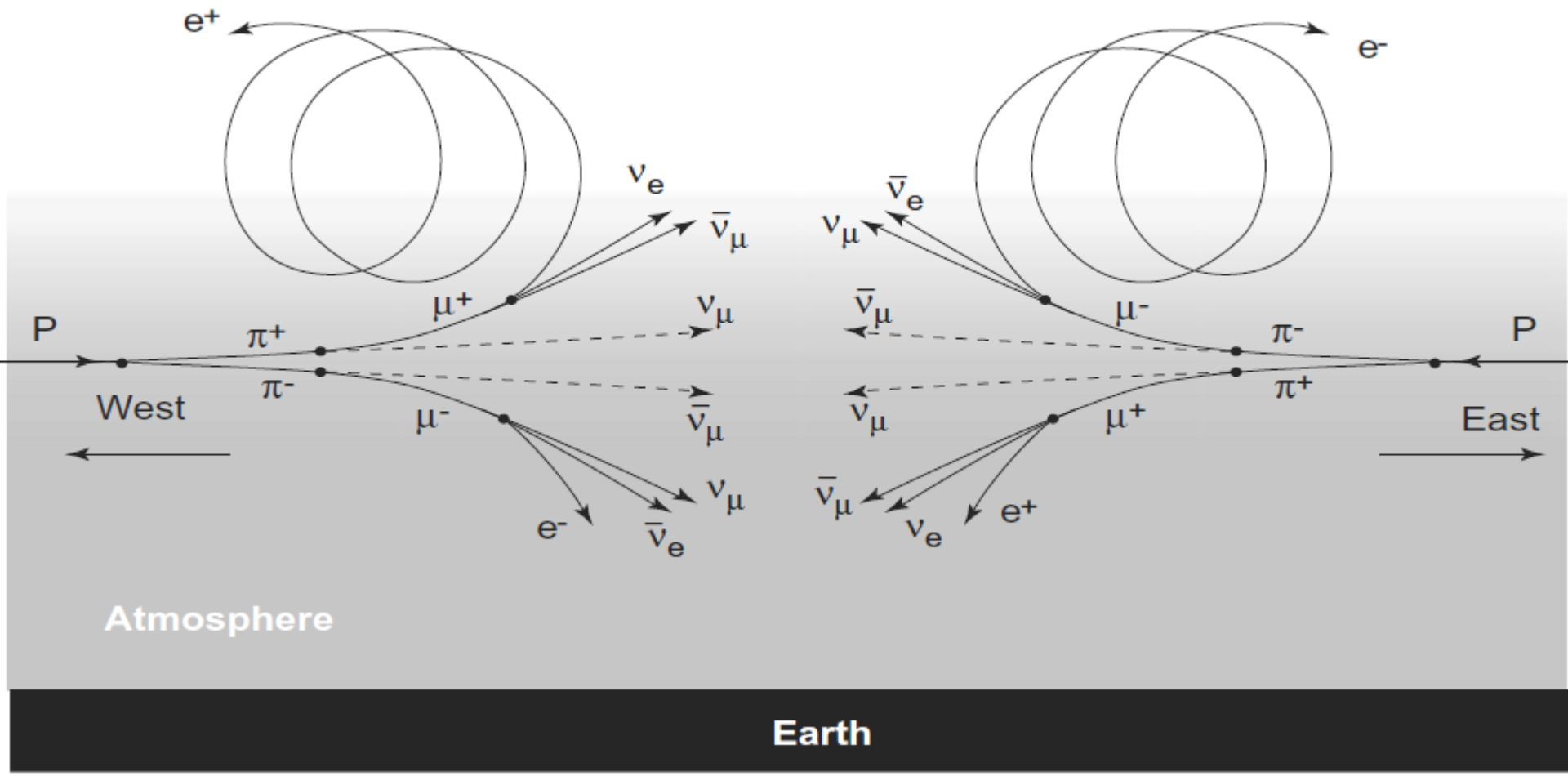


Earth radiation belts

Charged particle interactions + directional information

Physics Prague

Production of secondary particles in inelastic interactions of cosmic rays with atmosphere



Hybrid semiconductor pixel detector Medipix
Per–pixel signal readout electronics

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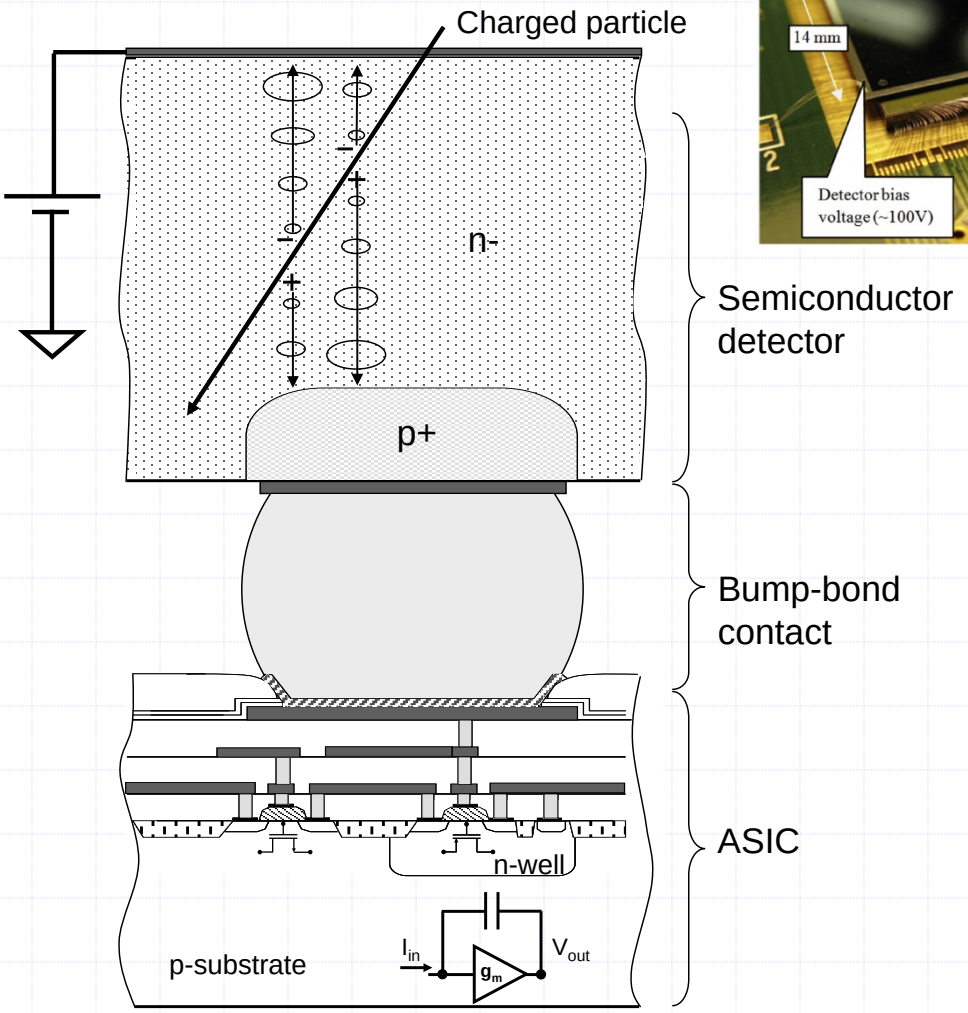
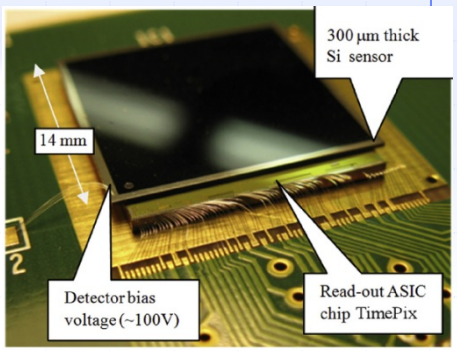
Core architecture of the hybrid pixel detectors where the sensor chip (top) is bump-bonded to the readout ASIC (bottom). Hybrid technology allows using semiconductor sensors of different

- material (e.g, Si, CdTe, GaAs)
- thickness (e.g. 300, 500, 700, 1000 um).

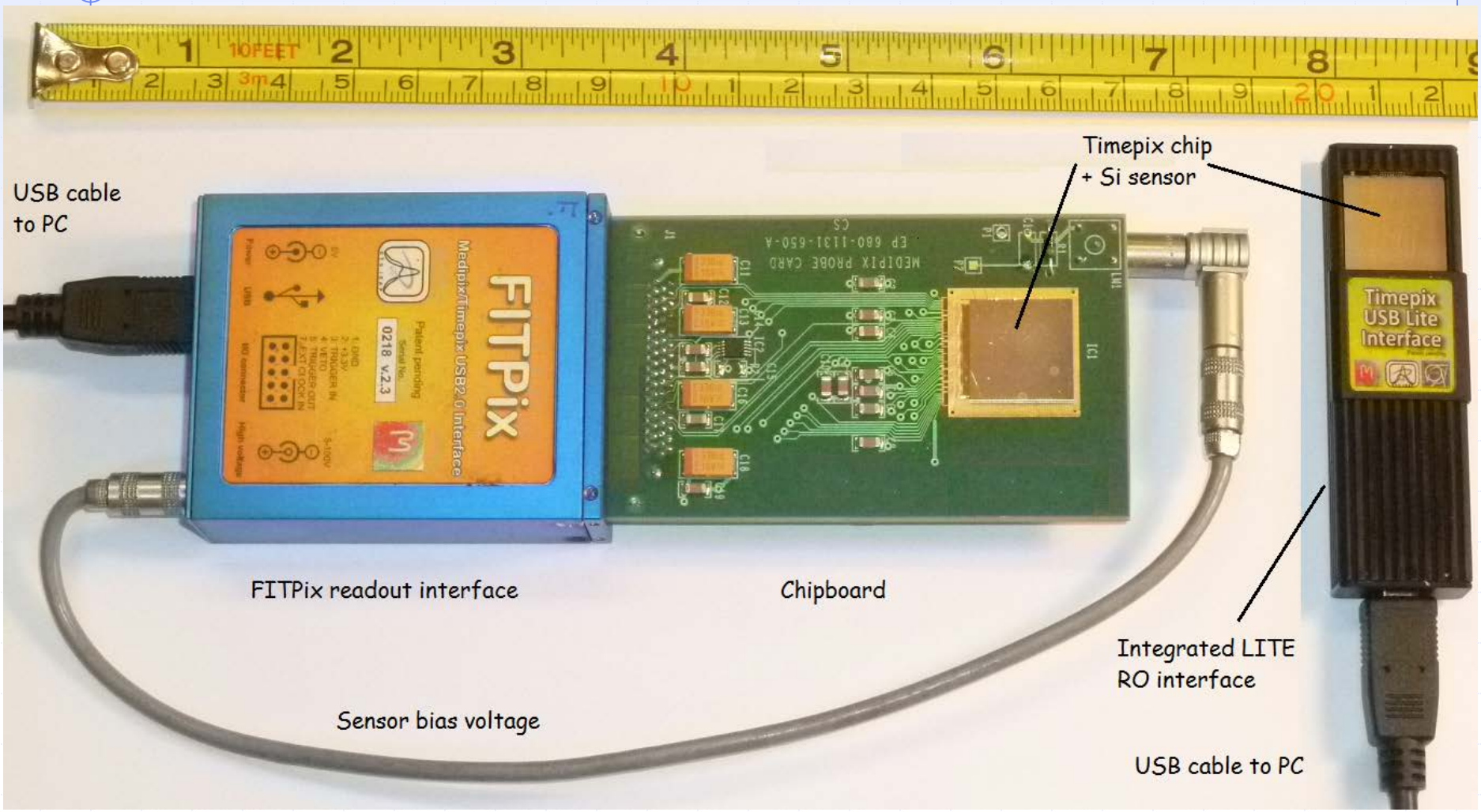
Per-pixel pulse processing electronics provides simultaneously fast and dark-current free images of single particles (quantum counting).





Pixel detectors Medipix/Timepix + Integrated RO electronics + Online & data processing SW + Nuclear Physics know-how: Integrated Radiation Camera

www.cern.ch/medipix



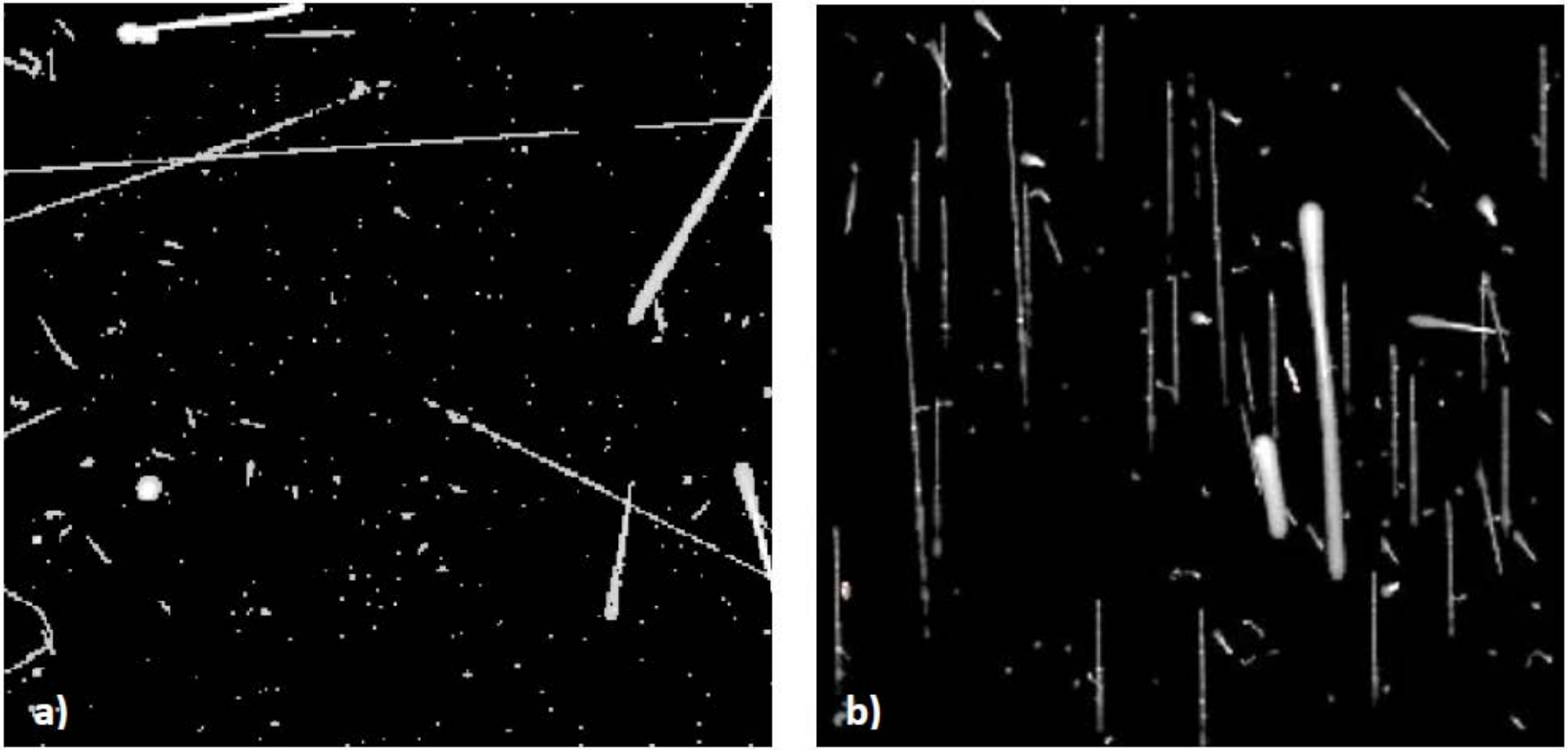
Radiation camera assembled from the Timepix chip, detector chipboard and FITPix readout interface (left). Highly miniaturized Timepix LITE (right). Straightforward connection to PC via USB cable.

In cooperation with DKFZ/HIT Heidelberg

Timepix: Energetic Particle Tracking
Energetic radiation: Atmosphere & Hadron Therapy

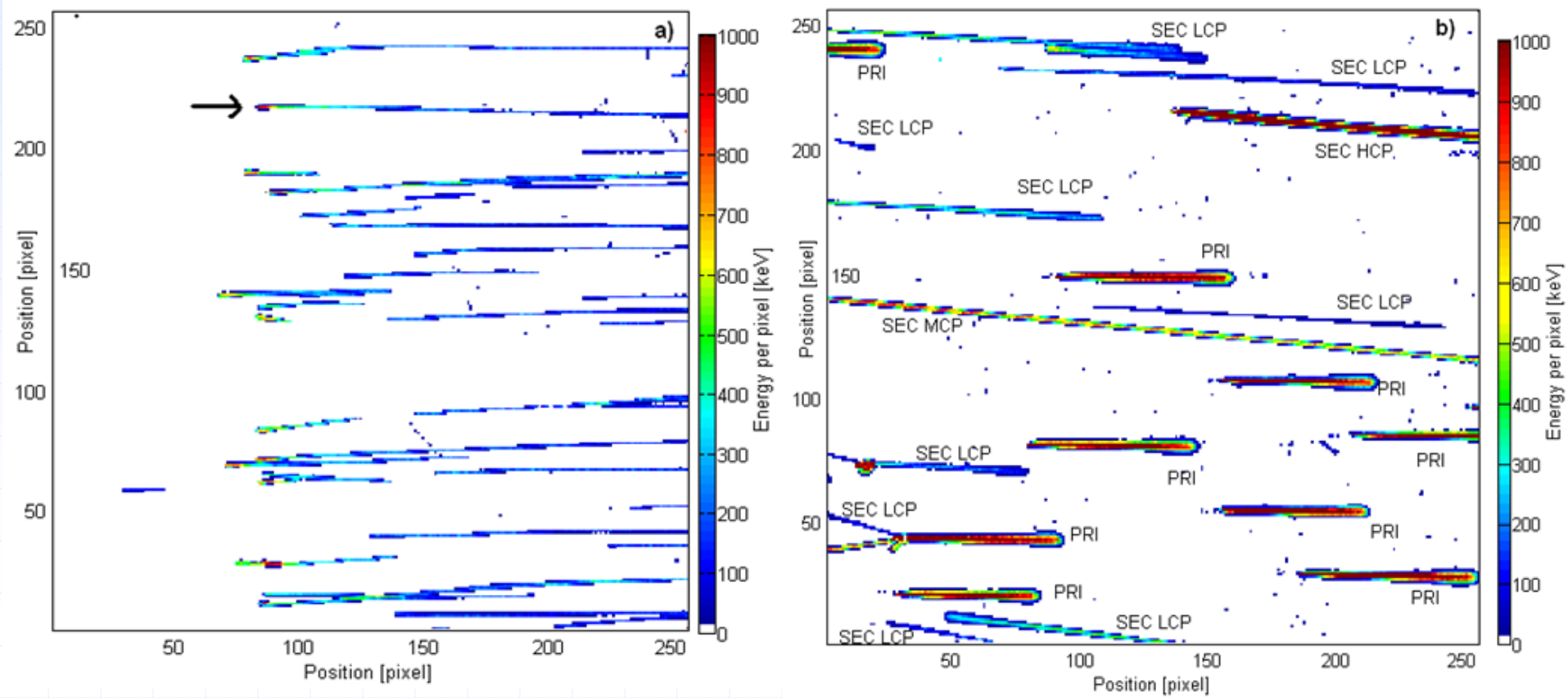
Cosmic rays @ 10 km

Ion beam therapy: 221 MeV proton beam



Registration of atmospheric cosmic rays at 10 km (a) and 221 MeV synchrotron protons at grazing angle (b) by Timepix. The images correspond to the entire sensor area (14 mm × 14 mm) which consists of an array of 256 × 256 sq. pixels of pitch size 55 µm. The white depth is a measure of the energy deposited per pixel. Single particles are detected and distinguished by their characteristic tracks resolving electrons (fast, slow, delta), muons and energetic and recoiled ions. Directional information can be obtained with µm resolution.

Timepix: Energetic Particle Tracking
HCP's: 48 MeV protons and 1.1 GeV ^{12}C



Detection of 48 MeV protons (a) and 88 MeV/u ^{12}C ions (b) by Timepix operating in TOT mode (the energy deposited in each pixel is recorded and is shown by the vertical bar in color in keV). The beam was incident from right to left at 0° (i.e. parallel) and 5° to the sensor plane, respectively. The undeflected protons are fully stopped in the sensor. The ^{12}C ions cross the sensor volume. The event labeled with an arrow in (a) is shown in detail next. On figure (b) are indicated primary beam ^{12}C ions (PRI) as well as secondary particles (SEC) which can be grouped into light- (LCP), medium- (MCP) and heavy- (HCP) mass charged particles.

Timepix in orbit + in open space

Composition + spectral characterization + particle visualization

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Quantum counting/spectrometric/imaging/directional detector + integrated RO electronics + data processing SW + nuclear physics/radiation spectrometry/imaging/tracking

sensitivity

- **p, α, ions, e^-, muons, neutrons, X-rays: dE + particle species resolving power**

tasks

- **Detection, radiation monitoring, quantum imaging dosimetry + wide DR**
- **Tracking , visualization, directional information (particle telescope)**
- **Spectrometry (dE), coincidence spectroscopy, reaction/fragmentation, …**

capability, dynamic range

- **Single-quantum sensitivity, noiseless detection, high signal-to-noise ratio**
- **Wide dynamic range (particle flux, particle energies, particle species)**
- **Linear-energy transfer (LET) measurement, low level threshold ≈ 4 keV**
- **High spatial resolution (sub-pixel resolution ≈ μm)**
- **Directional angular resolution: ≈ 1° (single sensor), ≈ 0.1° (stack telescope)**
- **Wide field-of-view: 2π, even 4π (no collimators, full sky mapping)**

instrumentation

- **Single device, integrated electronics, no cryogenics, no shielding**

technical

- **Light weight: e.g. (only) launch cost ≈ 100 EUR per g**
- **Miniaturized size, low power**

!

Timepix-based
space payloads/instruments

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Czech Technical University in Prague

L. Pinsky, et al., U Houston/NASA, D. Turecek, Z. Vykydal, S. Pospisil, IEAP

T. Kuwahara, U Tohoku, Japan

M. Platkevic, V. Kraus, D. Turecek, IEAP

platform device | open space | Scientific payload

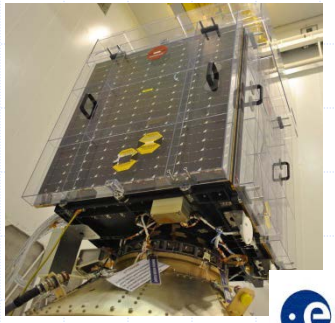
International Space Station

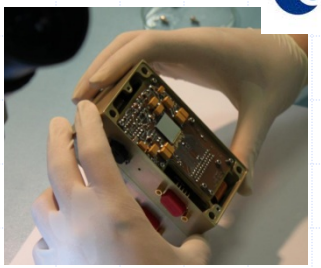
In orbit since 3Q 2012 | 400 km

5 x Timepix devices

ESA Proba V satellite

Launched 7th May 2013 | 820 km

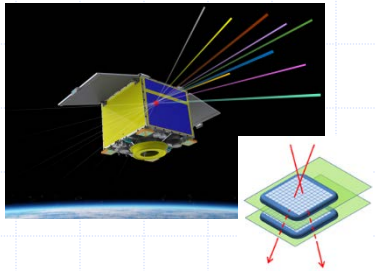


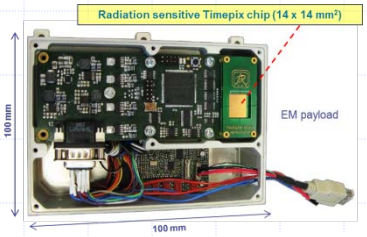


150 Kg

RISESAT satellite

Launch 2014/5

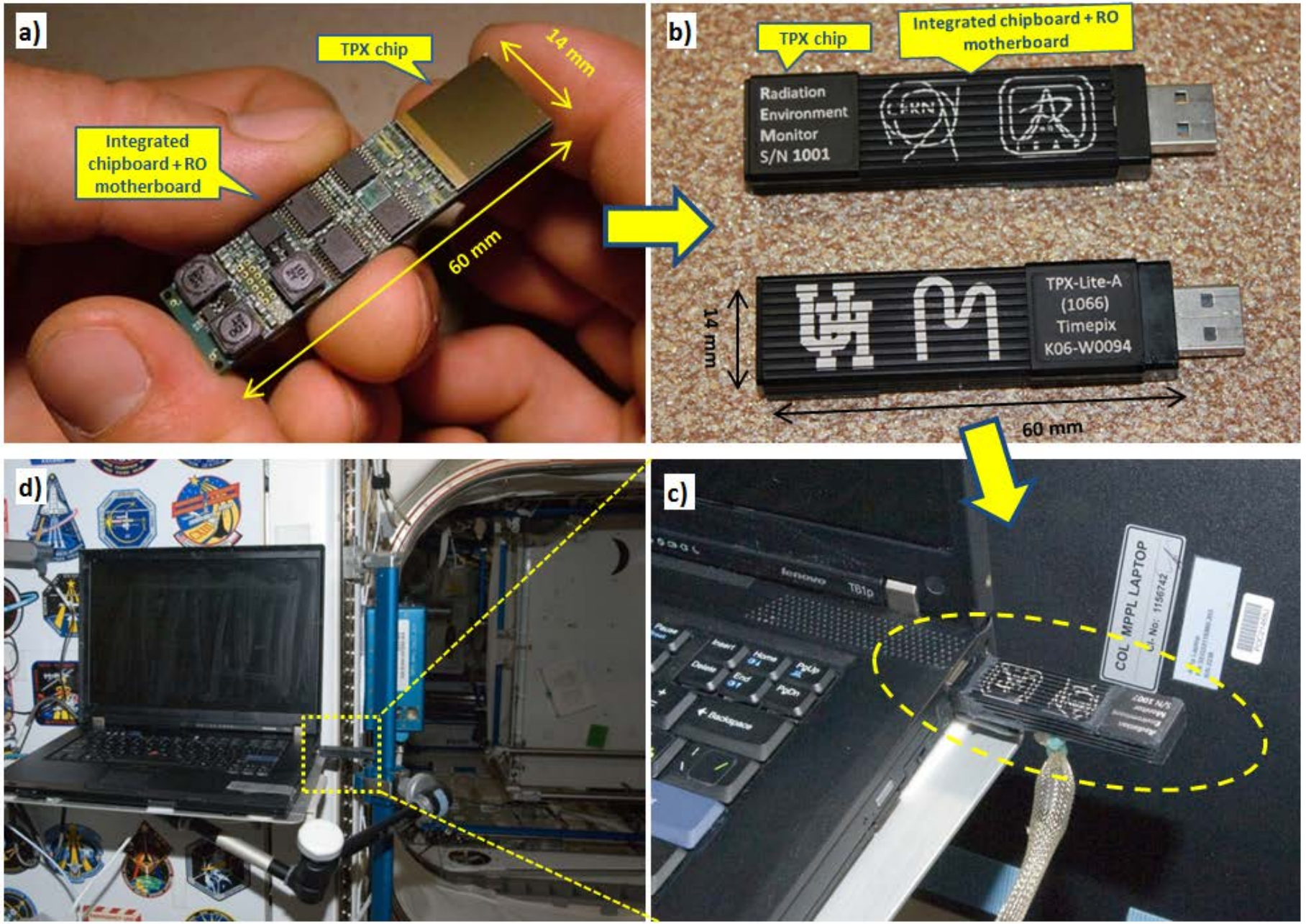




東北大学
TOHOKU UNIVERSITY

50 Kg

Type	Size (mass)
Minisatellite	100 – 200 Kg
Microsatellite	10 – 100 Kg
Nanosatellite	1 – 10 Kg
Picosatellite	< 1 Kg



Timepix detector in the highly miniaturized LITE architecture (a) customized for the ISS (b) as deployed with an on-board laptop via USB port (c) in a NASA Module at the ISS (d). Work done in cooperation with NASA and the University of Houston.

Online miniaturized Timepix Quantum Dosimeter
for the International Space Station (ISS)

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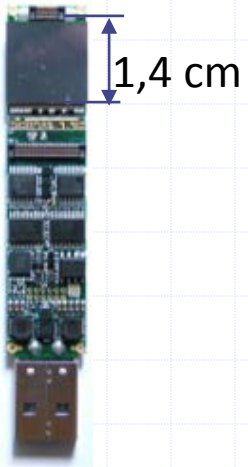
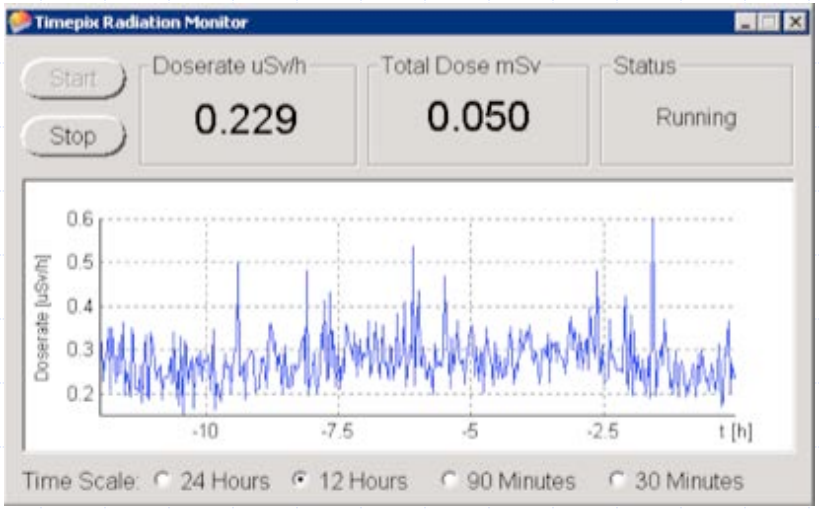
Czech Technical University in Prague

5 detector units launched in space on August 2012, all running since, taking data

HW + Physics methodology + SW





Timepix onboard the ISS
Detection, meaurement of charged particle flux, visualization

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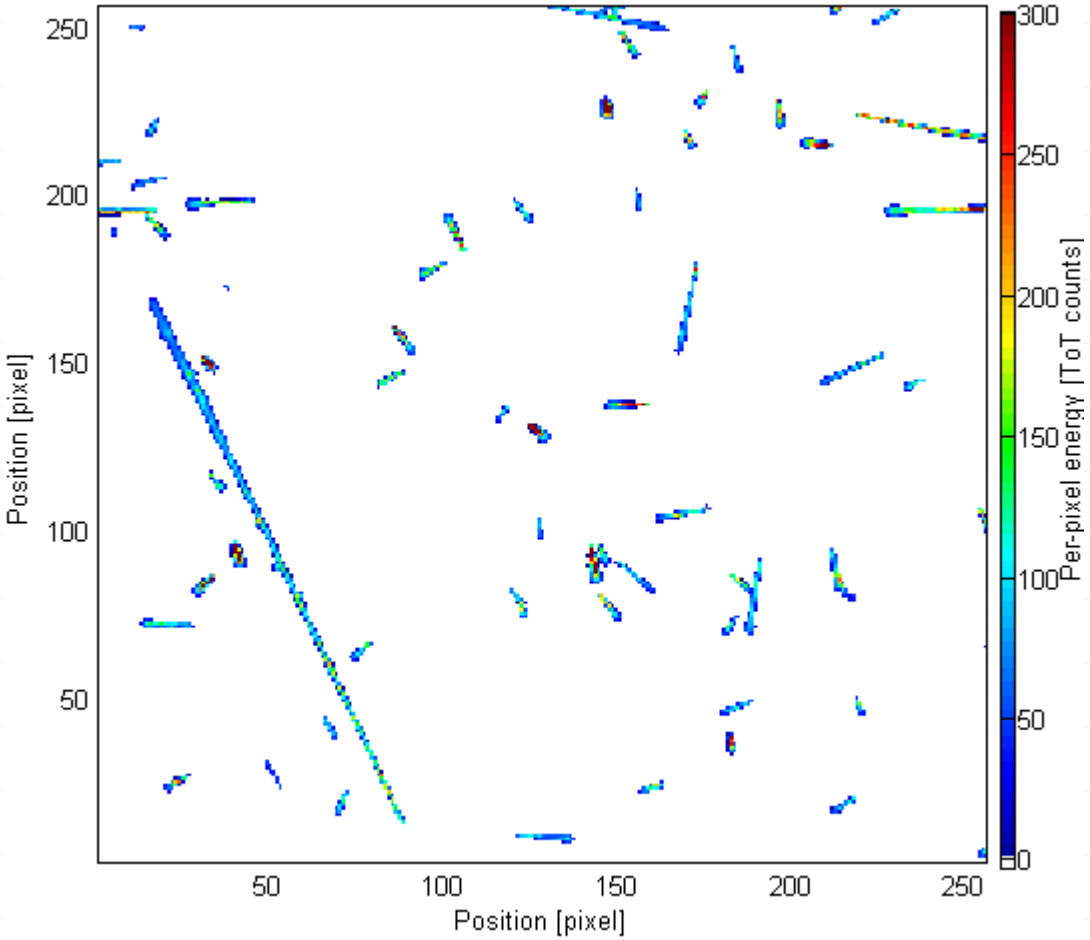
Radiation field at the ISS, acq t = 4 s



Timepix onboard the ISS

Radiation over the South Atlantic Anomaly (SAA)

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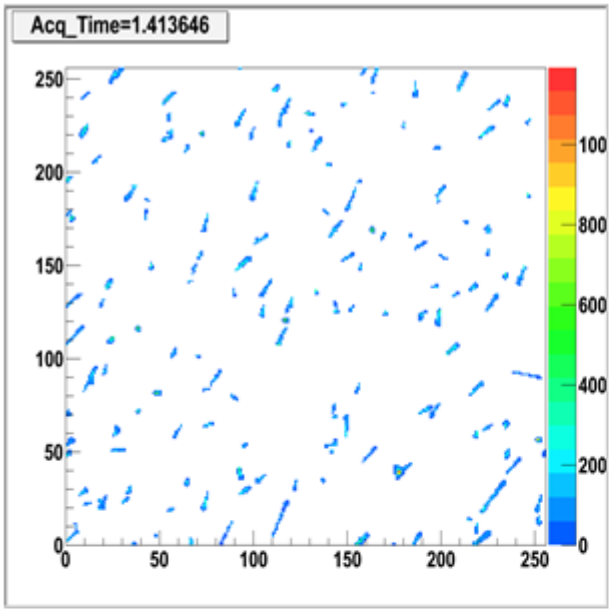

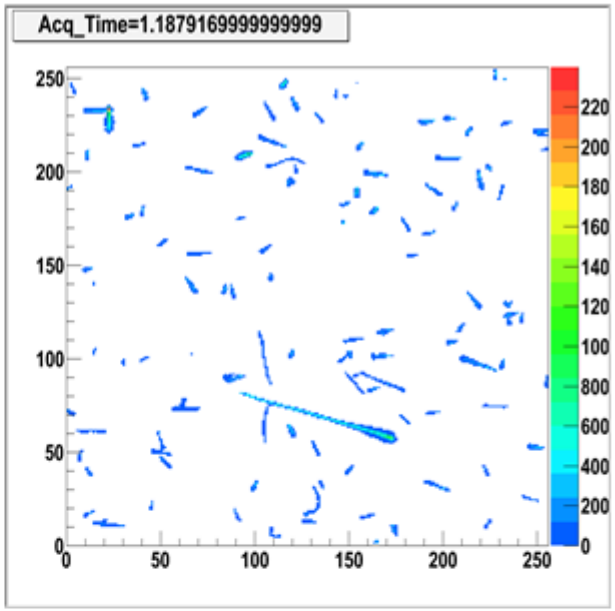

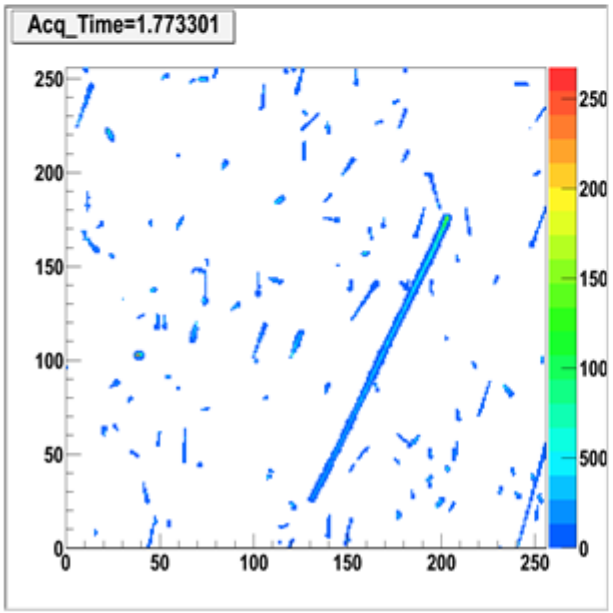

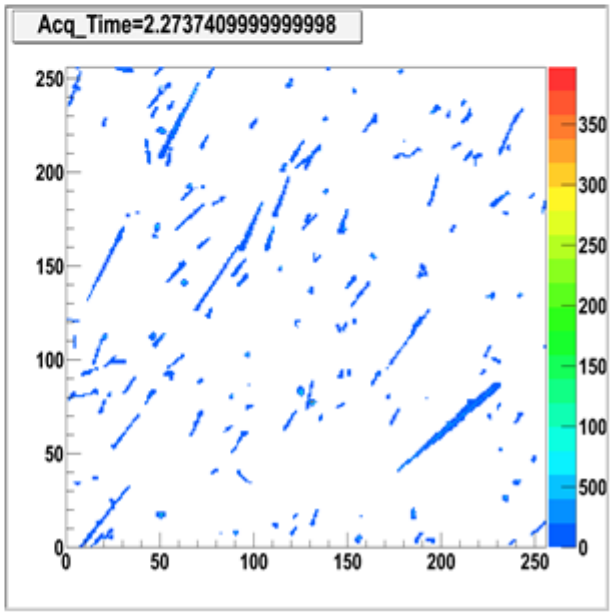

Timepix onboard the ISS

Time-correlated flux of charged particles

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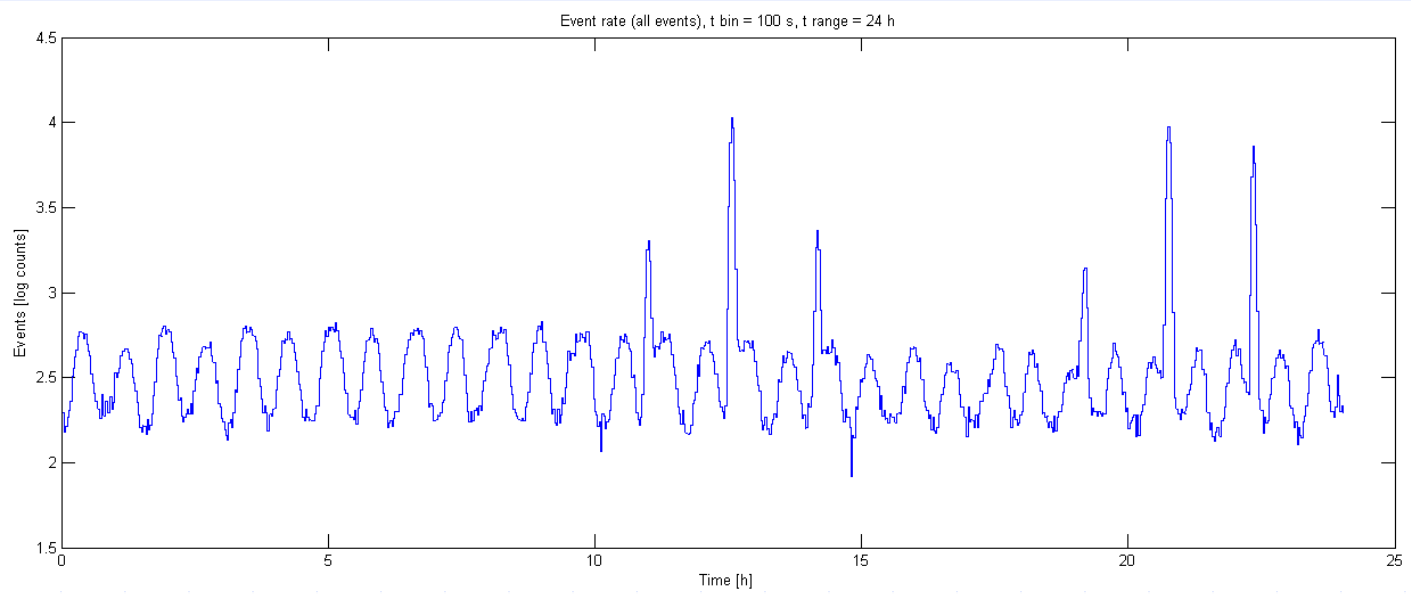
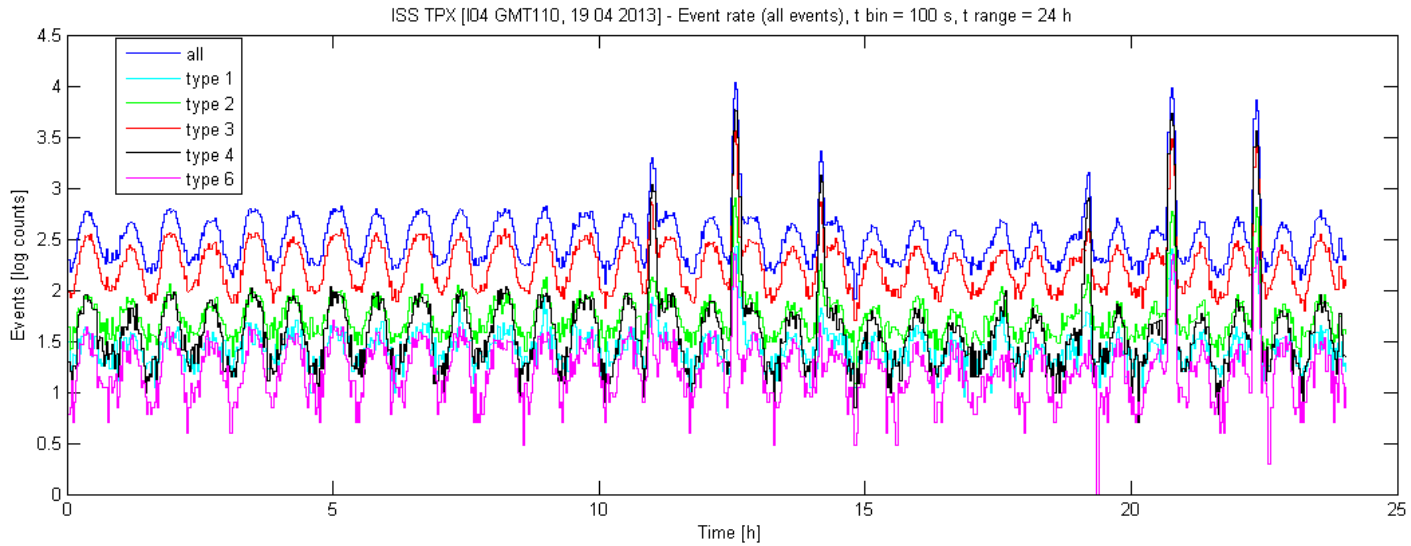
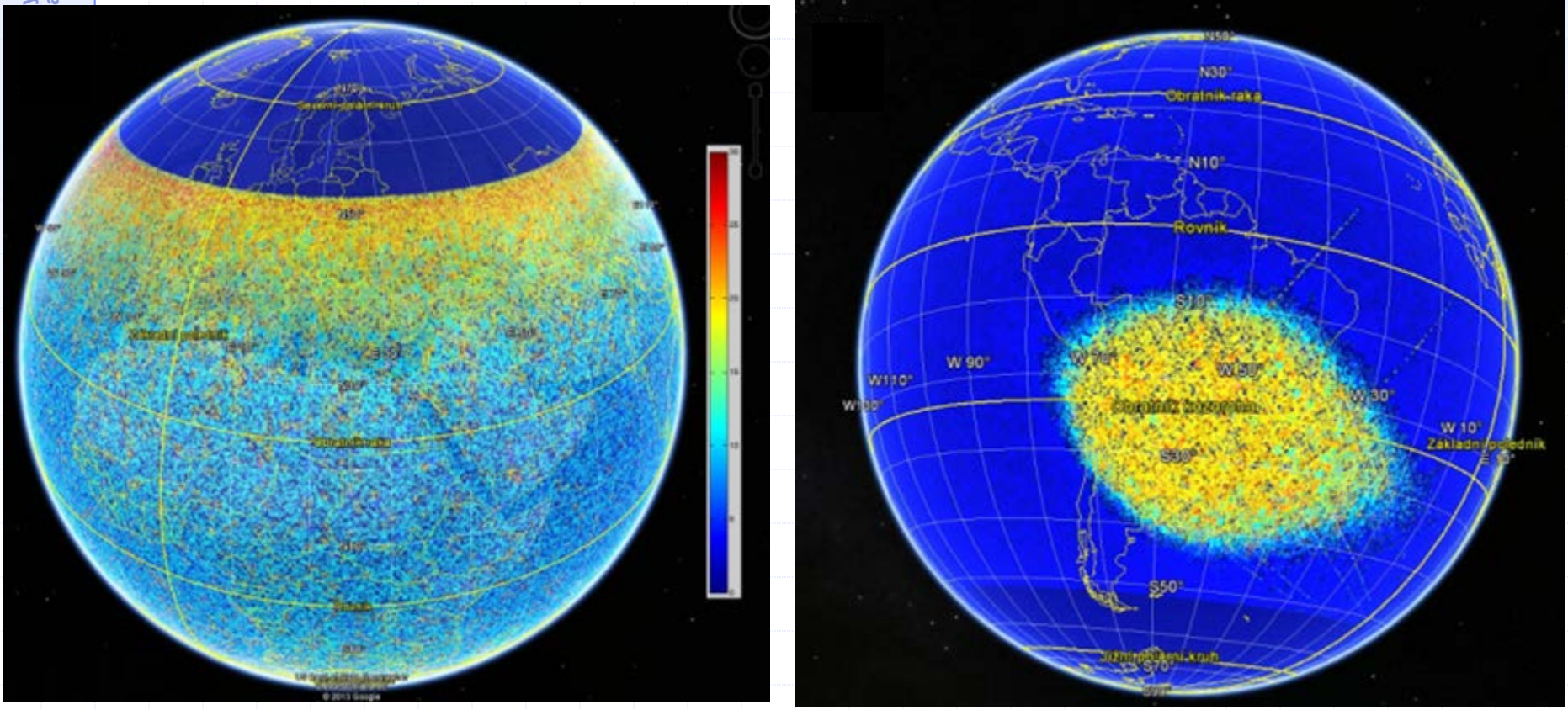




Timepix onboard the ISS

Spatial-correlated flux of charged particles



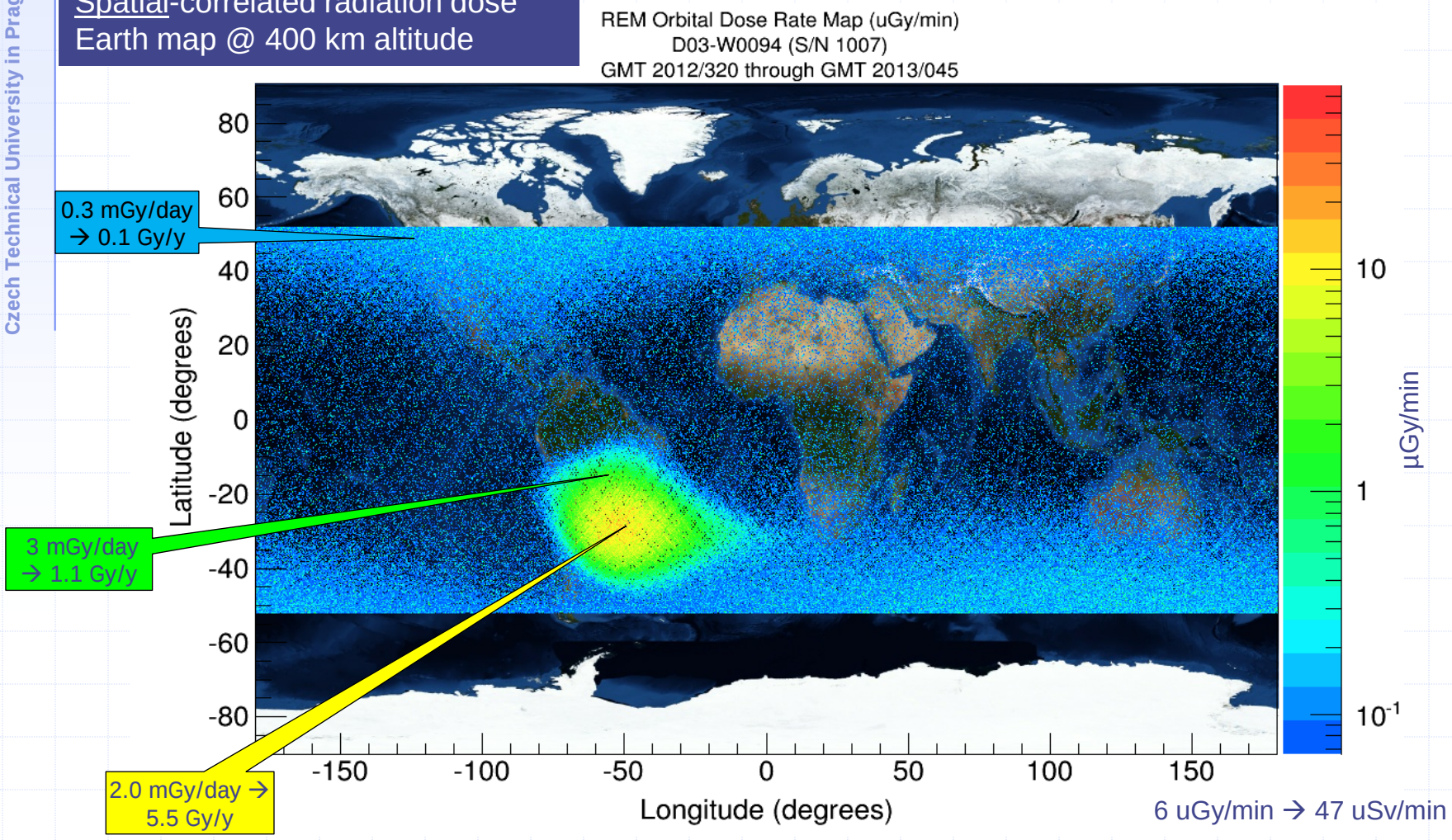
Detection and distribution of energetic radiation at the ISS measured by Timepix. Display on Earth position coordinates showing the Northern (left) and Southern (right) hemispheres.

Timepix onboard the ISS
Quantum dosimetry + wide dynamic range

Airline altirude 11 km (Madrid-Bogota): 0,025 µGy/min = 0.036 mGy/d = 13 mGy/y

Ground level (Prague): 0,001 µGy/min = 0.0015 mGy/d = 0.54 mGy/y

Spatial-correlated radiation dose
Earth map @ 400 km altitude



6 uGy/min → 47 uSv/min

REM Dose Rate Data (µG/min) measured by Timepix onboard the ISS

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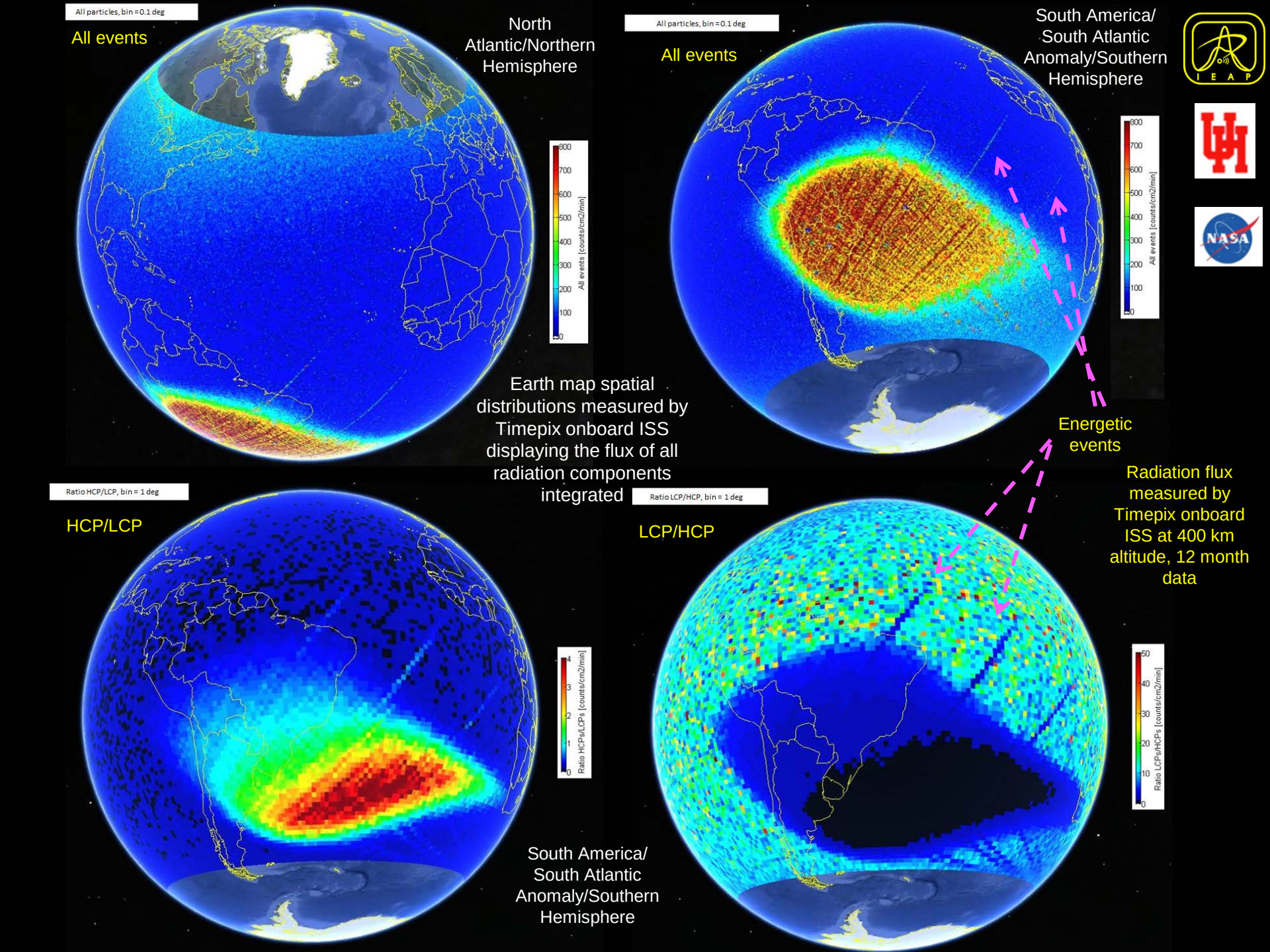

All particles, bin = 0.1 deg
All events
North Atlantic/Northern Hemisphere
All events [counts/cm2/min]
All particles, bin = 0.1 deg
All events
South America/ South Atlantic Anomaly/Southern Hemisphere
All events [counts/cm2/min]
Energetic events
Earth map spatial distributions measured by Timepix onboard ISS displaying the flux of all radiation components integrated
Radiation flux measured by Timepix onboard ISS at 400 km altitude, 12 month data
Ratio HCP/LCP, bin = 1 deg
HCP/LCP
Ratio HCPs/LCPs [counts/cm2/min]
Ratio LCP/HCP, bin = 1 deg
LCP/HCP
Ratio LCPs/HCPs [counts/cm2/min]
South America/ South Atlantic Anomaly/Southern Hemisphere

Data visualization and evaluation:
Web-portal display & time-distributions

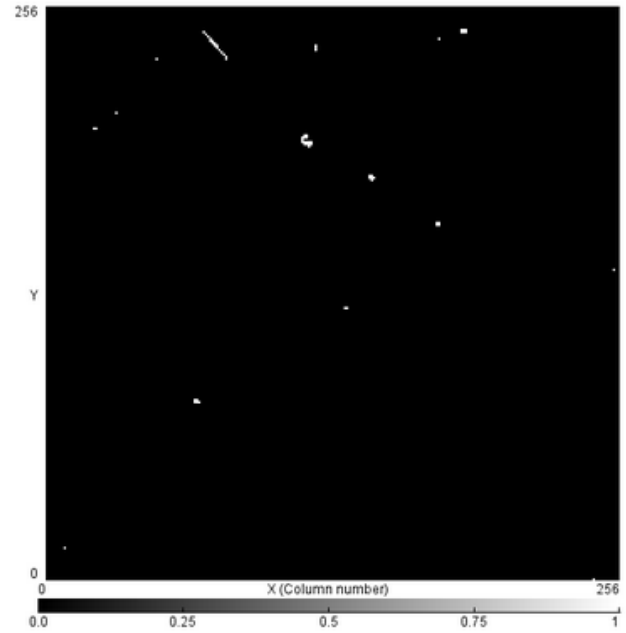
Medipix Radiation Monitor at Institute of Experimental and Applied Physics

UTEF | ZCU | VDG | MOEDAL | SURO | REZ | ISS | SATRAM

mpx01

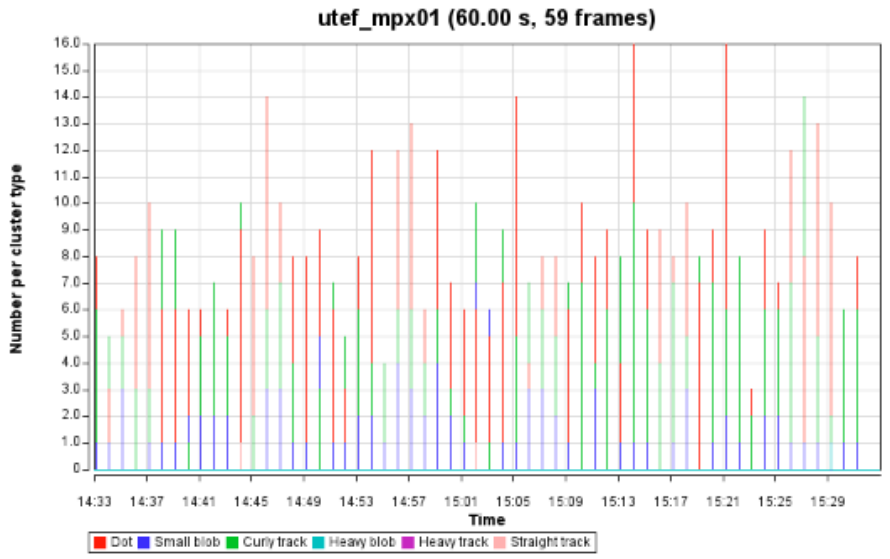
Last Frame

12.05.2014 15:32:07



Cluster Time Plot

Last hour (6) | Last 24 hours (7) | Last week (8) | Last month (9)



User Manual

Change location
- 1 ... move to previous locati
- 2 ... move to next location

Change plot time range
- 6 ... 1 hour
- 7 ... 24 hours
- 8 ... last week
- 9 ... last month

Change detector
- + ... move to next detector
- - ... move to previous detect

Cluster Statistics

Track type	Sum	Average [s-1]
All	15	0.250
Dots	8	0.000
Small blobs	1	0.000
Curly tracks	6	0.000
Heavy blobs	0	0.000
Heavy tracks	0	0.000
Straight tracks	0	0.000

Energy Statistics

Track type	Sum	Average [s-1]
All	0	0.000
Dots	0	0.000
Small blobs	0	0.000
Curly tracks	0	0.000
Heavy blobs	0	0.000
Heavy tracks	0	0.000
Straight tracks	0	0.000

Cluster Statistics

Track type	Sum	Average [s-1]
All	928	0.262
Dots	484	0.137
Small blobs	104	0.029
Curly tracks	333	0.094
Heavy blobs	1	0.000
Heavy tracks	0	0.000
Straight tracks	6	0.002

Timepix in open space

Spacecraft payload HW/SW Redesign + space qualification testing

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Spacecraft payload + constraints/limitations/requirements

- **HW: front-end + readout electronics**
  - Low power, heating dissipation, high vacuum
  - Light weight, shielding, payload accommodation
  - DAQ & memory/downlink capacity
  - Space-qualified components/parts/FPGA's etc
- **SW: firmware + control + readout**
  - Remote/on-board control, autonomous operation
  - On-board memory buffer (limited capacity)
  - Data downlink (limited capacity)
  - Telecommanding + file compression + data parsing
- **Qualification/space flight testing**
  - Thermal, heating dissipation, high vacuum
  - Vibrational + G-force acceleration
  - EM interference
- **Integration to satellite system**

- Reengineering
- Downgrade

- Breadboard model
- Engineering model (EM)
- Flight model (FM)

Spacecraft payload

Spacecraft Payload SATRAM
Space Application of Timepix Radiation Monitor

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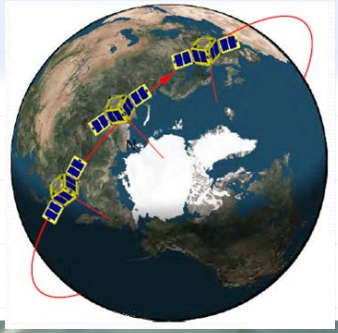
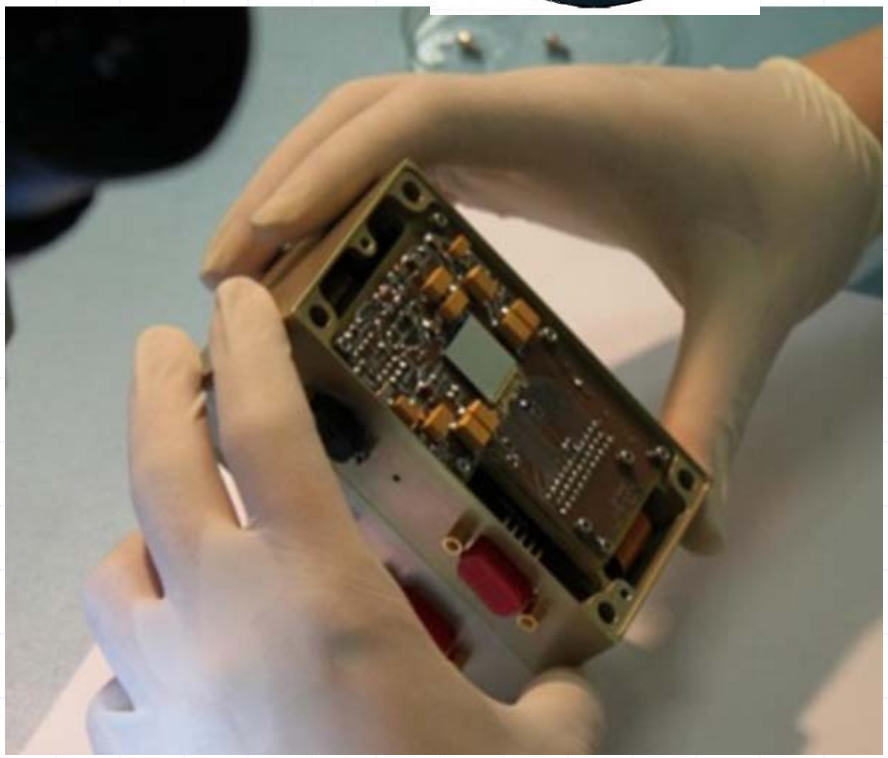


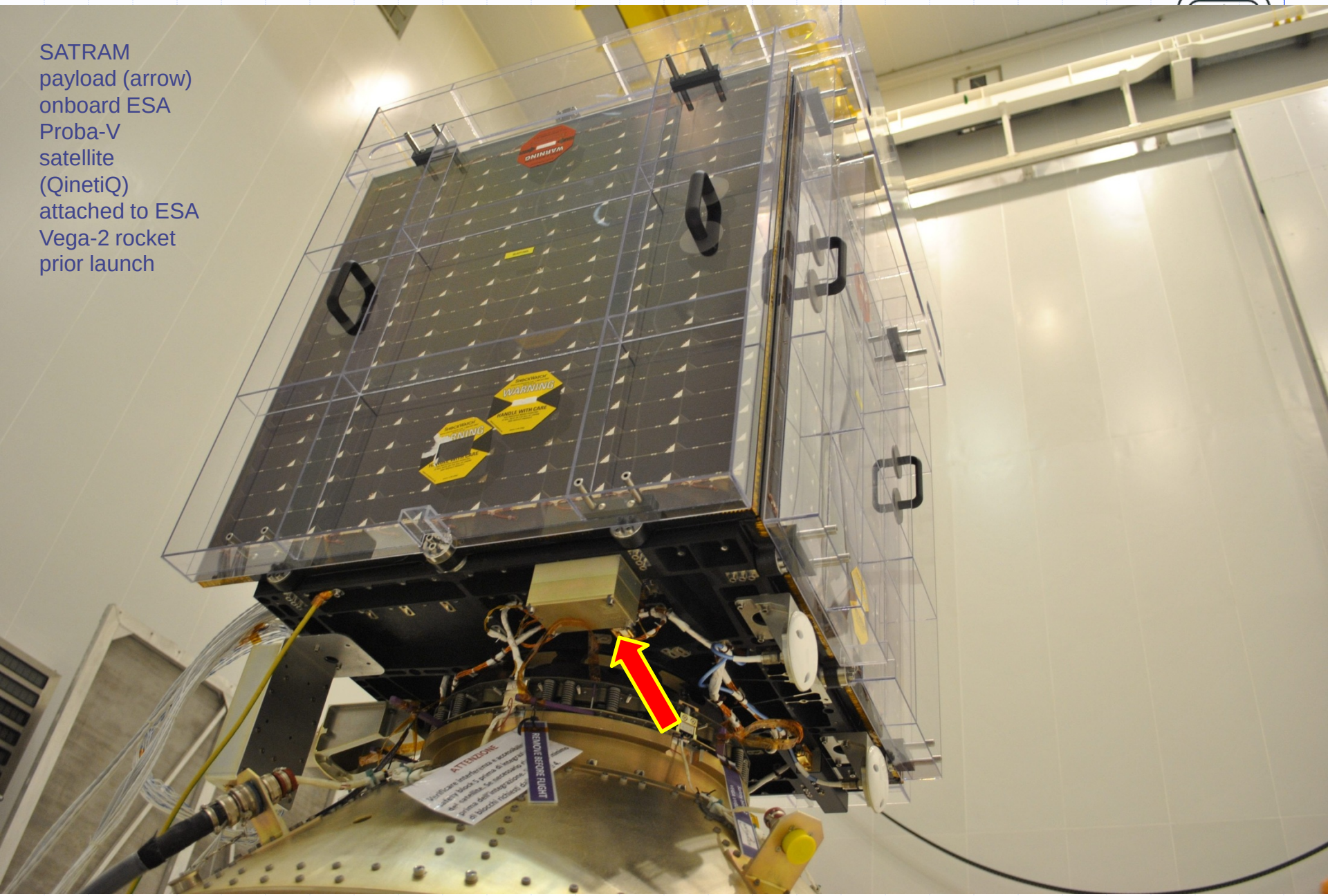
Characterization of space radiation in Low Earth Orbit (LEO) onboard ESA PROBA-V satellite

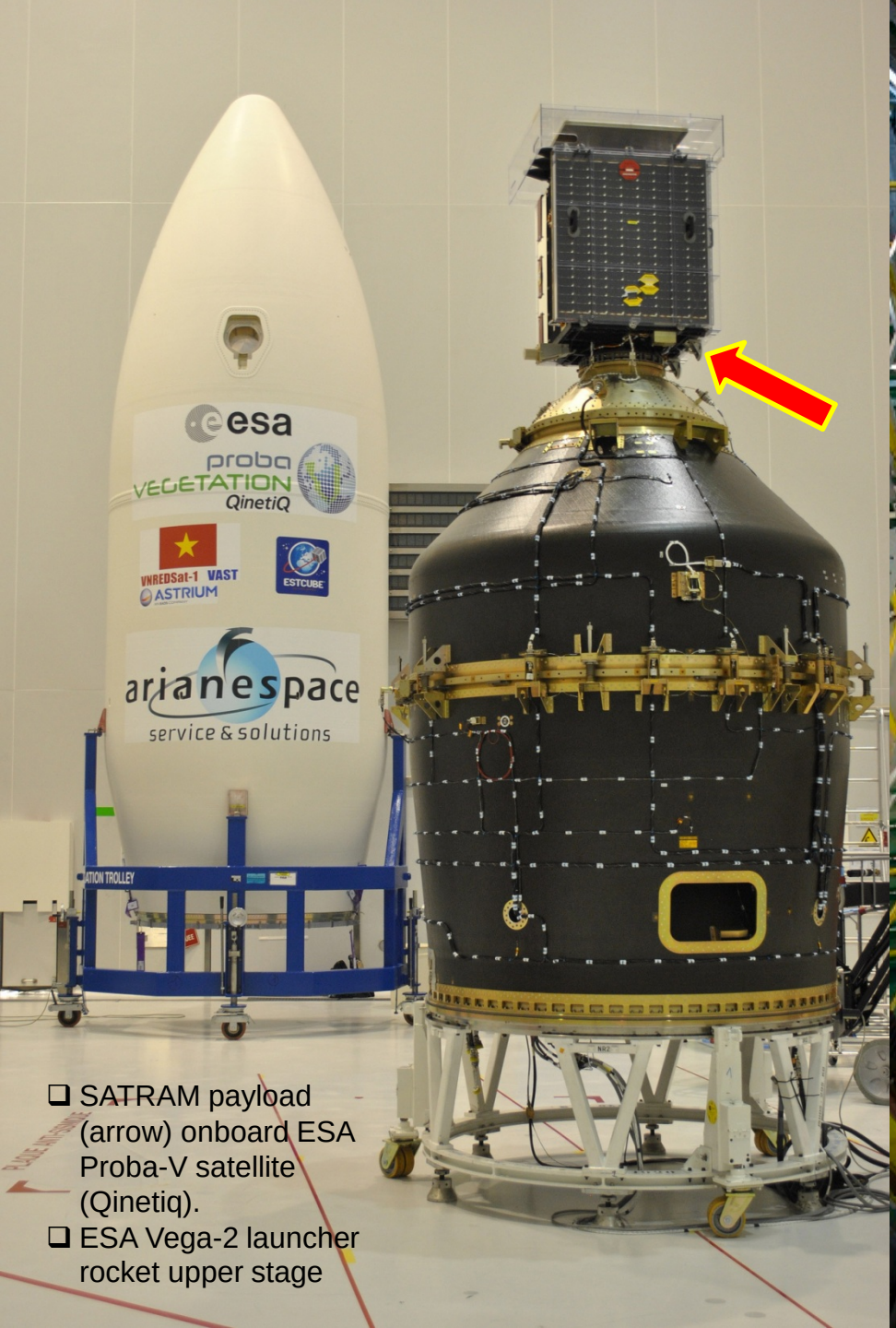
- Altitude ~ 820 km, sun synchronous orbit, 82º inclination
- Timepix for the first time in **open space** – currently TRL 9
- Launched 7th May 2013, duty cycle up to 90%



- *Size: 108 mm × 63 mm × 56 mm,* volume of 380 ml and *weight 172 g including casing/shield box,* 28 V voltage input, power consumption ≤ 3 W
- Wide field of view (2π), spatial resolution px size & sub-px, angular resolution 10°-0.1°,
- Energy threshold 4 keV (behind shielding casing), energy resolution 100 keV FWHM for 5.5 MeV alpha particles

SATRAM payload (arrow) onboard ESA Proba-V satellite (QinetiQ) attached to ESA Vega-2 rocket prior launch



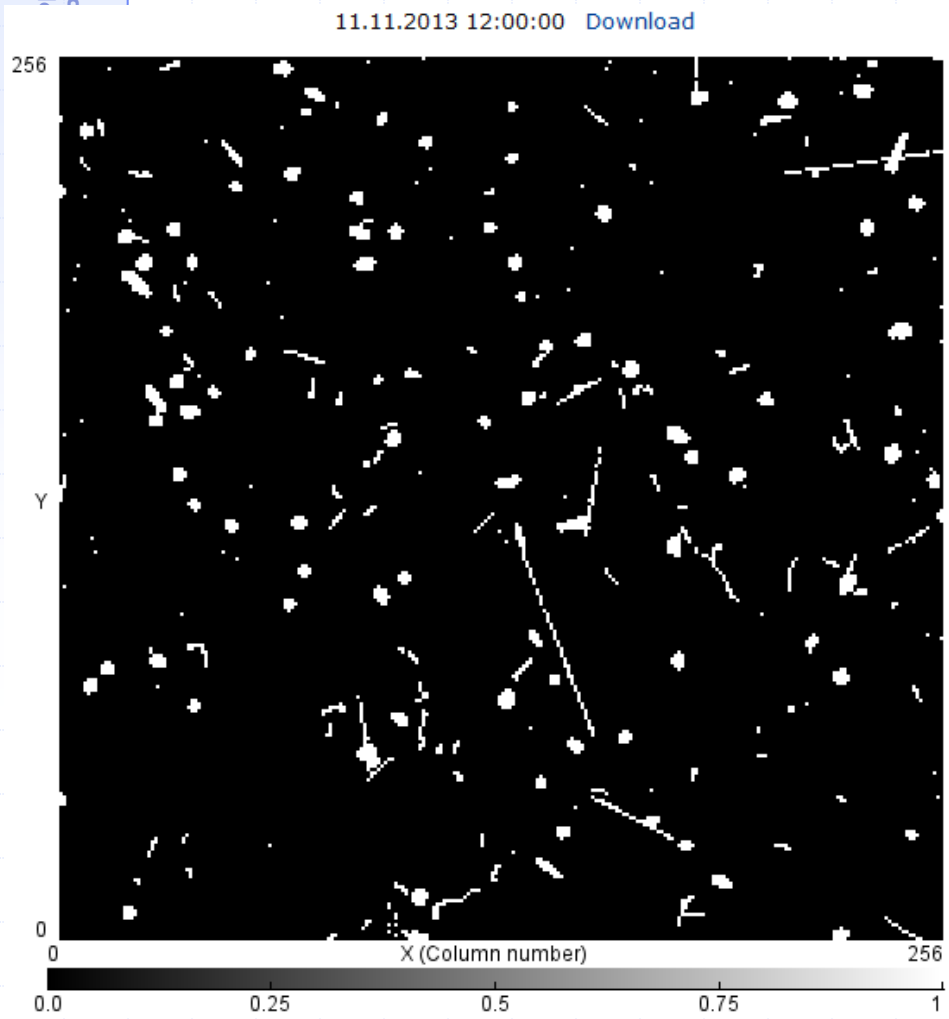


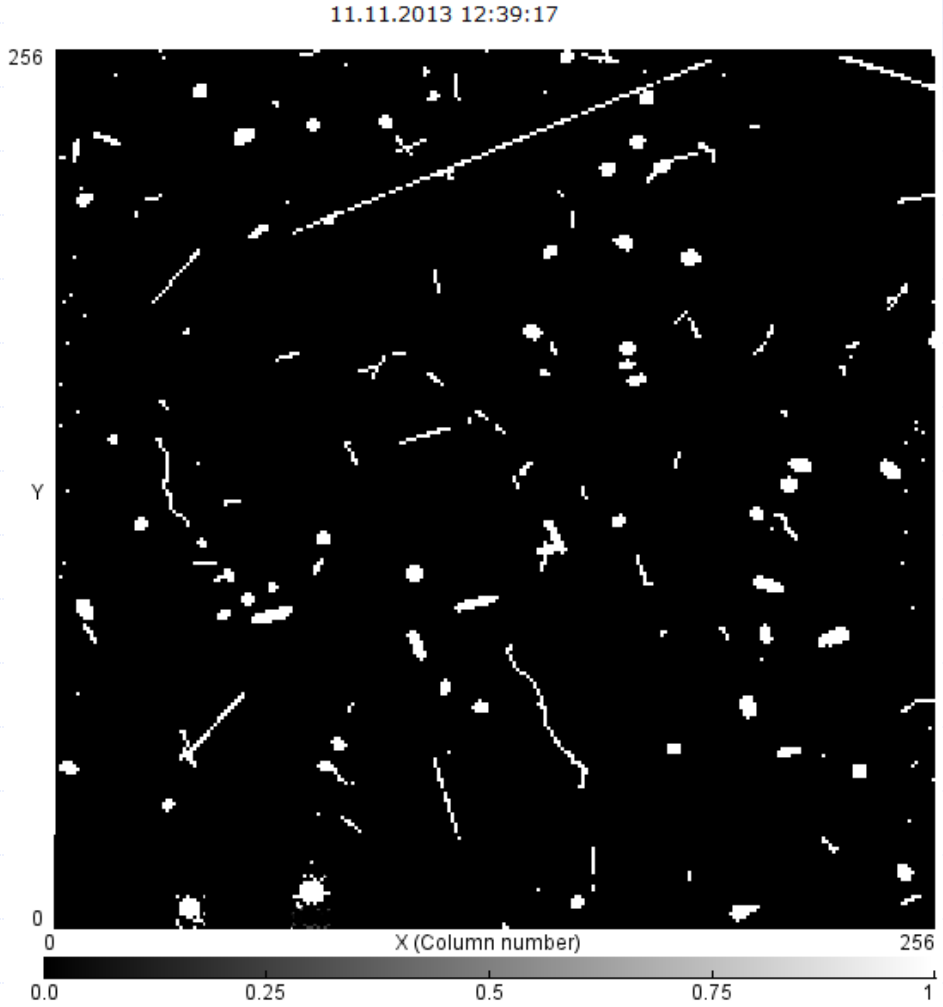
- SATRAM payload (arrow) onboard ESA Proba-V satellite (Qinetiq).
- ESA Vega-2 launcher rocket upper stage

Timepix in counting mode

Timepix/ESA Proba-V
Quantum imaging detection/monitoring of space radiation

High radiation regions & dominant flux of heavy charged particles (p's)

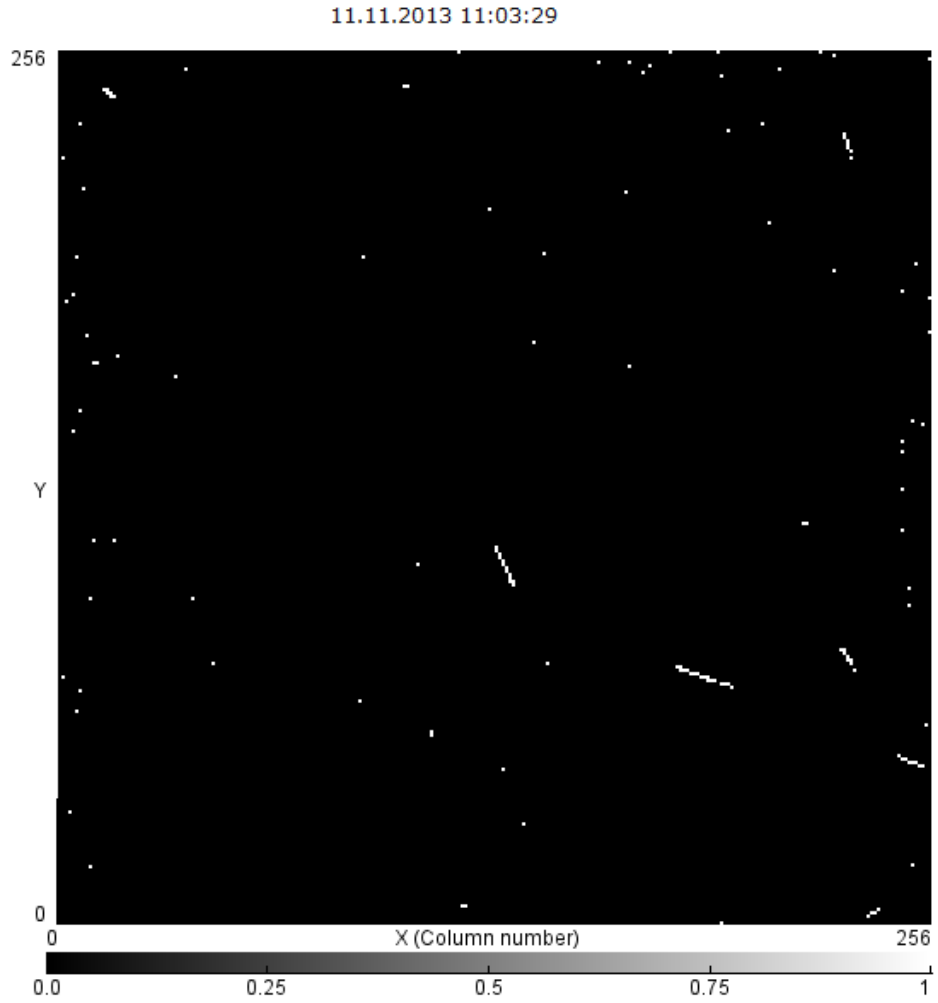


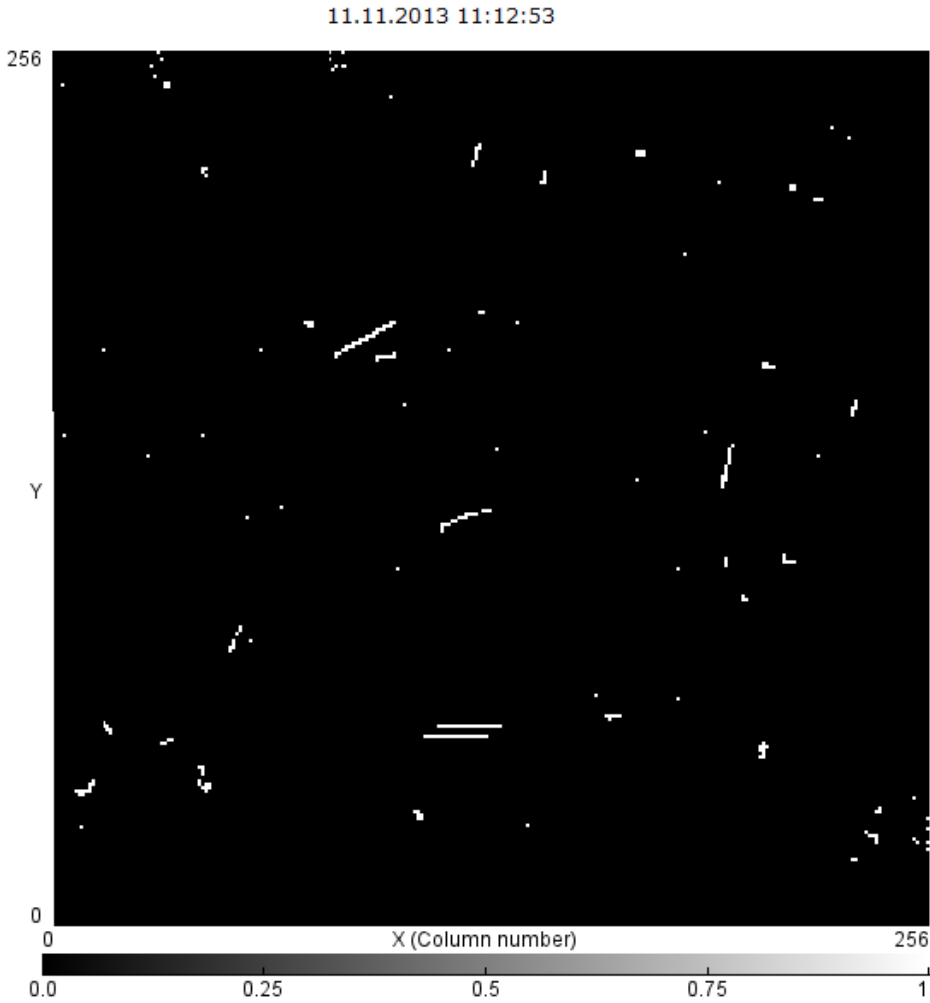


Timepix in counting mode

Timepix/ESA Proba-V
Quantum imaging detection/monitoring of space radiation

Low radiation regions & light charged particles (p's)

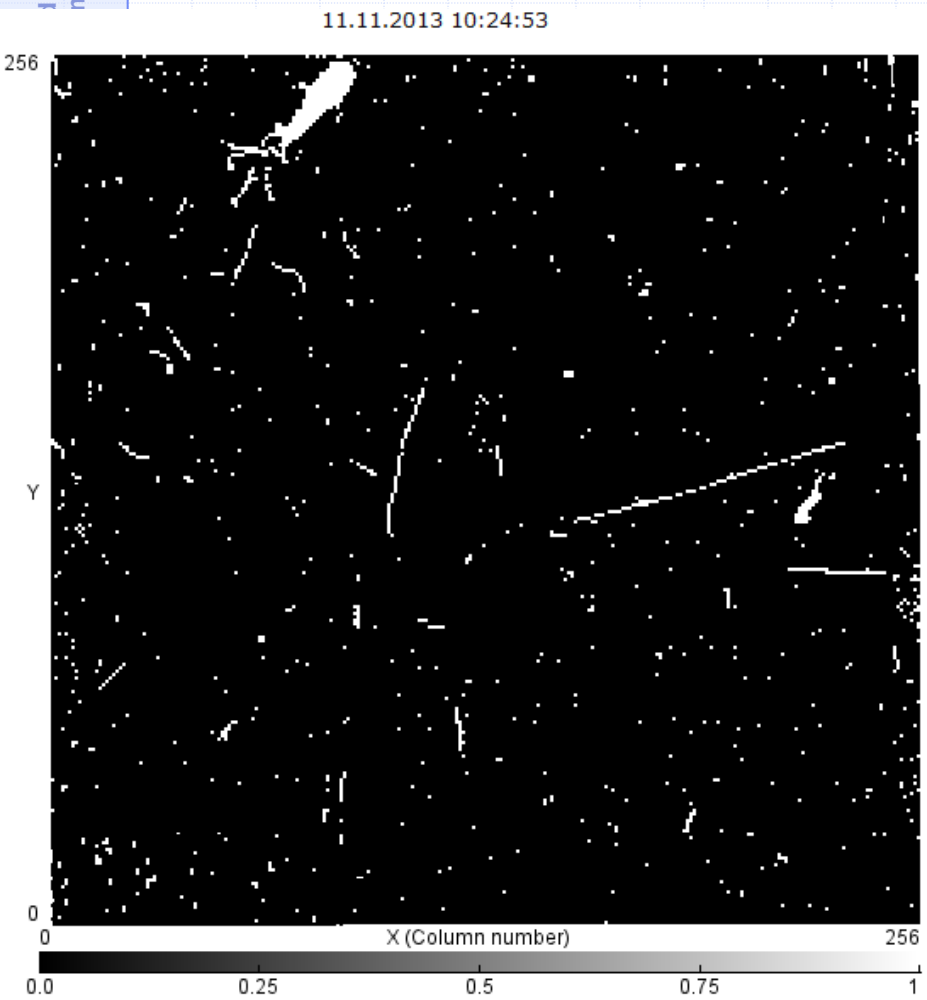


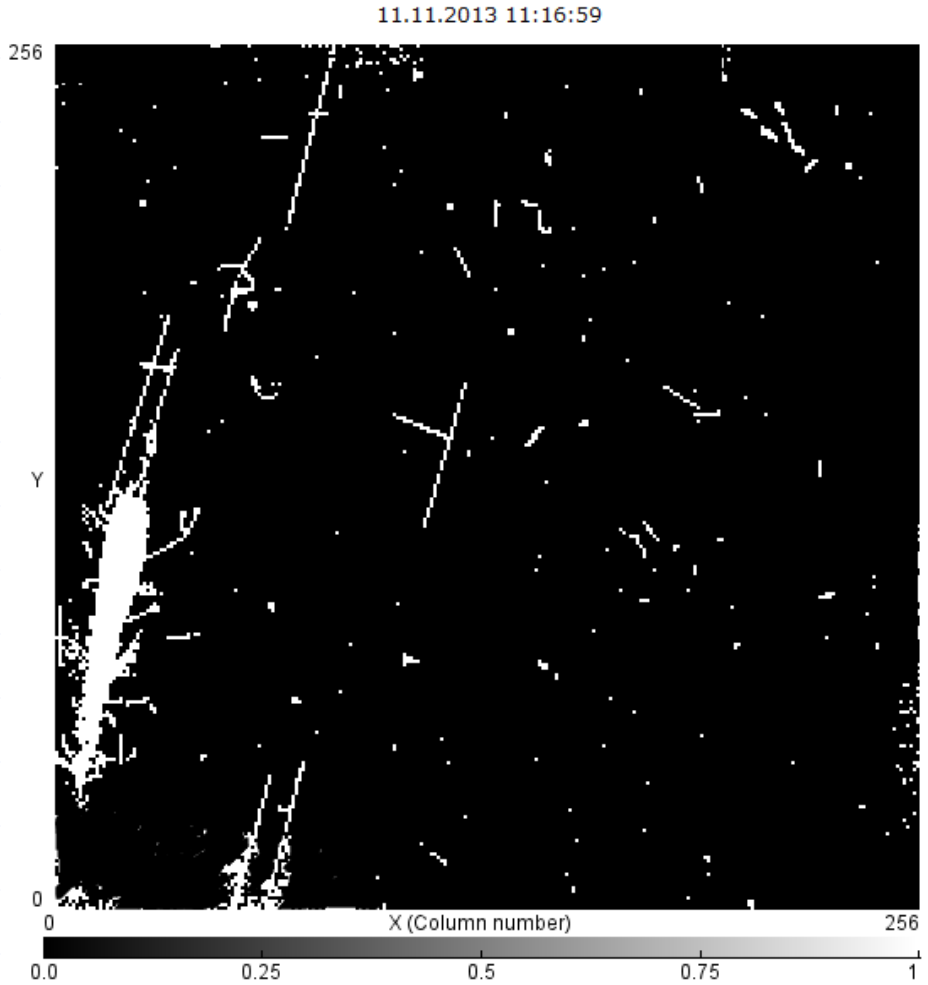


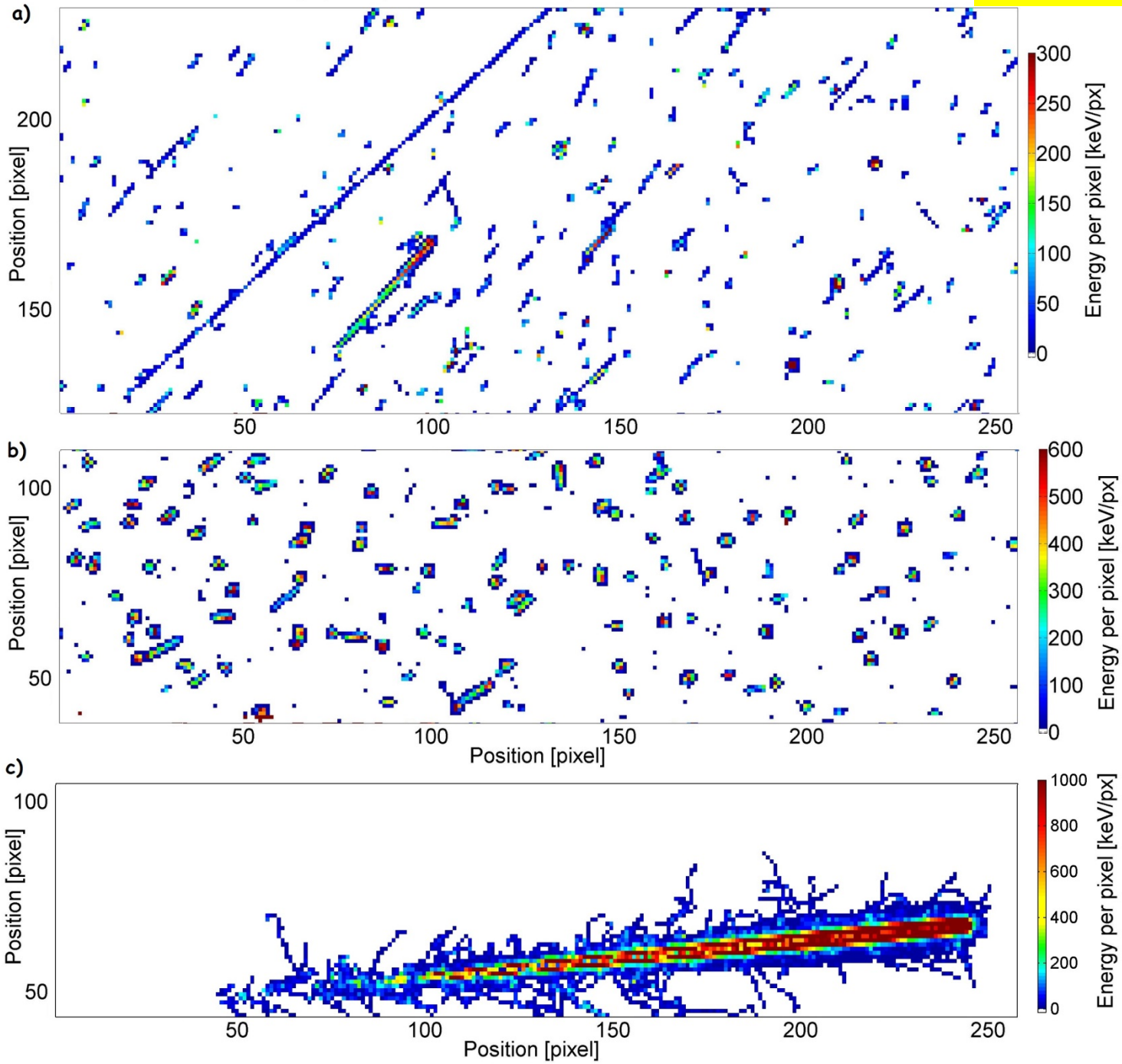
Timepix in counting mode

Timepix/ESA Proba-V
Quantum imaging detection/monitoring of space radiation

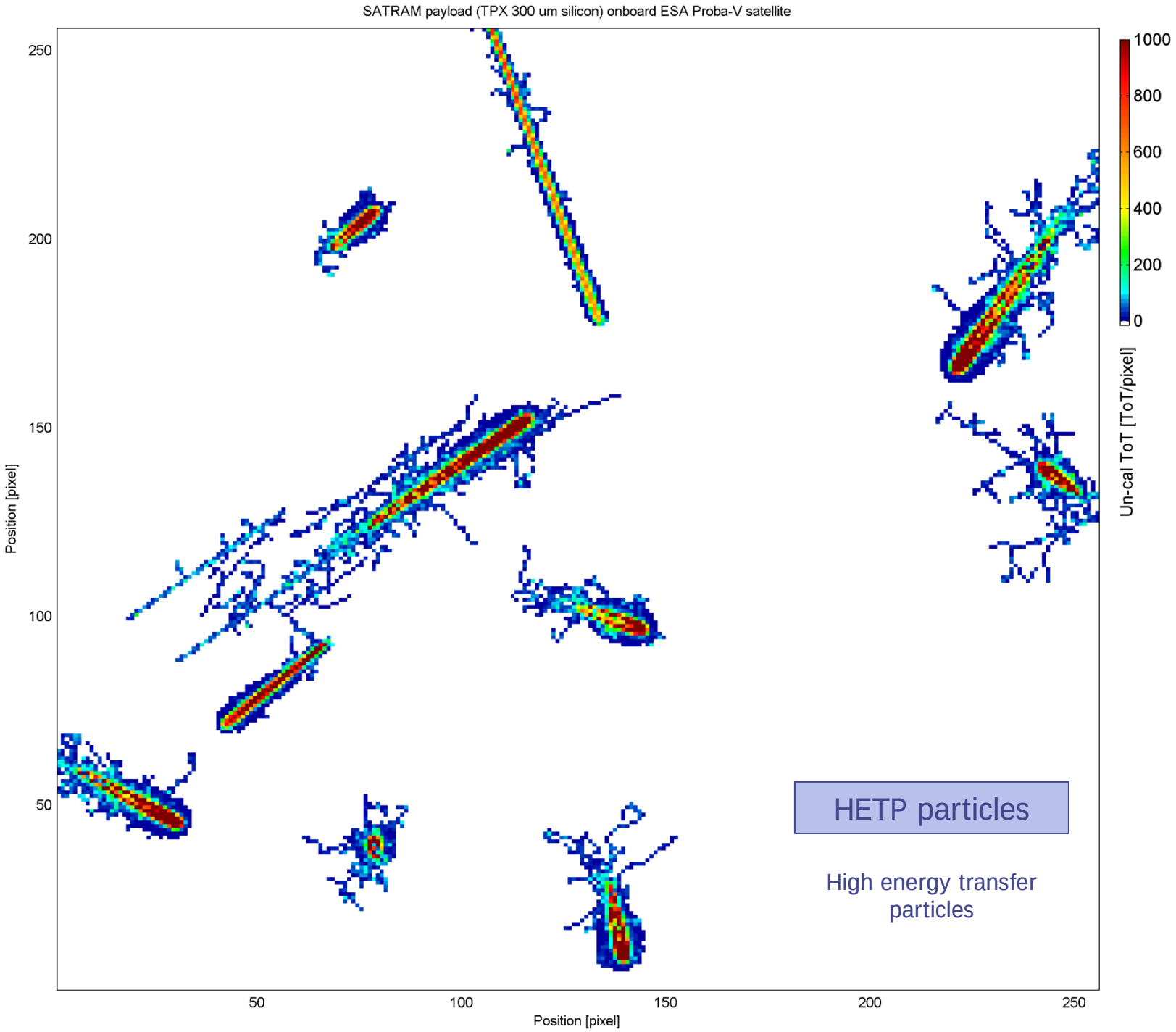
Energetic heavy charged particles (ions)







- Quantum imaging detection
- Resolving power radiation components
- directional sensitivity
- dE + track path → LET

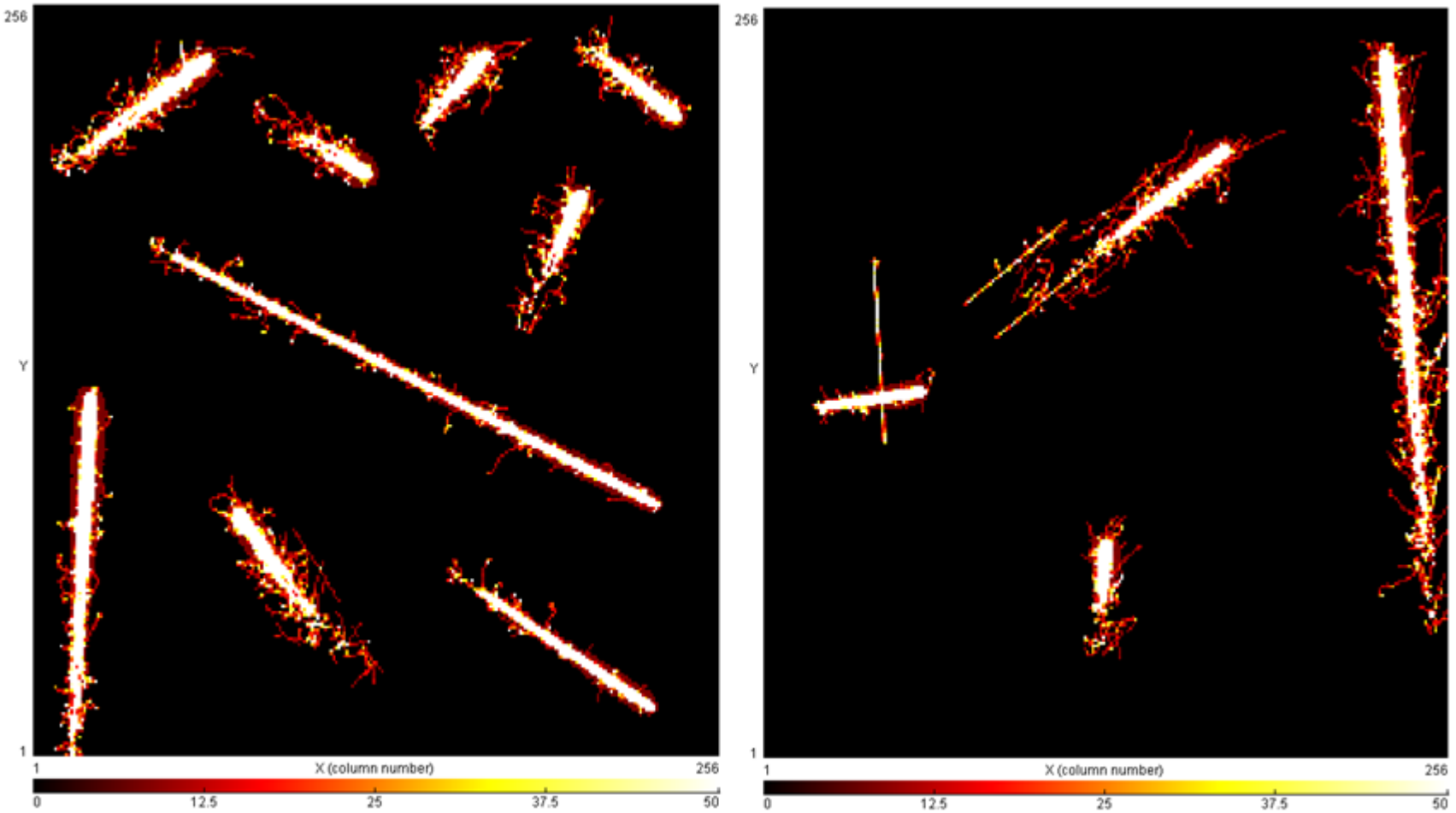

SATRAM payload (TPX 300 um silicon) onboard ESA Proba-V satellite
Position [pixel]
Position [pixel]
Un-cal ToT [ToT/pixel]
250
200
150
100
50
50
100
150
200
250
1000
800
600
400
200
0
HETP particles
High energy transfer particles

Timepix in energy mode

Timepix/ESA Proba-V
Quantum imaging detection/monitoring of space radiation

Institute of Experimental and Applied Physics
Czech Technical University in Prague

HETPs: Highly energetic heavy charged particles (ions) → HZE's

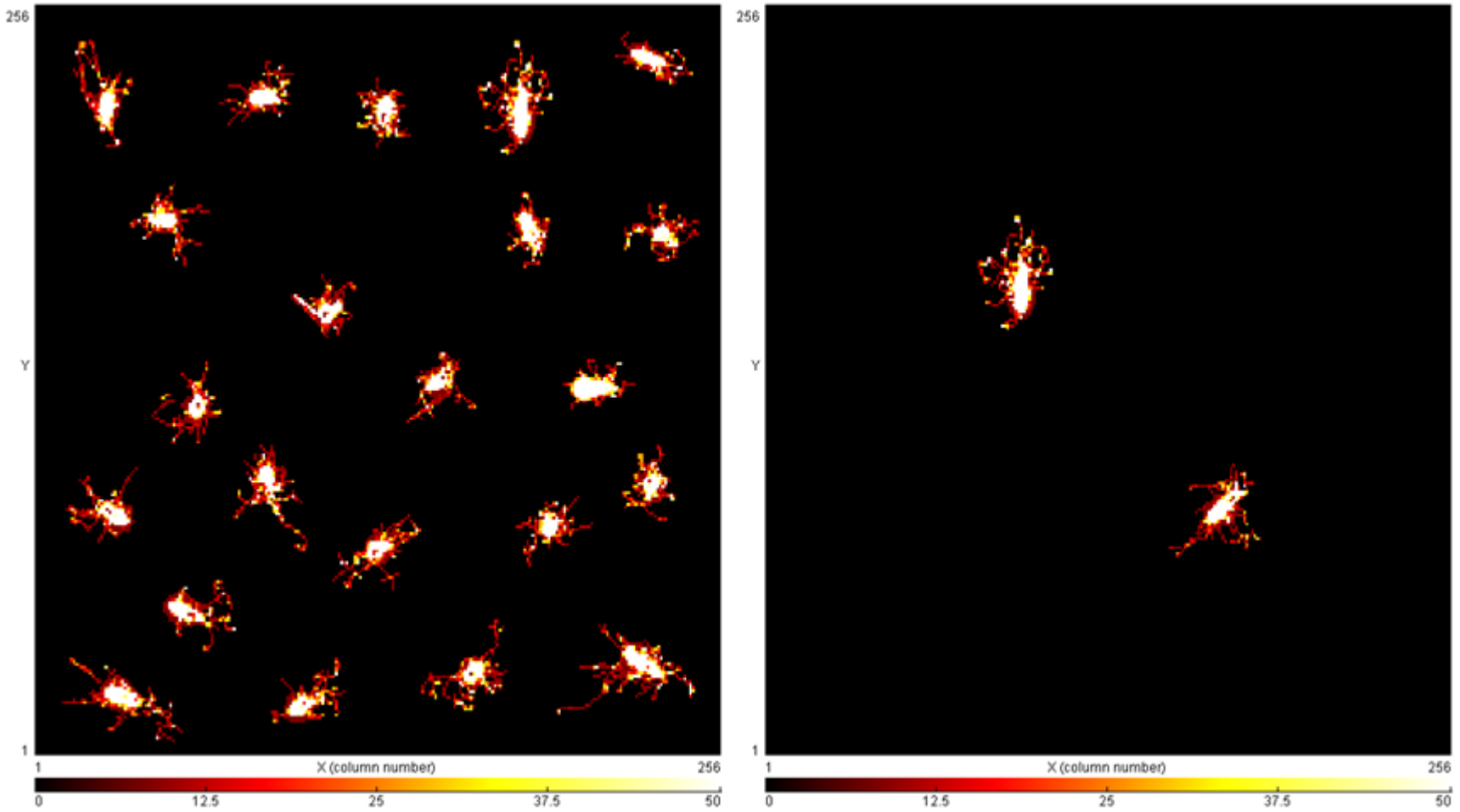


Timepix in energy mode

Timepix/ESA Proba-V
Quantum imaging detection/monitoring of space radiation

Institute of Experimental and Applied Physics
Czech Technical University in Prague

HETPs: Highly energetic heavy charged particles (ions) → HZE's

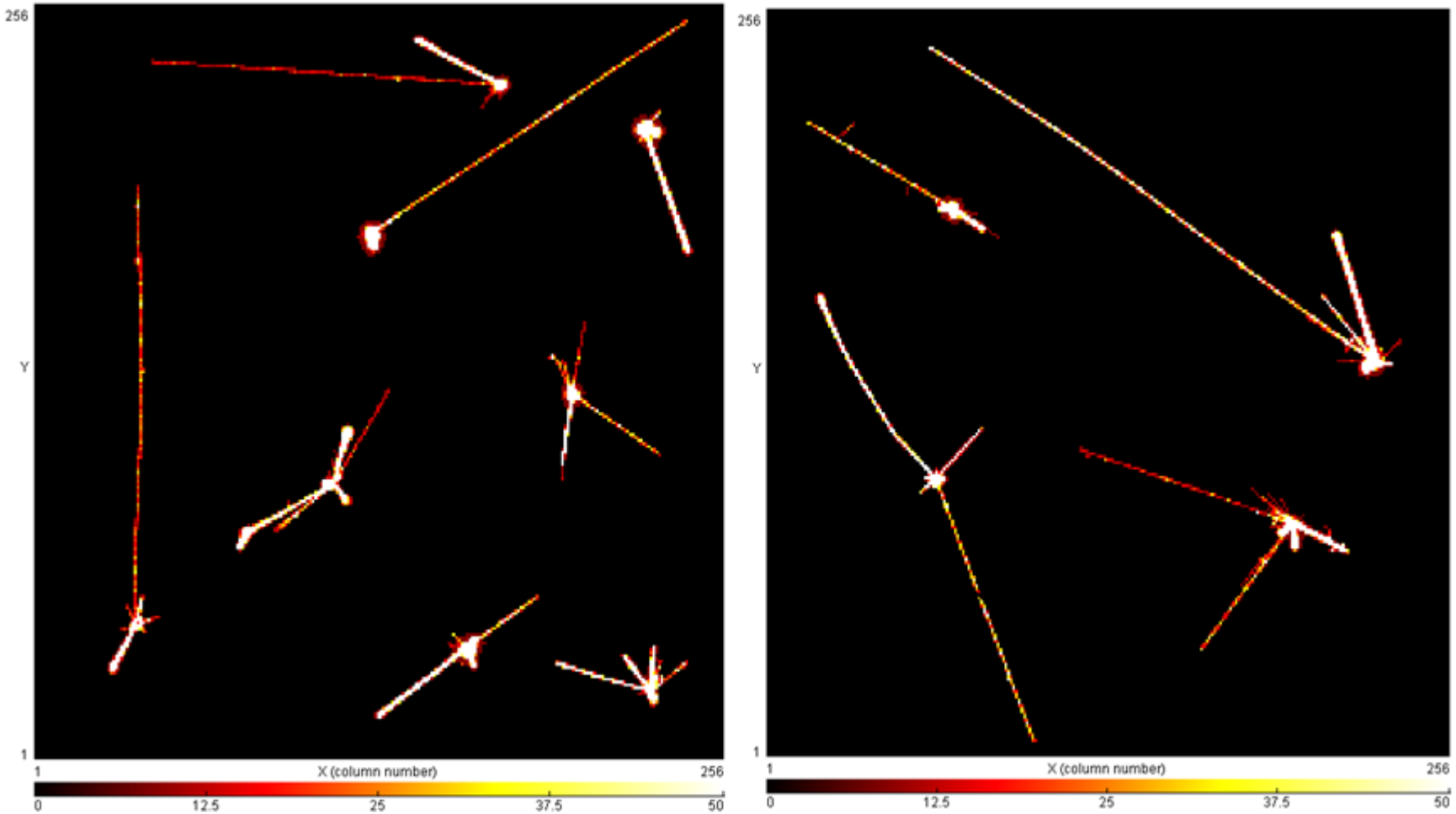


Timepix in energy mode

Timepix/ESA Proba-V
Quantum imaging detection/monitoring of space radiation

Institute of Experimental and Applied Physics
Czech Technical University in Prague

LETPs: Energetic light charged particles (I) + nuclear interactions/high-energy transfer events

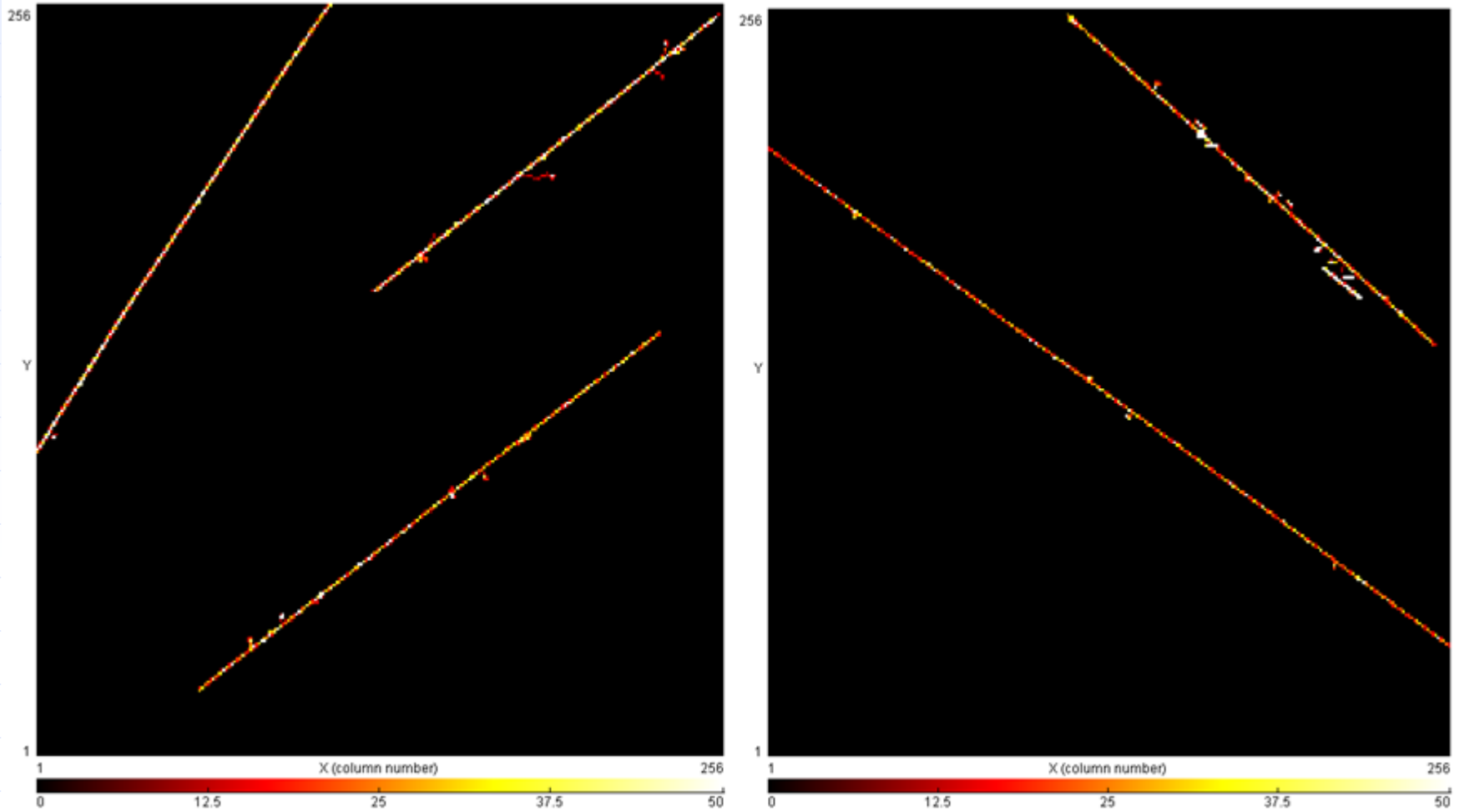


Timepix in energy mode

Timepix/ESA Proba-V
Quantum imaging detection/monitoring of space radiation

Institute of Experimental and Applied Physics
Czech Technical University in Prague

LETPs: Energetic light charged particles (II)



Timepix in energy mode

Timepix/ESA Proba-V
Quantum imaging detection/monitoring of space radiation

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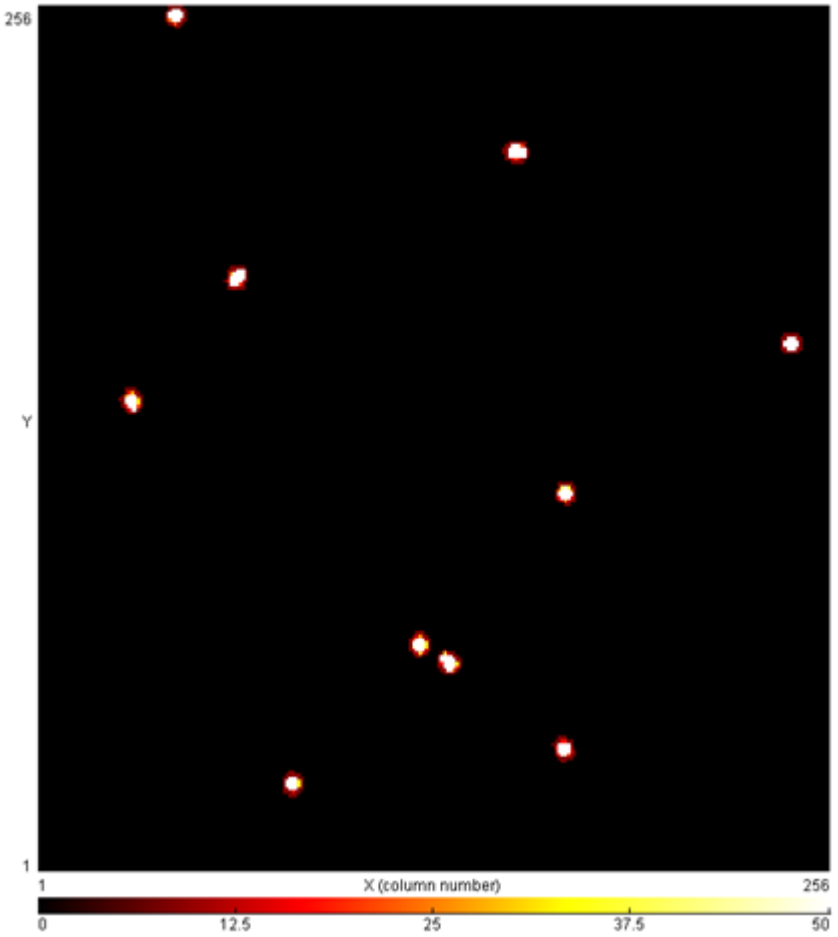
HETPs: mid-energetic heavy charged particles (protons)

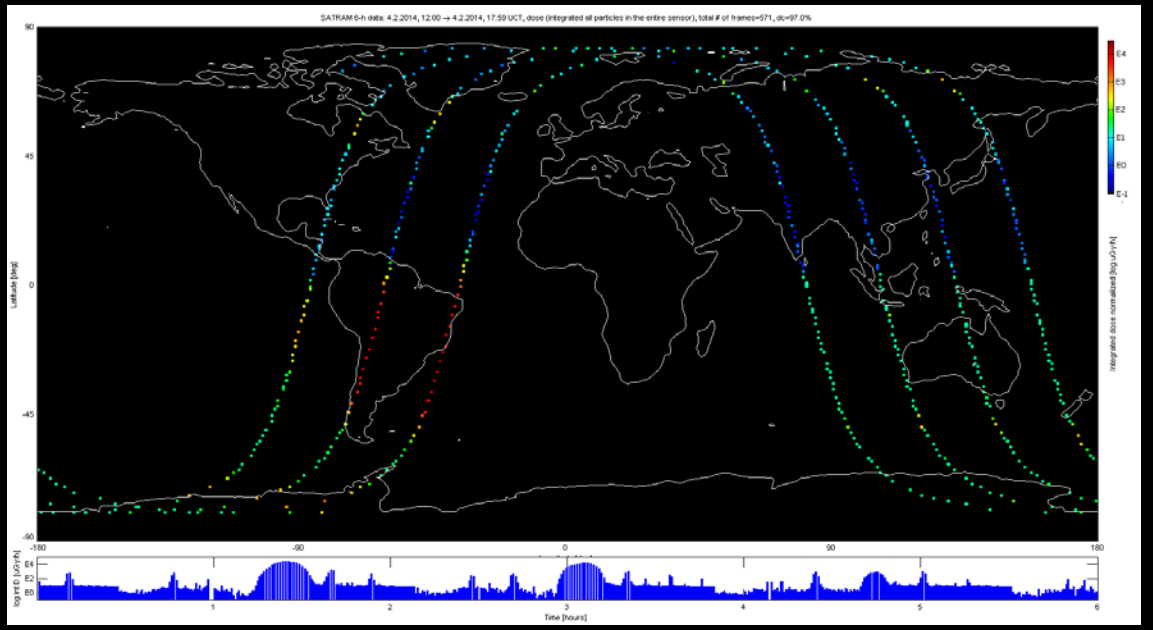


6 h: 4th Feb 2014

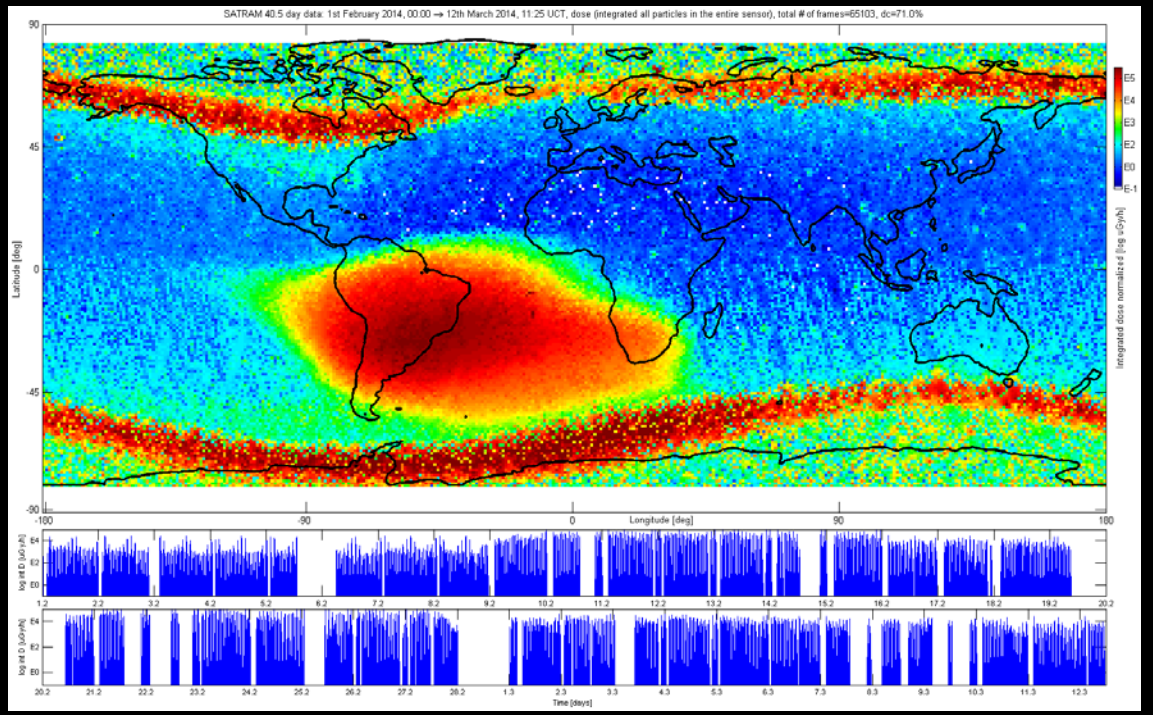
Spatial and time distributions of total absorbed dose at 820 km LEO orbit measured by SATRAM.

Data averaged from 571 and 65.103 Timepix frames collected over these periods, respectively (overall SATRAM operation duty cycle 97% and 71%, respectively).

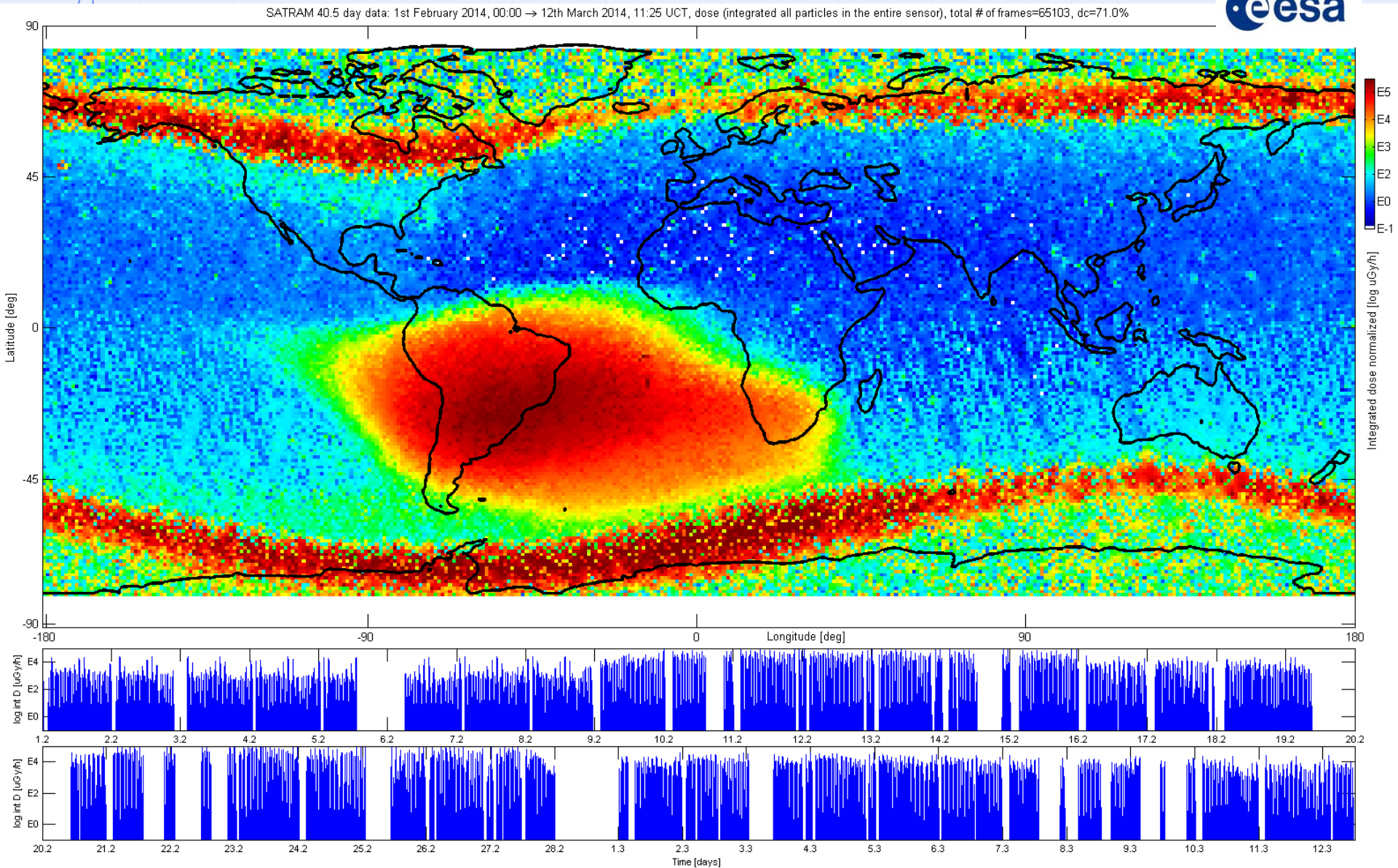
The quantity displayed (total absorbed dose, displayed in uGy/h) covers 6 orders of magnitude (see color bar log scale).

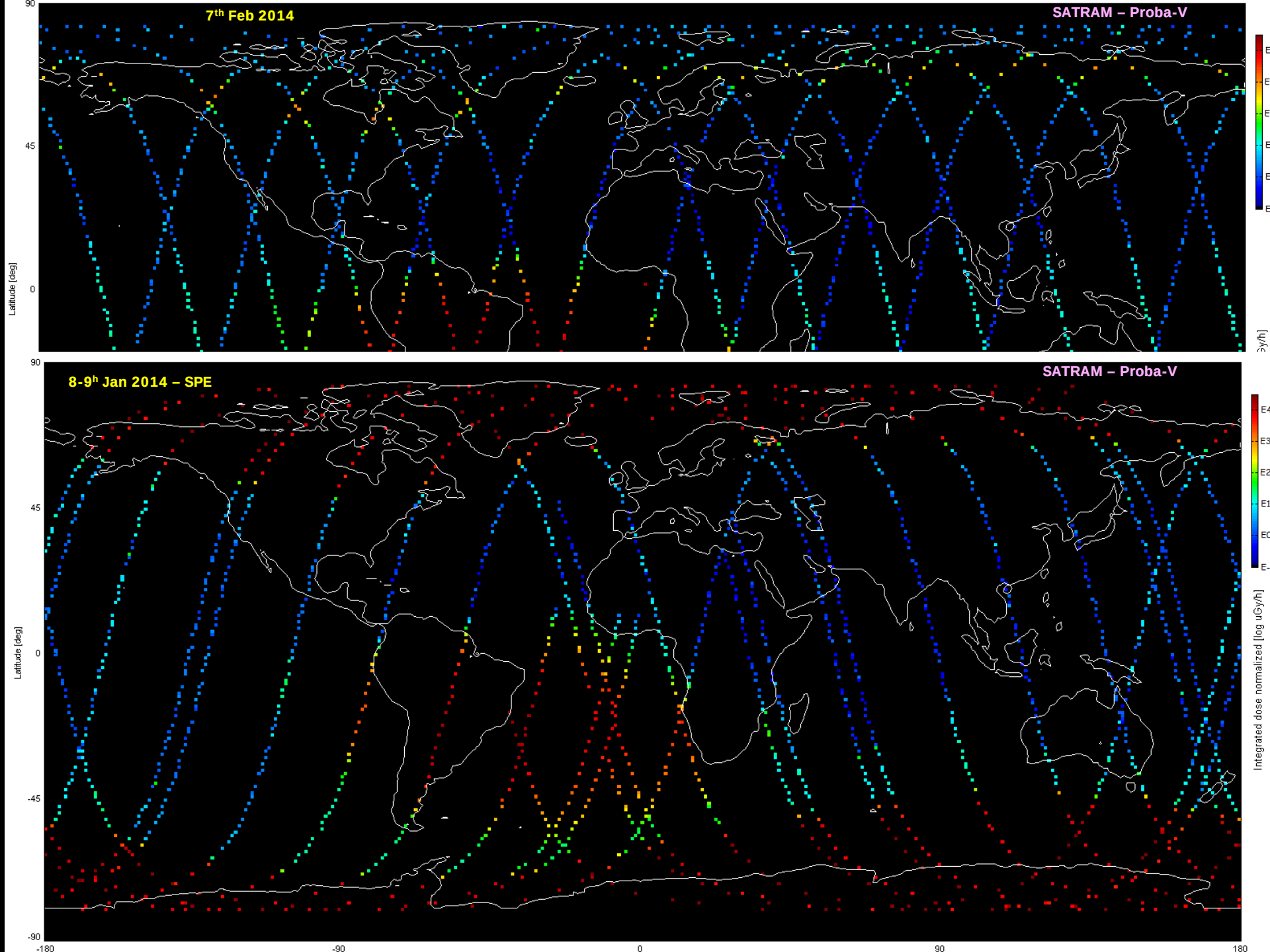


40 days: 1st Feb – 13th March 2014

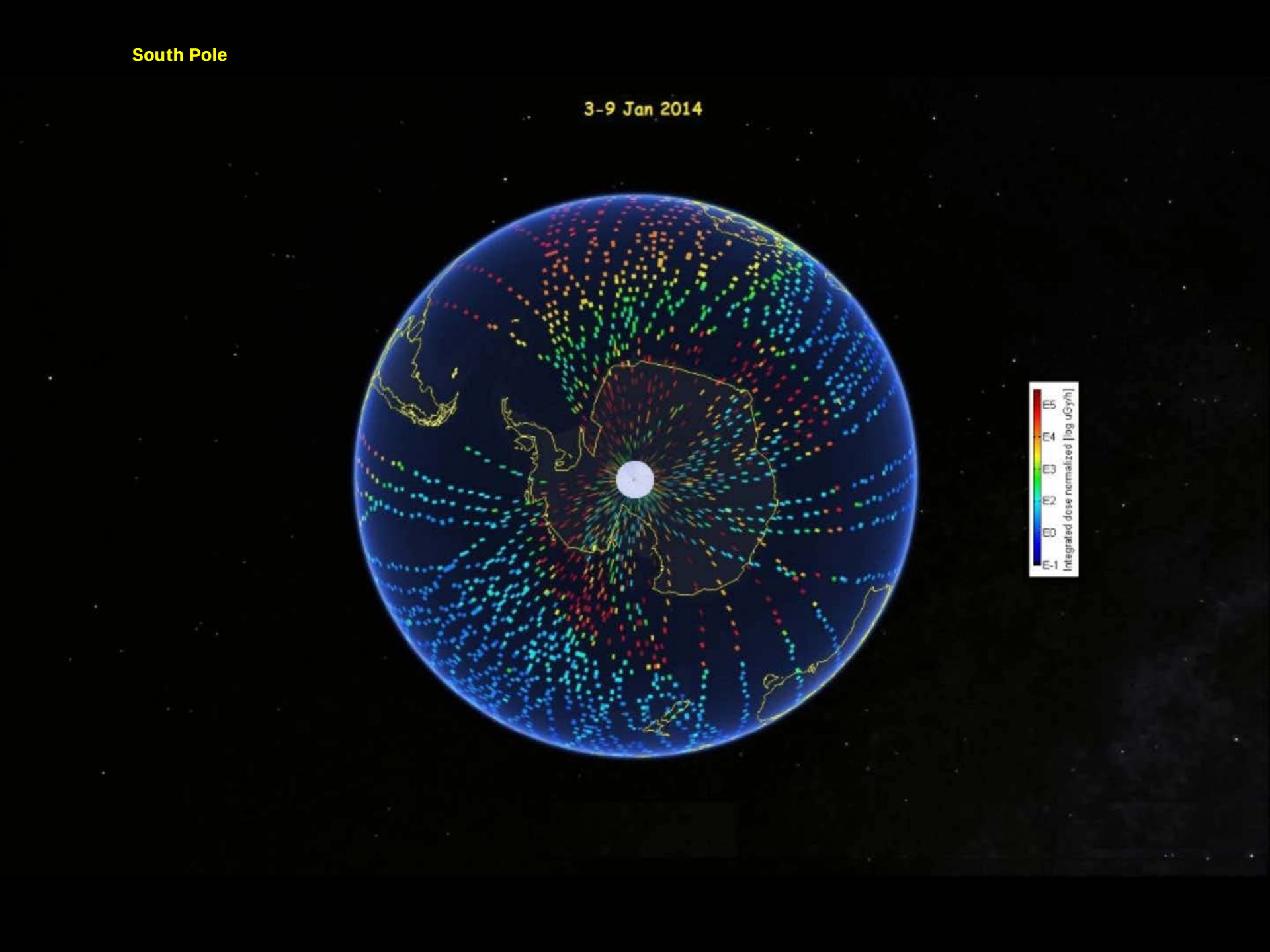


Timepix/ESA Proba-V + LEO space radiation @ 820 km
Spatial + time correlated distributions

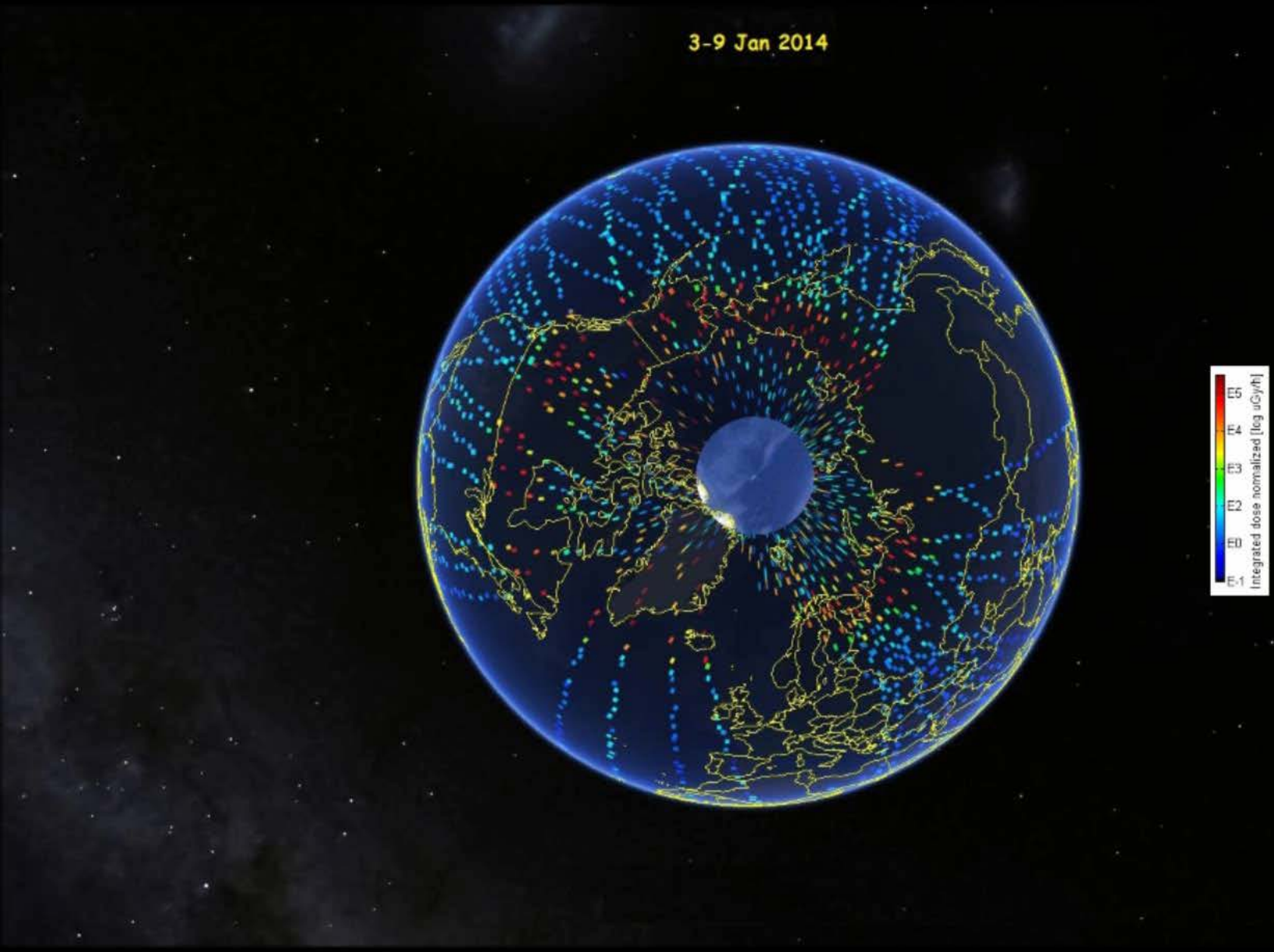



7th Feb 2014
SATRAM – Proba-V
8-9h Jan 2014 – SPE
SATRAM – Proba-V
Latitude [deg]
90
45
0
-45
-90
-180
-90
0
90
180
E4
E3
E2
E1
E0
E-
Integrated dose normalized [log uGy/h]

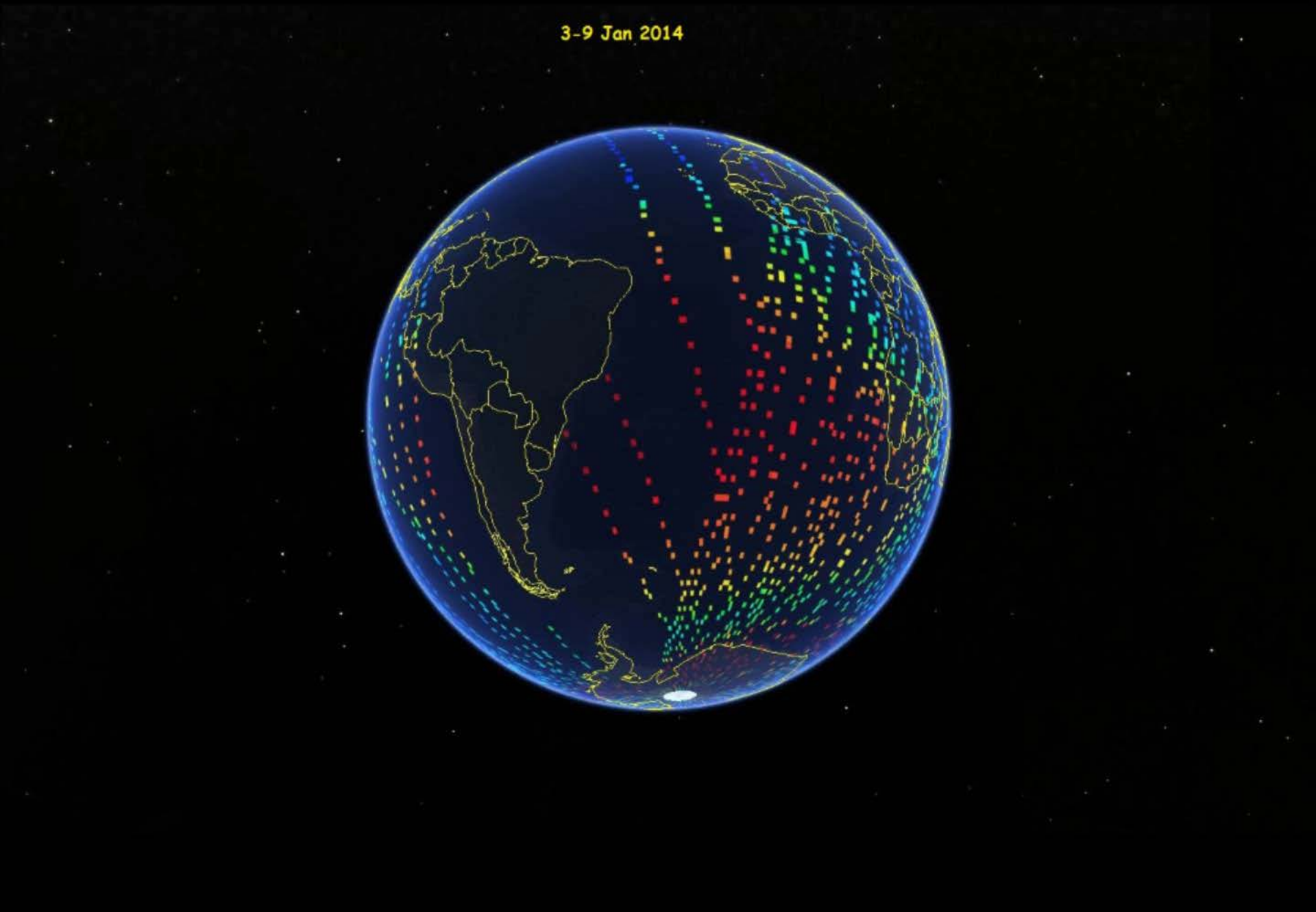
South Pole


3-9 Jan 2014
E5
E4
E3
E2
E1
Integrated dose normalized [log uGy/h]

North Pole

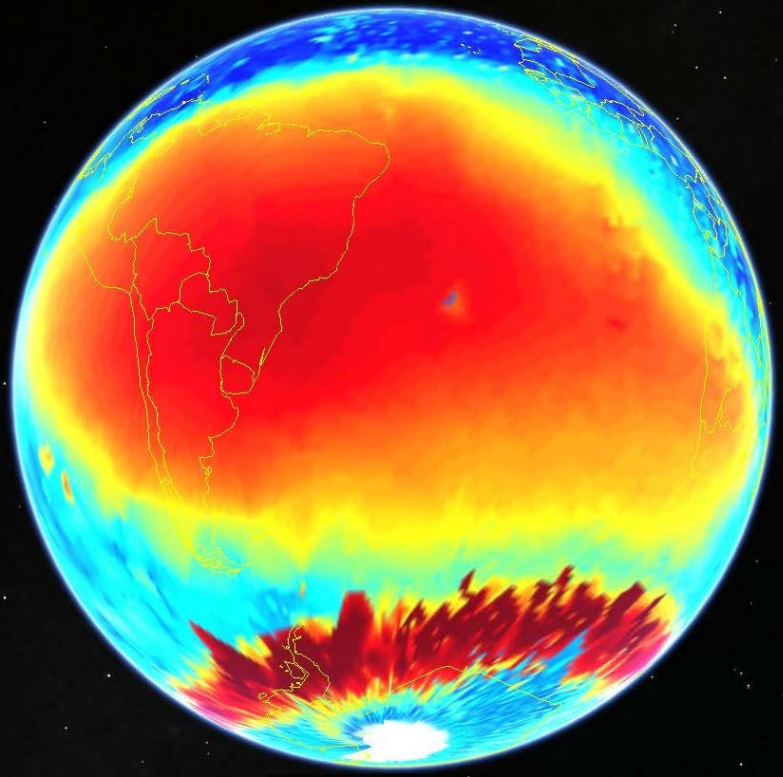

3-9 Jan 2014
E5
E4
E3
E2
E0
E-1
Integrated dose normalized [log uGy/h]

South Atlantic Anomaly



Thank you

Project funded by the European Space Agency,
Project No. 4000105089/11/NL/CBi



South America, Antarctica, South Atlantic Anomaly SAA

- Radiation field Earth map spatial distributions measured by Timepix onboard ESA Proba-V satellite LEO orbit 820 km altitude displaying all radiation components integrated over 5.5 months
- Detailed data analysis in progress (radiation component & directional distributions)

The Americas