Medipix Collaboration Meeting – CERN, 19-20.2.2014

Seminář o malých družicích v ČR, CSO / FEL ČVUT, Praha, 4.3.2014

Science/physics research

- Space radiation physics + space weather
- Space crew dosimetry + shielding
- Radiation effects (SEE, SEU) on spacecraft, payloads and EECs

Space technology

- Spacecraft platform device

Timepix in open space

Detection and track visualization of space radiation at LEO orbit onboard ESA Proba-V satellite

Carlos Granja, Štepan Polansky*, Daniel Tureček*, Stanislav Pospíšil, Zdeněk Vykydal*, Václav Kraus*, Jan Jakůbek

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

Karim Mellab, Alan Owens, Petteri Nieminen

European Space Agency (ESA), ESTEC, Netherlands

M. Šimčák, Z. Dvořák, Z. Kozaček$, P. Vána$, J. Mareš$

Czech Space Research Center, Brno, Czech Republic

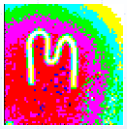
**PhD student*

$ *former staff*

Research performed in frame of the CERN Medipix Collaboration

Project funded by the European Space Agency

IEAP–CTU Prague



Other projects, teams/co-authors

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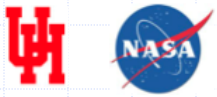
Czech Technical University in Prague

- 5x TPX devices onboard ISS since 2012, Houston/NASA (launched/in orbit 3Q 2012)
- Timepix tracker/particle telescope for micro-satellite RISESAT, Japan (2015)
- Pixel detector payload for ESA BEXUS Ballon, Ch. Univ. Prague (2011)

Michal Platkevic*, Iván Caicedo*&, Benedikt Bergmann*#%
Institute of Experimental and Applied Physics, Czech Technical University in Prague, Czech Republic

Petteri Nieminen
European Space Agency (ESA), ESTEC, Netherlands

Lawrence Pinsky, et al.
University of Houston/NASA, USA



Toshinori Kuwahara
Tohoku University, Sendai, Japan

東北大学
TOHOKU UNIVERSITY

Jaroslav Urbar*
Charles Univ. Prague/Czech Space Office, Czech Republic

 # MC simulations

** PhD student* *% U of Erlangen, Germany* *& U de los Andes, Bogota, Colombia*

Timepix in open space

Characterization and particle visualization of mixed radiation fields in space

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Quantum counting/pos-sen/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

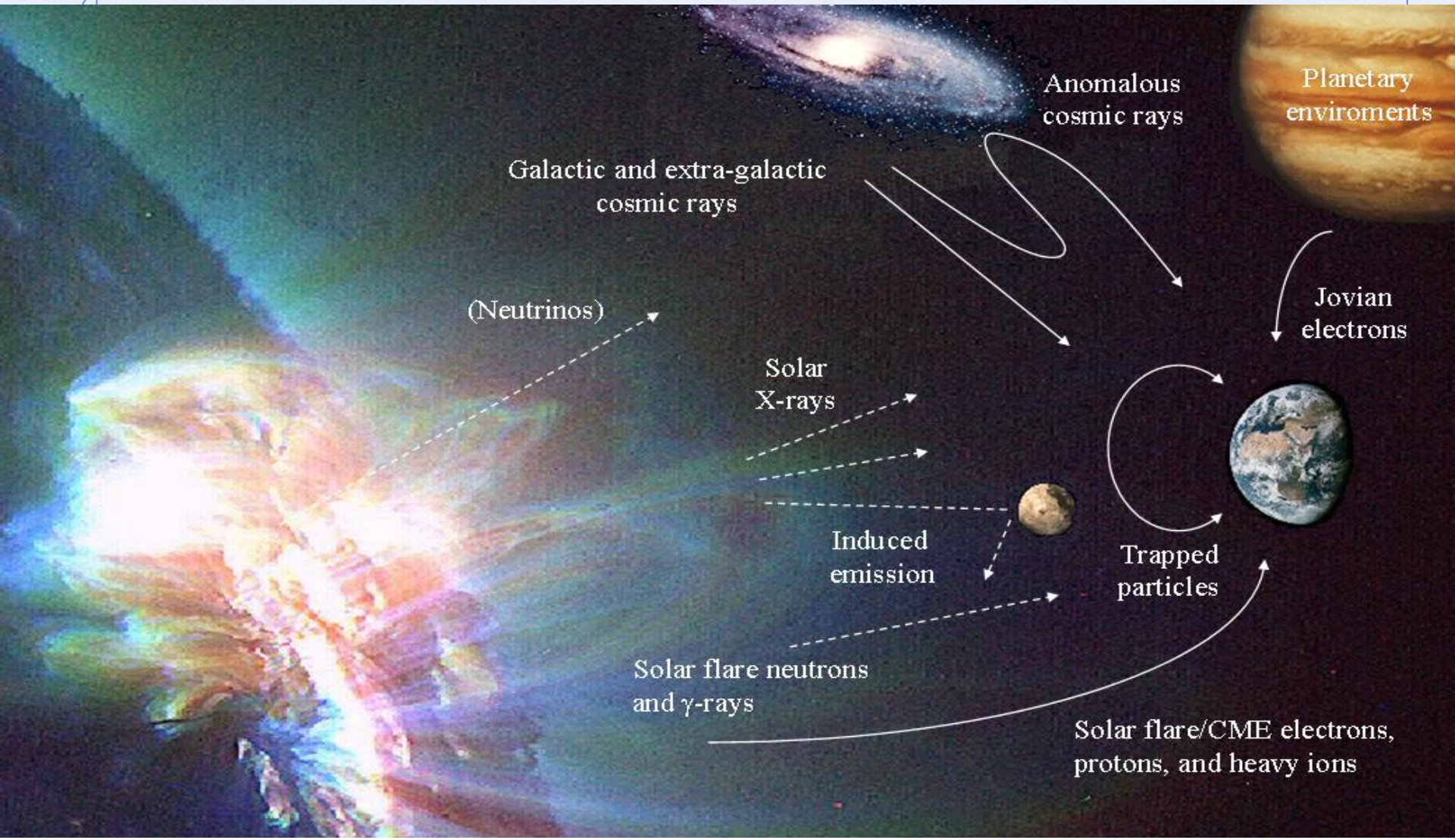
technical

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

!

Space Radiation Environment

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



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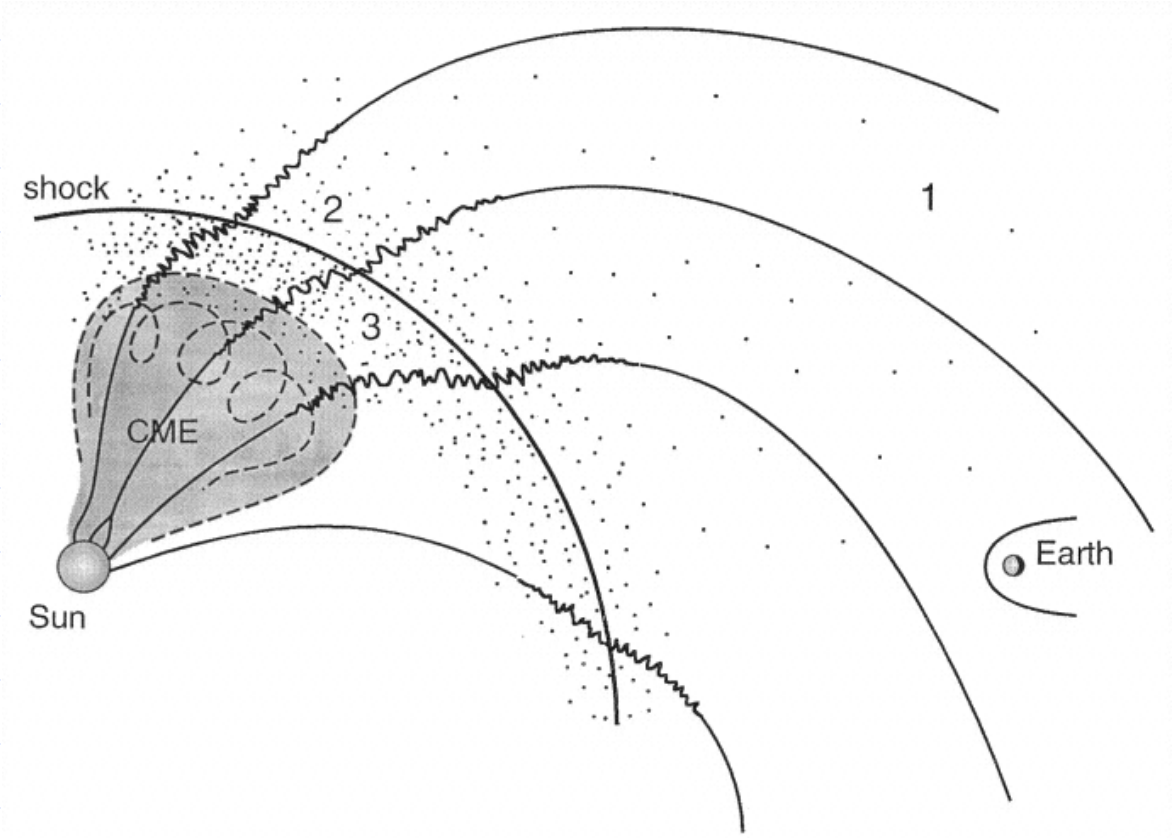
Solar Particle Events

Coronal mass ejections – CMEs

CMEs are directional..!



Energetic solar particles follow curved dynamical field lines

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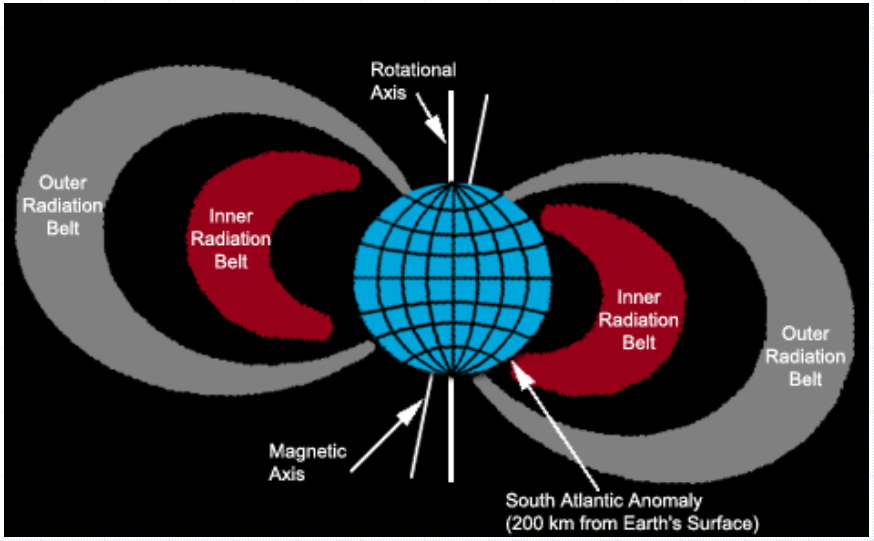
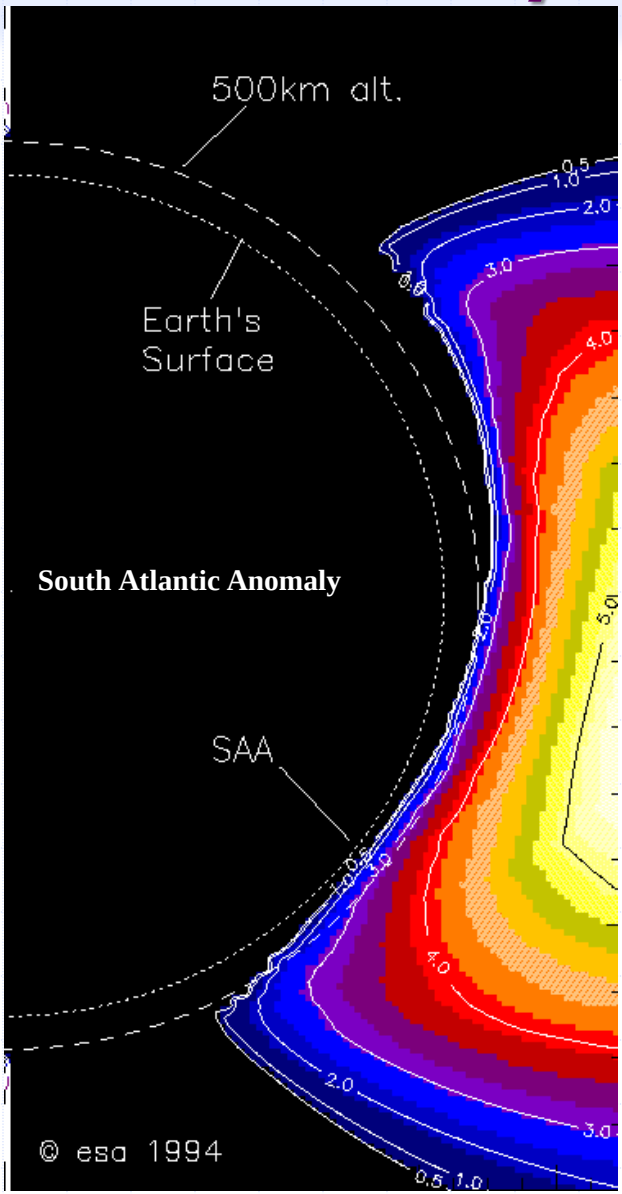
Earth radiation belts & South Atlantic Anomaly

- **Inner Belt**
  - mainly protons; energies up to ~500 MeV
  - 400 MeV peak ~1.3 R_E
  - 4 MeV ~2.0 R_E
- **Outer Belt**
  - mainly electrons; energies > several MeV
  - Large variations (2-4 orders of magnitude) over periods of hours to days
- **Rapid transits through belts limit doses to crews**





Space Radiation Environment

Solar particle/proton events (SPEs): intense, temporal & highly directional..!

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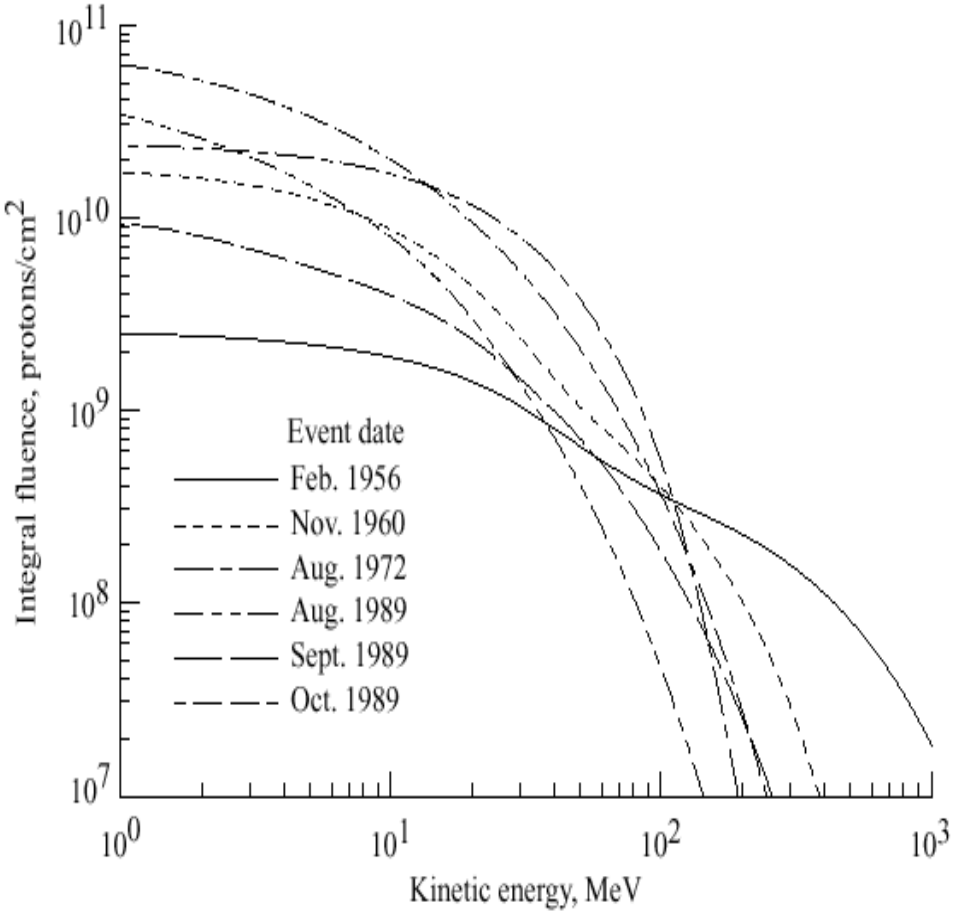
- Rapid onset times (minutes), with durations up to hours or days
- Essentially unpredictable, however generally coincide with solar maximum periods
- Proton energies up to ~100s of MeV, sometimes GeV range
- Integral fluence up to ~10^9 – 10^{10} p/cm^2 (>1 MeV)
- Contribution from heavy ions and e-
- In the main phase of an event, local particle fluxes isotropic

Integral fluence of protons [events/cm^2]



SPACE WEATHER

Where did all the electrons go?

Geomagnetic storms driven by the solar wind can cause the flux of high-energy electrons in the Earth's Van Allen belts to rapidly fall. Analysis of data obtained during one such event from multiple spacecraft located at different altitudes in the magnetosphere reveals just where these electrons go.

Mary K. Hudson

As the Sun's activity increases towards the peak of its approximately eleven-year cycle, predicted to occur in 2013 (ref. 1), there will be increased attention paid to the resulting surges of high-energy electrons that are trapped by the Earth's magnetic field. These electrons — also known as killer electrons[2] — pose a direct hazard to astronauts and spacecraft. The severest of these space weather events can even affect systems on the ground, including communications networks and power grids[3]. Yet, the relationship between these events and the solar activity that generates them is not as simple as one might expect. Indeed, weather satellites — often by many orders of magnitude in just a few hours. The mechanism that causes these 'flux dropouts' has never been clear. Yet, it is necessary to better understand this flux decrease at the beginning of storms if we are ever to understand, and better predict, the processes that drive subsequent increases that threaten the systems on which our modern society depends. The first step is to work out where these electrons go. Do they simply move somewhere else in the equatorial plane? Do they fall to Earth and get lost in its atmosphere? Or are they funnelled back out into space?

moderate geomagnetic storm that began on 6 January 2011. Figure 1 shows data collected during this event by the National Oceanic and Atmospheric Administration (NOAA)'s Geostationary Operational Environmental Satellites (GOES) located over the eastern and western United States. To build a complete picture of this event, the authors combined the GOES data with data that was simultaneously collected by NOAA's Polar Operational Environmental Satellites (POES) in low-altitude polar orbit, and by NASA's Time History of Events and Macroscale Interactions during Substorms (THEMIS) satellites in high-altitude,

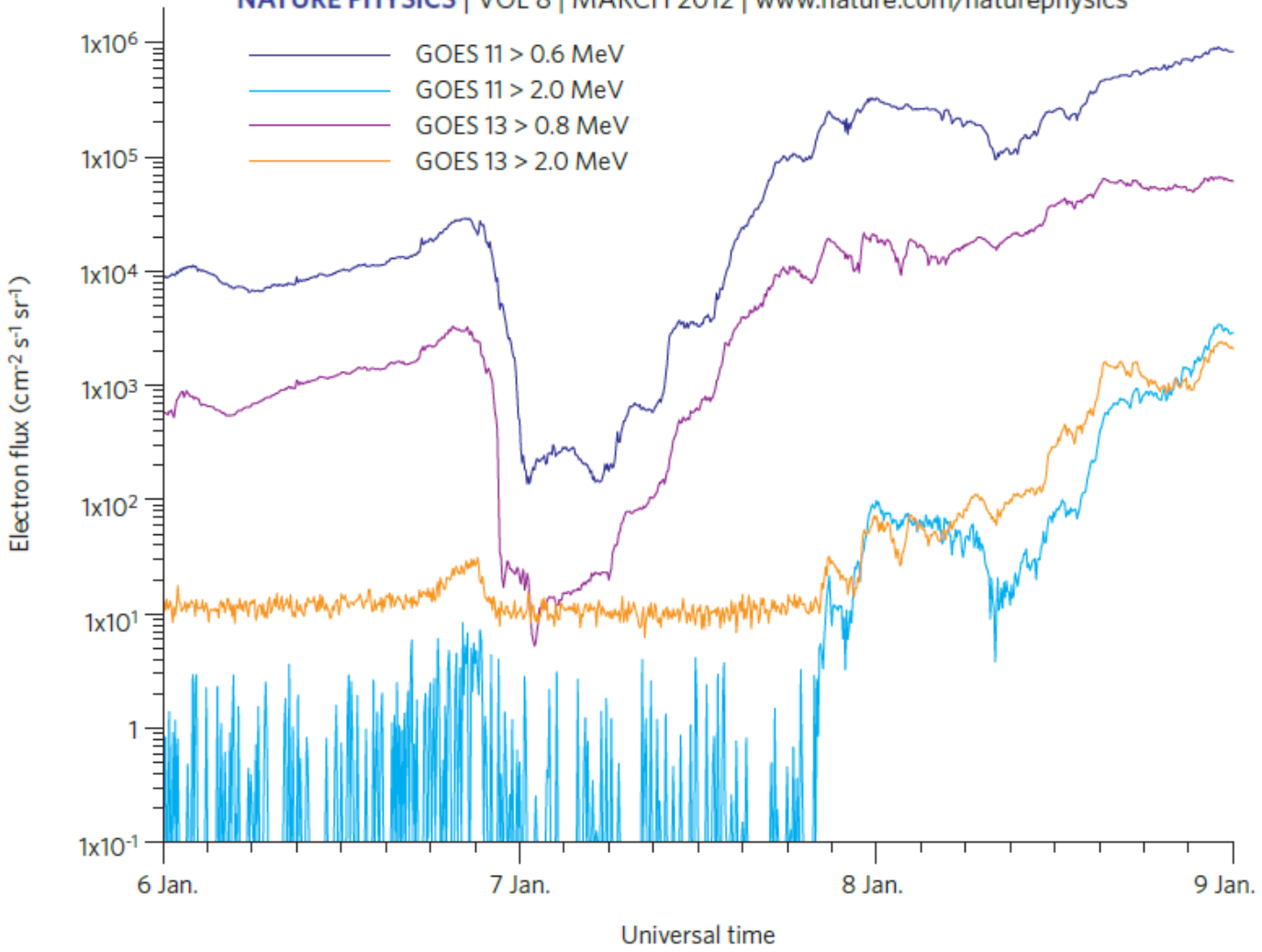


Figure 1 | High-energy electron flux measurements collected by NOAA GOES satellites 11 and 13 during a geomagnetic storm that began on 6 January 2011. Just before midnight of the eve of 6 January, the flux of electrons with energies above 0.6 and 0.8 MeV measured by satellites 11 and 13, respectively, decreased rapidly by over two orders of magnitude. Several hours later, the flux of these electrons recovered and was accompanied by an increase in the flux of higher-energy electrons above 2.0 MeV as the main phase of the storm took hold. Figure courtesy of Howard Singer, National Oceanic and Atmospheric Administration.

Timepix-based
space payloads/instruments

Institute of Experimental and Applied Physics
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

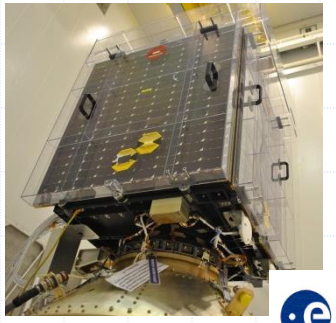
International Space Station

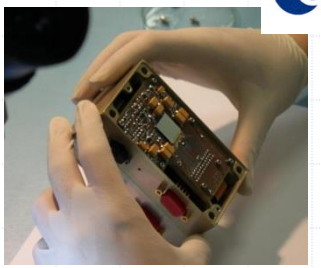
In orbit since 3Q 2012 | 400 km

5 x Timepix devices

ESA Proba V satellite

Launched 7th May 2013 | 820 km

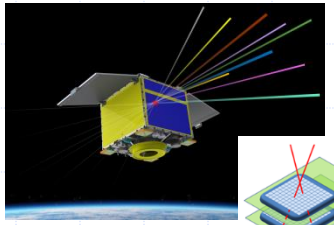


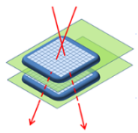


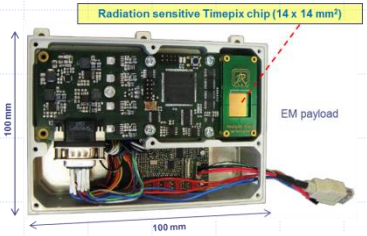
150 Kg

RISESAT satellite

Launch 2014/5







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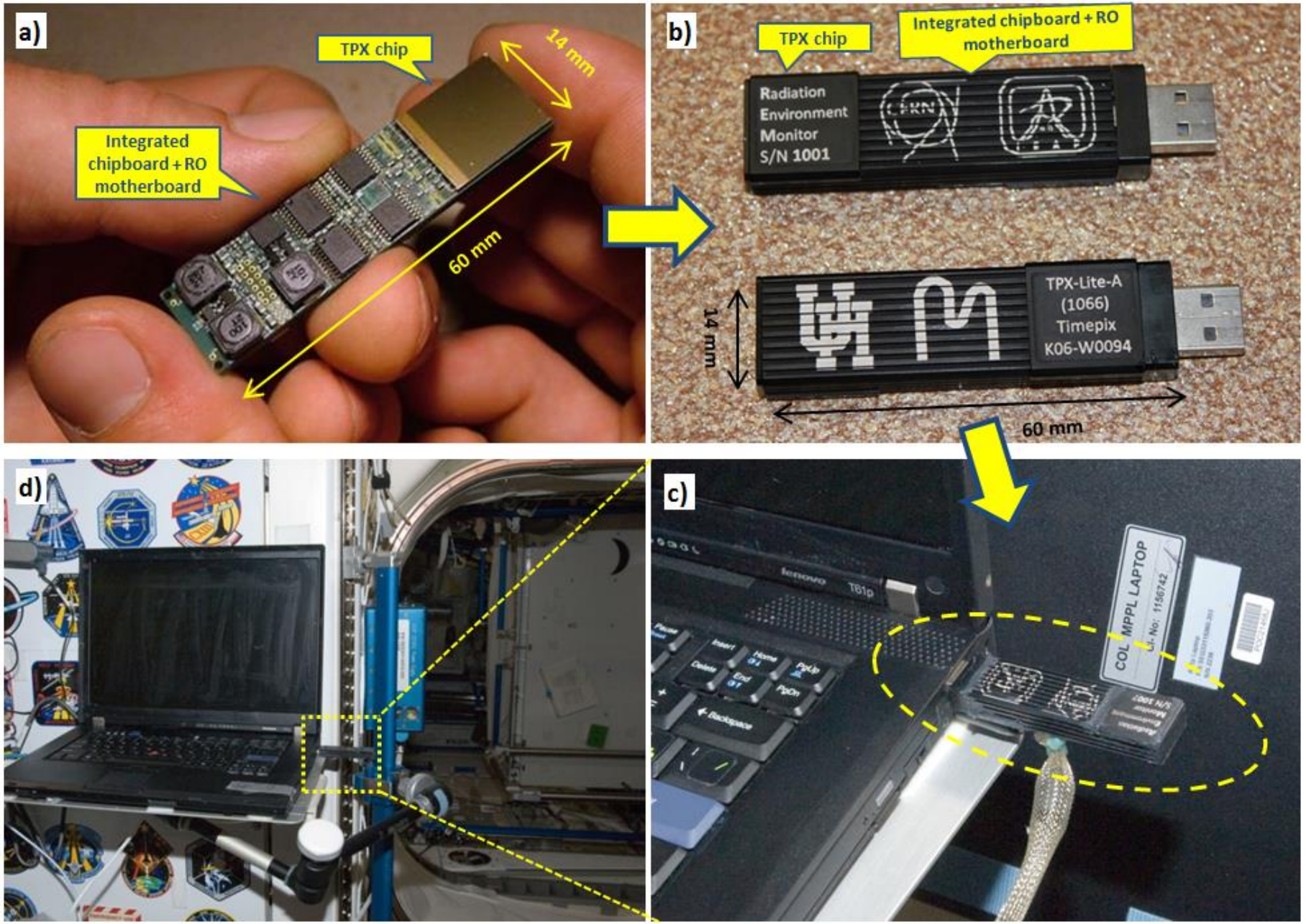
50 Kg

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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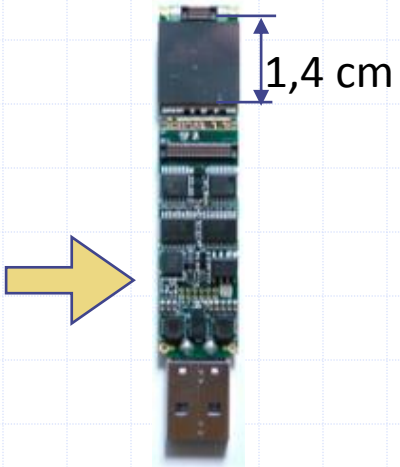
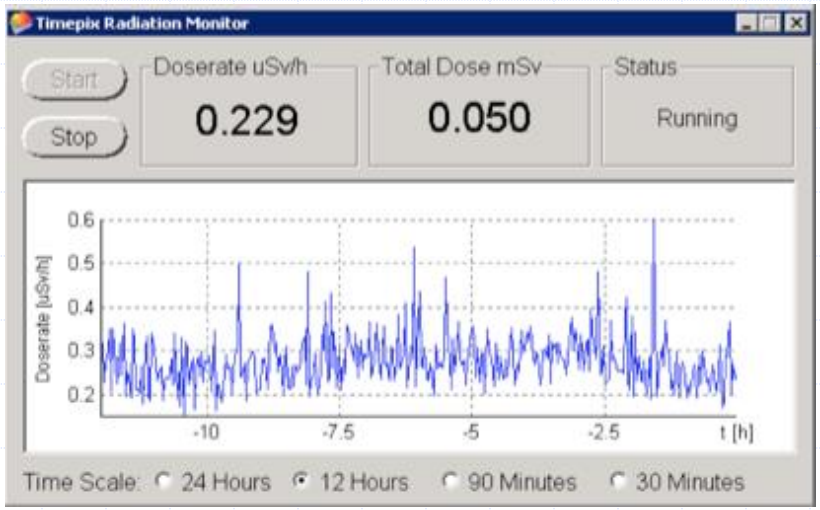
Czech Technical University in Prague

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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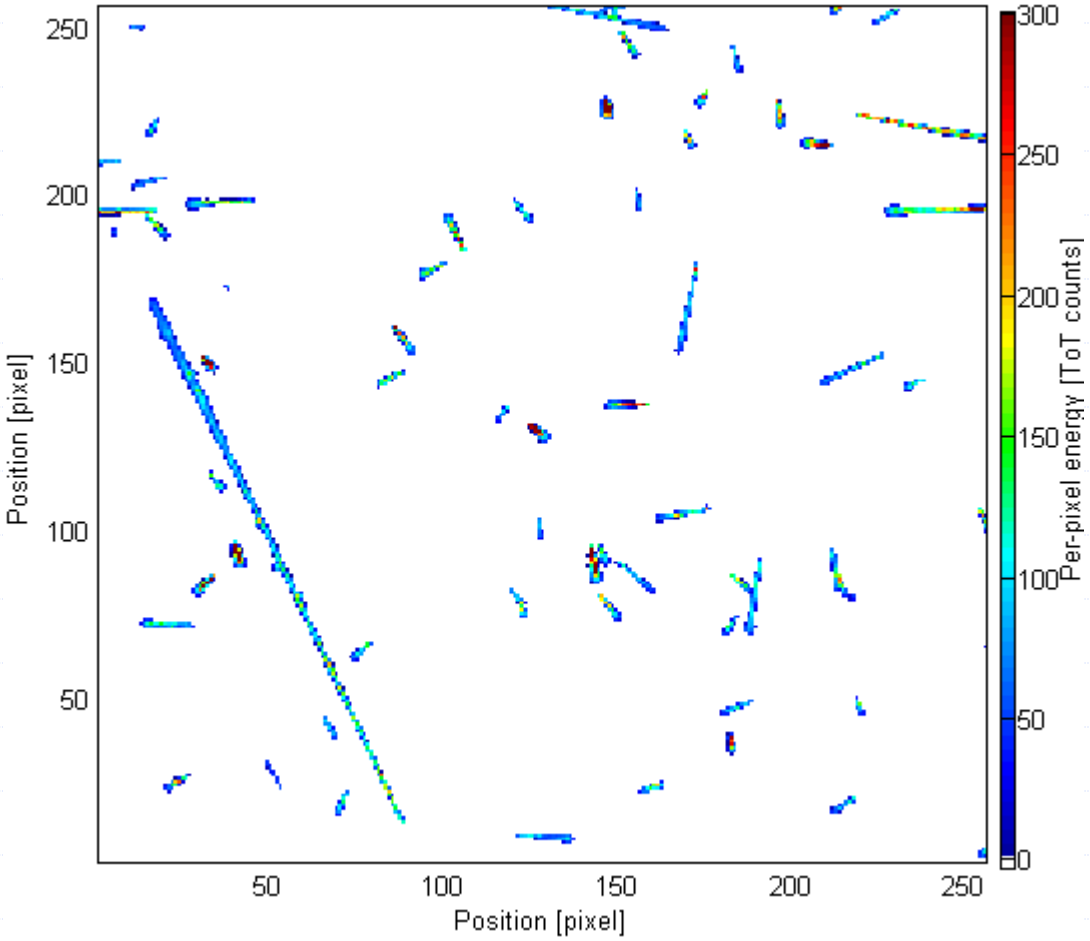
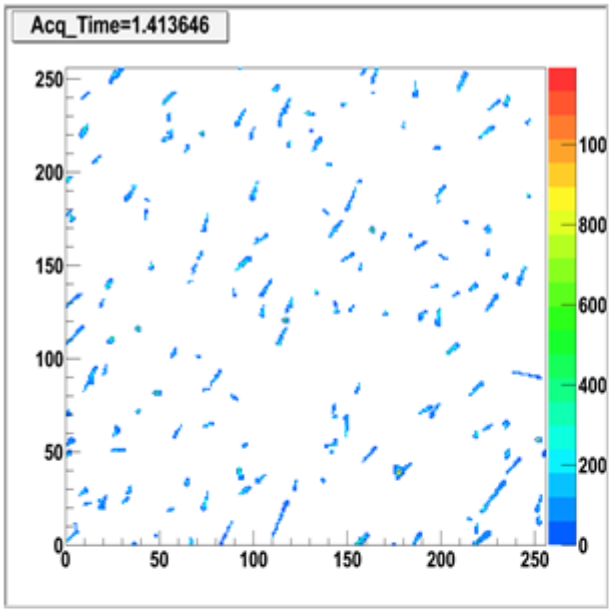
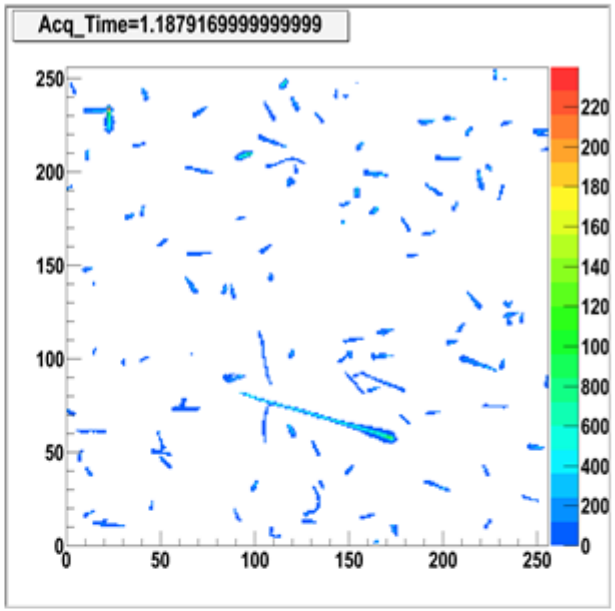
Radiation field at the ISS, acq t = 4 s

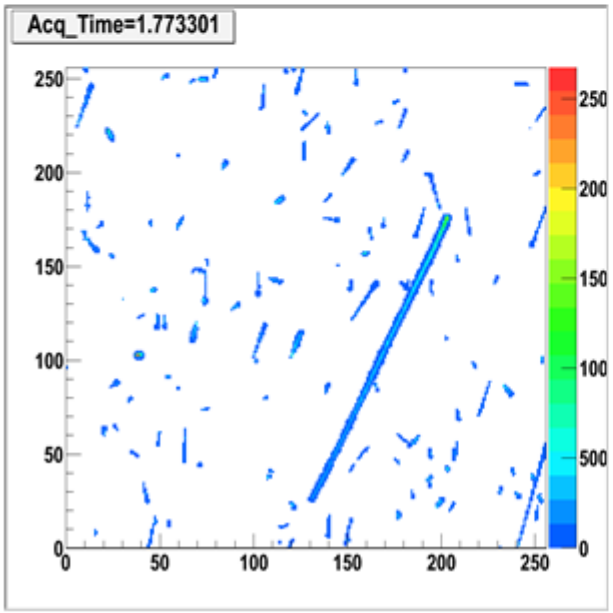


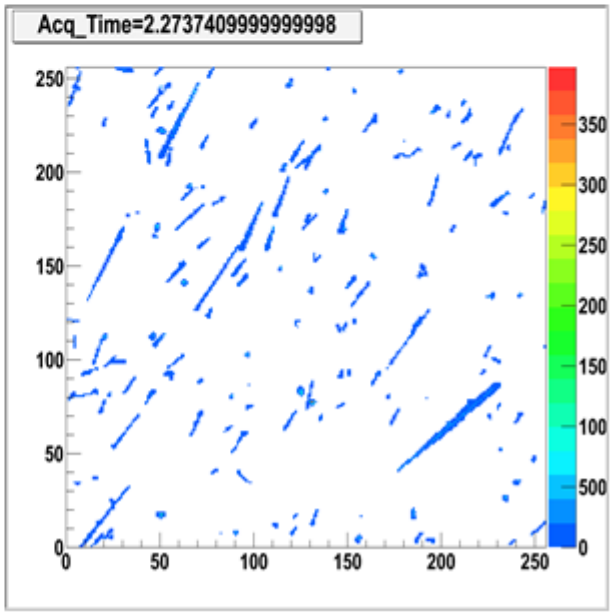
Timepix onboard the ISS

Radiation over the South Atlantic Anomaly (SAA)









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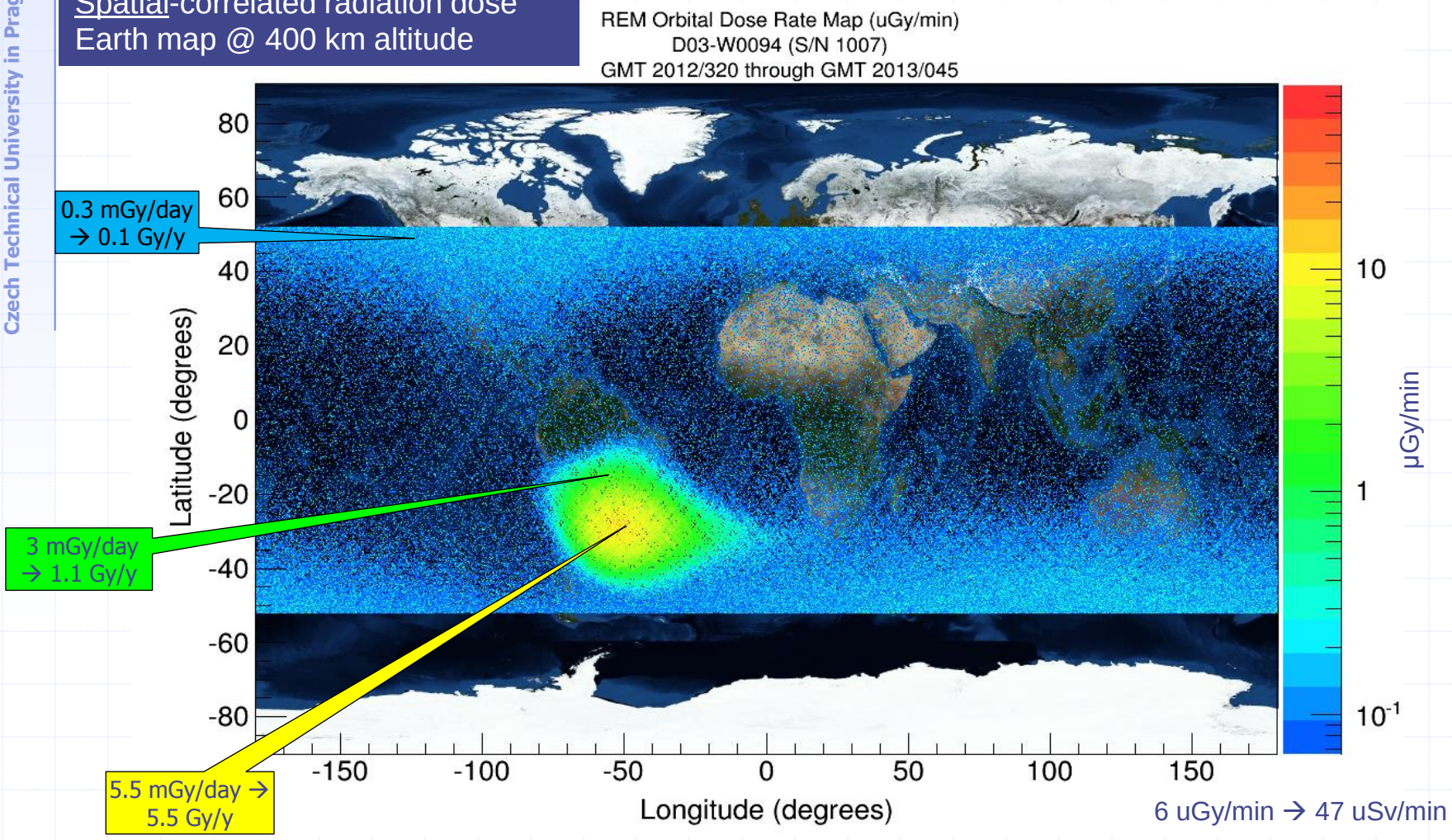
Timepix onboard the ISS
Quantum dosimetry + wide dynamic range

Airline altirude 11 km (Madrid-Bogota): 0,025 µGy/min = 0.036 mGy/d = 0.013 Gy/y

Ground level (Prague): 0,001 µGy/min = 0.0015 mGy/d = 0.0005 Gy/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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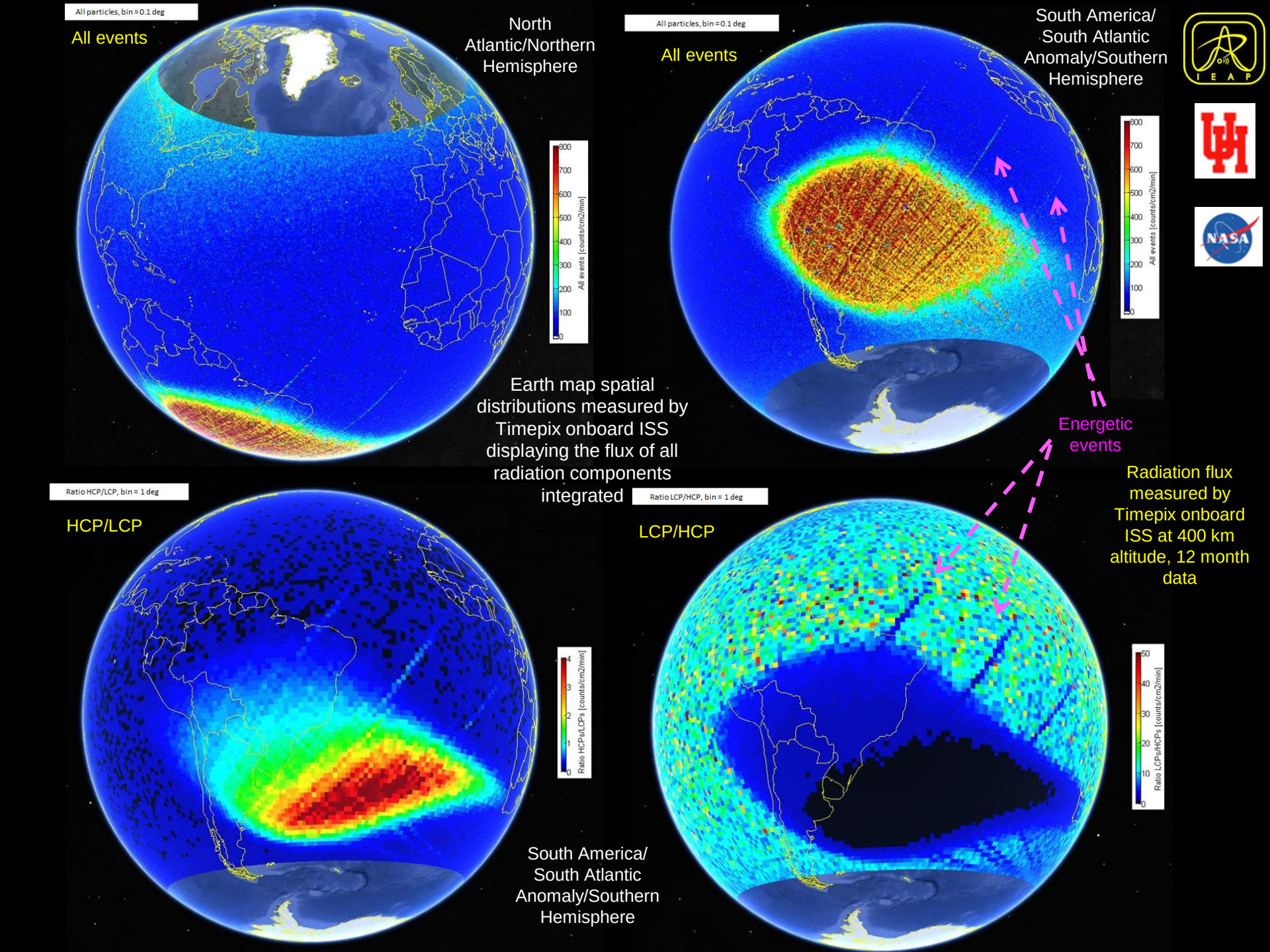
All particles, bin = 0.1 deg
All events
North Atlantic/Northern Hemisphere
All events [counts/cm2/min]
All particles, bin = 0.1 deg
All events
South America/ South Atlantic Anomaly/Southern Hemisphere
All events [counts/cm2/min]
Earth map spatial distributions measured by Timepix onboard ISS displaying the flux of all radiation components integrated
Energetic events
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

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 into satellite system**

- Reengineering
- Downgrade

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

Spacecraft payload

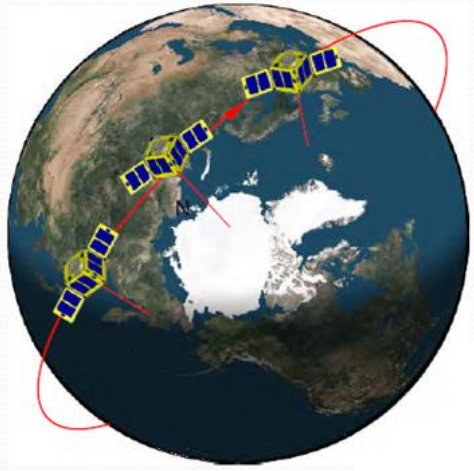
Timepix SATRAM Payload
ESA Proba-V satellite

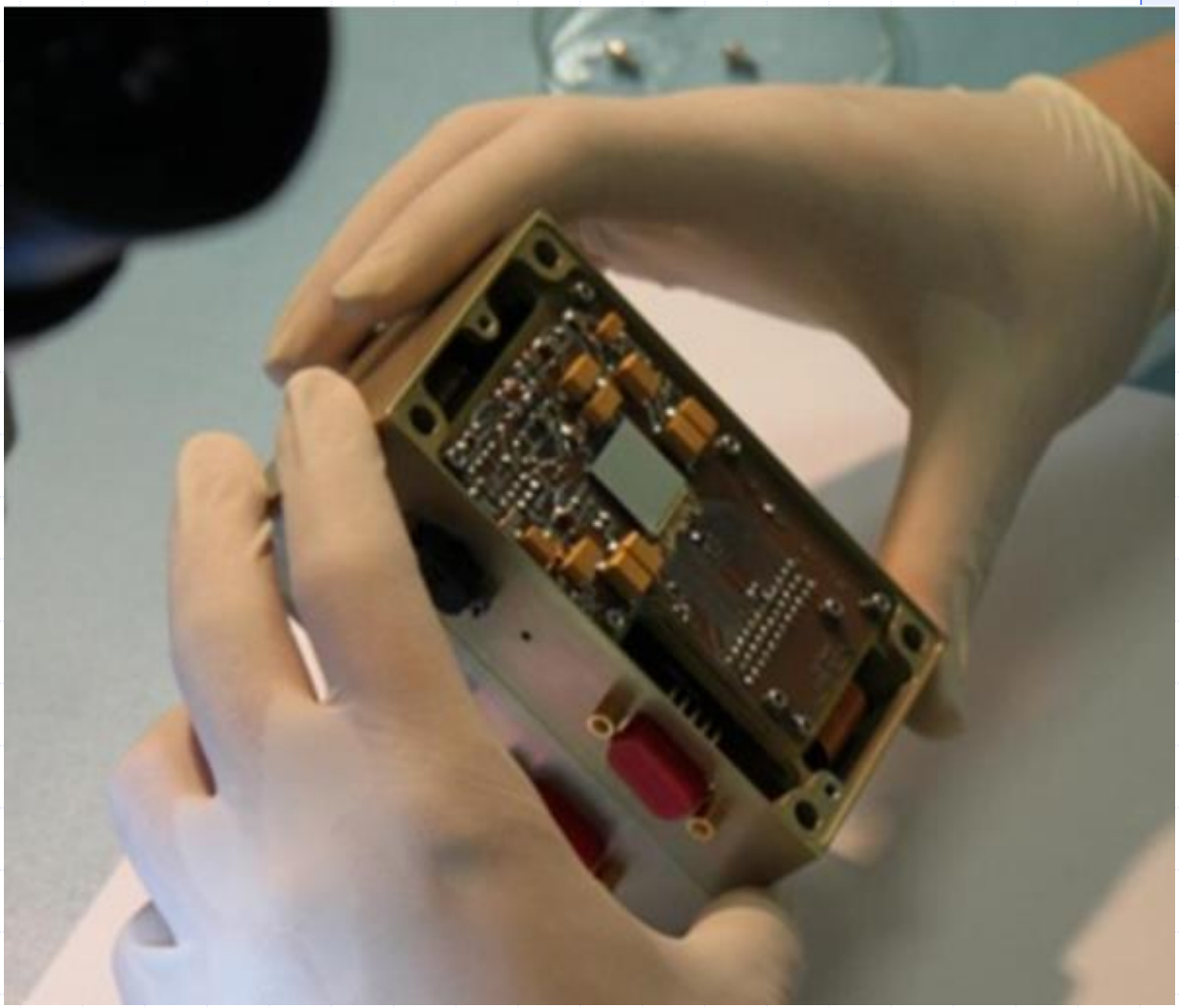
Institute of Experimental and Applied Physics
Czech Technical University in Prague

SATRAM payload: **Space Application of Timepix Radiation Monitor**

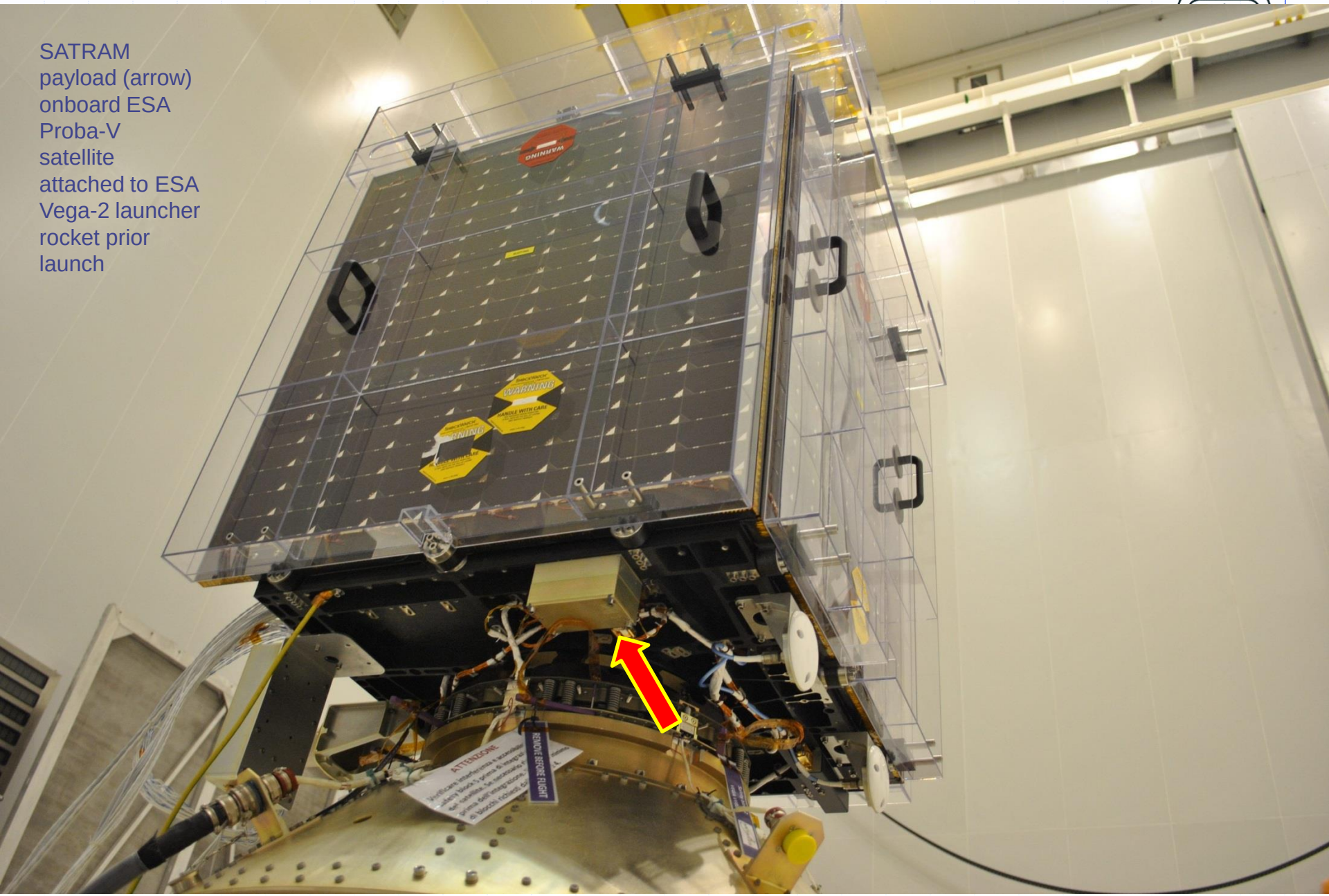
Characterization of space radiation at the Low Earth Orbit (LEO) on ESA PROBA-V satellite

- Altitude ~ 820 km
- Timepix for the first time in **open space** – currently TRL 9
- Launched May 2013





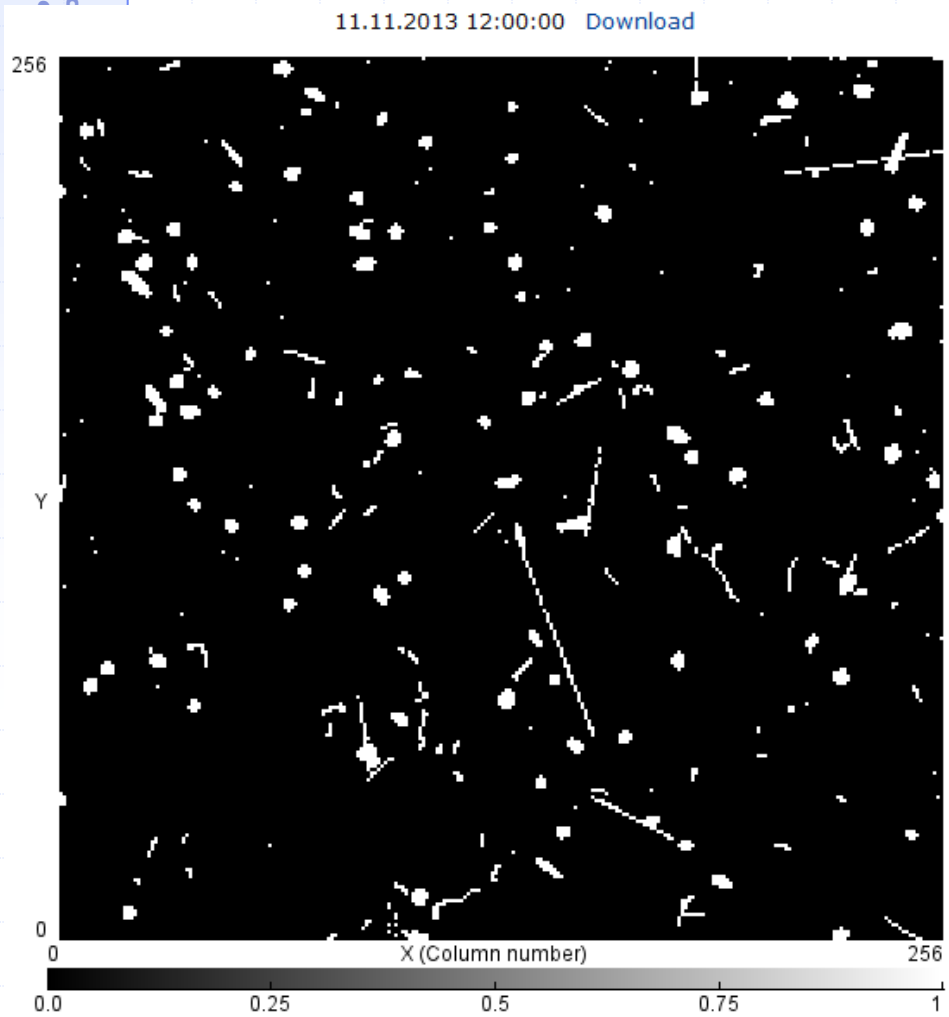
SATRAM payload (arrow) onboard ESA Proba-V satellite attached to ESA Vega-2 launcher rocket prior launch

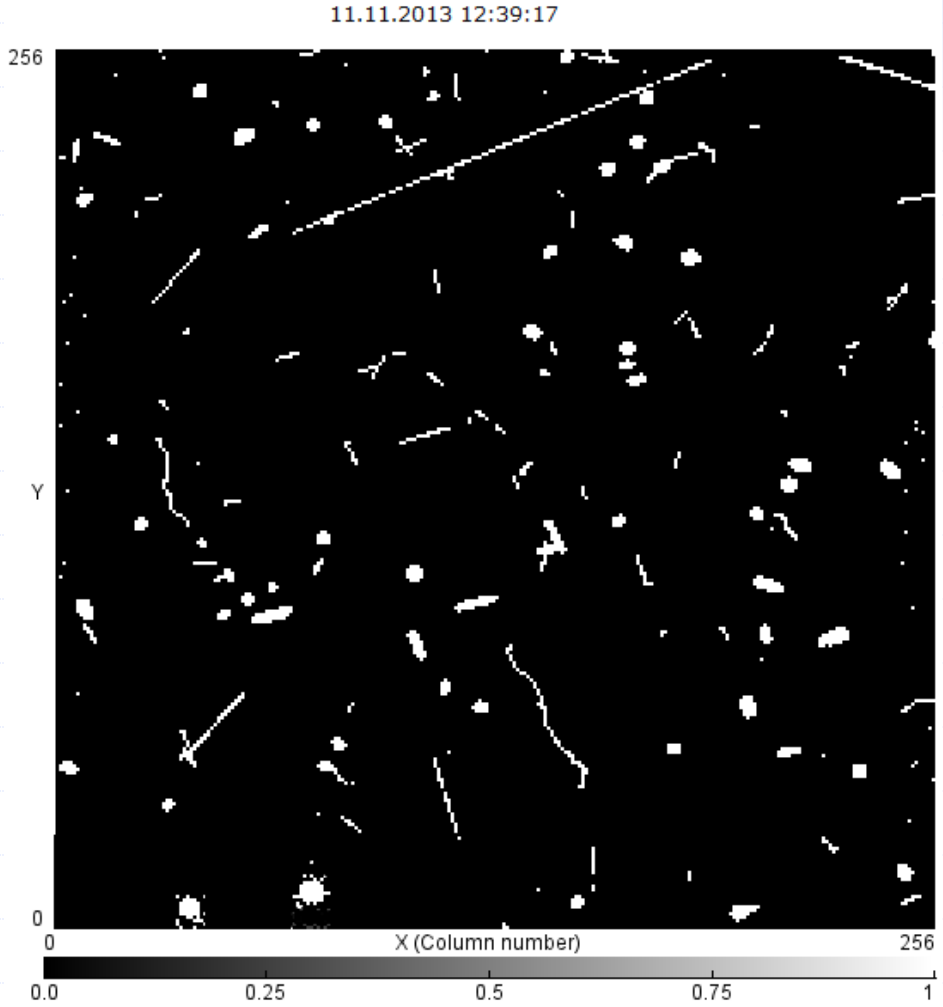


- SATRAM payload (arrow) onboard ESA Proba-V satellite.
- ESA Vega-2 launcher rocket upper stage

Timepix/ESA Proba-V:
LEO space radiation @ 820 km

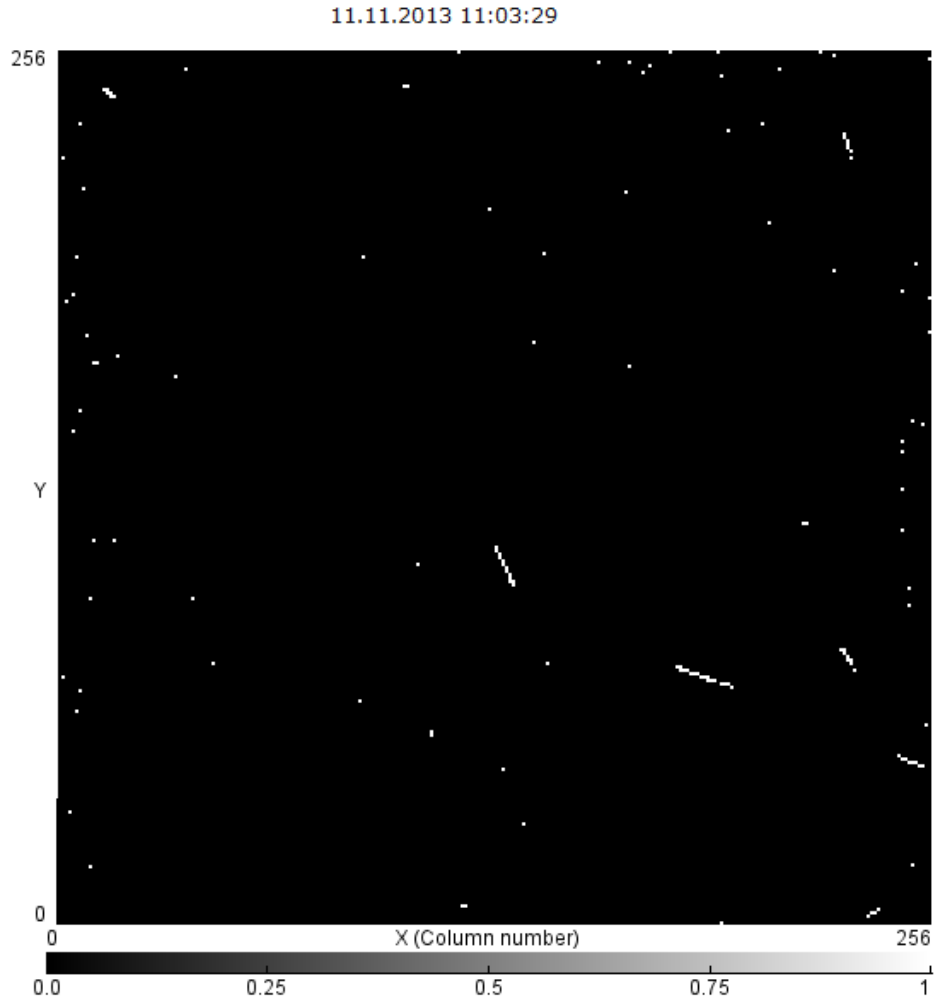
High radiation regions & heavy charged particles (p's)

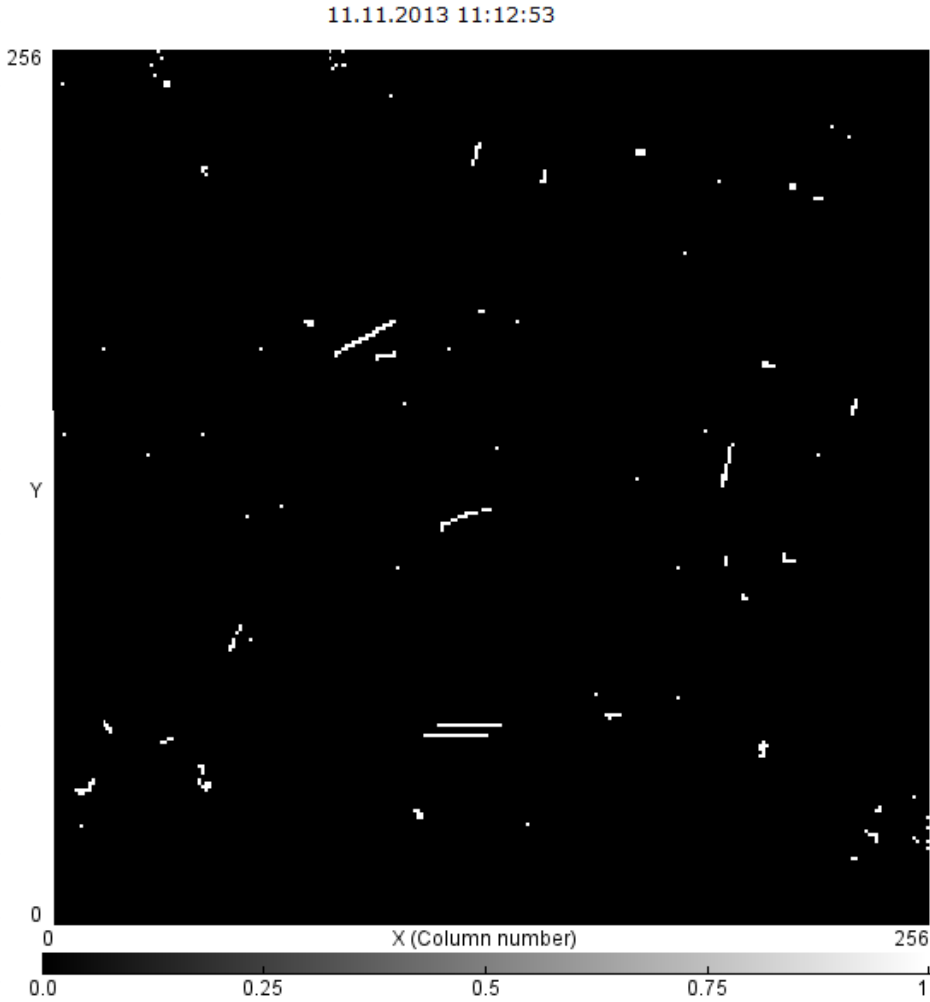




Timepix/ESA Proba-V:
LEO space radiation @ 820 km

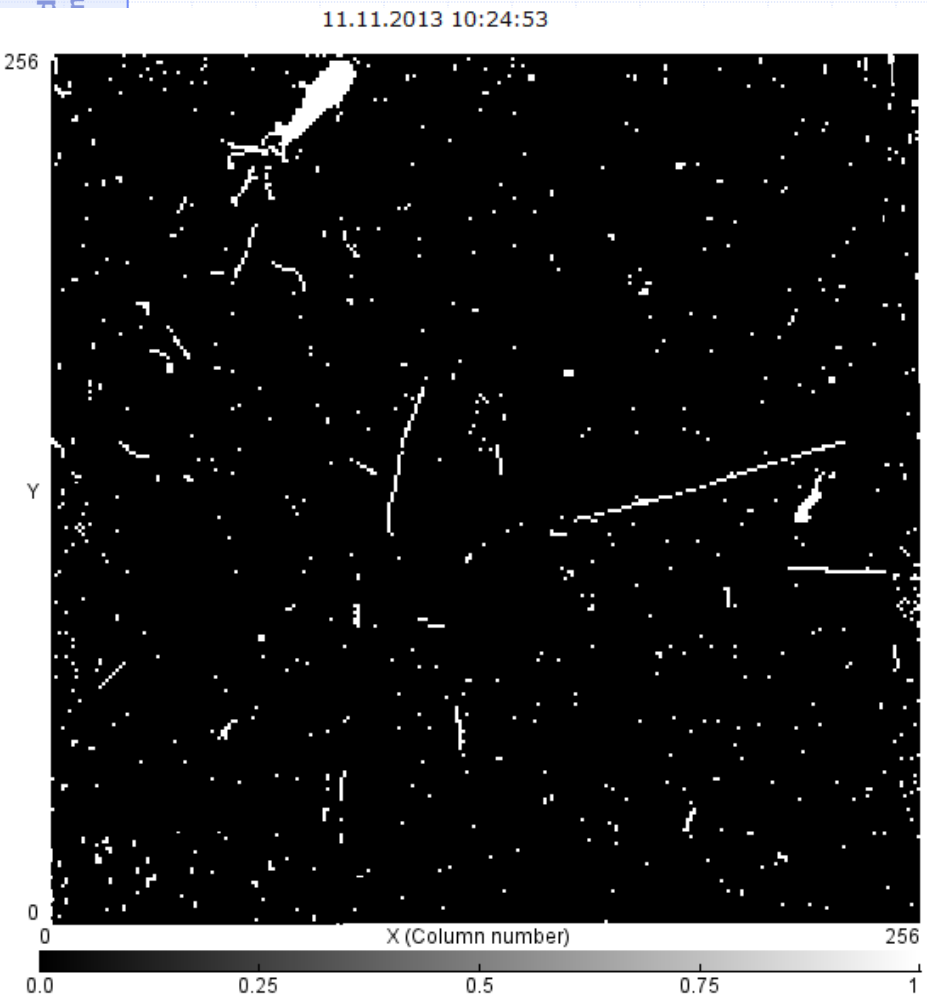
Low radiation regions & light charged particles (p's)

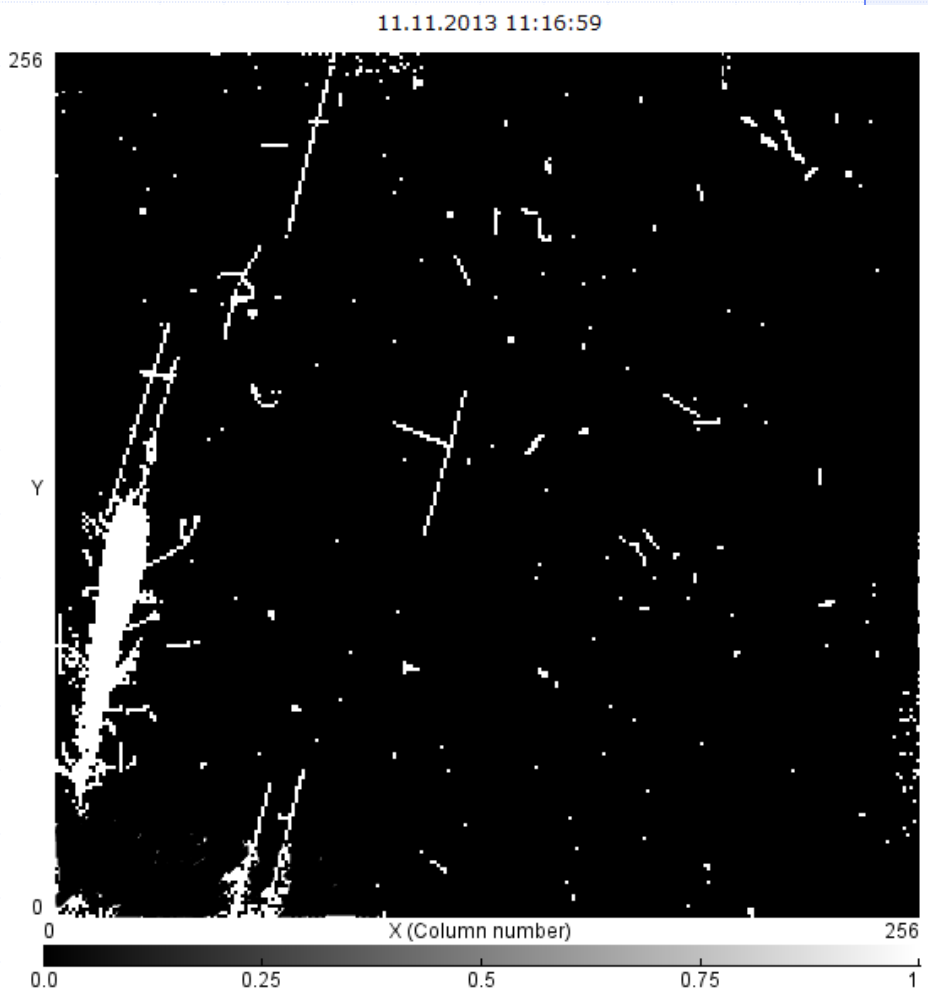


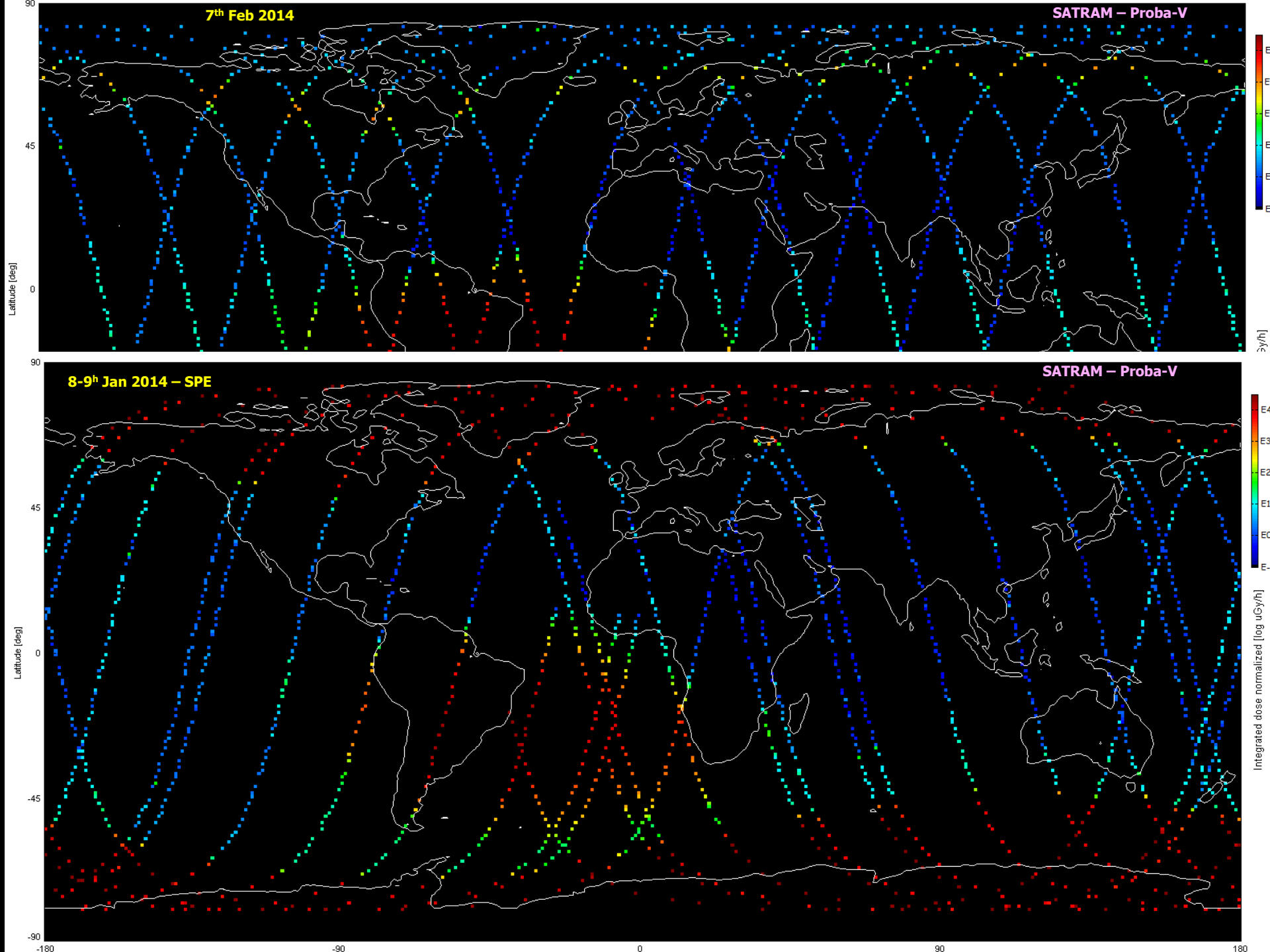


Timepix/ESA Proba-V:
LEO space radiation @ 820 km

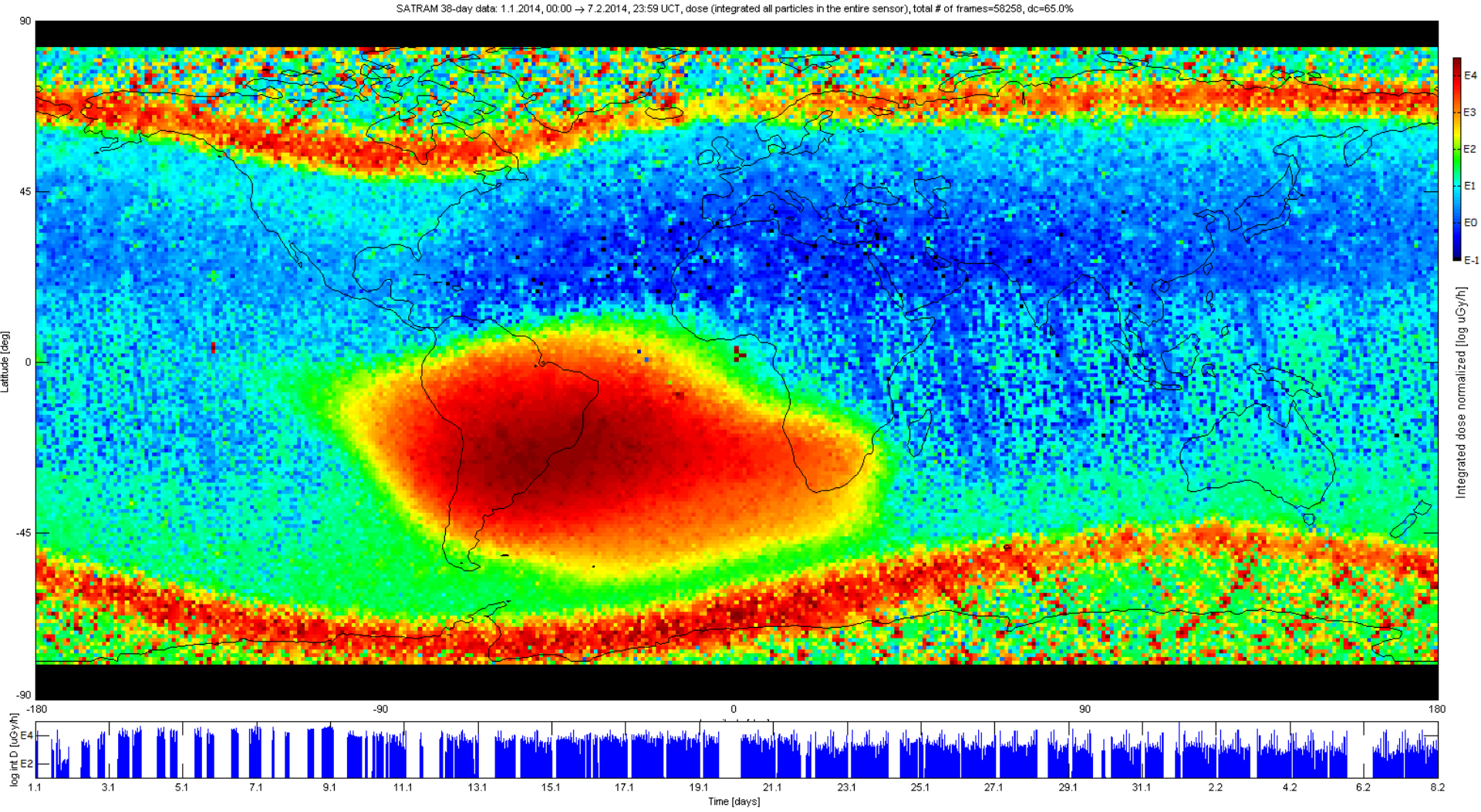
Energetic heavy charged particles (ions)

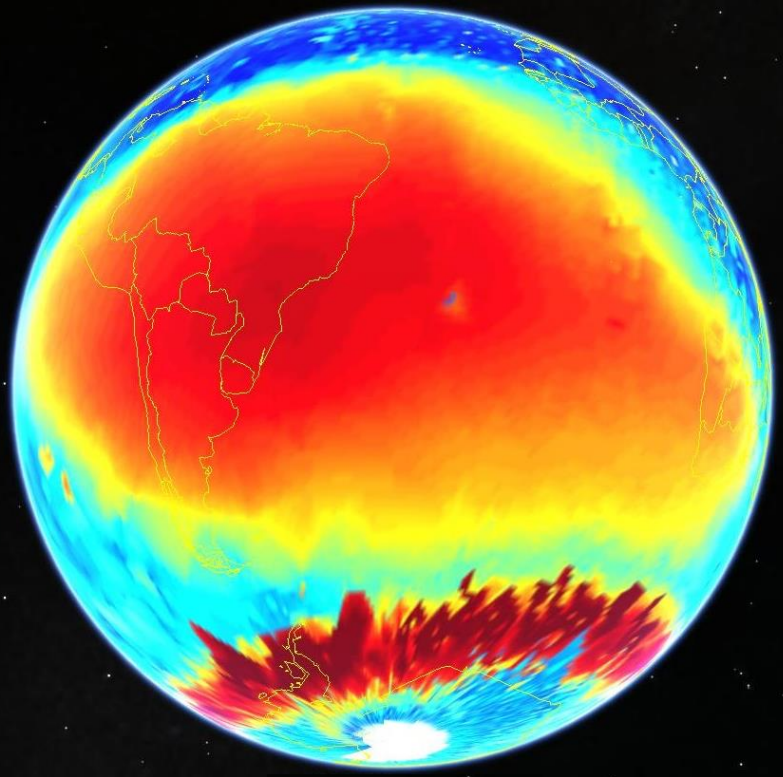


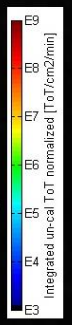



7th Feb 2014
SATRAM – Proba-V
8-9h Jan 2014 – SPE
SATRAM – Proba-V
Latitude [deg]
90
45
0
-45
-90
-180
-90
0
90
180
Integrated dose normalized [log uGy/h]

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

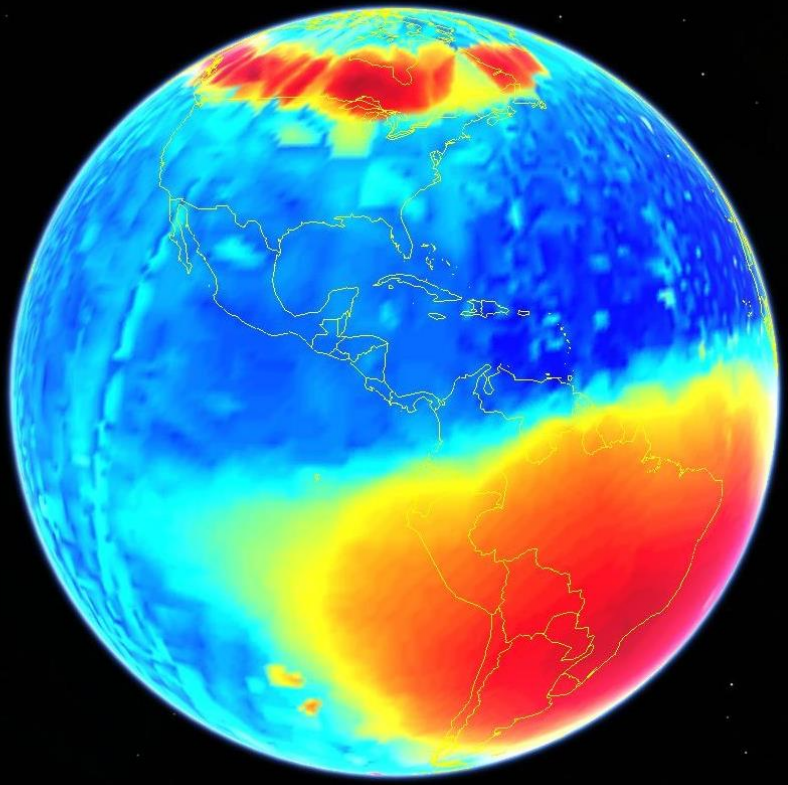


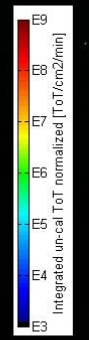




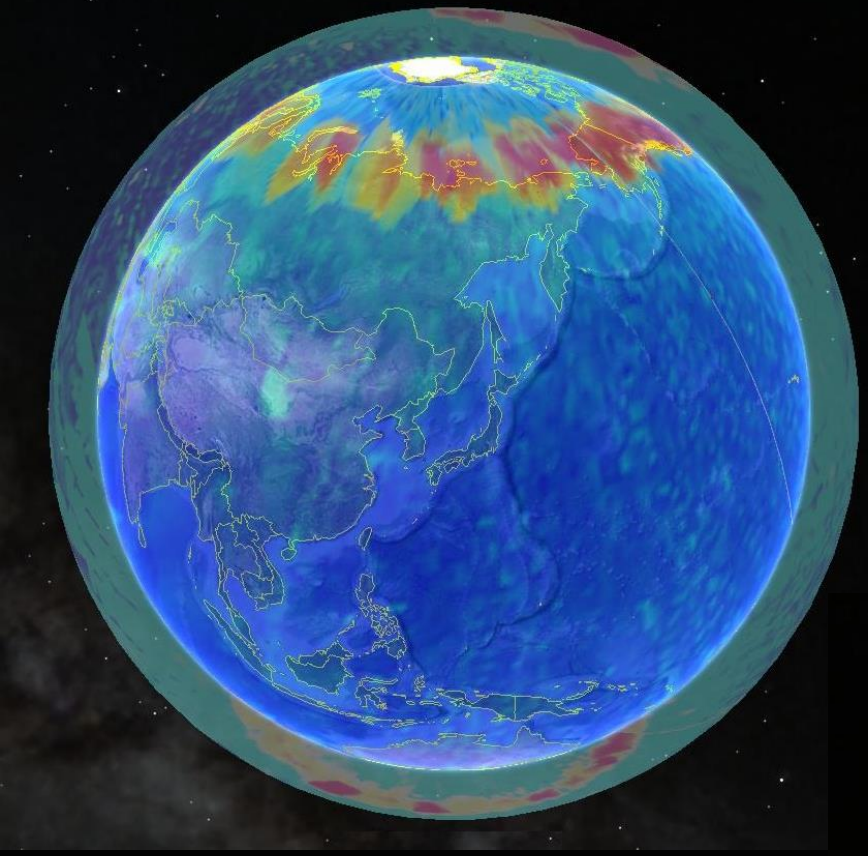
South America, Antarctica, South Atlantic Anomaly SAA

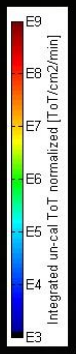
The Americas





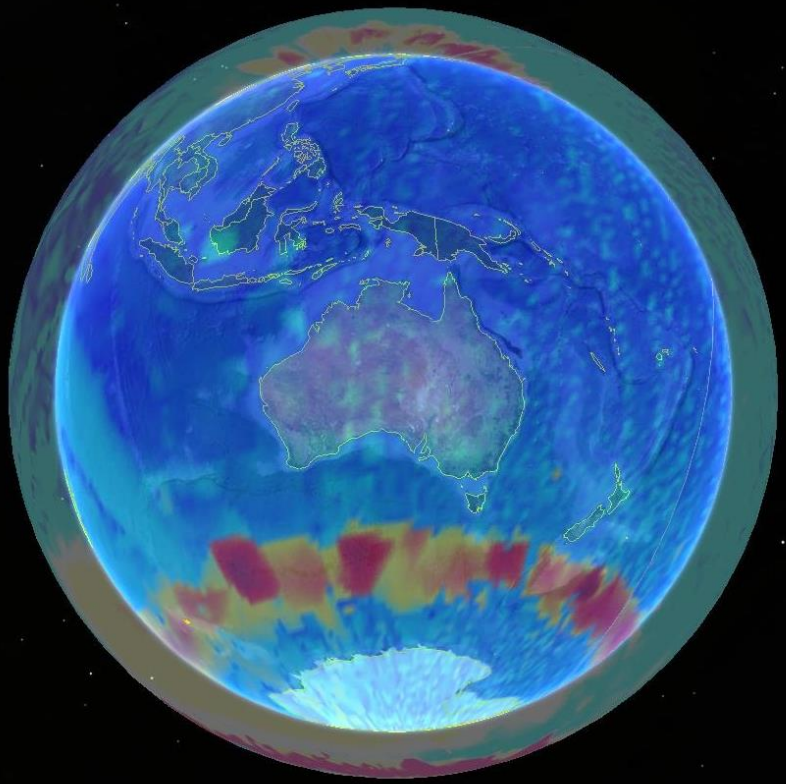
Radiation field Earth map spatial distributions measured by Timepix based SATRAM payload onboard ESA Proba-V satellite LEO orbit 820 km altitude displaying all radiation components integrated over 5.5 months

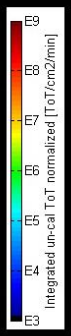




Asia/west Pacific

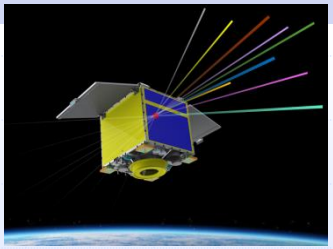
Australia/Oceania





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

RISESAT + Timepix particle tracker payload
Particle visualization + telescope



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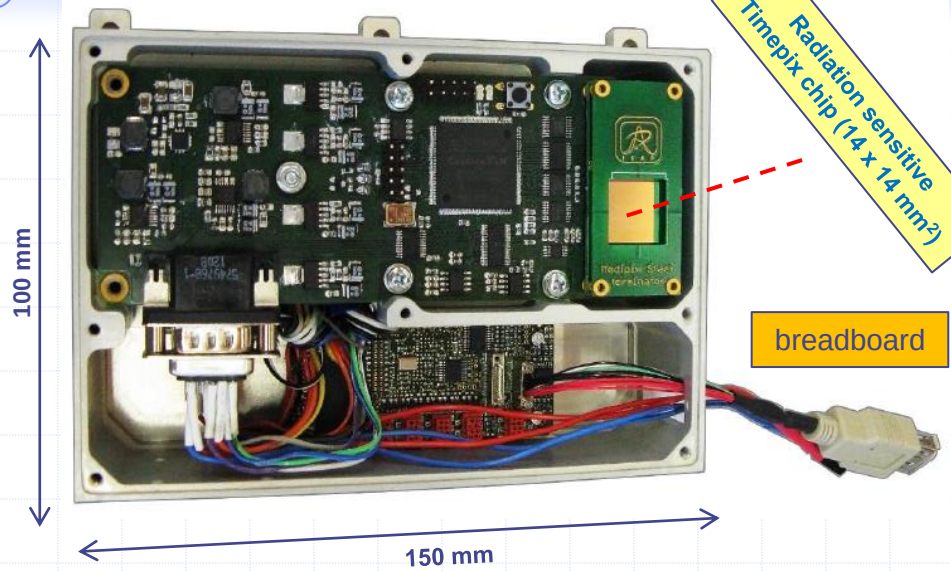
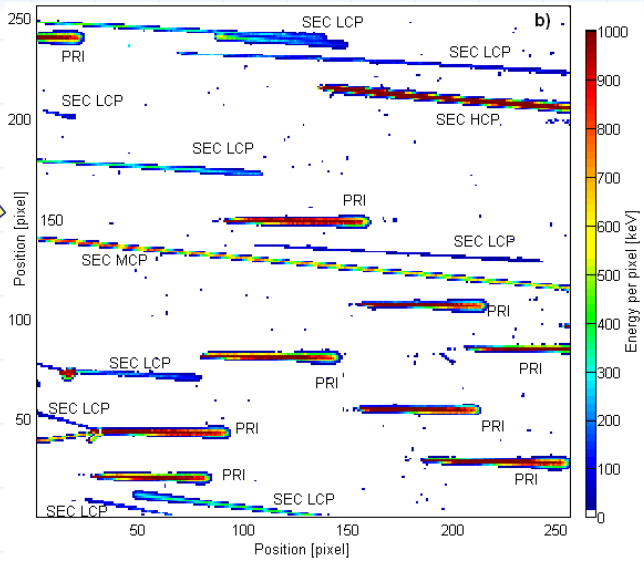
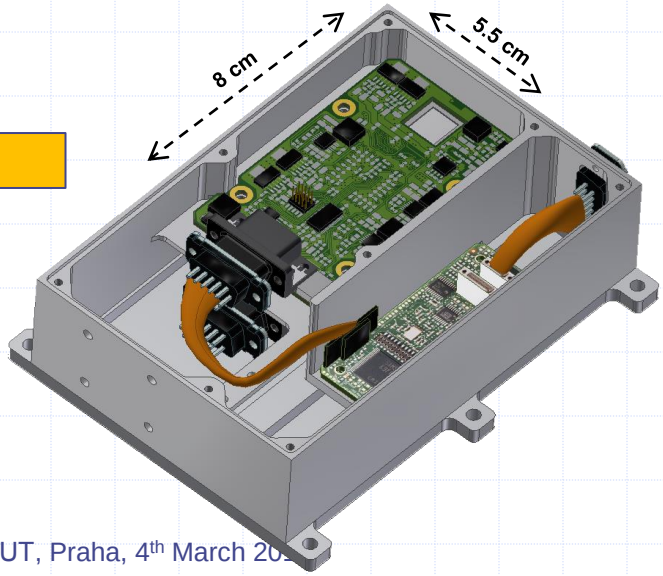


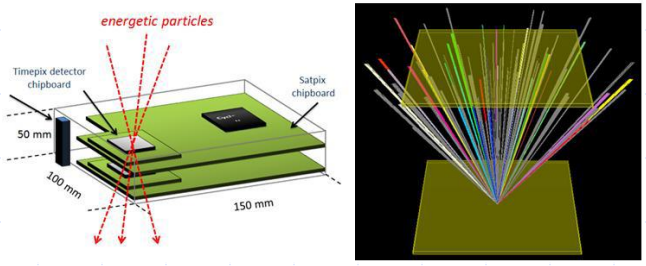
breadboard



Visualization of direction of energetic particles with single layer Timepix in hadron therapy (^{12}C) field

EM





Enhanced visualization of direction of energetic particles with stacked Timepix → particle telescope

Small satellite(s)

Timepix-based compact payloads: Science instrument, platform device

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Czech Technical University in Prague

Characterization and particle visualization of space radiation

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
- Configurability, sensor array modularity/assembly, particle telescope,

technical

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

!