Study of the radiation fields in LEO with the Timepix detector

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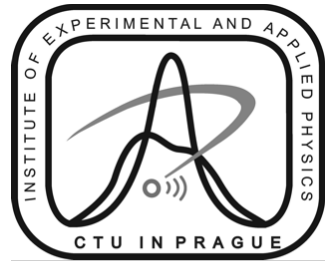
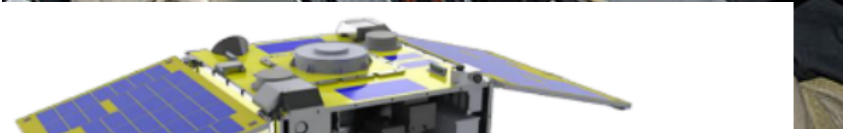
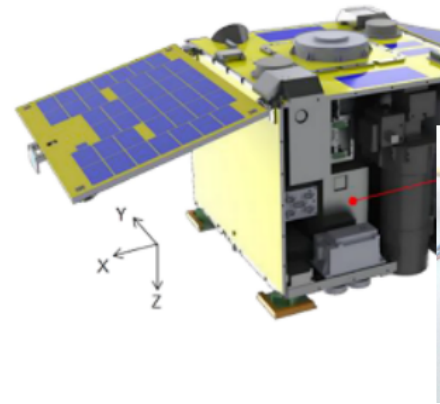
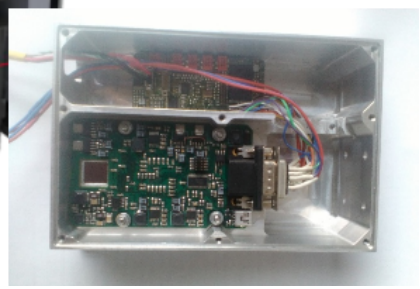
16th Baksan Cosmology School



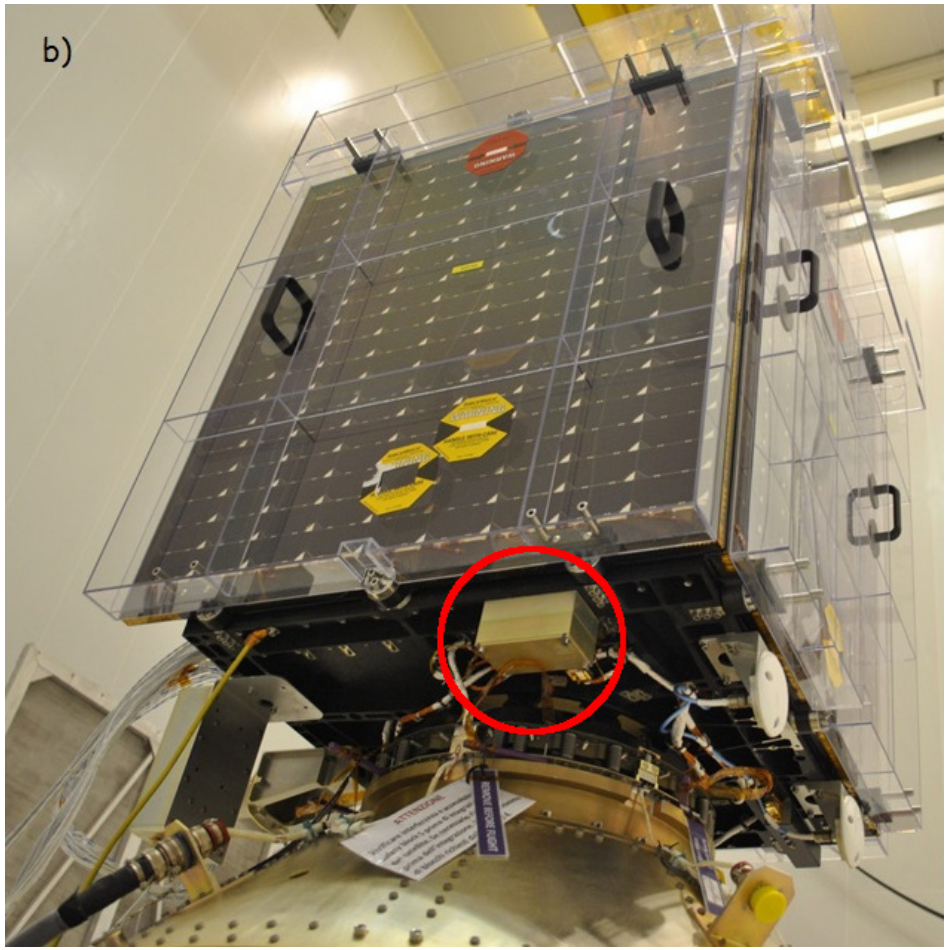
Timepix in space

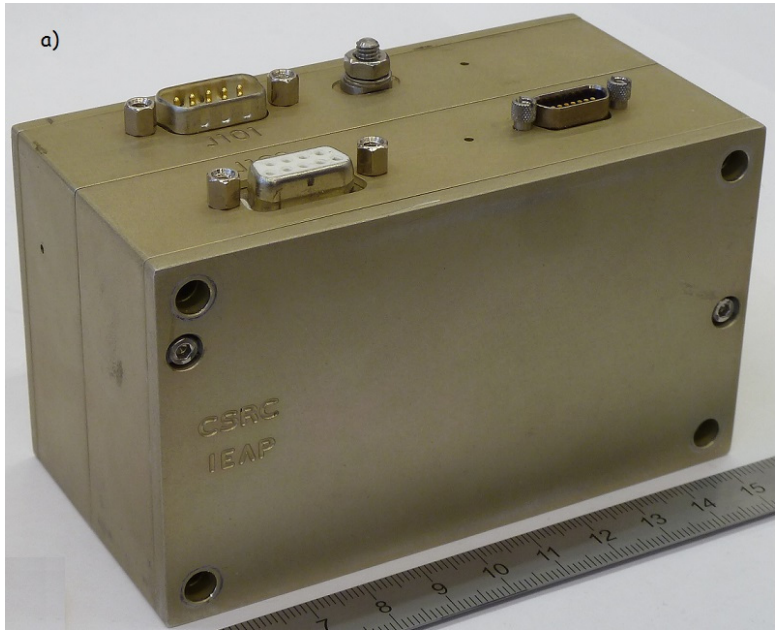






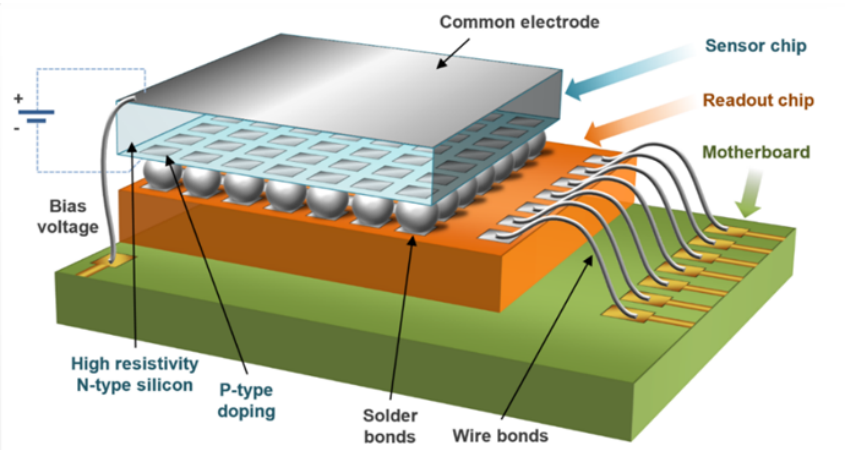
Proba-V

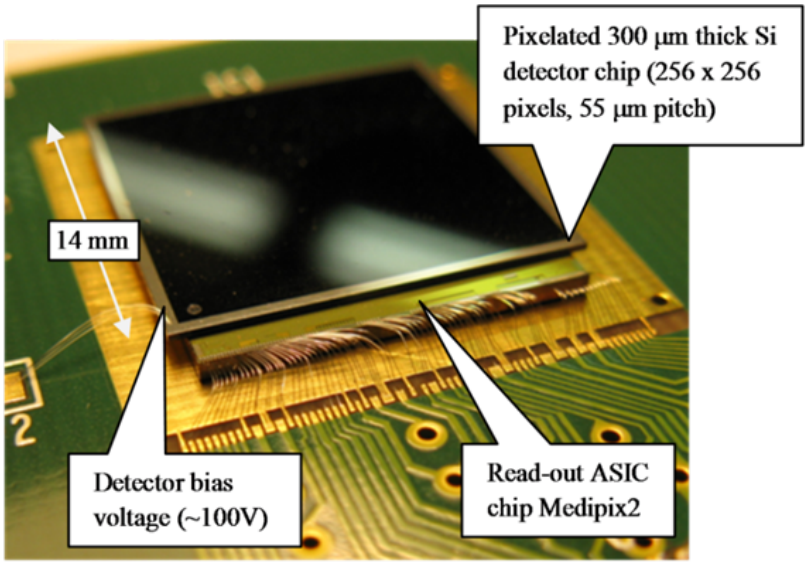




- Altitude = 820 km
- Inclination = 98.8°
- Sun-synchronous orbit
- in orbit since May 2013

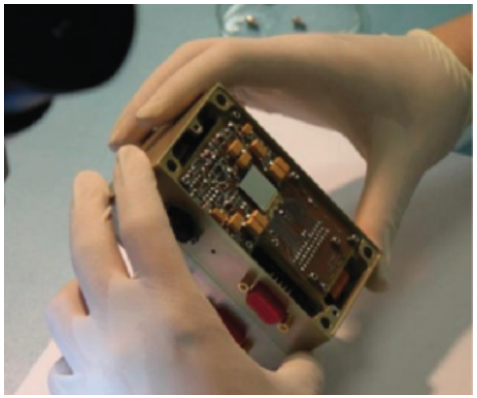
Timepix



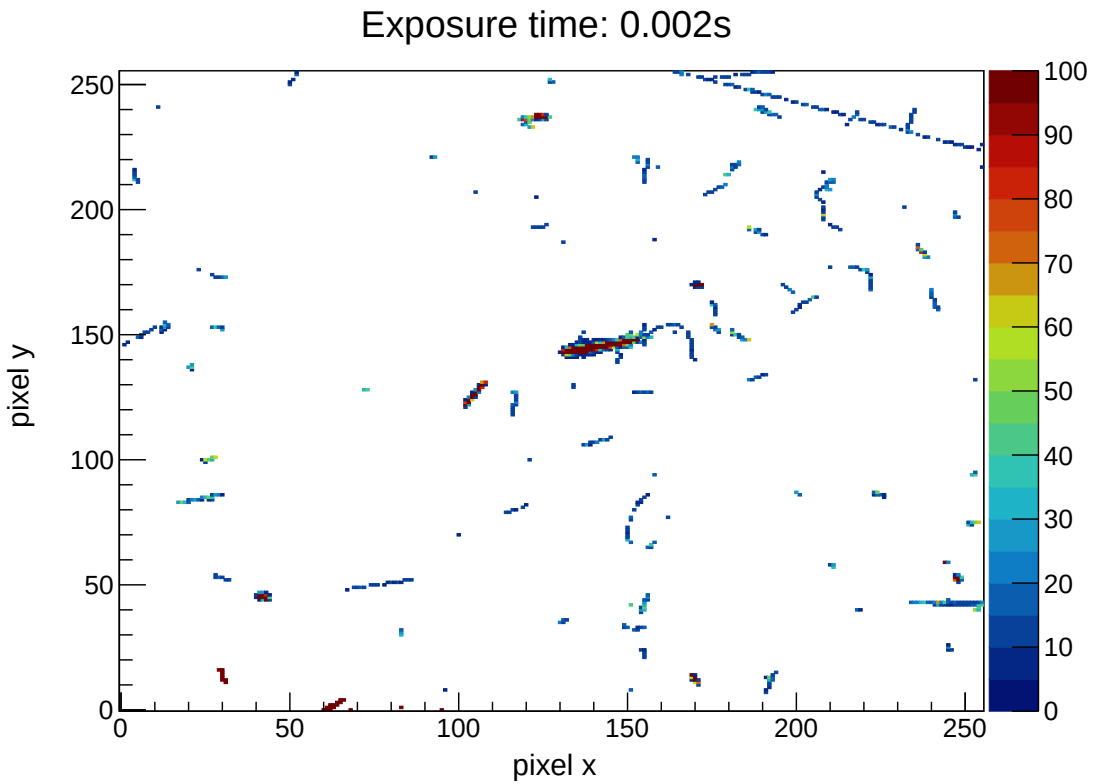


- Planar pixelated semiconductor sensor (Si, thickness: 300 μm)
- Bump-bonded to readout chip containing in each pixel cell: amplifier, discriminator, digital counter or ADC or Timer
- Single particle counting chip
- Features:
  - 256 x 256 pixels
  - 55 μm pixel pitch
  - 14 bits/pixel
  - Minimal threshold: 3.5 keV

Space Application of Timepix RAdiation Monitor (SATRAM)

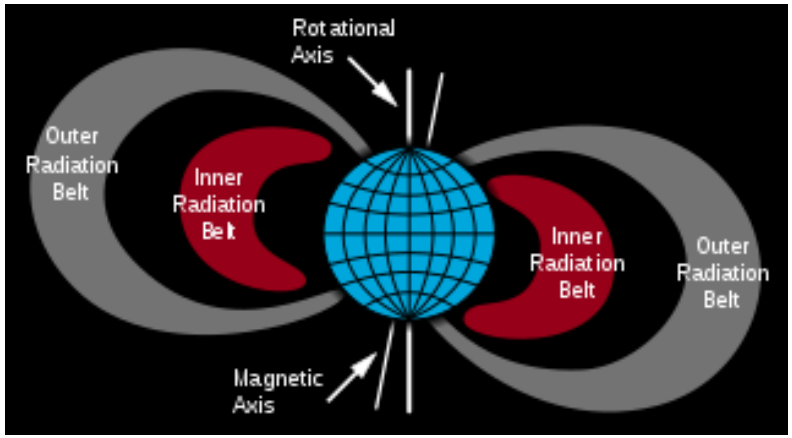


- Power consumption: 2.5W
- Total mass: 380g (107x70x55 mm)
- Radiation tolerance 1 Mrad for the sensor, 100 krad for the electronics
- SATRAM is platform technology demonstrator



- 3 frame exposure times: 20s, 0.2s and 0.002s

Van Allen Belts



Inner belt:

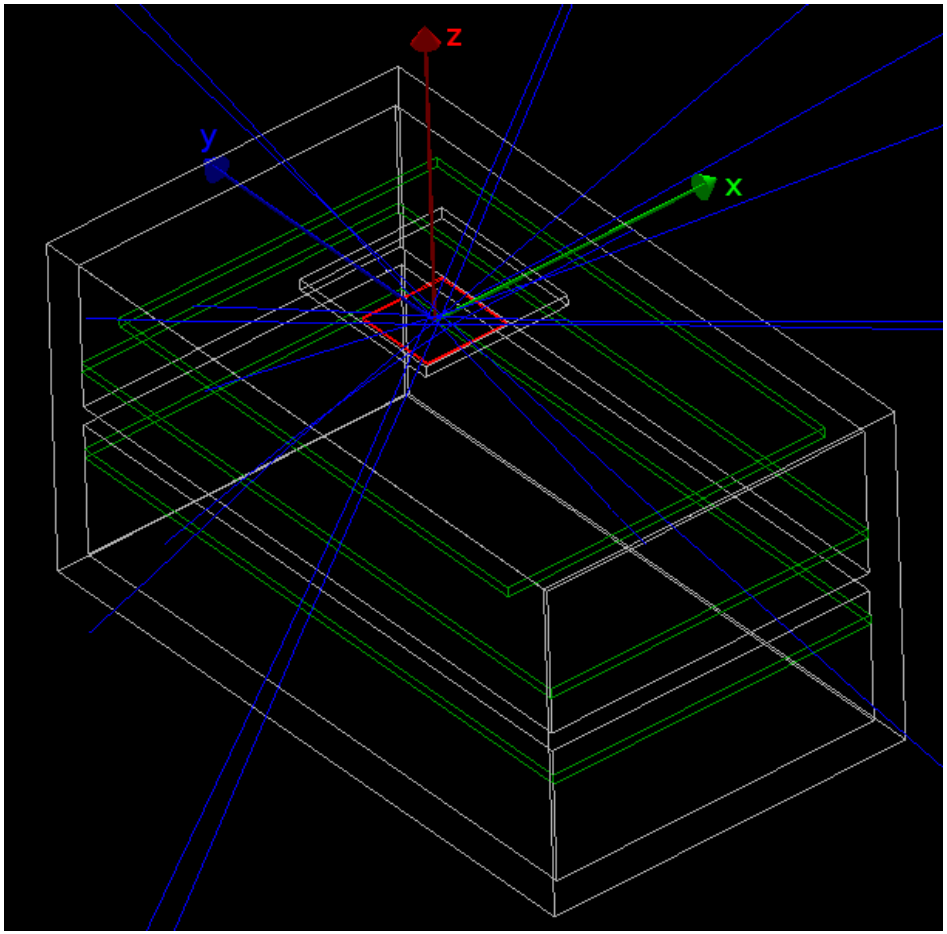
- Altitude: 1.000 - 6.000 km
- Electrons: 0.1 - 7 MeV
- Flux: 10^8 cm^{-2} s^{-1}
- Protons: 5 MeV - 400 MeV
- Flux: 10^4 cm^{-2} s^{-1}

Outer belt:

- Altitude: 13.000 - 60.000 km
- Electrons: 0.1 - 10 MeV
- Flux: 10^7 cm^{-2} s^{-1}

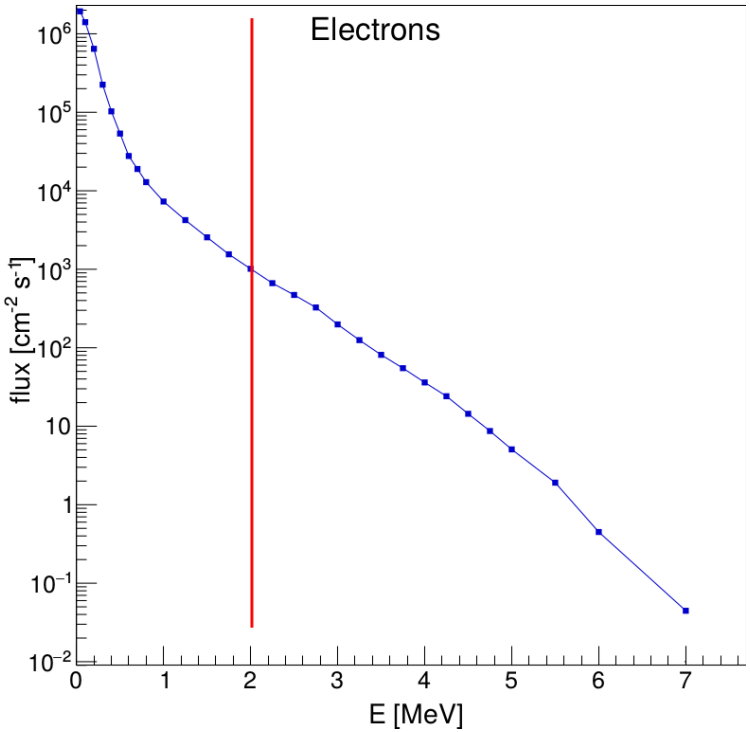
Due to the slight offset of the belts from Earth's geometric center, the inner Van Allen belt makes its closest approach to the surface at the South Atlantic Anomaly.

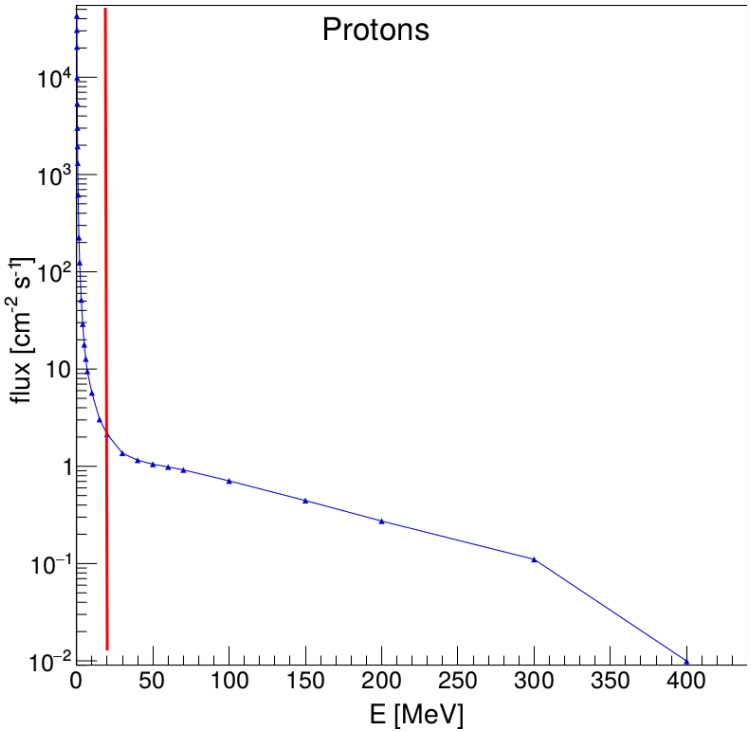
Geant4 SATRAM model



- Red: Timepix sensor
- Green: PCB's
- Grey: housing + satellite (later)
- Top panel: 3.5 mm thick, side: 3 mm, window 1.75 mm
- irradiated with e^- and protons with an omnidirectional flux

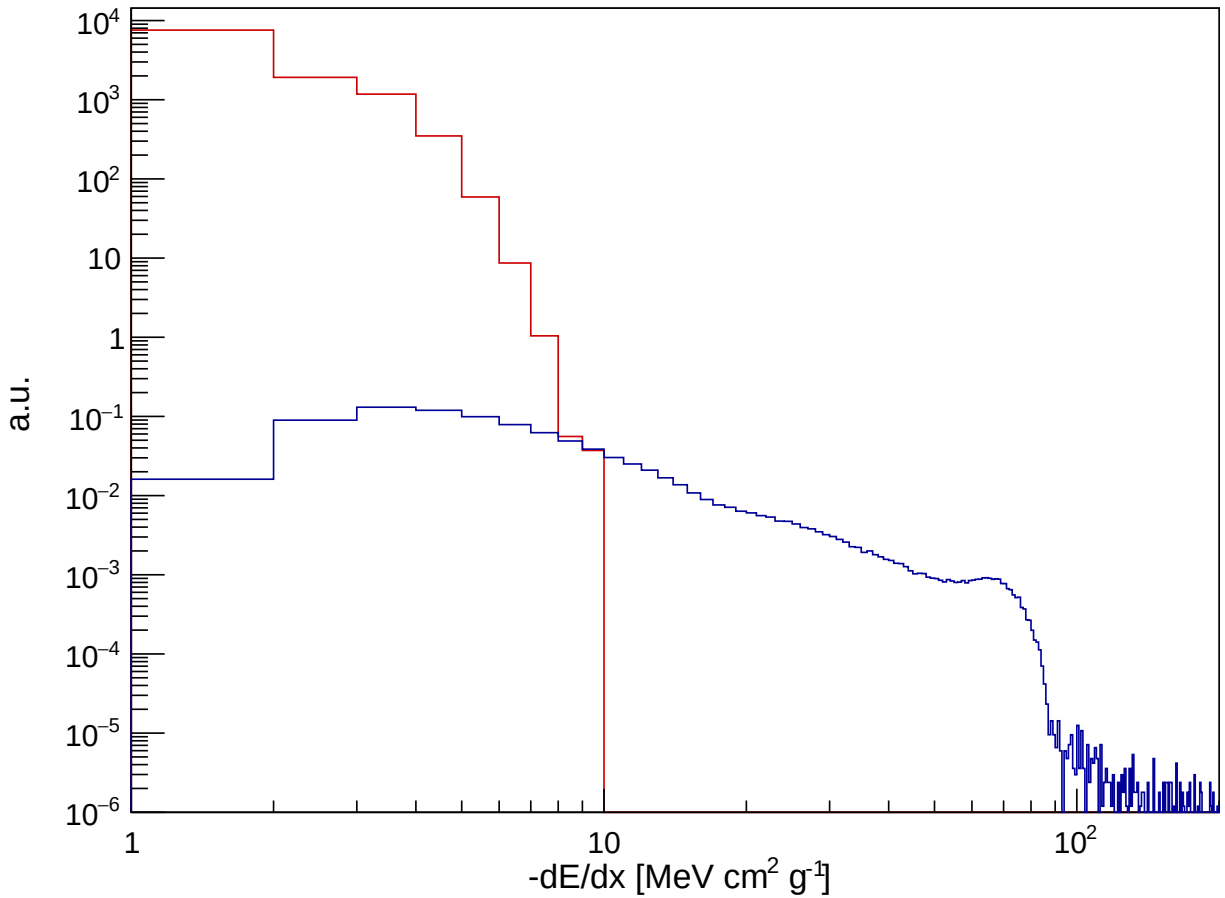
Input spectra for the simulation





Both spectra were created with the SPENVIS online tool. Electrons and protons left of the red line do not penetrate the aluminium cover of the SATRAM device. They were not considered in the simulation.

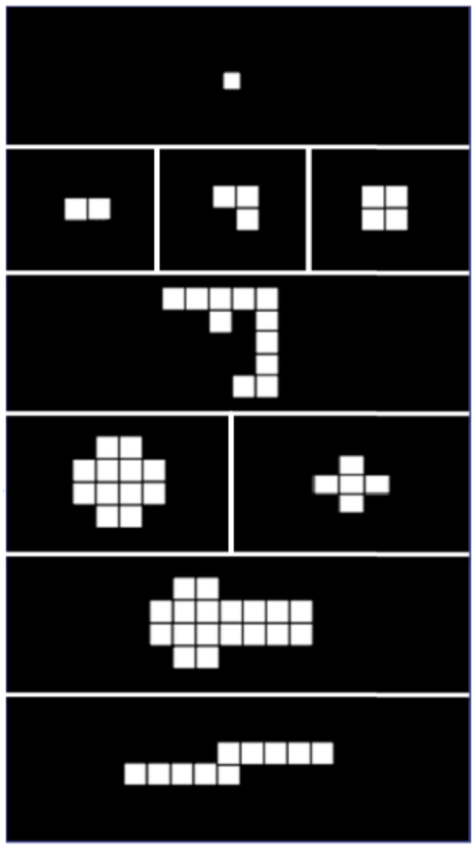
Energy loss response



- $\approx 1.7 \cdot 10^6$ simulated protons
- $\approx$ 700.000 simulated electrons
- The distribtutions were scaled so that they resemble the expected composition in LEO
- Electrons lose $\leq$ $10\,\mathrm{MeV\,cm^2\,g^{-1}}$

Strategy for particle identification

Cluster shape, cluster height and energy loss are used to distinguish between particle species.



$\Rightarrow$ e^-, X-ray: height $< 300\,\text{keV}$

$\Rightarrow$ e^-: height $< 300\,\text{keV}$

proton: height $> 300\,\text{keV}$

$\Rightarrow$ e^-

$\Rightarrow$ proton: $-\frac{dE}{dx} < 100\,\frac{MeVcm^2}{g}$

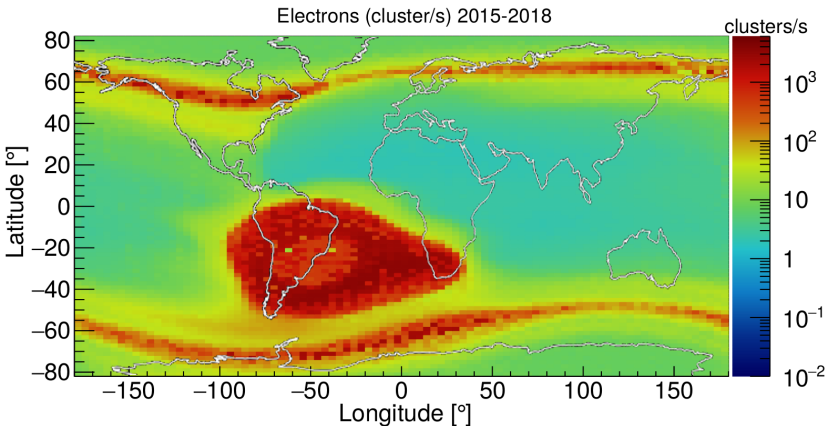
ion: $-\frac{dE}{dx} > 100\,\frac{MeVcm^2}{g}$

$\Rightarrow$ same as heavy blob

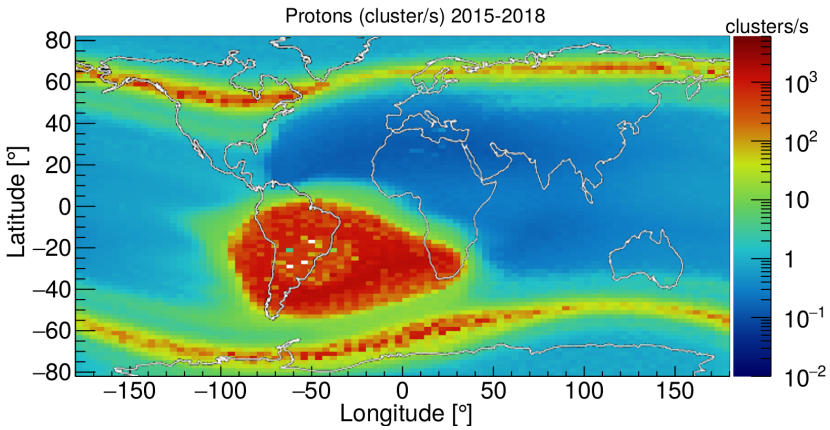
$\Rightarrow$ e^-: $-\frac{dE}{dx} < 10\,\frac{MeVcm^2}{g}$

proton: $-\frac{dE}{dx} > 10\,\frac{MeVcm^2}{g}$

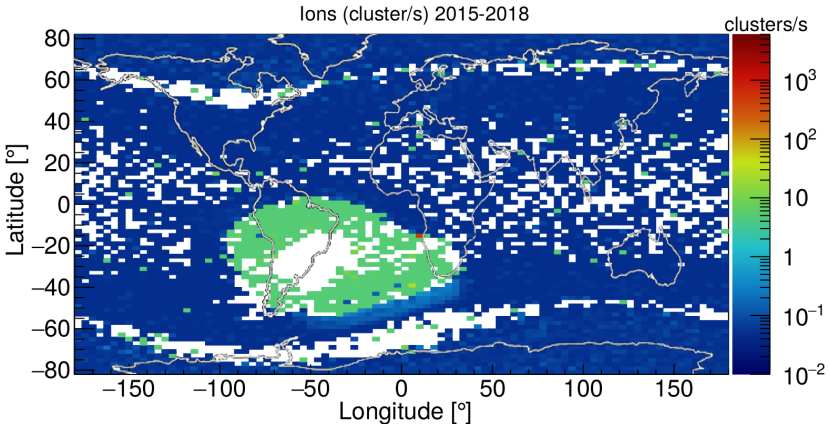
Separation of electrons and protons



(a) Dominated by electrons



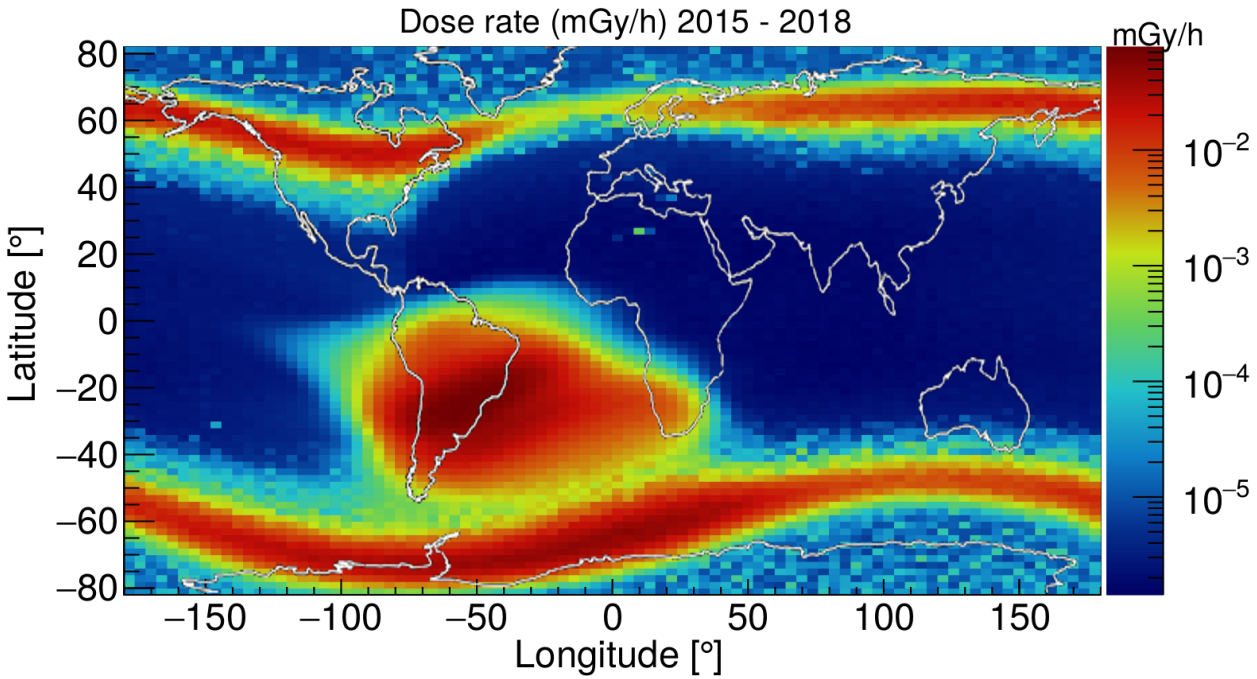
(b) Dominated by protons



(c) Dominated by Ions

Frames with less than 20% occupancy were selected to reduce overlap which causes an underestimation of the flux in the center of the SAA.

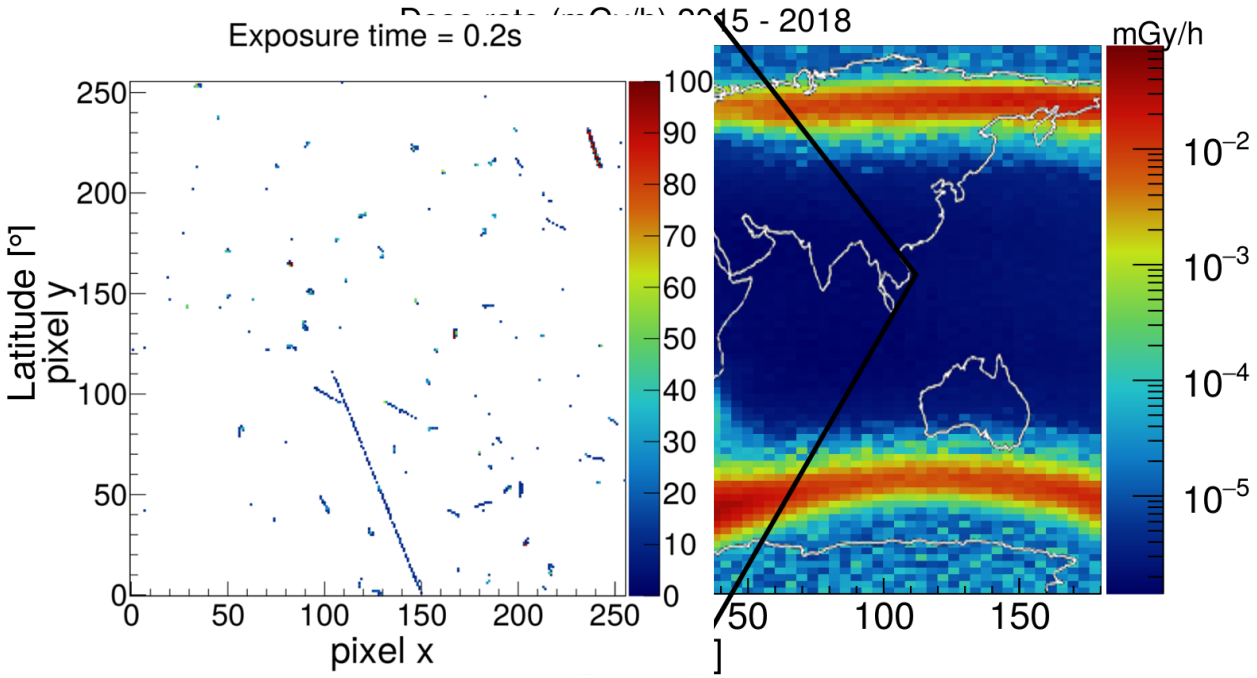
Dose rate



Dose rate:

$$\frac{dD}{dt} = \frac{\sum_{i=0}^{\#pixel} E_i}{m_{sensor} \cdot dt} \qquad (1)$$

Dose rate



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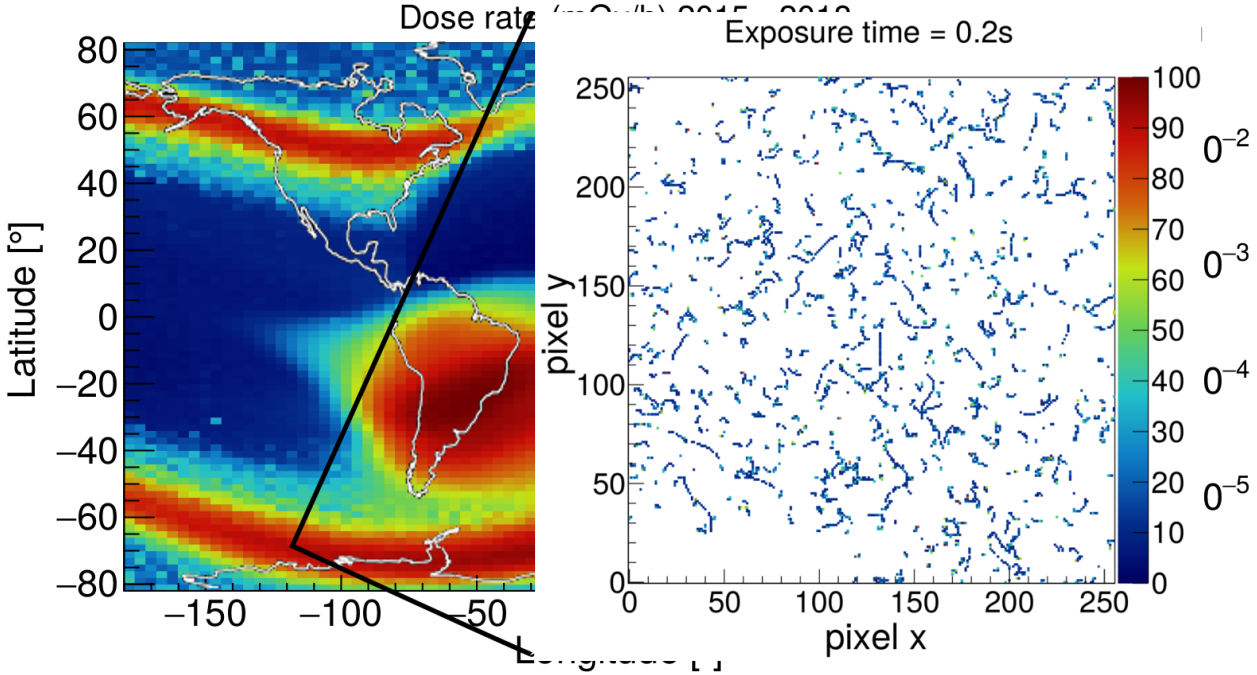
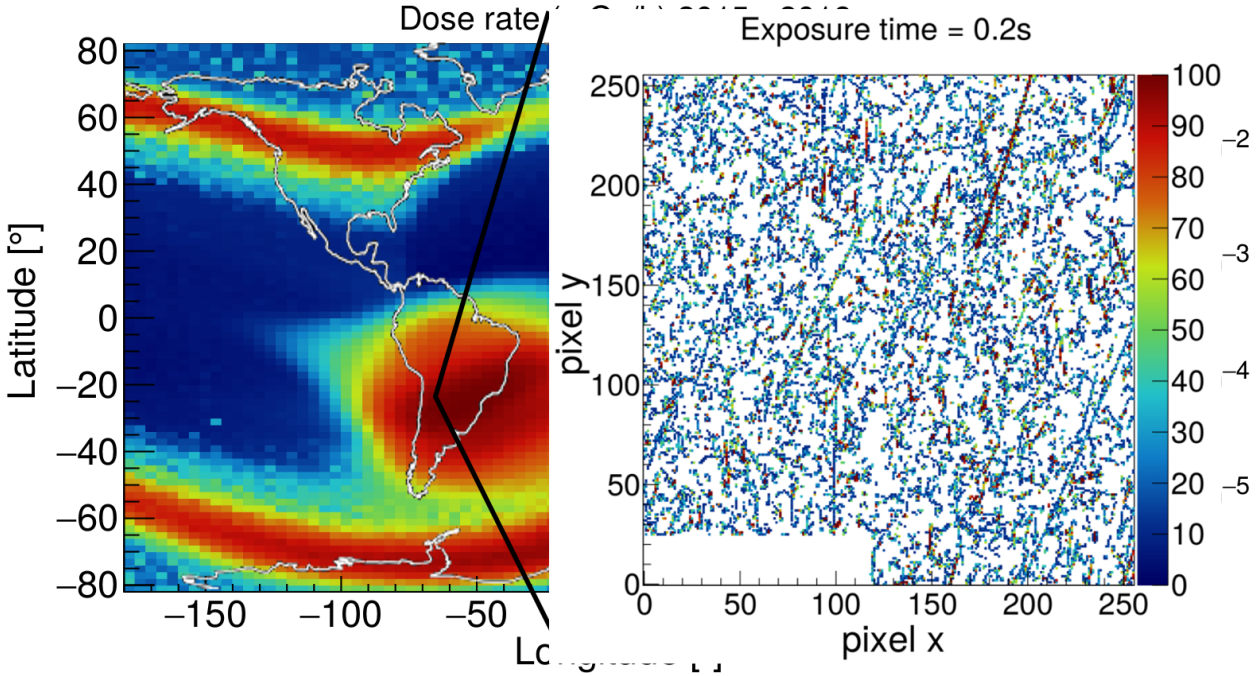
Dose rate



Dose rate:

$$\frac{dD}{dt} = \frac{\sum_{i=0}^{\#pixel} E_i}{m_{sensor} \cdot dt} \qquad (1)$$

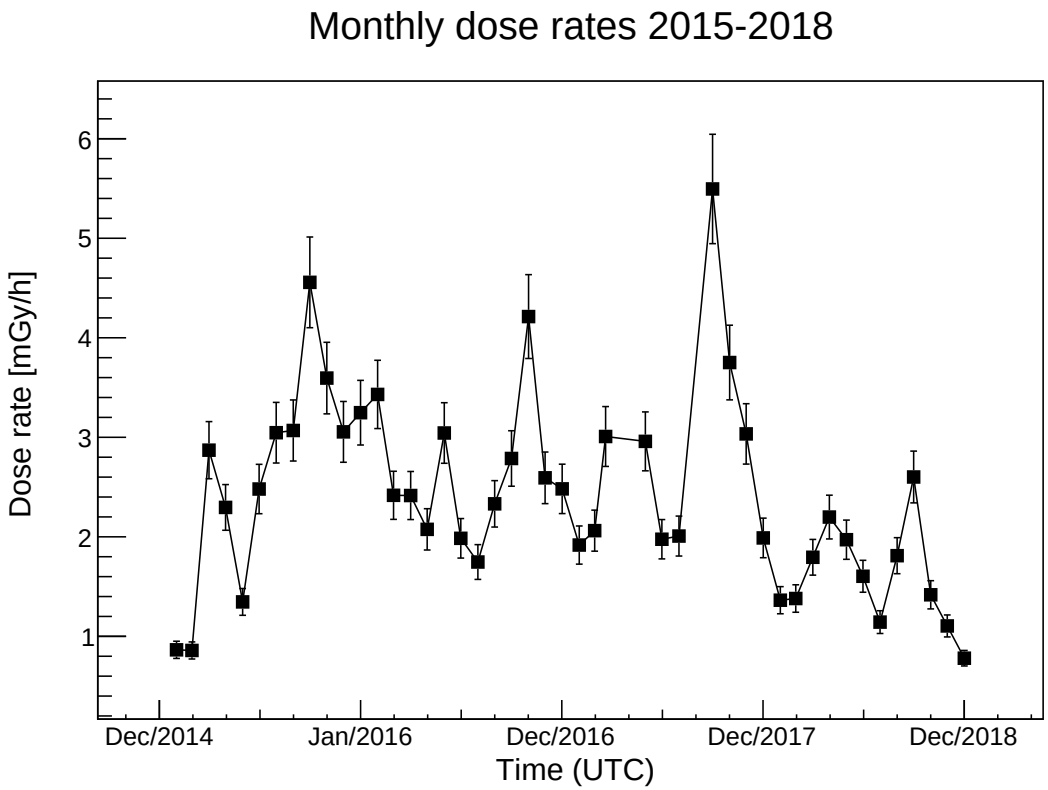
Dose rate



Dose rate:

$$\frac{dD}{dt} = \frac{\sum_{i=0}^{\#pixel} E_i}{m_{sensor} \cdot dt} \qquad (1)$$

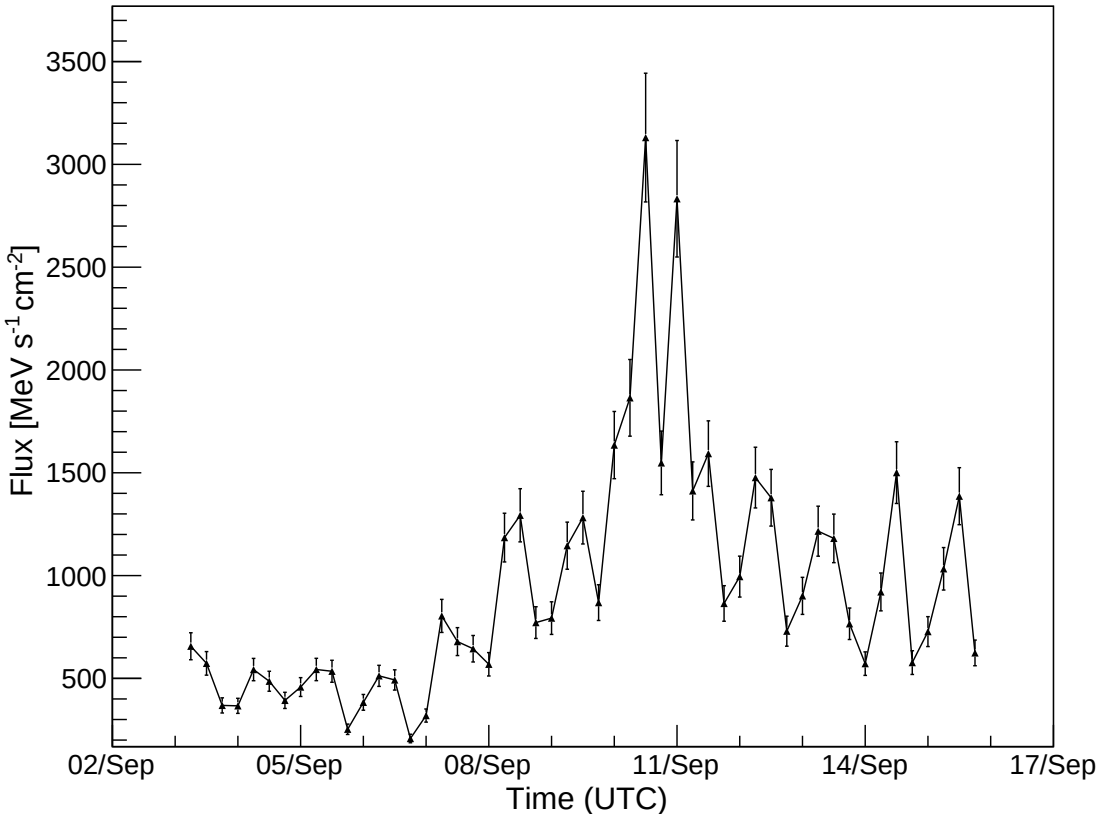
Monthly dose rate



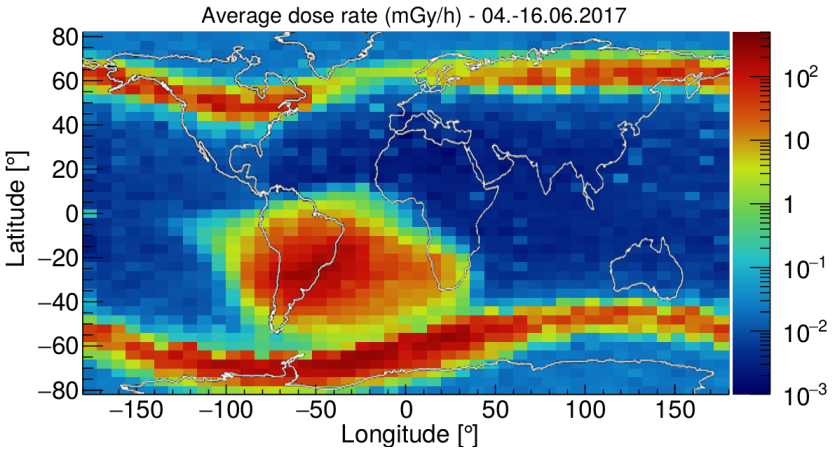
The peaks in the monthly dose rate can be associated with solar events which cause a geomagnetic strom.

Solar Proton Event (SPE) in September 2017

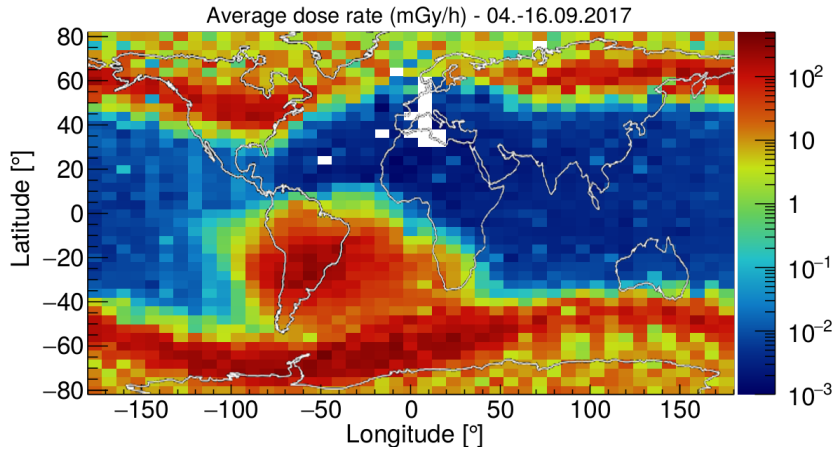
- 2 Solar Proton Events, Sep. 6th and 10th
- 1st event with rather low proton energy ($< 50\,\mathrm{MeV}$)
- 2nd event with protons $> 100\,\mathrm{MeV}$
- SATRAM sees clearly 2nd event



Solar Proton Event (SPE) in September 2017 - 2

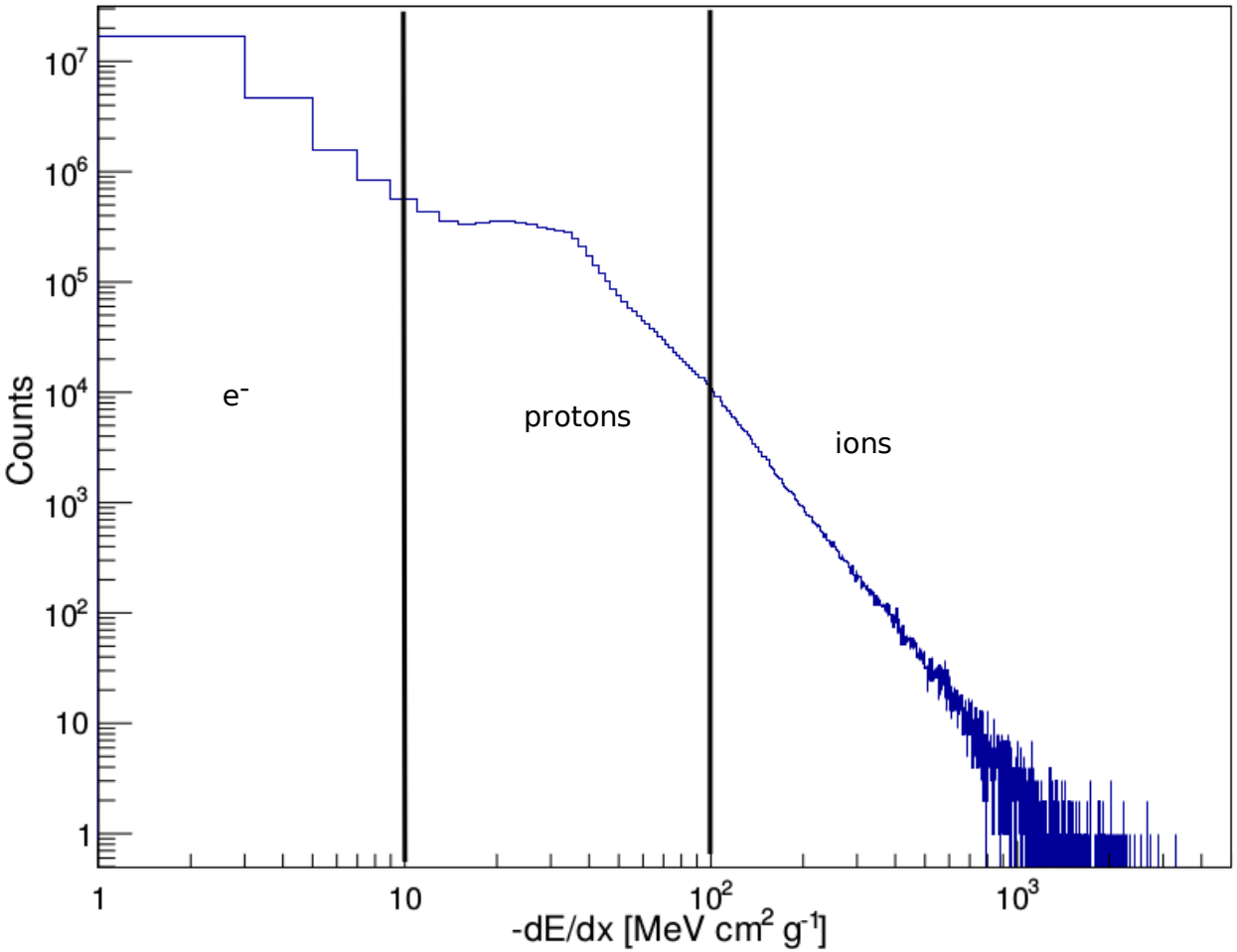


(a) Measured flux from 04.06. to 16.06.2017 for comparison. No SPE or other events were seen during this time.



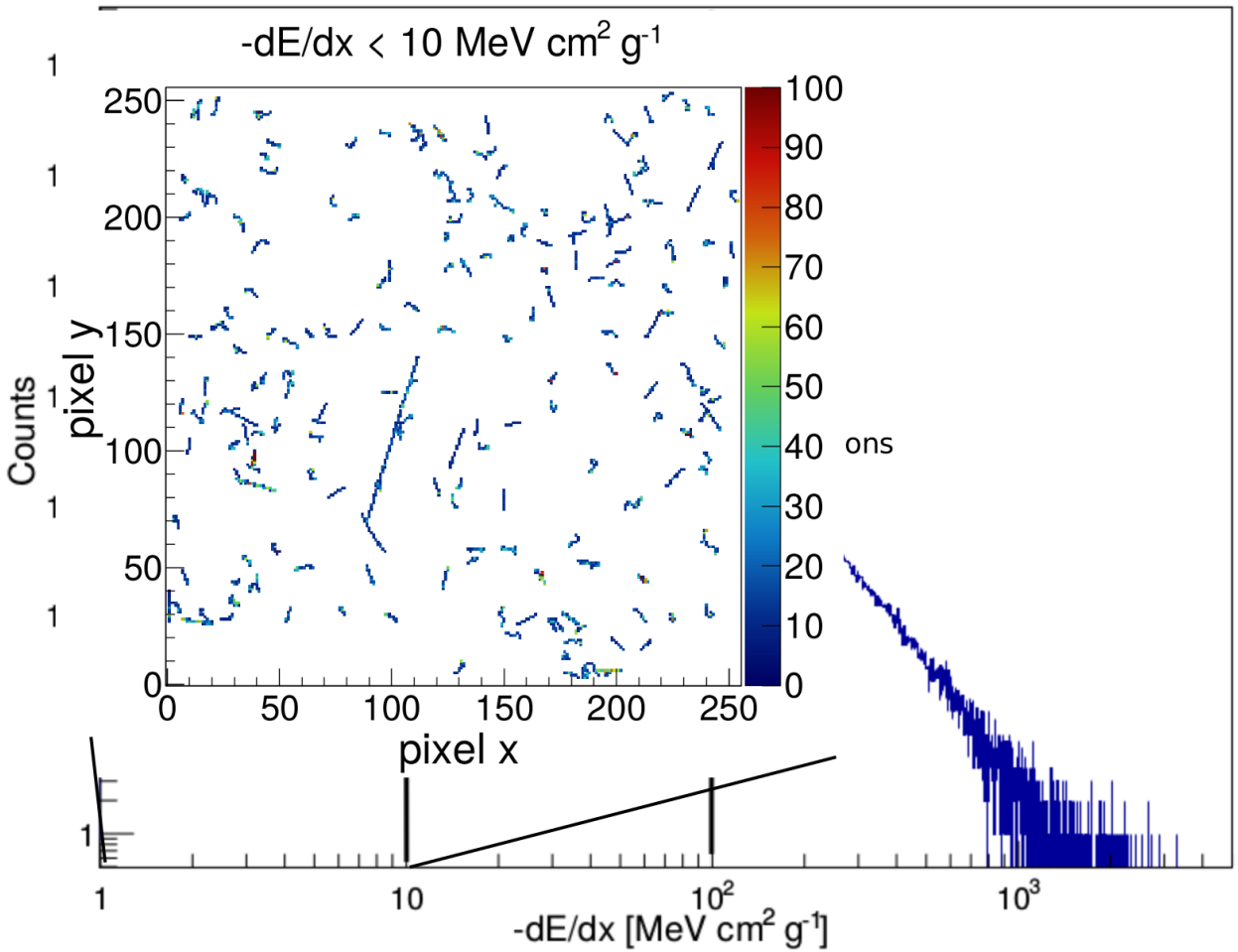
(b) Measured flux from 04.09. to 16.09.2017.

Energy loss spectrum



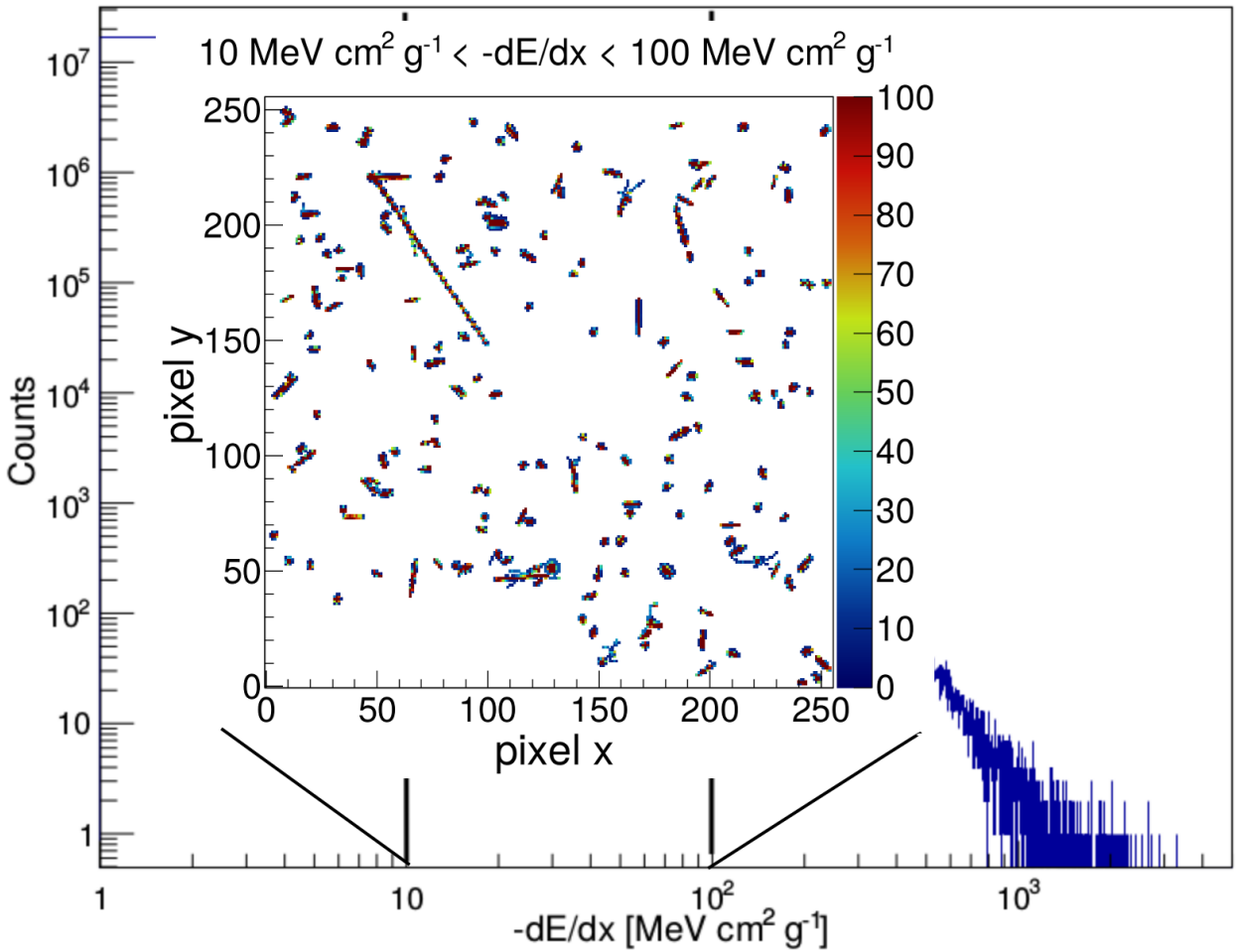
- Time period: 01.01.2015 to 31.12.2017
- Includes electrons, MIP's, protons and heavier ions

Energy loss spectrum



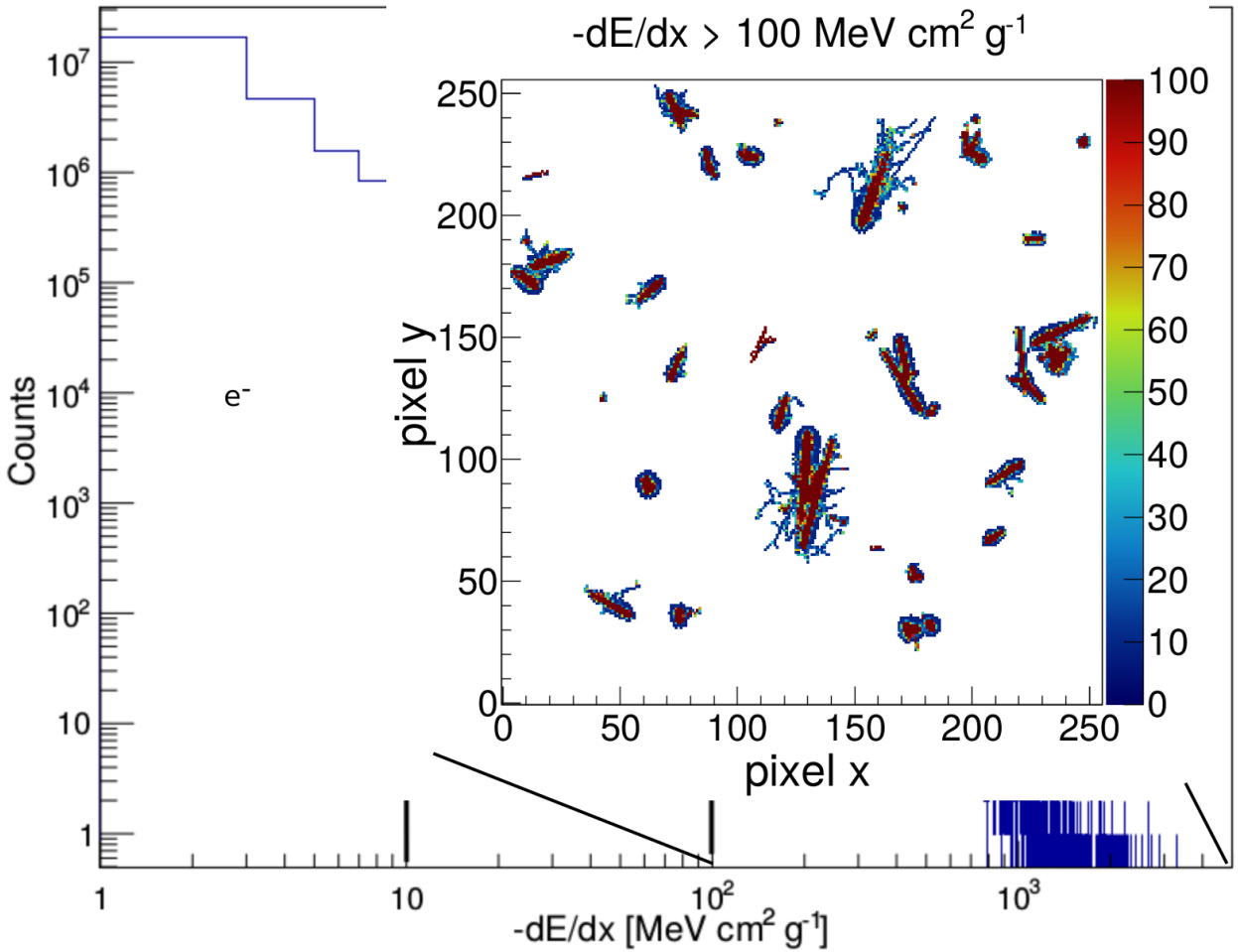
- Time period: 01.01.2015 to 31.12.2017
- Includes electrons, MIP's, protons and heavier ions

Energy loss spectrum



- Time period: 01.01.2015 to 31.12.2017
- Includes electrons, MIP's, protons and heavier ions

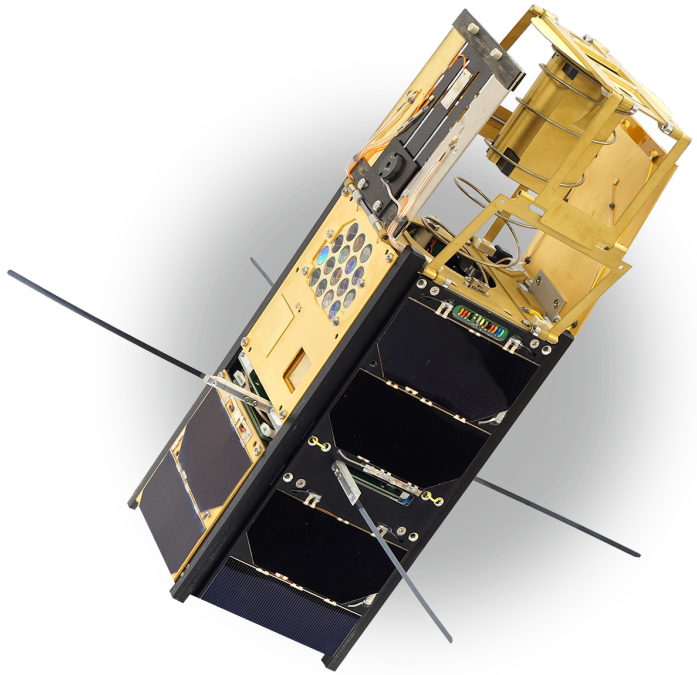
Energy loss spectrum



- Time period: 01.01.2015 to 31.12.2017
- Includes electrons, MIP's, protons and heavier ions

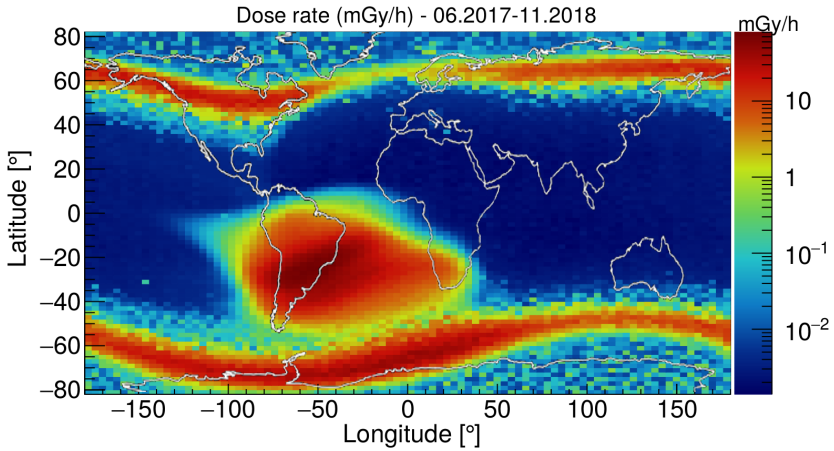
VZLUSAT-1

- Launched from India on June 23, 2017
- 2 unit cubesat
- Altitude: 505 km
- 2kg weight
- Partner: Faculty of mathematics and Physics, Charles University; Czech Space Research Centre; Frentech Aerospace; VZLU; 5M;CTU IN PRAGUE; FEE UWB; HVM PLASMA; IST; RIGAKU; TTS

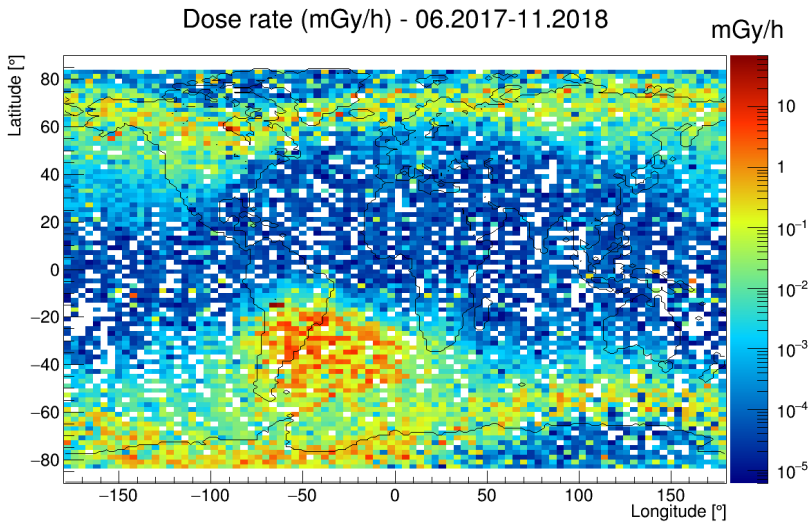


- lost attitude control after start

Dose rate



SATRAM
detector life time: $\approx$ 340 days



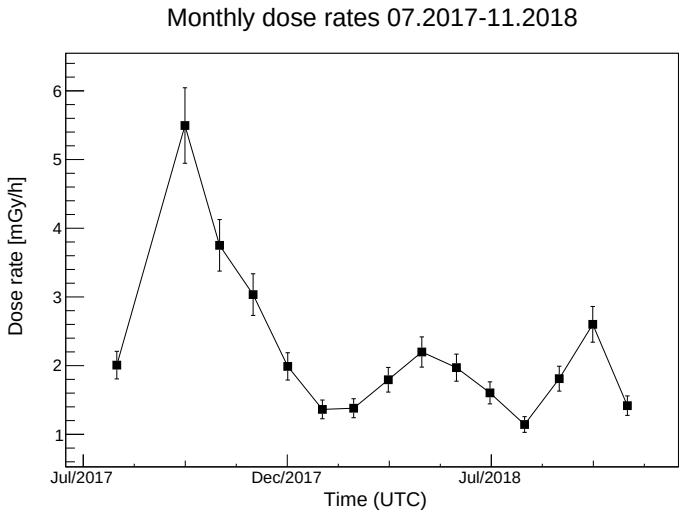
VZLUSAT-1
detector life time: $\approx$ 11 hours

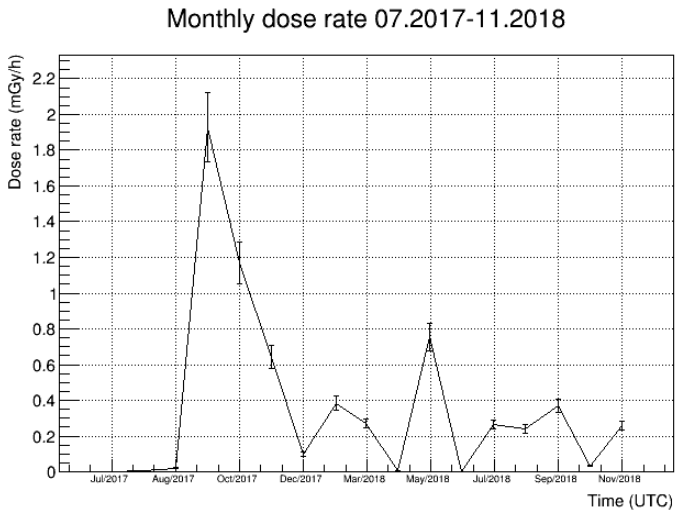
Monthly dose rate

SATRAM

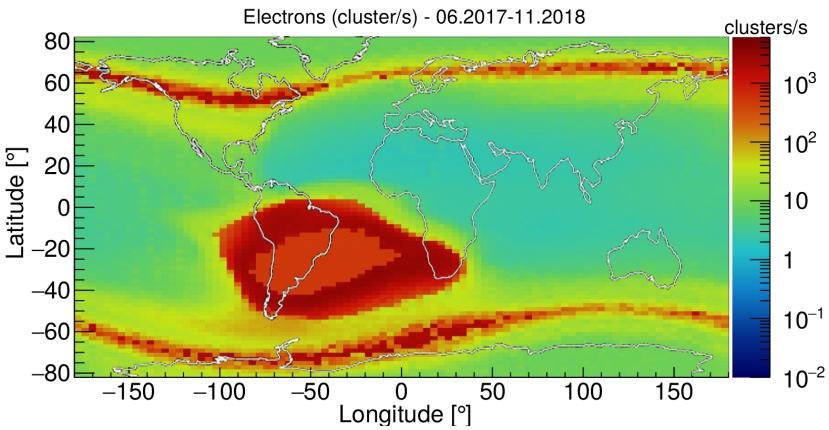
The dose rates agree between the 2 satellites with VZLUSAT showing lower dose due to the lower orbit. VZLUSAT also registered the SPE event in September 2017.

VZLUSAT-1





Cluster rate: Electrons



SATRAM
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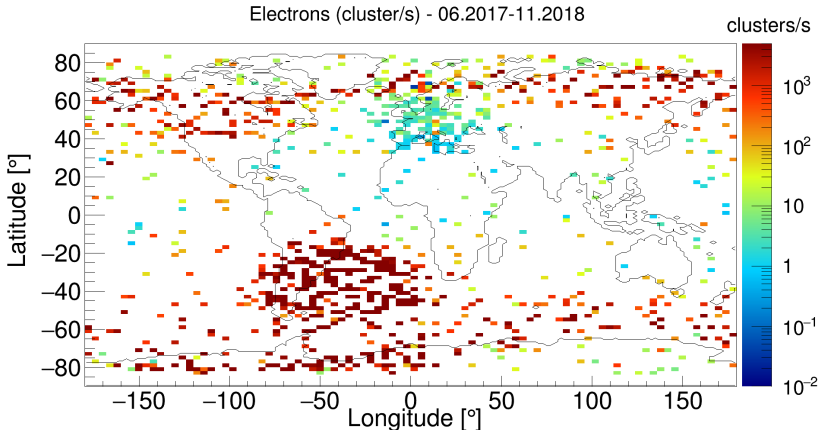
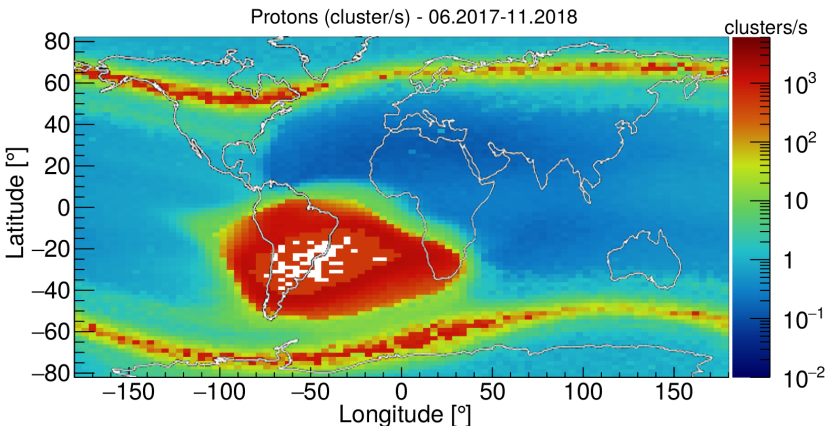
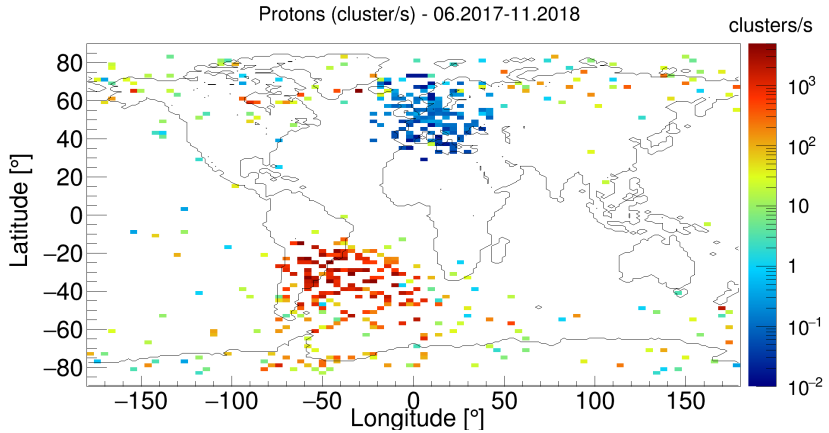


VZLUSAT-1
detector life time: $\approx$ 11 hours

Cluster rate: Protons

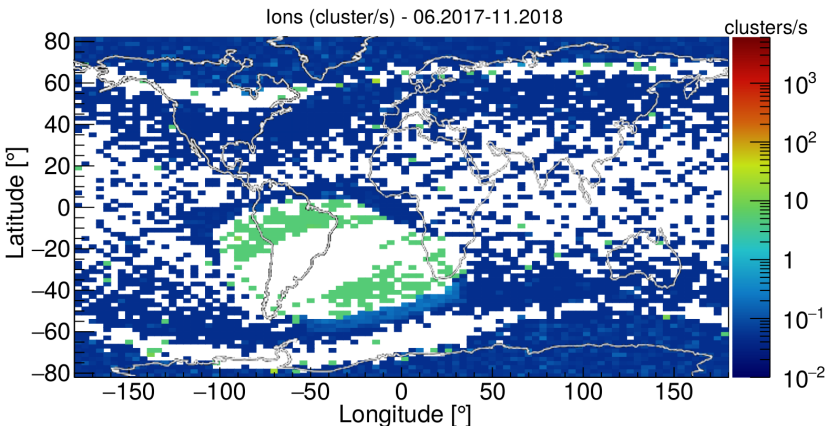


SATRAM
detector life time: $\approx$ 340 days

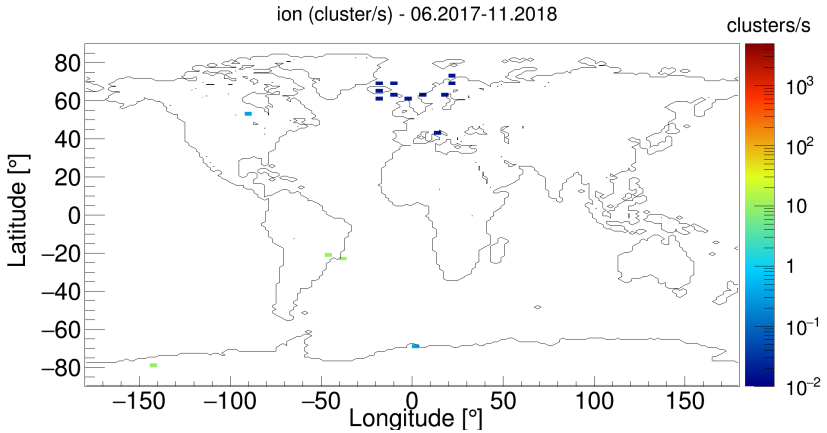


VZLUSAT-1
detector life time: $\approx$ 11 hours

Cluster rate: Ions



SATRAM
detector life time: $\approx$ 340 days



VZLUSAT-1
detector life time: $\approx$ 11 hours

Summary

SATRAM:

- Flown for almost 6 years in orbit
- First successful demonstration of a Timepix working in open space
- Measured dose
- Strategy for particle identification

VZLUSAT-1:

- Measured for 17 months
- Results agree with results from SATRAM

Thank you for your attention!