European Space Projects with Timepix based detetors

Benedikt Bergmann

on behalf of the

Institute of Experimental and Applied Physics

Czech Technical University in Prague

Outline

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1. Van Allen Radiation Belts
2. Instrumentation: why Timepix?

3. Ongoing missions (Low Earth Orbit):
   - SATRAM (Space Application of Timepix Radiation Monitor)
   - VZLUSAT-1
   - RISESAT

4. Current development and Future
   - MIRAM – GOMX-10
   - PAN (Penetrating particle analyser)
   - RADMONSSA
   - iSpace – Timepix on the Moon (exploration)
   - Democritos – Moon, Mars and beyond!

Van Allen radiation belts

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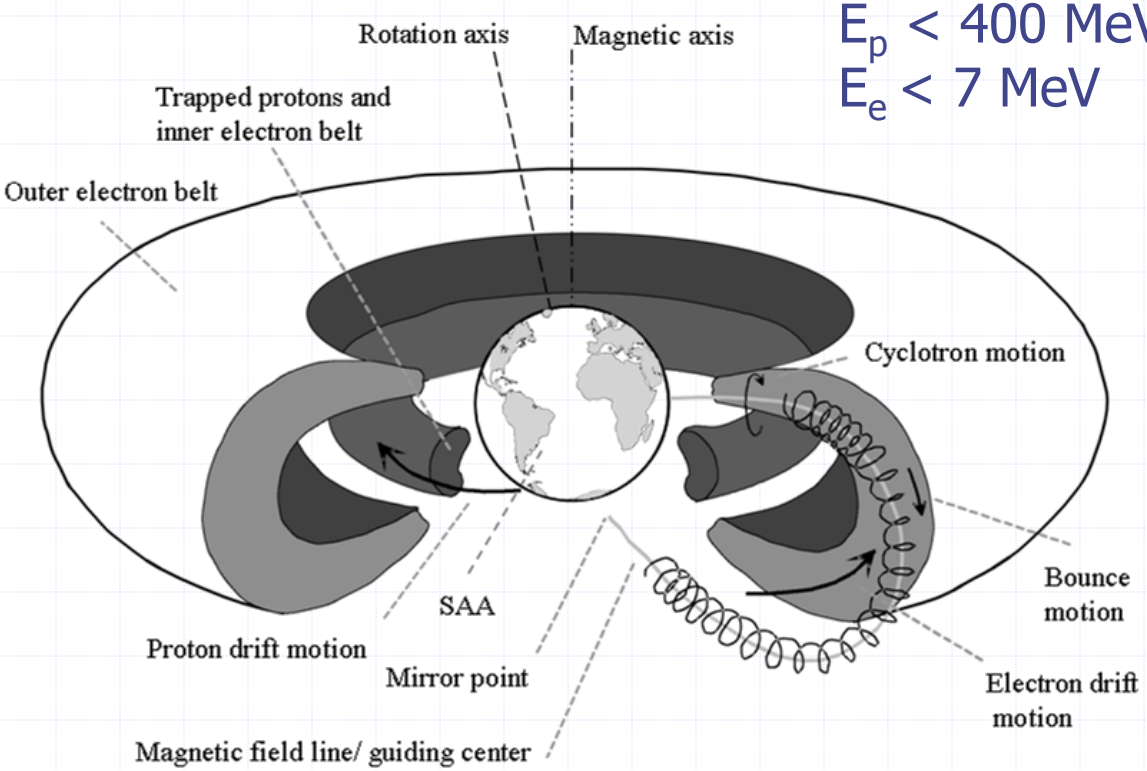
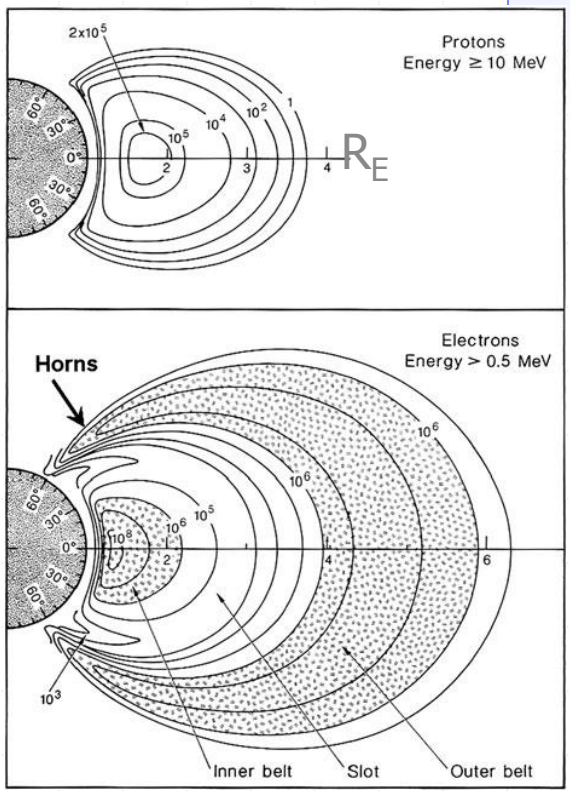
A. Owens, "*Semiconductor Radiation Detectors*", CRC Press, Bocca Raton, Fl (2019) ISBN-13: 978-1138070745.

$E_p < 400$ MeV
$E_e < 7$ MeV





Mauk, B.H., Fox, N.J., Kanekal, S.G. et al. Space Sci Rev (2013) 179: 3.

Temporal fluctuations of the radiation belts

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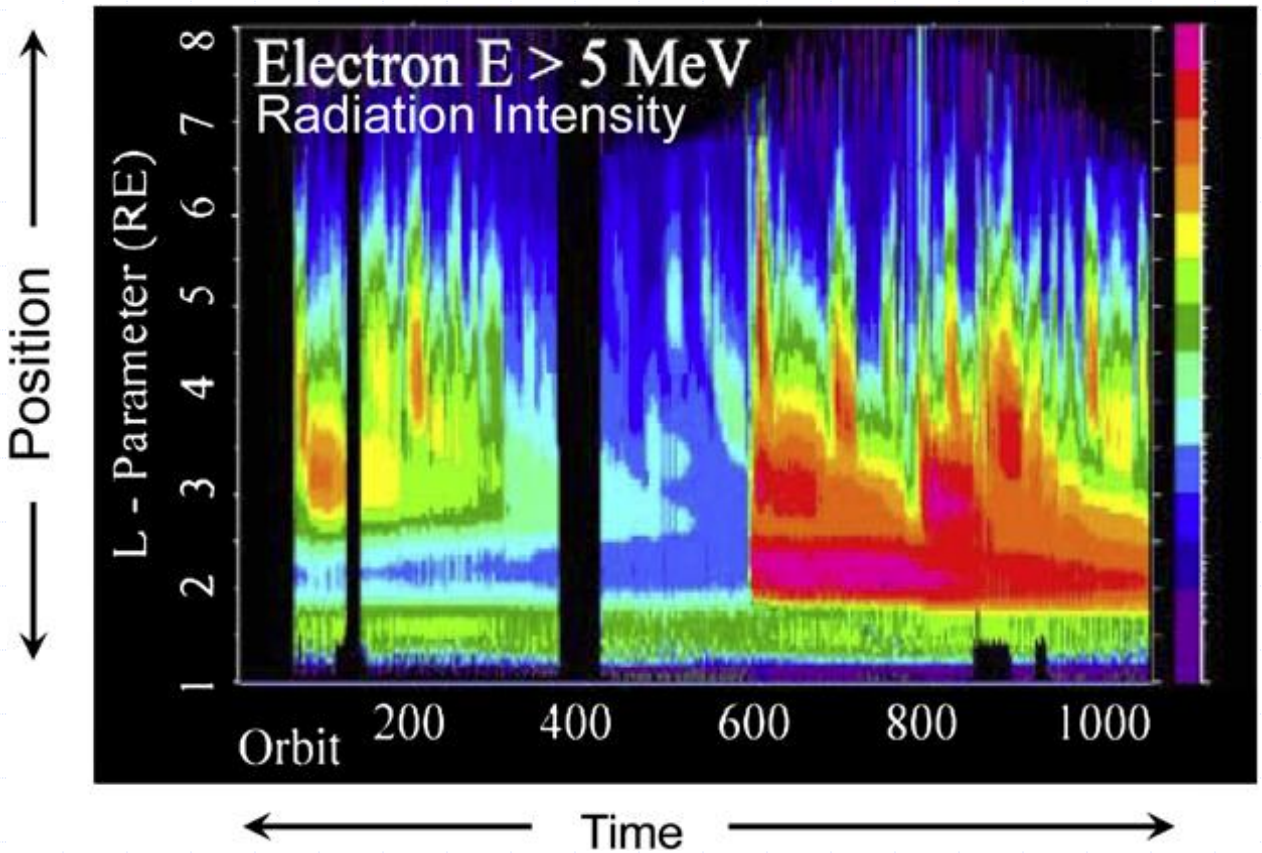
Radiation belts are not stable in time. They react to Solar Flares, Solar Particle Events, interplanetary shock waves, ...

CRRES*) spacecraft observation of the creation of a new electron radiation belt that filled the slot region between 2 and 3 R_E.

Mauk, B.H., Fox, N.J., Kanekal, S.G. et al. Space Sci Rev (2013) 179: 3.



*) **C**ombined **R**elease and **R**adiation **E**ffects **S**atellite

Instruments for space weather monitoring

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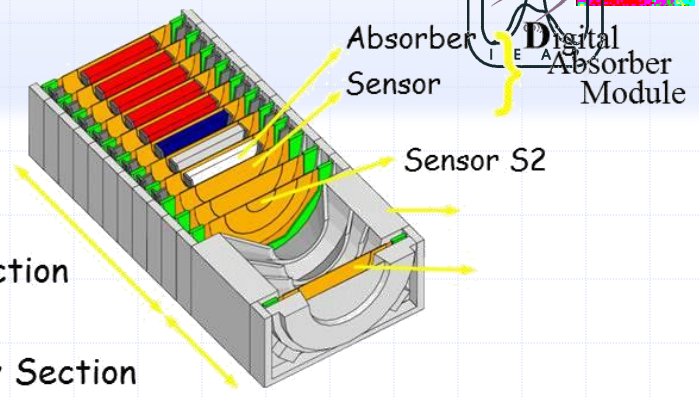

EPT (Energetic Particle Telescope)

- Dimensions: 13 x 16 x 21 cm^3
- Mass: **4.6 kg**
- Power consumption: **5.6 W**
- **Science class instrument**

ICARE (Influence of Space Radiation on Advanced Components)**:**

- Dimensions: 28 x 15.5 x 7.1 cm^3
- Mass: **2.4 kg**
- Power consumption: **3 W**

SREM (Standard Radiation Environment Monitor)

- Dimensions: 20 x 12 x 10 cm^3
- Mass: **2.6 kg**
- Power consumption: **2.5 W**

Why Timepix?

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- High dynamic range (energy, count rate)
- Single layer particle discrimination capability (electrons, protons, ions)
- Small dimensions and low mass (< 500 g)
- Wide field of view

Ongoing missions:

- SATRAM on Proba-V (820 km, since 2013)
- VZLUSAT-1 (510 km, since 2017)
- RISEPix on RISESAT (500 km, since 2019)

SATRAM

Space Application of Timepix Radiation Monitor

SATRAM:

Space Application of Timepix Radiation Monitor

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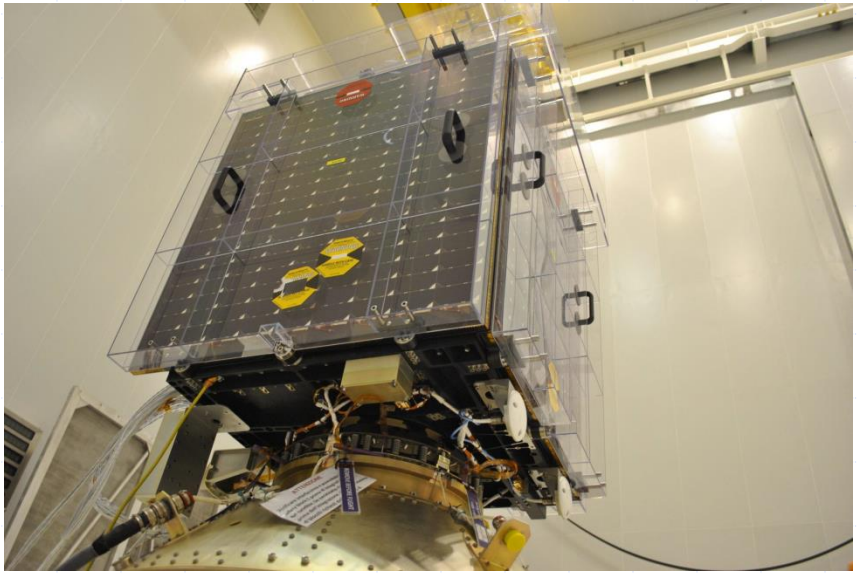
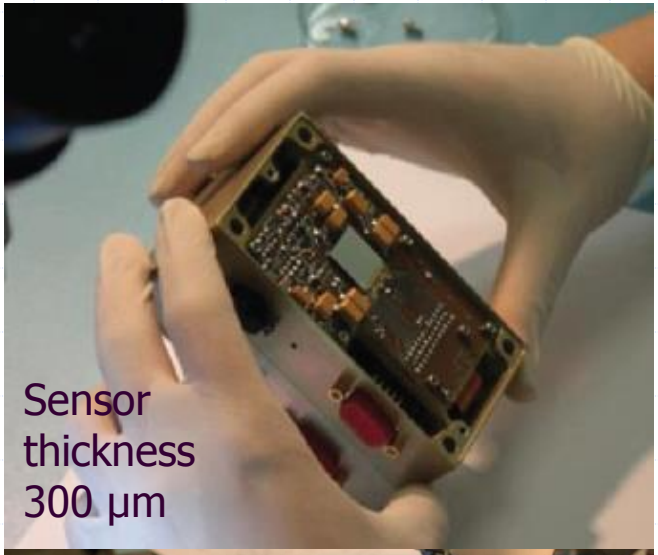
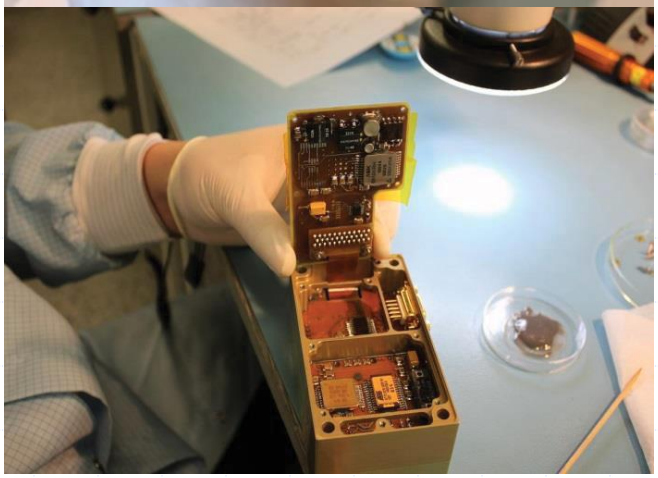
- Secondary instrument mounted on ESA Proba-V satellite
- Timepix for the first time in open space
- Power consumption of 2.5 W
- Total mass **380 g** (10 x 7 x 5.5 cm^3)
- Launched in 2013







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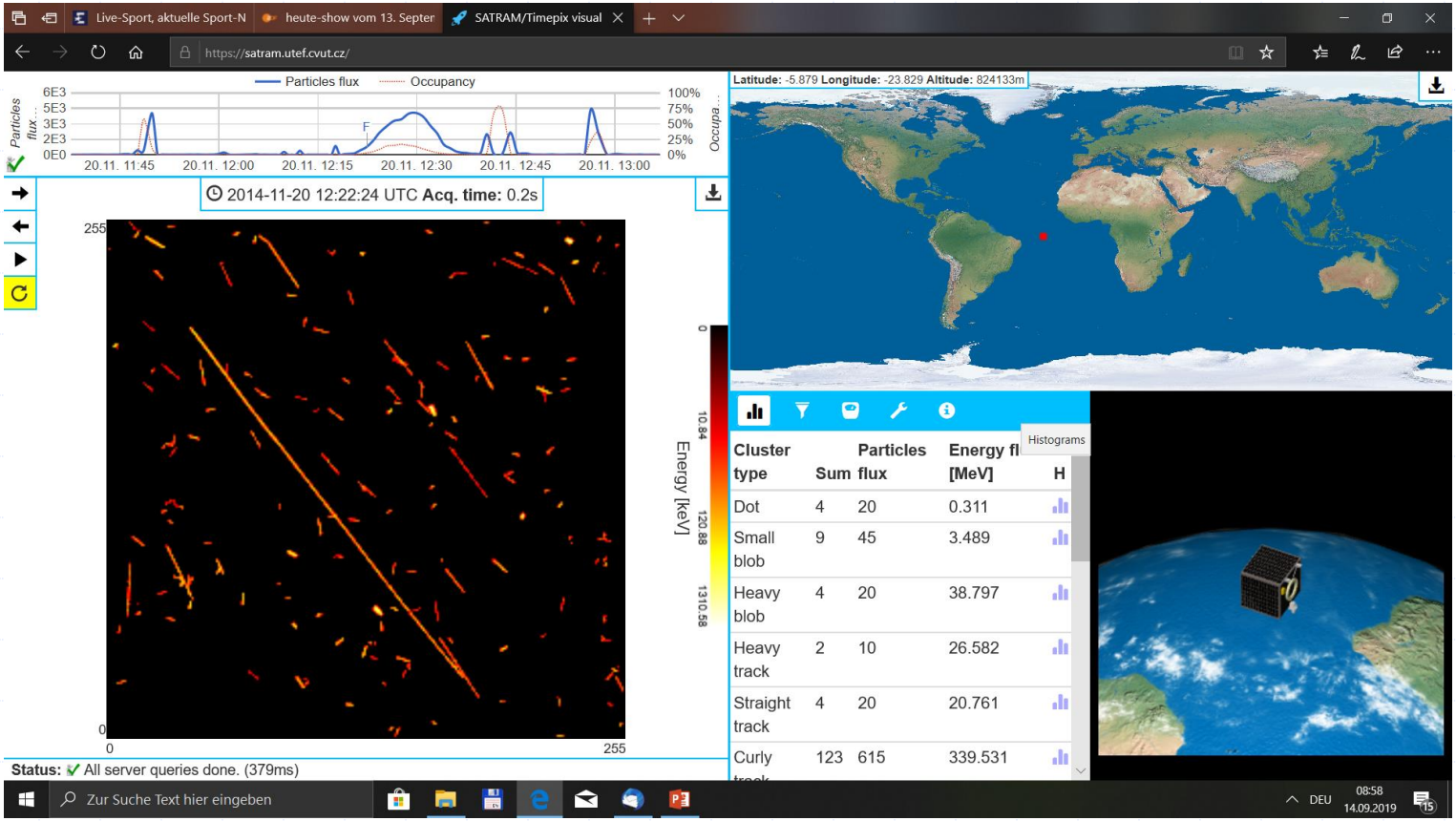
Web visualization

https://satram.utef.cvut.cz/



H. Waage, "Web portal for visualizing data from the satellite instrument SATRAM/Timepix", Master Thesis, Faculty of Information technology, CTU in Prague, 2017.

Timepix SATRAM/ESA Proba-V in Open Space

Quantum imaging detection/monitoring of space radiation

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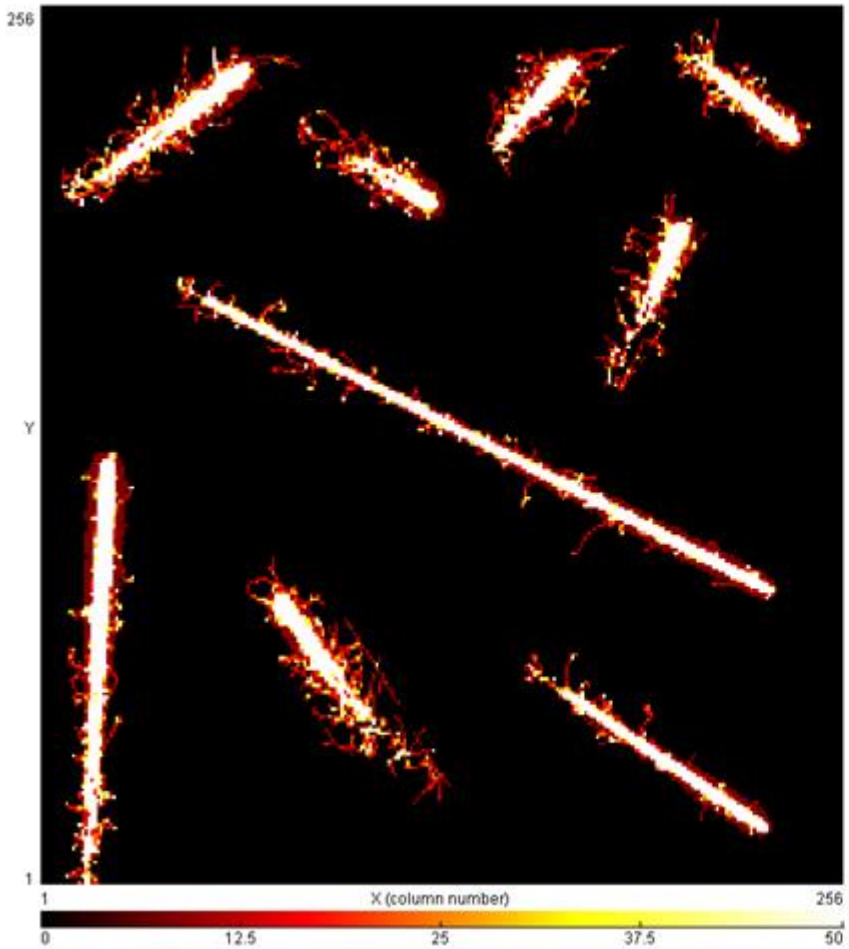
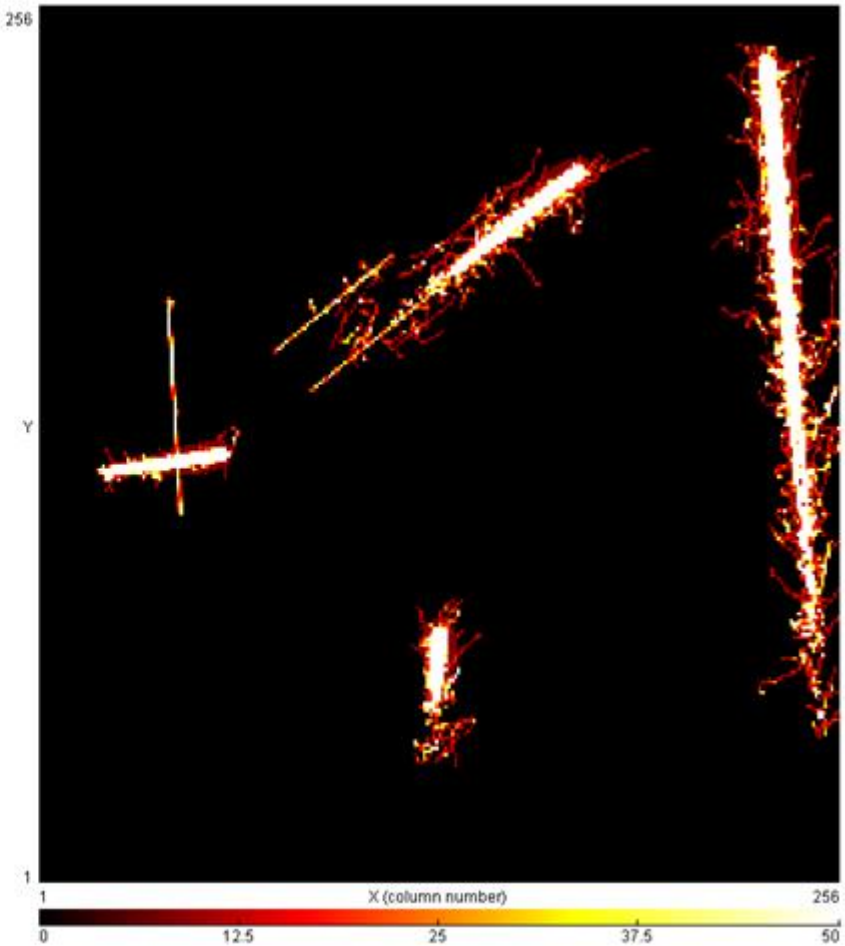
HETPs: Highly energetic heavy charged particles (ions) → HZE's





Timepix SATRAM/ESA Proba-V in Open Space
Quantum imaging detection/monitoring of space radiation

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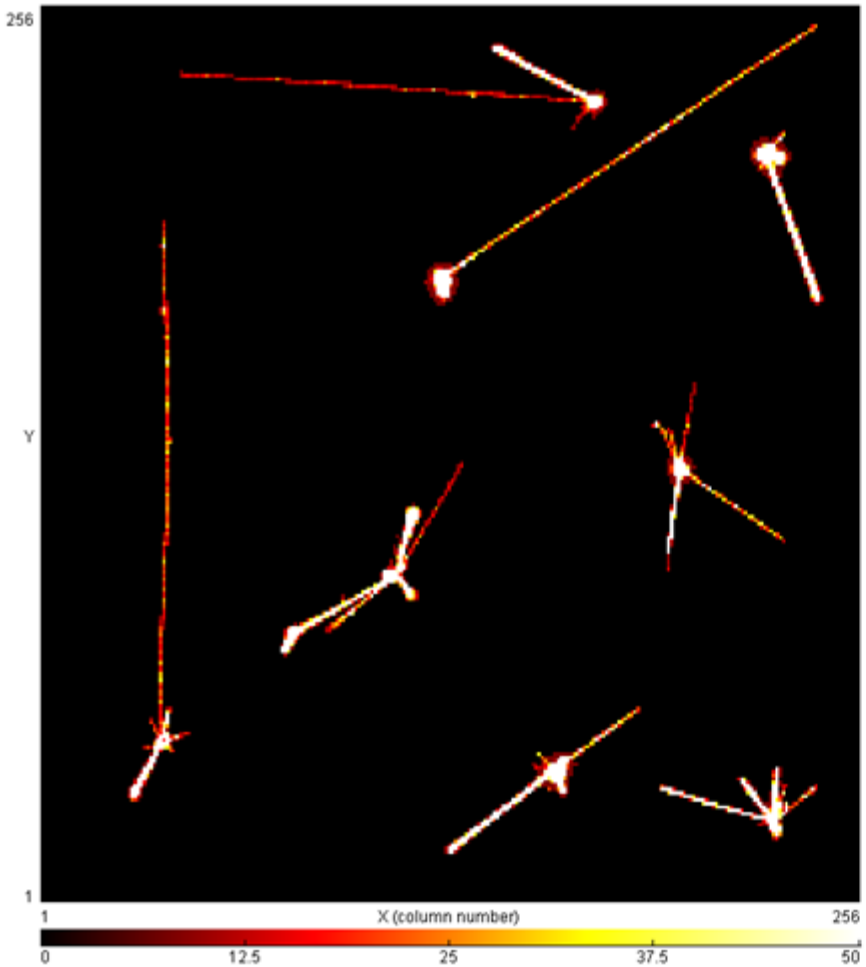
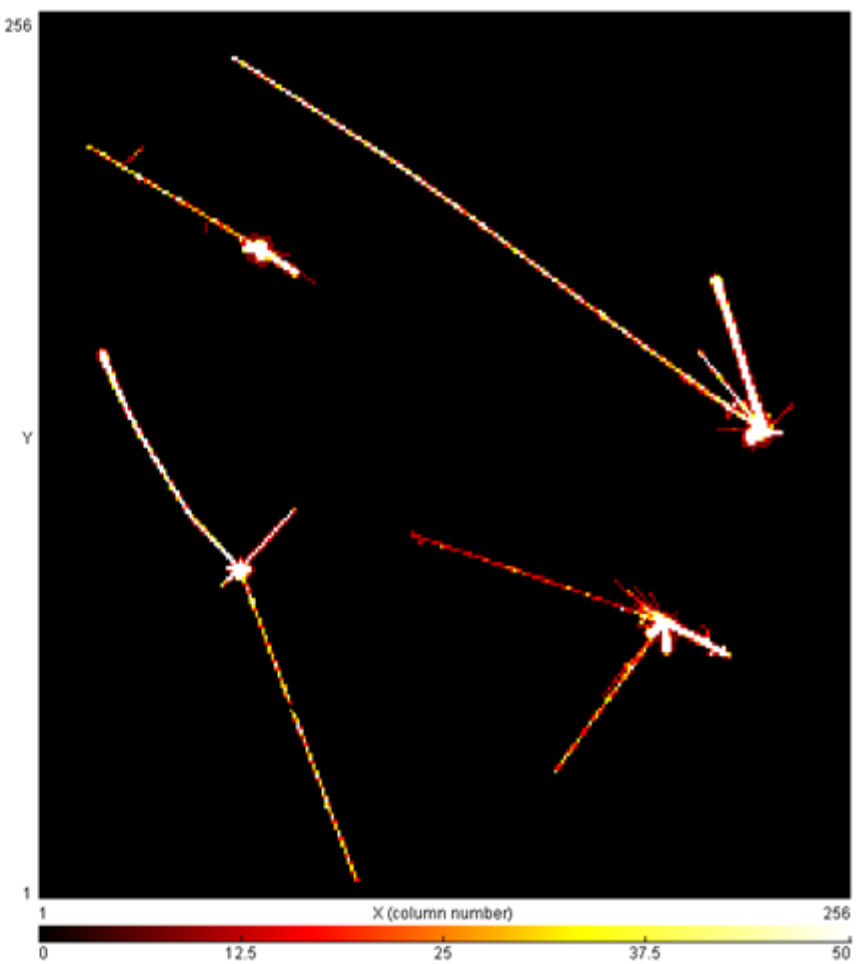
nuclear interactions – spallation reactions





SATRAM: Solar proton event (SPE) in September 2017

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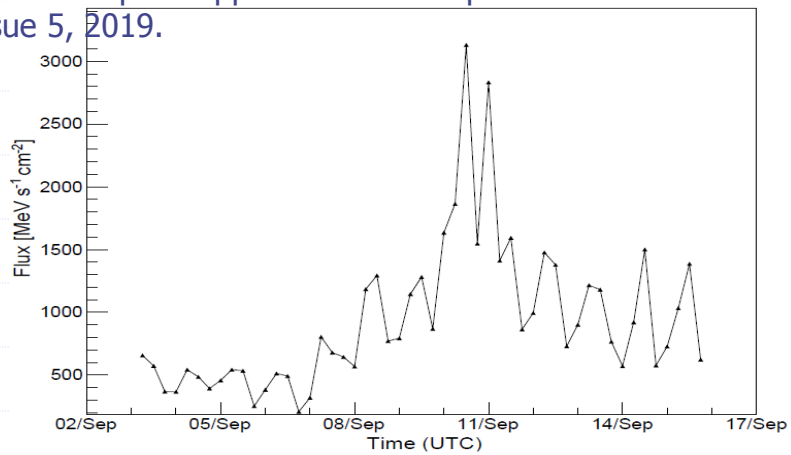
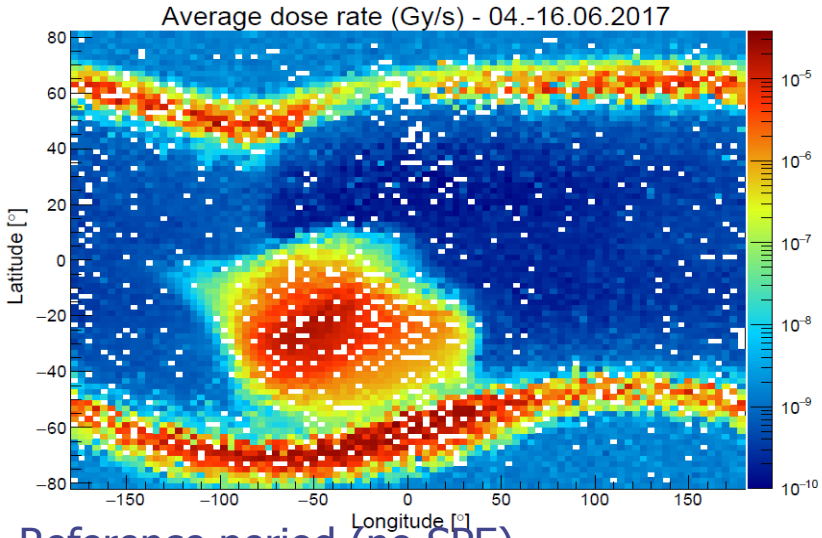
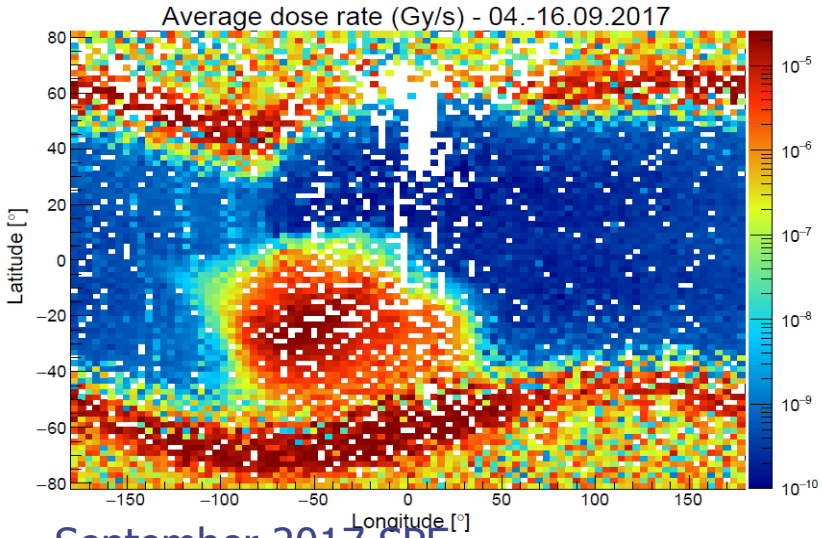
Stefan Gohl et al., "Study of the radiation fields in LEO with the Space Application of Timepix Radiation Monitor (SATRAM)", Advances in Space Research, Volume 63, Issue 5, 2019.

- 2 SPE (September 6 and 10)
- 1st event with proton energies < 50 MeV (not seen in SATRAM)
- 2nd event with higher energy protons (> 100 MeV) seen



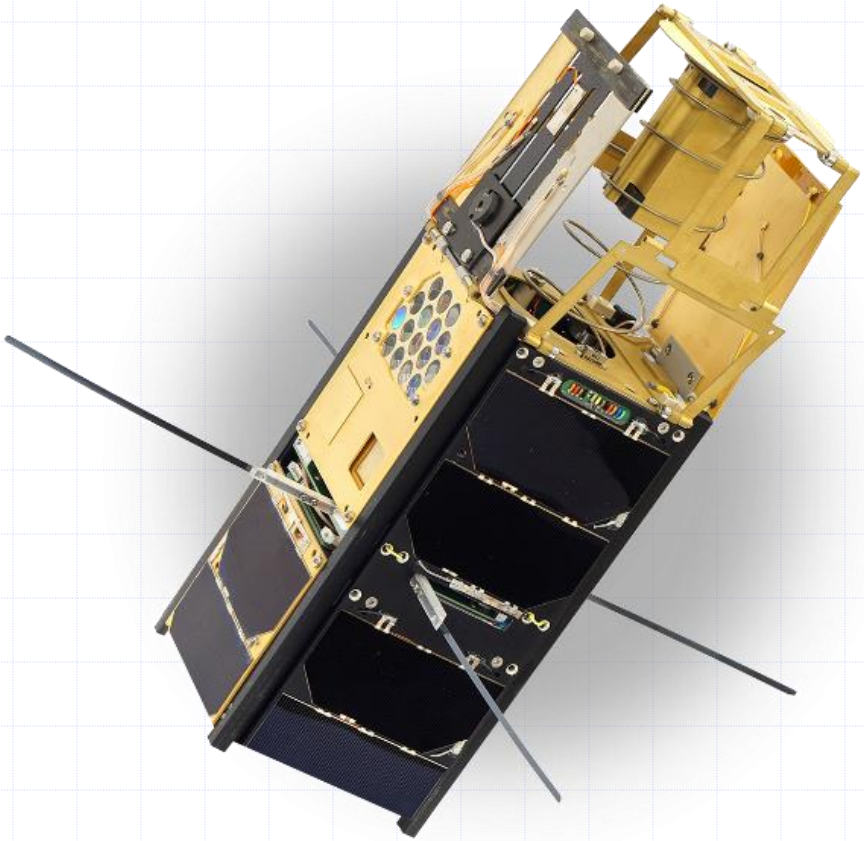


Reference period (no SPE)



September 2017 SPE

VZLUSAT-1



VZLUSAT-1

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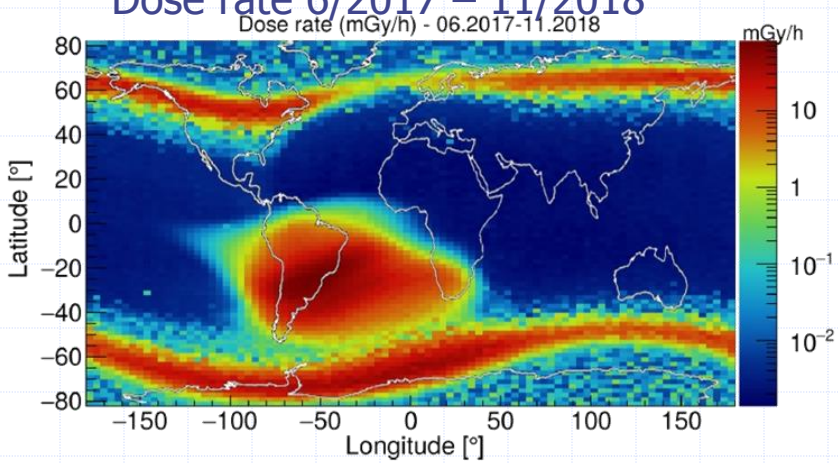
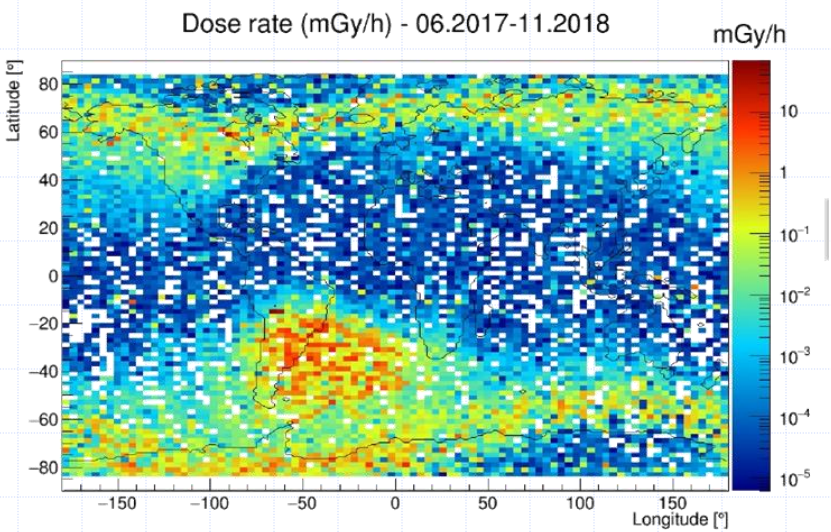
- Timepix detector as part of miniature X-ray telescope onboard VZLUSAT-1 Cubesat since 2017. The first Czech satellite since 1996.
- Over 5,000 exposures, monitoring radiation environment at altitude of 500km

Dose rate 6/2017 – 11/2018





SATRAM
detector life time: $\approx$ 340 days

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

VZLUSAT-1 – Exposure to direct sunlight

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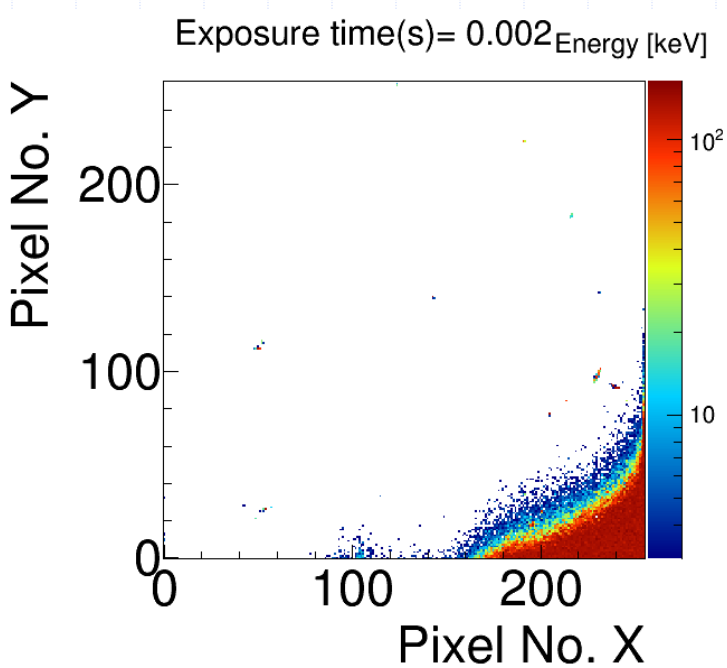
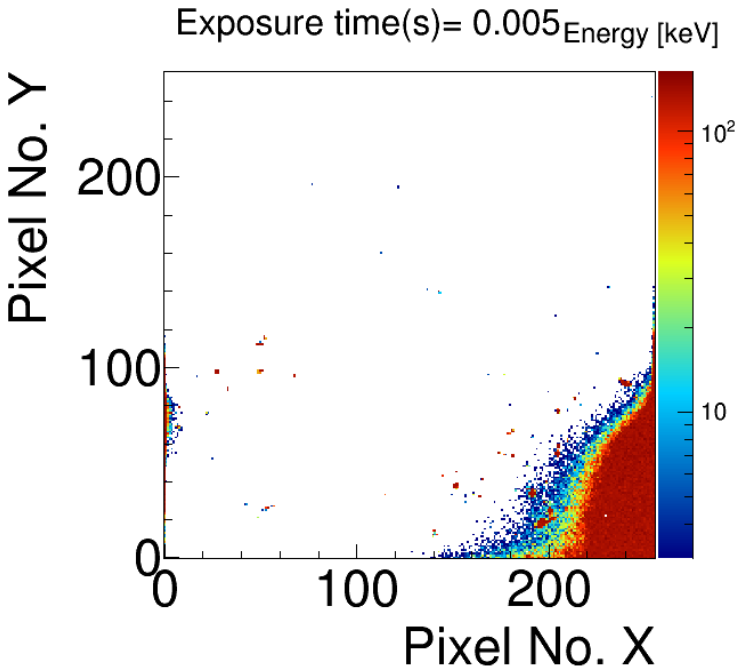
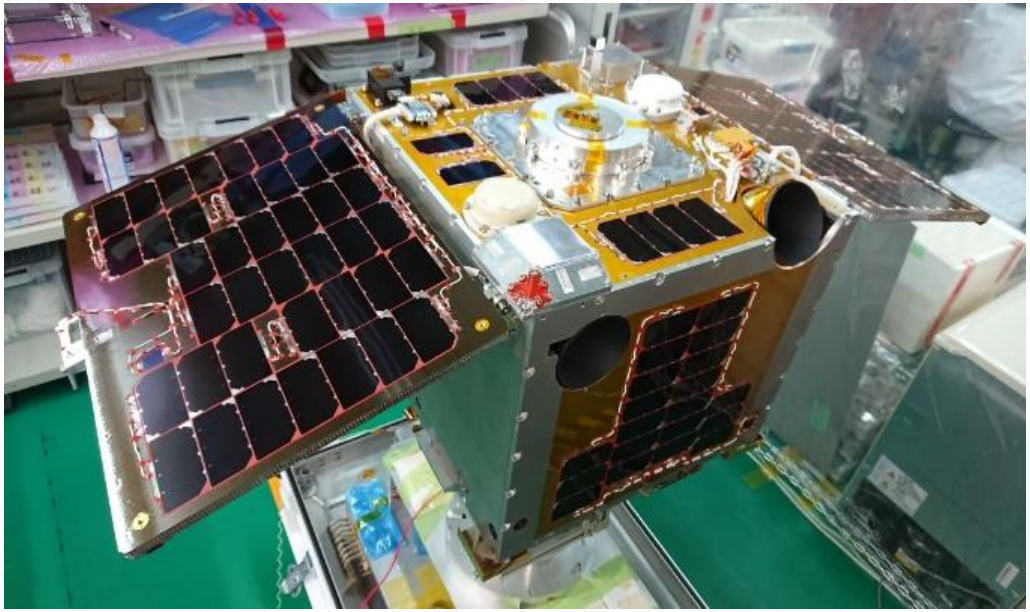




- UV-triggered solar imaging not properly working due to problems in the attitude recognition system.
- Sometimes radiation from the sun directly hits the Timepix sensor.

Japanese Rapid International Scientific Experiment Satellite (RISESAT)

RISEPix



- Microsatellite (~50 kg, 50x50x50 cm)
- Development led by Tohoku University and Hokkaido University

RISEPix design – Temporal evolution

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- Design changed substantially during development – box dimensions needed to remain identical
- Two-layer Timepix stack for improved particle type sensitivity using coincidence information

~2013

~2015

~2019

RISESAT

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- Launched to Sun-synchronous orbit ~500 km in January 2019 by Epsilon 4 rocket from the Uchinoura Space Center (JAXA)
- Mission duration 2-3 years.

Present developments and future projects

Miniaturized Radiation Monitor (MIRAM)

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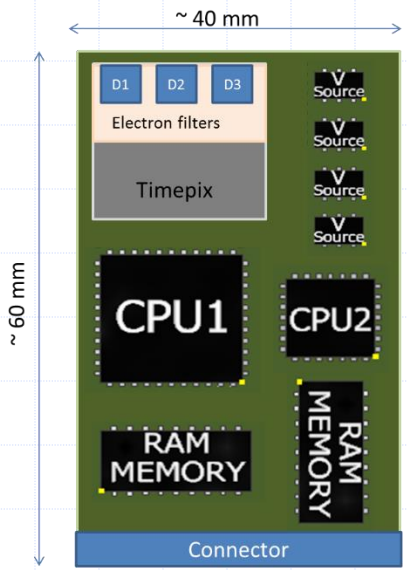
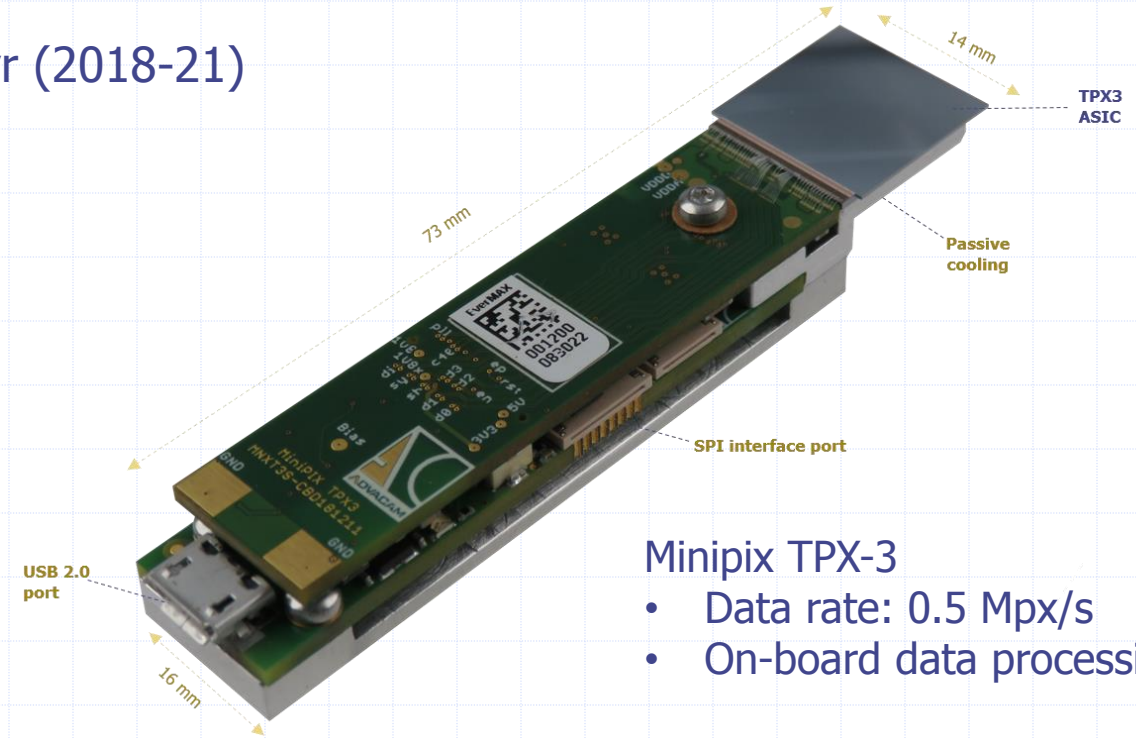
Development of space radiation monitor with:

- Mass < 0.2 kg
- Power consumption < 1 W
- Price < 50 kEUR

Project duration: 2.5 yr (2018-21)





Minipix TPX-3

- Data rate: 0.5 Mpx/s
- On-board data processing

Miniaturized Radiation Monitor (MIRAM) – First test(s)

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Tested preliminary MIRAM breadboards in Fe Beam (230MeV/A, 350MeV/A, 1,000 MeV/A).

Goals of experiments:

- Experimental determination of the Timepix2/3 detector response in a heavy ion beam(s)
- Experimental verification of the low power circuit (LPC) functionality (diode)
- First beam test of the Katherine R/O for Timepix2
- Test of coincidencing schemes of LPC and Timepix2/3
- First beam test of the MiniPix in Timepix3 technology (pixel detector part of MIRAM)

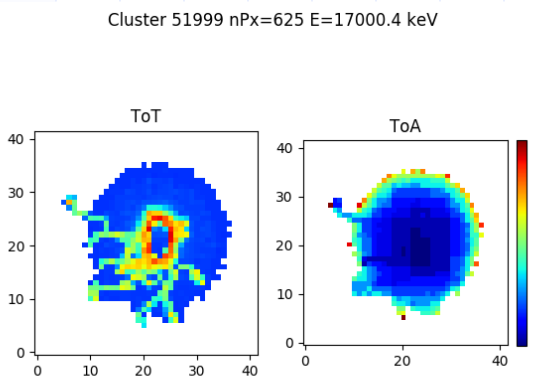

Fig.1: Example of an Fe track as seen in Timepix3 (left: Energy [keV]; right: relative Time of Arrival [ns])

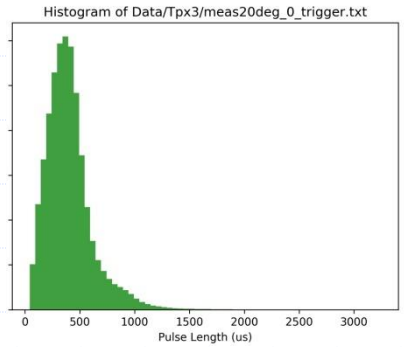

Fig.2: Pulse height spectrum measured with the single pad diode

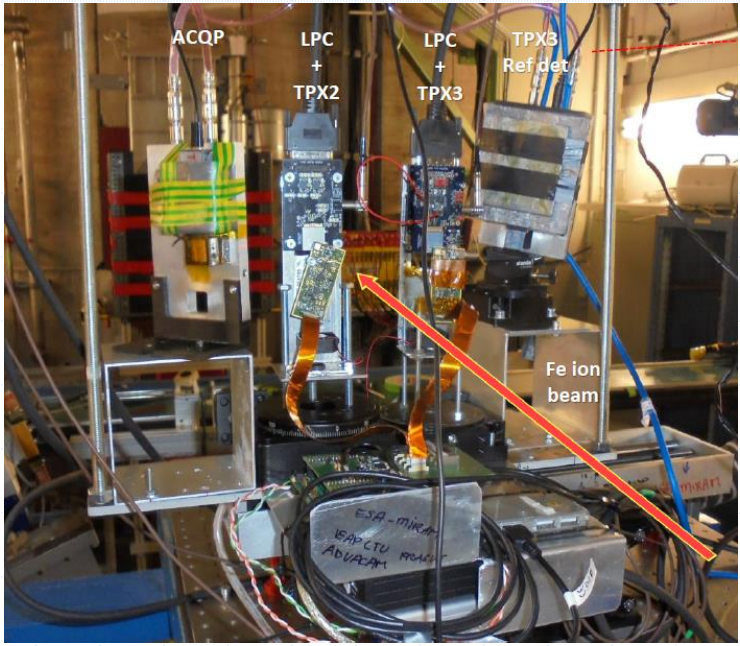

Fig.3: Picture of the experimental setup in GSI. 4 devices under test are mounted on a movable stage (horizontal and vertical movements, rotation) and were operated remotely.

MIRAM in Space: GOMX-5 Cubesat

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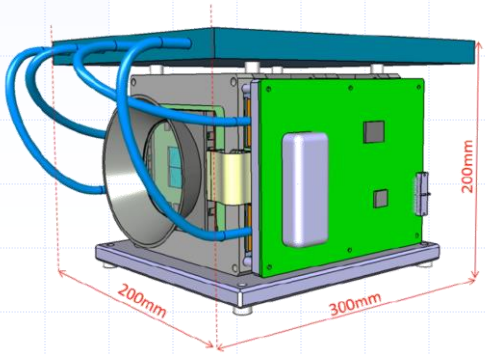
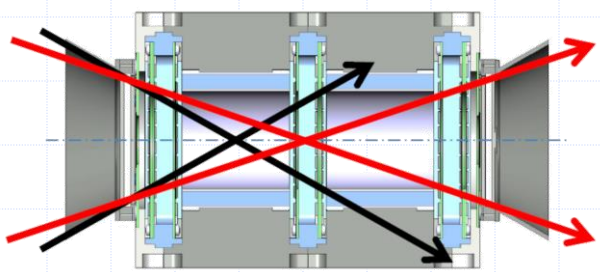
- MIRAM was chosen as a payload for GOMX-5 Cubesat mission, 12U, 20 kg
- Planned launch in 2021
- Technology demonstration of MIRAM

Other projects

(mini.)PAN (**P**enetrating **P**article **A**nalyzer)

- Magnetic spectrometer (strip, pixel + magnet)
- dE/dx in pixel and strip detectors
- TOF (SiPM) for exit and entry
- Mass ~20 kg, power consumption 20 W

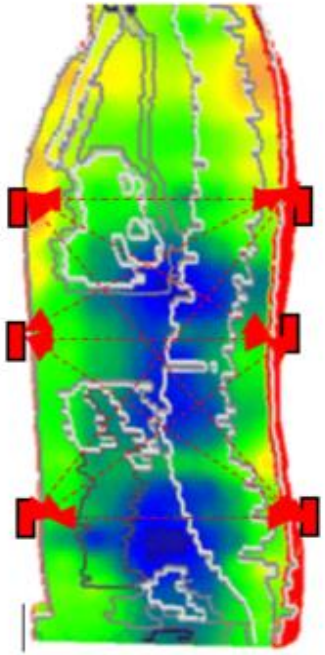




X. Wu et al., "Penetrating particle ANalyzer (PAN)", Advances in Space Research, Volume 63, Issue 8, 2019. https://doi.org/10.1016/j.asr.2019.01.012.

RADMONSSA '**RA**diation **D**etection and **MON**itoring **S**pace **S**uit for **A**stronauts'

- Development of a Timepix- based radiation detection and monitoring suit for space missions.



To the Moon and beyond …

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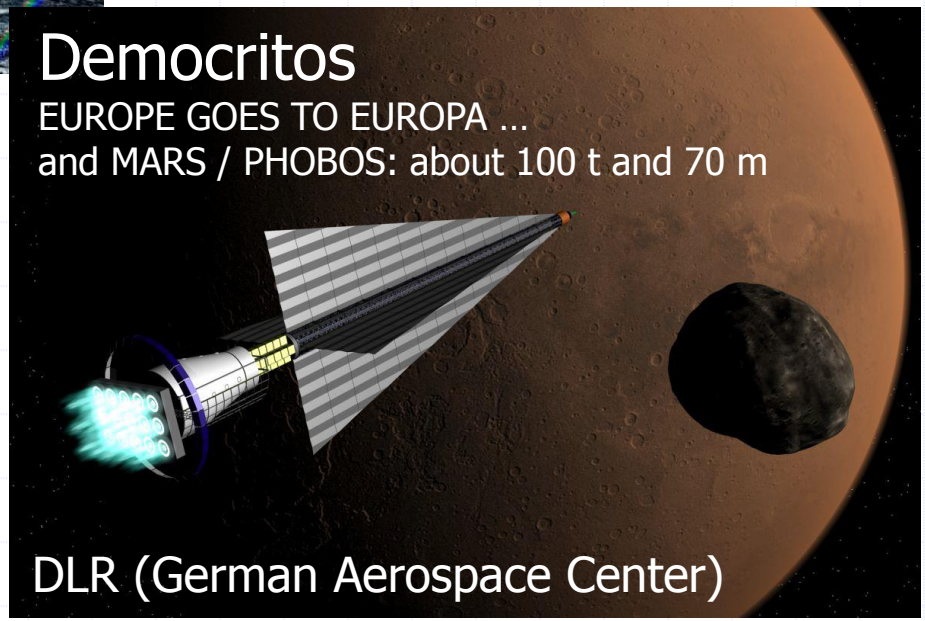
iSpace:

- Polar Ice Explorer Mission – mapping water/ice deposits on the Moon surface
- Timepix will be used as a neutron detector onboard robotic lunar rover

Democritos:

- Space craft with nuclear propulsion for interplanetary space travel
- Jupiter Moon Europa
- Timepix as scientific payload and for dose monitoring



Acknowledgement

The presented results have been born within research activities cultivated at IEAP CTU in Prague. Their achievement would not be possible without extensive partnerships in the frame of the Medipix2 and 3 collaborations, which have been coordinated through CERN since 1999, with significant contributions of the following colleagues:

P. Burian[1,4], R. Filgas[1], St. Gohl[1], C. Granja[1,2], M. Holík[1,4], J. Jakubek[1,2], F. Janssen[6], P. Manek[1], M. Malich[1], A. Owens[3], M. Platkevic[1], S. Pospíšil[1], S. Polansky[1], A. Smetana[1], D. Turecek[1], H. Waage[1], Z. Vykydal[1], X. Wu[5] ...

[1] Institute of Experimental and Applied Physics, CTU in Prague, Czech Republic
[2] Advacam s.r.o., Prague, Czech Republic
[3] European Space Agency, Nordwijk, Netherlands
[4] University of West Bohemia, Pilsen, Czech Republic
[5] Departement de physique nucleaire et corpusculaire, Universite de Geneve
[6] DLR (Deutsches Zentrum für Luft- und Raumfahrt, German Aerospace Center)

References

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[1] Stefan Gohl et al., "Study of the radiation fields in LEO with the Space Application of Timepix Radiation Monitor (SATRAM)", Advances in Space Research, Volume 63, Issue 5, 2019. https://doi.org/10.1016/j.asr.2018.11.016.

[2] St. Gohl et al, "Measurement of particle directions in low earth orbit with a Timepix", JINST 11 C11023, 2016.

[3] X. Wu et al., "Penetrating particle ANalyzer (PAN)", Advances in Space Research, Volume 63, Issue 8, 2019. https://doi.org/10.1016/j.asr.2019.01.012.

[4] Carlos Granja et al., "The SATRAM Timepix spacecraft payload in open space on board the Proba-V satellite for wide range radiation monitoring in LEO orbit", Planetary and Space Science, Volume 125, 2016. https://doi.org/10.1016/j.pss.2016.03.009.

[5] T. Baca et al, "Timepix in LEO Orbit onboard the VZLUSAT-1 Nanosatellite: 1-year of Space Radiation Dosimetry Measurements", JINST 13 C11010, 2018.

[6] Martin Urban et al., "VZLUSAT-1: Nanosatellite with miniature lobster eye X-ray telescope and qualification of the radiation shielding composite for space application", Acta Astronautica, Vol. 140, 2017. https://doi.org/10.1016/j.actaastro.2017.08.004.

[7] Mauk, B.H., Fox, N.J., Kanekal, S.G. et al. Space Sci Rev (2013) 179: 3. https://doi.org/10.1007/s11214-012-9908-y

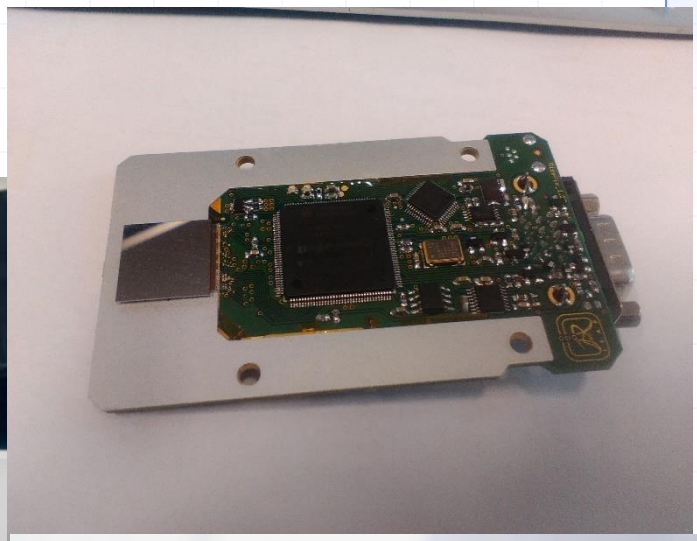
[8] https://directory.eoportal.org/web/eoportal/satellite-missions/s/sac-c

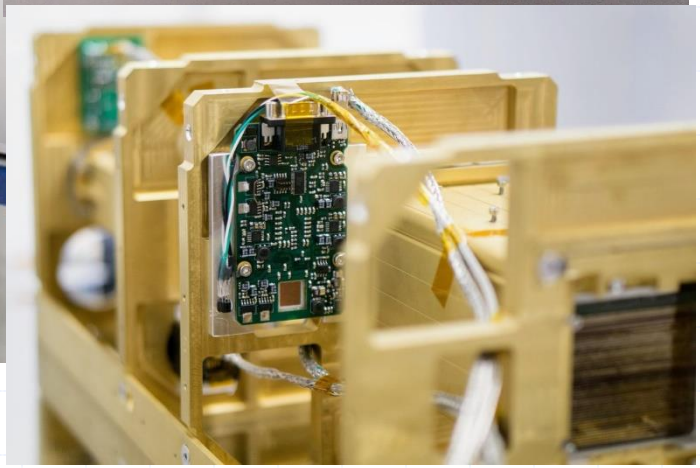
BACK UP

Ongoing space missions

Physics Prague

- Two Timepix detectors (RISEPix prototypes) as parts of X-ray telescopes onboard NASA sounding rocket. Collaboration with Penn State University, launched April 2018.





Ongoing space missions

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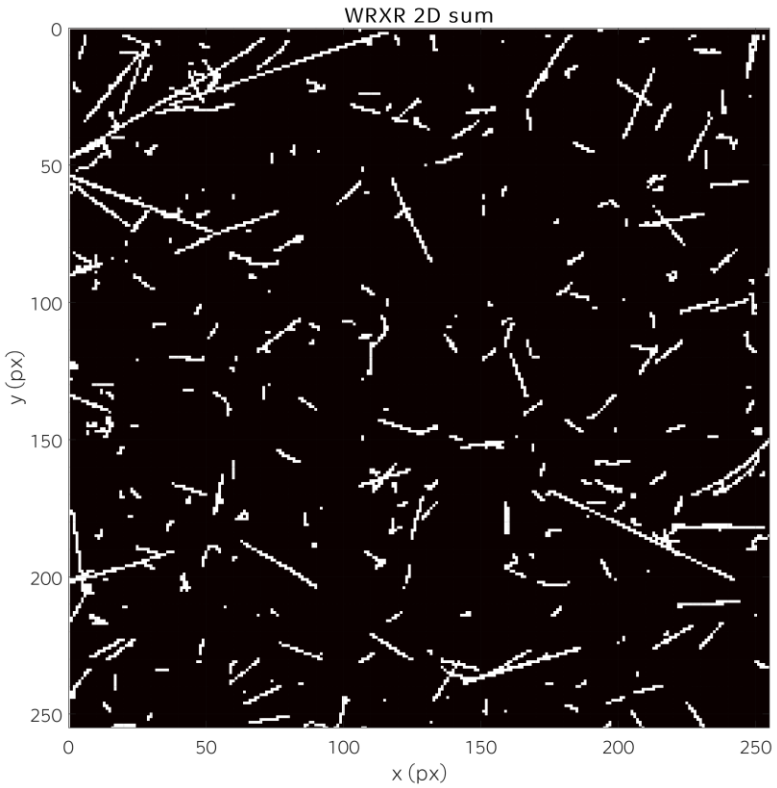

SATRAM:
Space Application of Timepix Radiation Monitor

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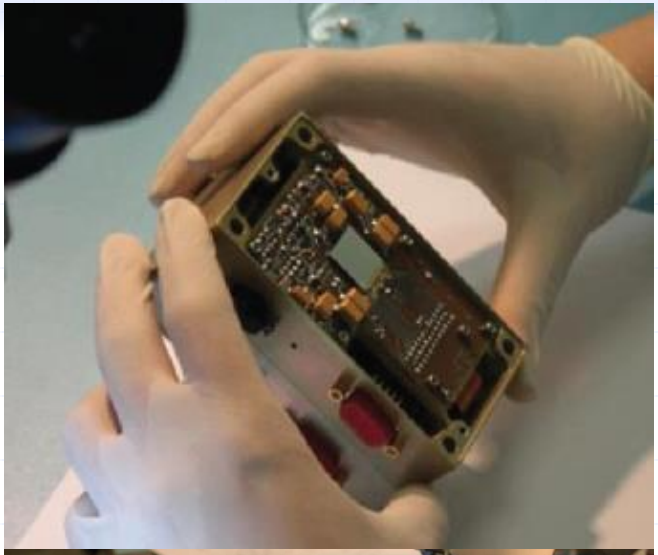
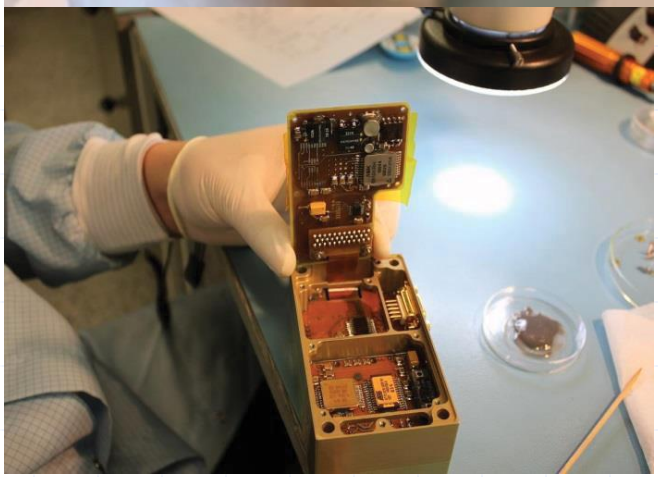
- Secondary instrument mounted on ESA Proba-V satellite
- Timepix for the first time in open space
- Power consumption of 2.5 W
- Total mass 380 g (10 x 7 x 5.5 cm^3)
- Radiation tolerance 1 Mrad for the sensor, 100 krad for the electronics
- Timepix data are correlated with satellite data
- Communication channel allows download up to 10 frames/min
- SATRAM is a platform technology demonstrator





SATRAM

Proba-V

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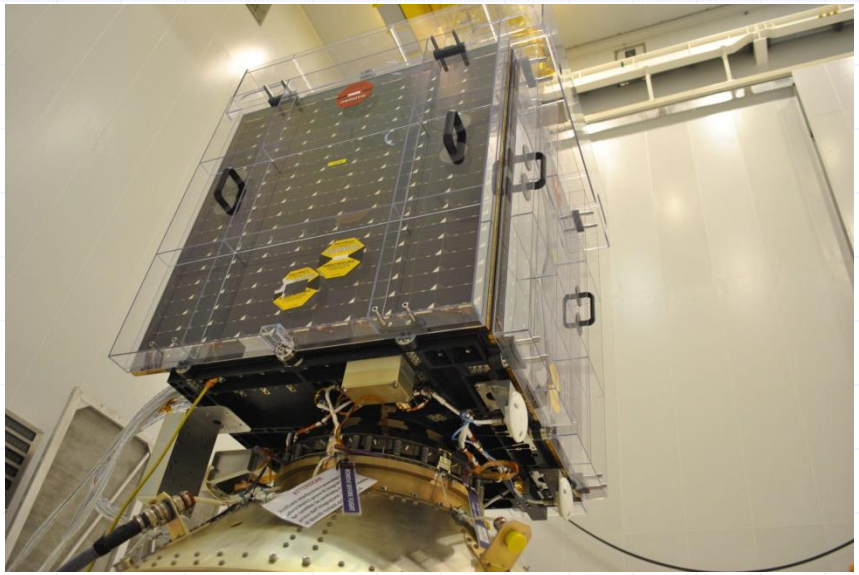
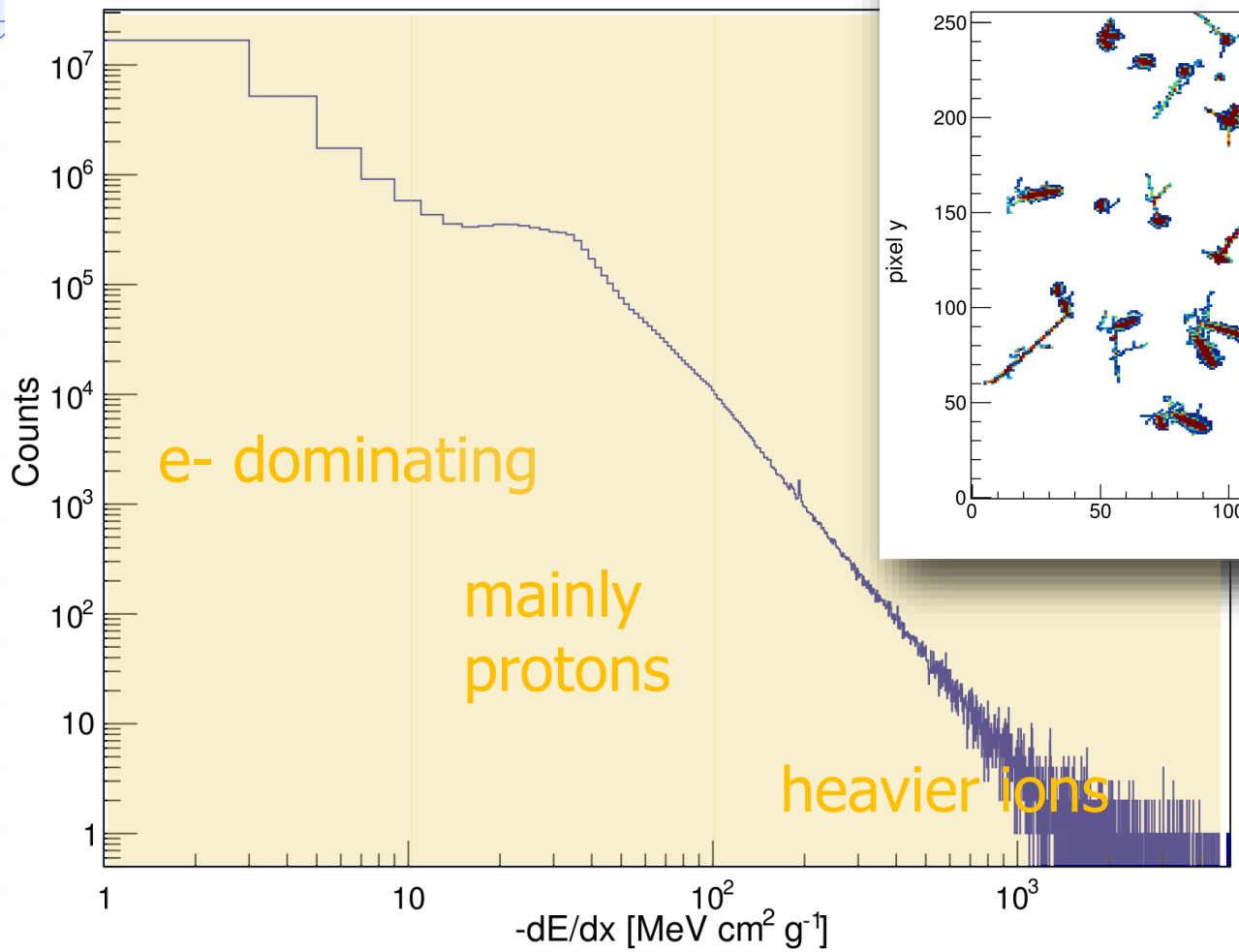
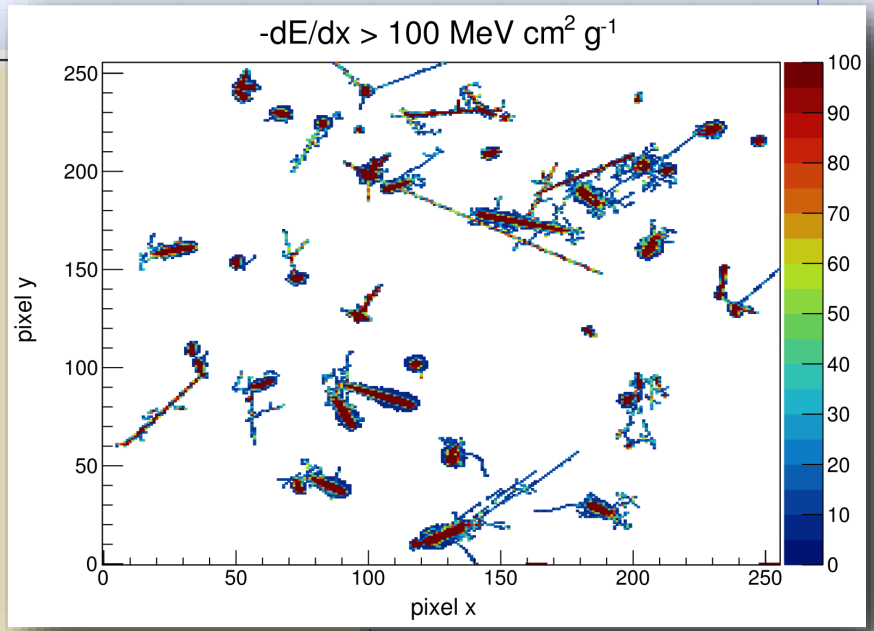
- Minisatellite (158 kg)
- Observe worldwide vegetation
- Altitude ~ 820 km (LEO)
- Period 101.21 minutes
- Latitude 80° N/S
- Launched March 7, 2013



SATRAM: Measured stopping power spectrum





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SATRAM: Cluster rate distribution

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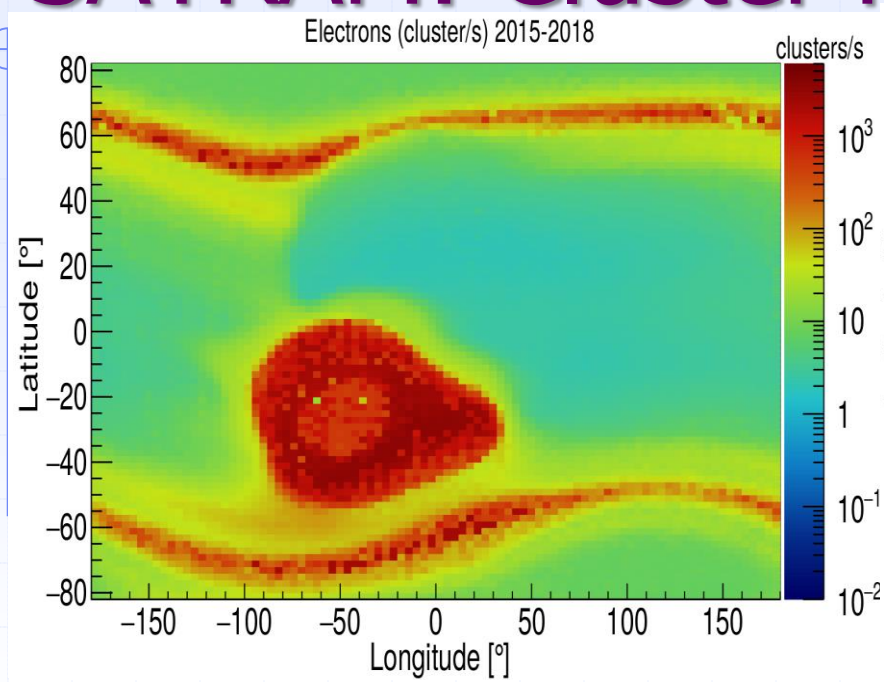
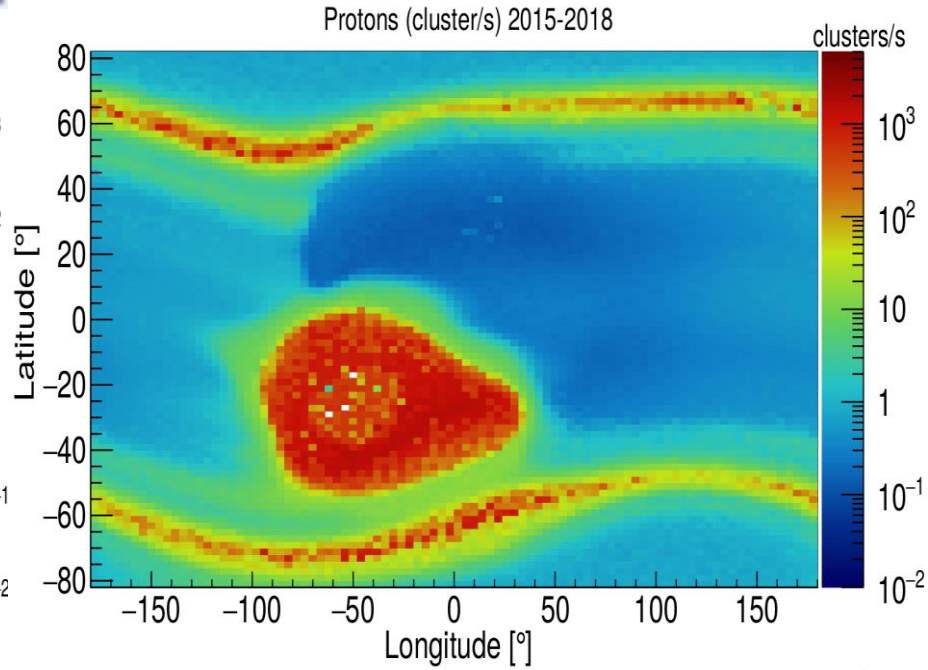


Electron dominated channel



Proton dominated channel

- Cuts on cluster properties (height, linearity, stopping power) for separation of protons and electrons (values deduced from simulation)
- For the analysis only frames whith an occupancy of less than 20% were selected