DLR

28th WRMISS Workshop on Radiation Monitoring on International Space Station

02 - 04 September 2025

2 VSB TECHNICAL UNIVERSITY OF OSTRAVA

6 esa

4 eutelsat OneWeb

3 oledcomm

1 ADVACAM Imaging the Unseen

Composition and Spectral Characterization of Space Radiation in LEO Orbit onboard JoeySat Satellite with MiniPix-Timepix3

VSB TECHNICAL UNIVERSITY OF OSTRAVA

ADVACAM Imaging the Unseen

Spinoff of the Medipix Collaboration/IEAP CTU Prague

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MiniPIX Timepix3 Space

MOTIVATION

Industry driven development

Deployment: telecommunication satellites/internet from orbit

Exploitation/application of Timepix/3 sensitivity/resolving power

Miniaturized COTS Electronics, low-power, low-mass, room-temp

Advanced radiation techniques: detection/imaging/particle tracking

Technology Transfer: CERN/IEAP CTU → space industry/commercial applications

Single particle imaging detection, spectrometry, tracking

Timepix: Spectral-sensitive tracking of single particles in wide field-of-view

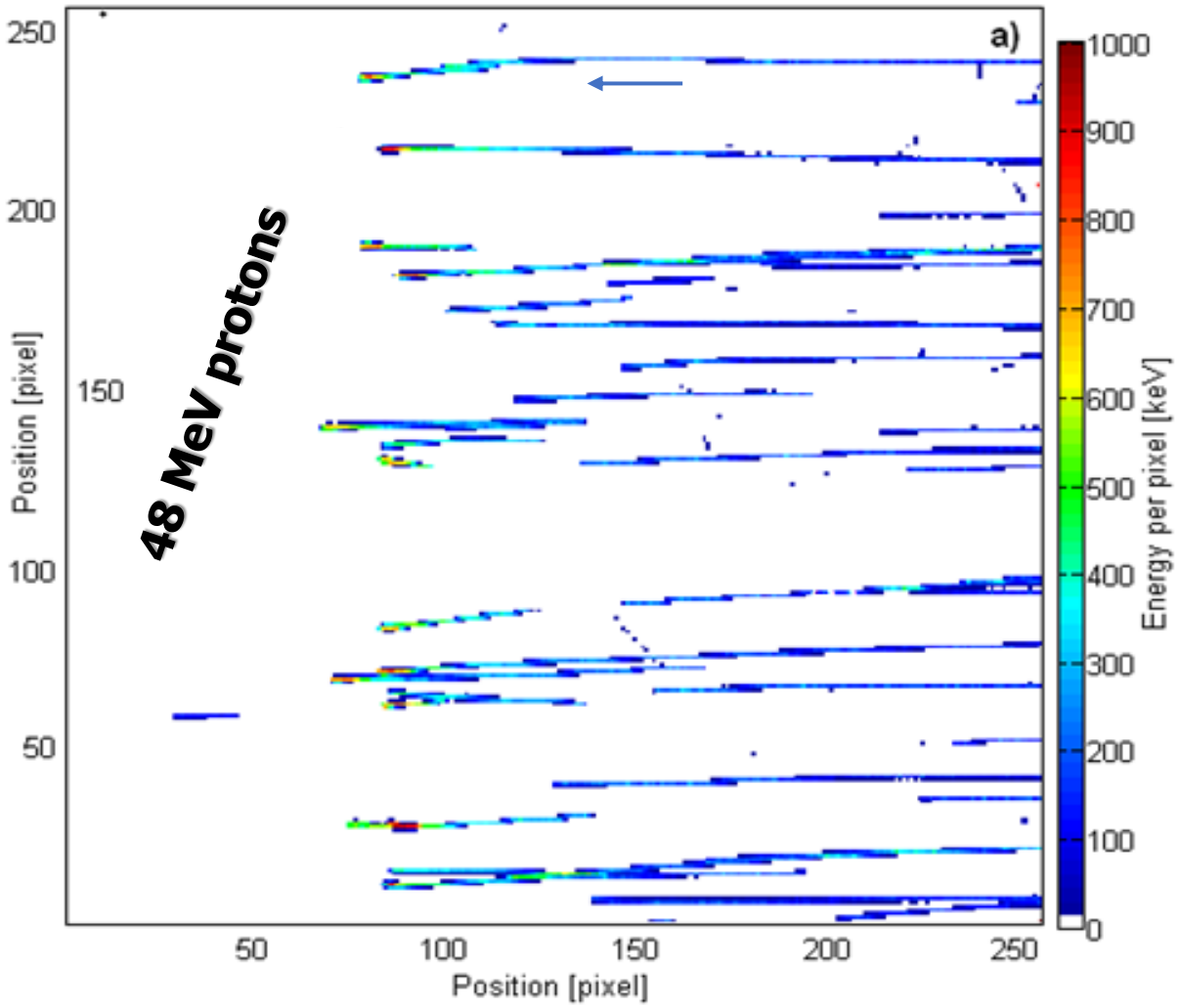
C. Granja, J. Jakubek, IEAP CTU Prague 2014

dkfz. GERMAN CANCER RESEARCH CENTER IN THE HELMHOLTZ ASSOCIATION

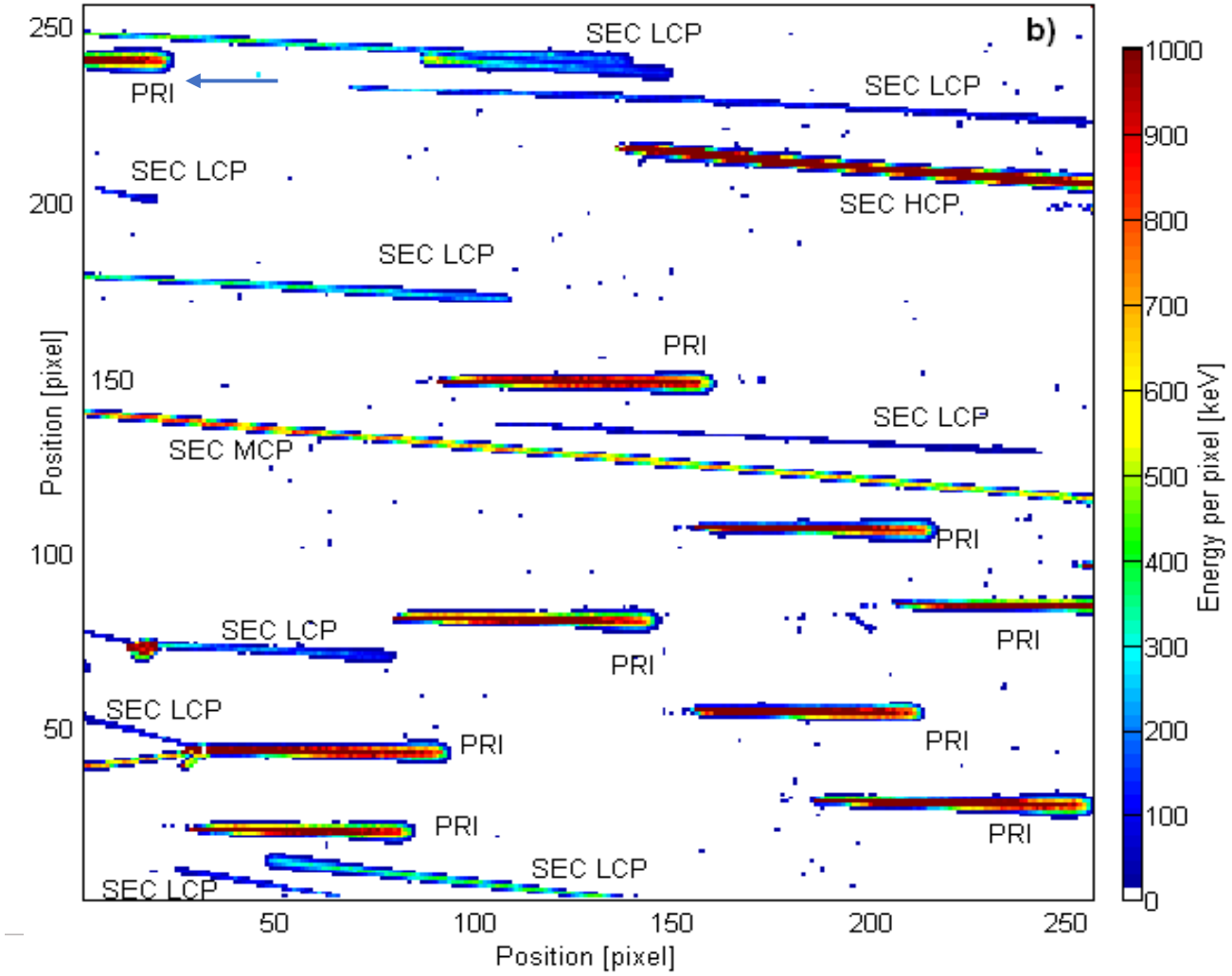
IEAP

HIT Heidelberger Ionenstrahl-Therapiezentrum

HERITAGE/BACKGROUND



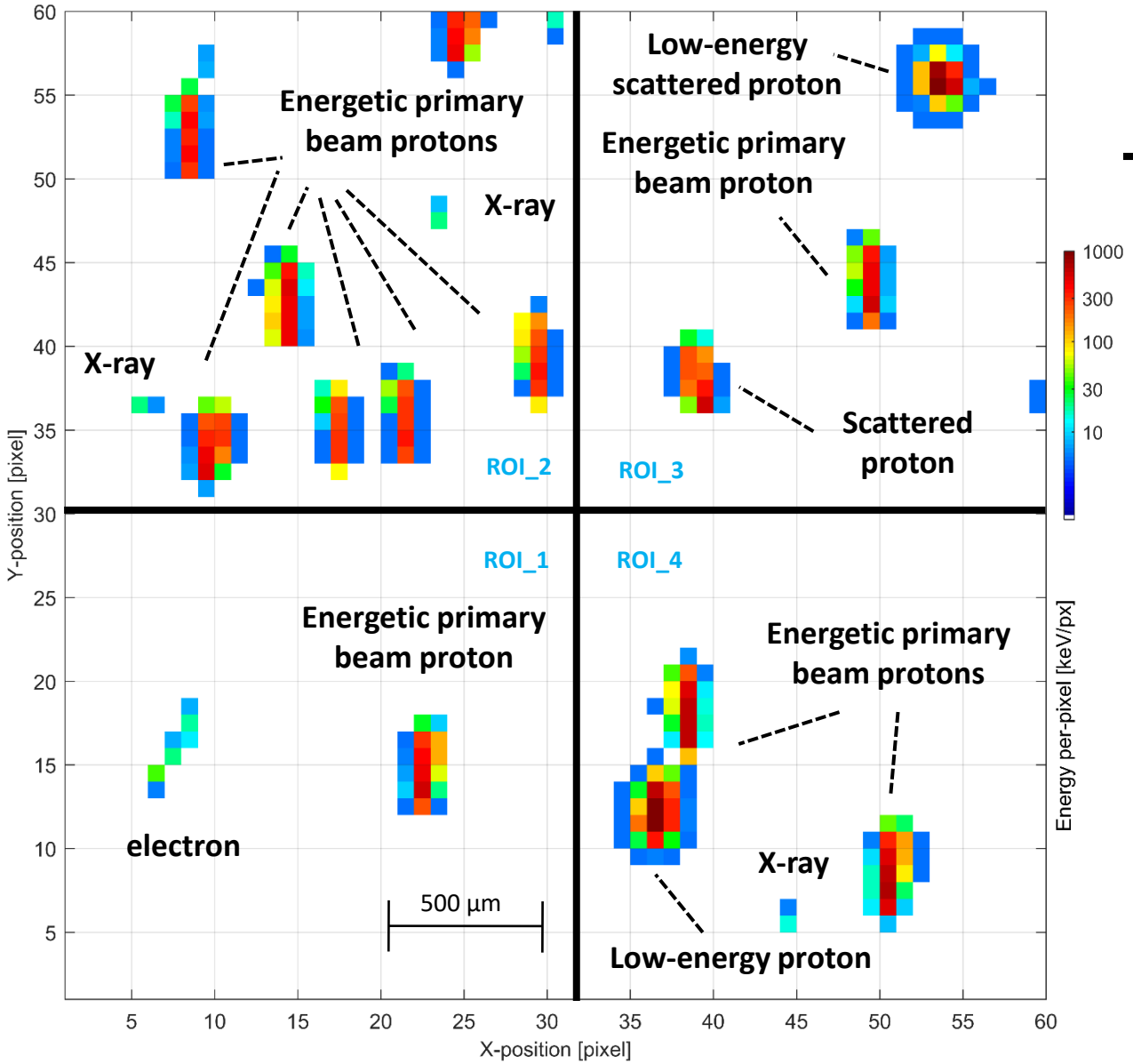
1.0 GeV ^{12}C ions



Particle tracking: Wide FoV, spectral sensitivity px level → dE/dx

Resolving power/classification of particle-type events: charged particles (e, p, ions), X rays, gamma rays

Timepix3 Si 500 µm: px matrix (30 × 30 px = 1.4 % detector area)



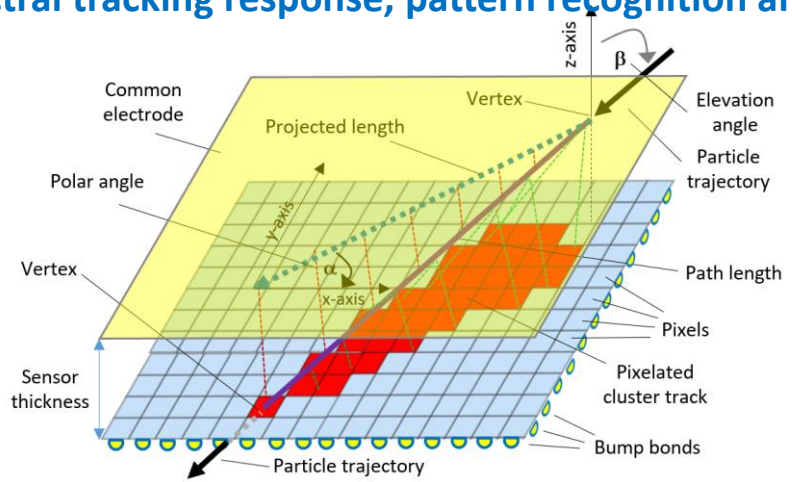
Experimental calibrations in well-defined / reference radiation fields

→ **Detector-radiation response functions**

30 MeV protons @ 45°

Light ion cyclotron accelerator, Nucl Phys Inst (NPI), CZ Acd Sci. Rez n Prague

Spectral tracking response, pattern recognition analysis



Degrees of freedom: particle type, energy, direction

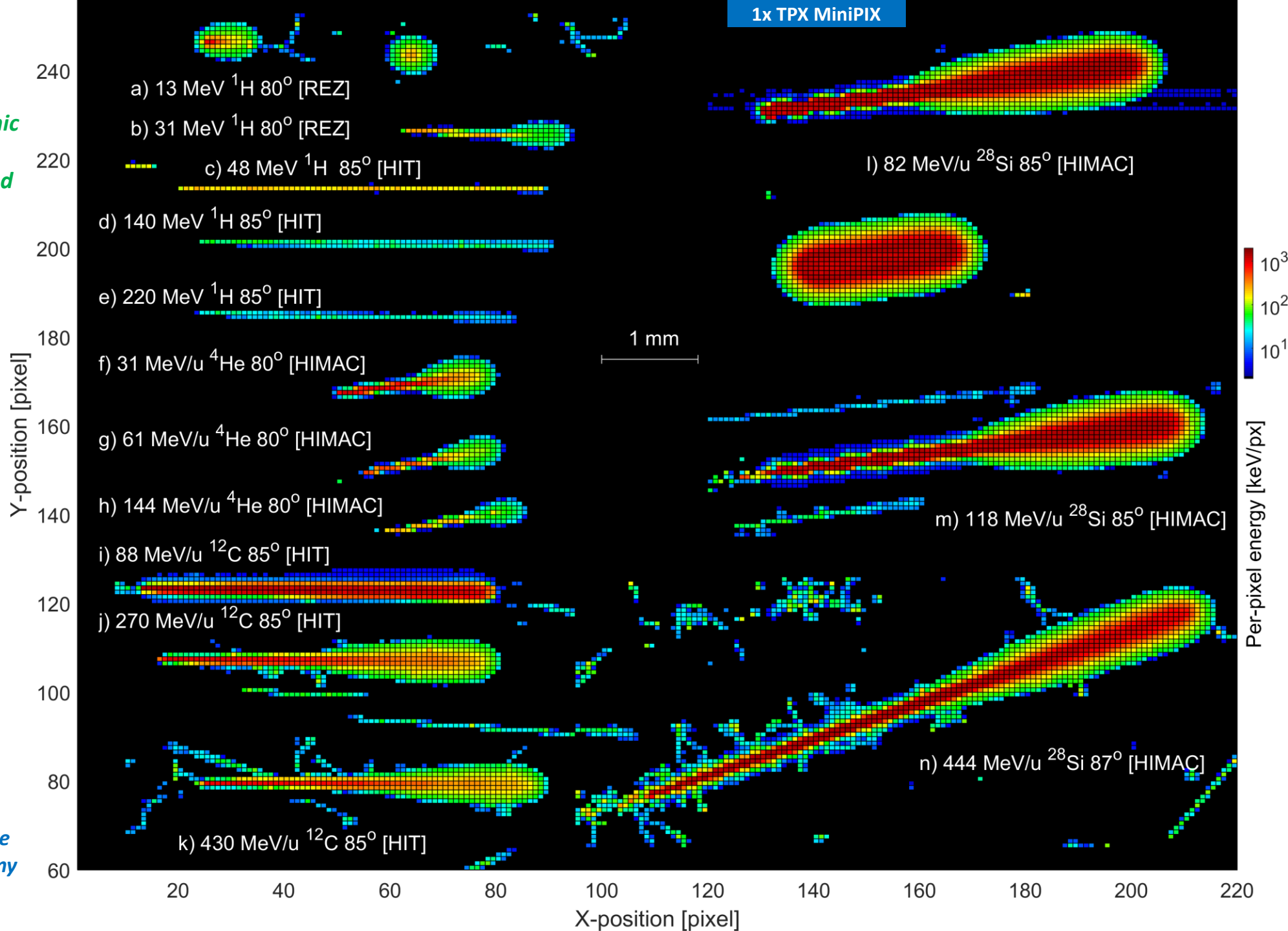
Calibrations

C. Granja, J. Jakubek, et al., ***Dynamic range and resolving power of the Timepix detector to Heavy Charged Particles***, J. of Instrum. JINST 13 (2018) C11003

Timepix + Heavy charged particles: protons, ions

Quantum imaging detection and track visualization of energetic charged particles: protons, alpha particles, ions

Light ion U-120 cyclotron, Rez-Prague
Synchrotron HIT, Heidelberg, Germany
Synchrotron, HIMAC, Chiba, Japan



Calibrations

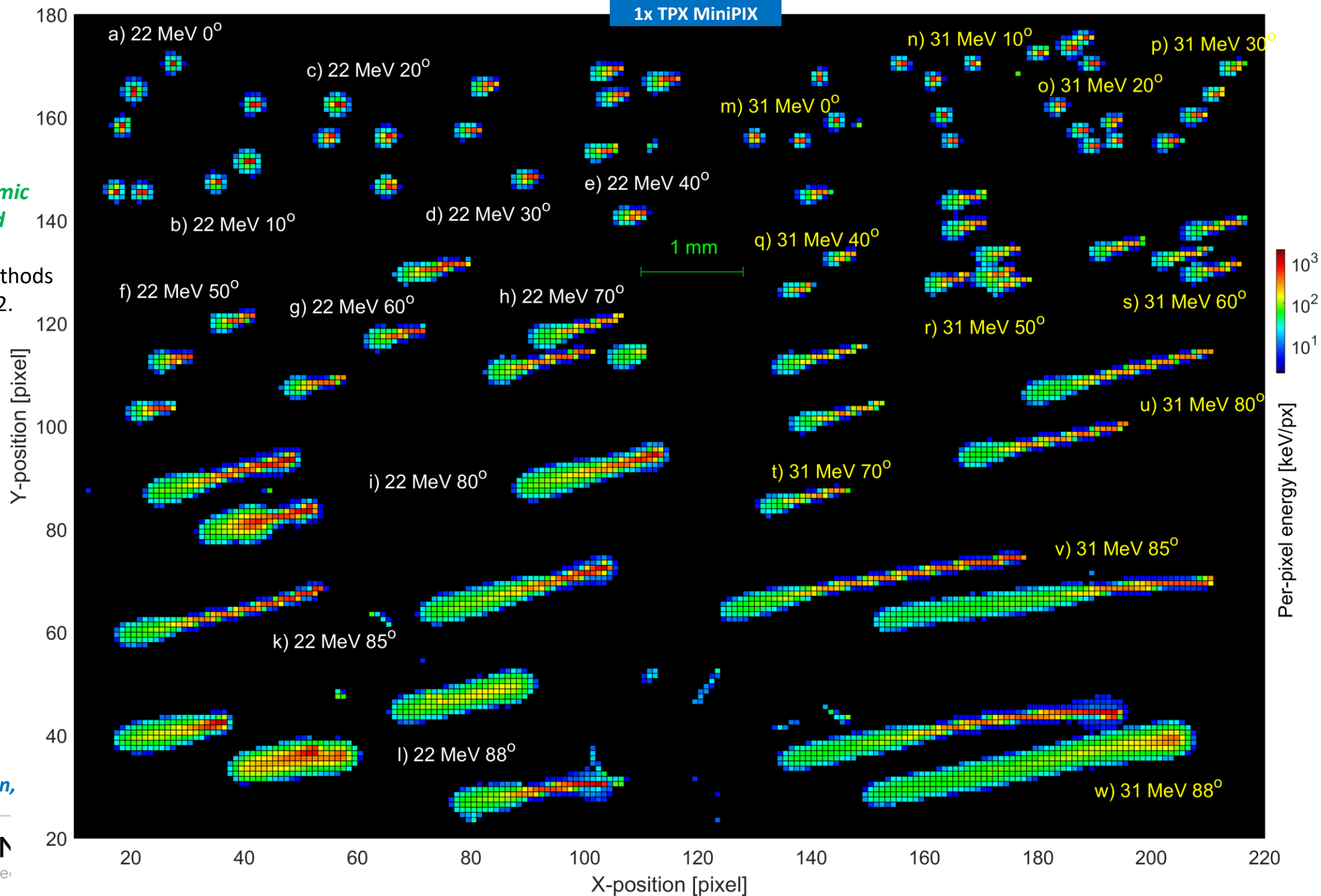
C. Granja, K. Kudela, et al., ***Directional detection of charged particles and cosmic rays with the miniaturized radiation camera MiniPIX Timepix***, Nuclear Instr. Methods NIM-A 911 (2018) 142–152.

Timepix Si 300 µm
Protons: monoenergetic
22 MeV (left)
31 MeV (right)

Quantum imaging detection and track visualization of energetic protons

Light ion U-120 cyclotron, NPI-CAS, Rez-Prague

ADVACAM
Imaging the Unseen



Satellite operations: Radiation effects

on spacecraft, components, electric-electronic components

MOTIVATION

Increasingly important due to miniaturization and increased complexity (and fragility) of space systems/satellites/components/COTS

Radiation effects in electronics

- ❑ Total ionizing dose (TID)
- ❑ Total non-ionizing dose (TNID), displacement damage dose (DDD) ← Non-ionizing energy loss (NIEL)
- ❑ Single-event effect (SEE)

Also

- ❑ mechanical/physical degradation of materials, surfaces, charging, etc

High-resolution radiation monitor MPX on JoeySat in LEO

MiniPIX-TPX3 Space: radiation imaging/spectrometry/particle tracking in wide range

MiniPIX Timepix3 Space

High-resolution & wide-dynamic range radiation characterization & monitoring telecommunication satellite (space industry) in variable orbit (LEO 600 – 1200 km) with miniaturized low-power radiation detector vacuum operation/room temperature

One Web, UK

Experimental micro-satellite JoeySat – LEO 600-1200 km

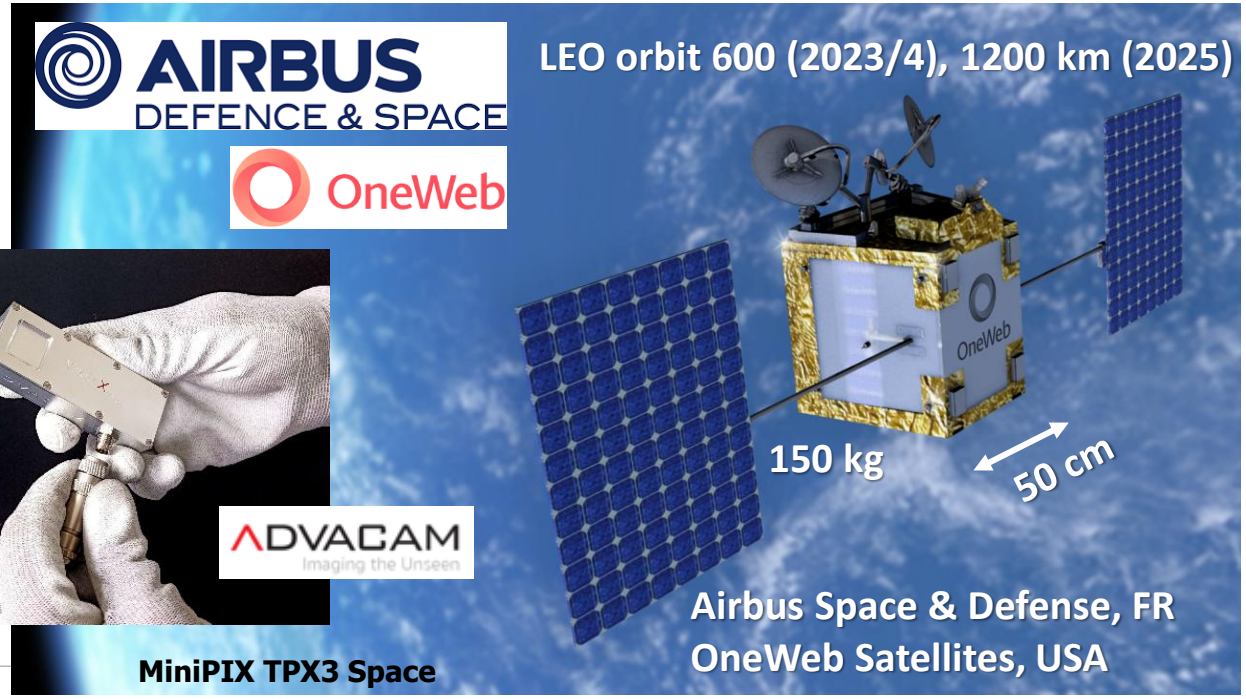
- Radiation effects studies with high-res rad monitor
- Radiation environment data, composition characterization
- Limited downlink data rate: ≤ 24 MB/day
- Miniaturized low-power COTS instrument
- Payload technology demonstrator IOD 1st Timepix3 in space/on spacecraft

Goals/tasks: high-resolution data on

- ❑ Mixed-field composition characterization
- ❑ Particle fluxes: total, partial, directional
- ❑ Dose rates: total, partial
- ❑ LET spectra, Directional fluxes, wide FoV

Launch 20th May 2023, SpaceX, Falcon-9

Micro-satellite JoeySat One Web telecommunications/internet from orbit



V. Colas One Web, L. Marek, C. Granja, ADV, 2022

MPX RADIATION MONITOR

OneWeb LAUNCH #19
JOEYSAT
BEAM HOPPING INTO THE FUTURE
esa UK SPACE AGENCY

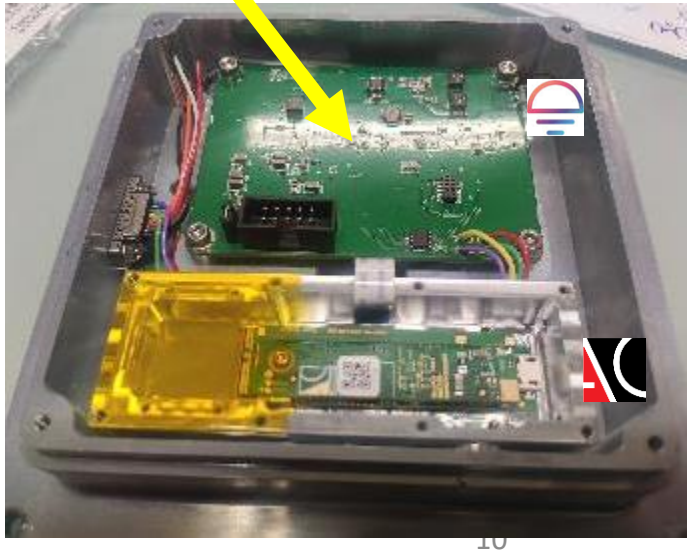
Telecommunication satellite Joeysat
Launched to LEO 600 km (May 2023)
+ transfer to 1200 km (2024 3Q)

on board JoeySat MPX radmon payload (ADV)
+ interface/computer (OC) + SOCAN bus (OW)

JoeySat FLIGHT MODEL MOUNTED EXTERNALLY (Mx PANEL)

MPX Radiation Monitor

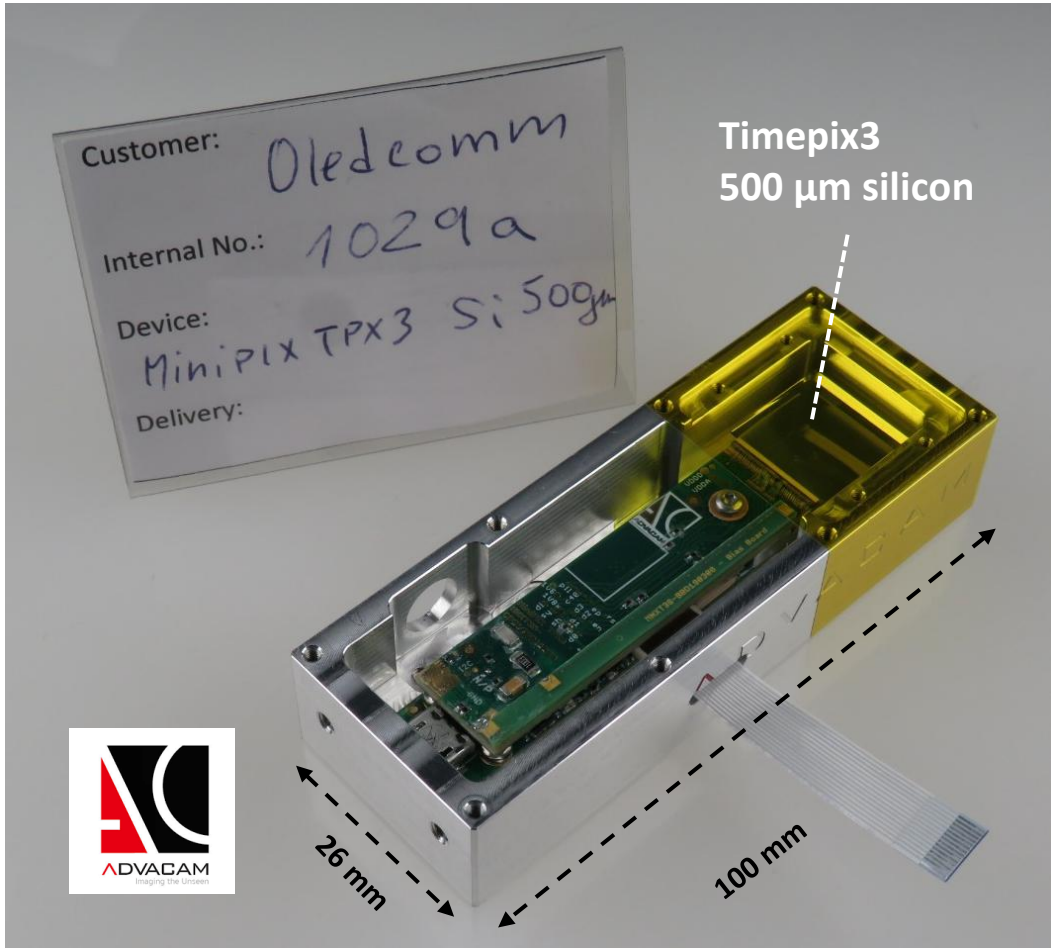
Control/DAQ/interface to sat bus



One Web JoeySat microsatellite: radiation environment characterization

High-resolution radiation monitor, particle tracker: ADV MPX TPX3 Space, COTS

MPX for OW JoeySat: MiniPIX TPX3 SPACE, Timepix 3 ASIC chip, 500 µm Si sensor +80 V



Mass ≈ 130 g (electronics 25 g)

Power ≈ 2 W

Size: 100 mm × 26 mm × 21 mm

TPX3 chip frame mode

per-px energy (ToT) + counting (CNT)

Active automatic tuning of frame acq time

Low hit-px occupancy → high-res data

5 mm Al shield

To suppress low-energy components

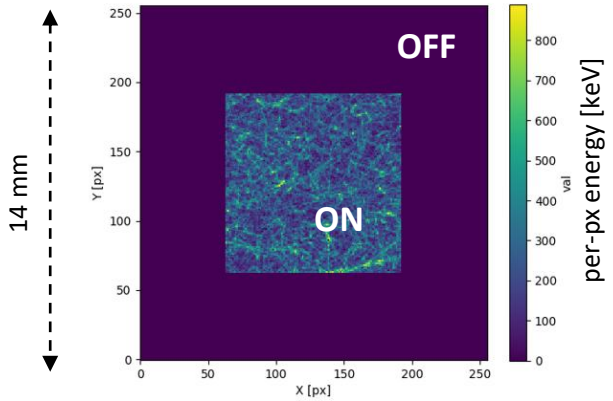
- < few MeV electrons
- < 35 MeV protons
- < keV X rays, plasma, UV

two temperature settings

embedded (+20°, +50°)

JoeySat limited data rate 24 MB/day

MPX TPX3 px matrix: 256 × 256 px's



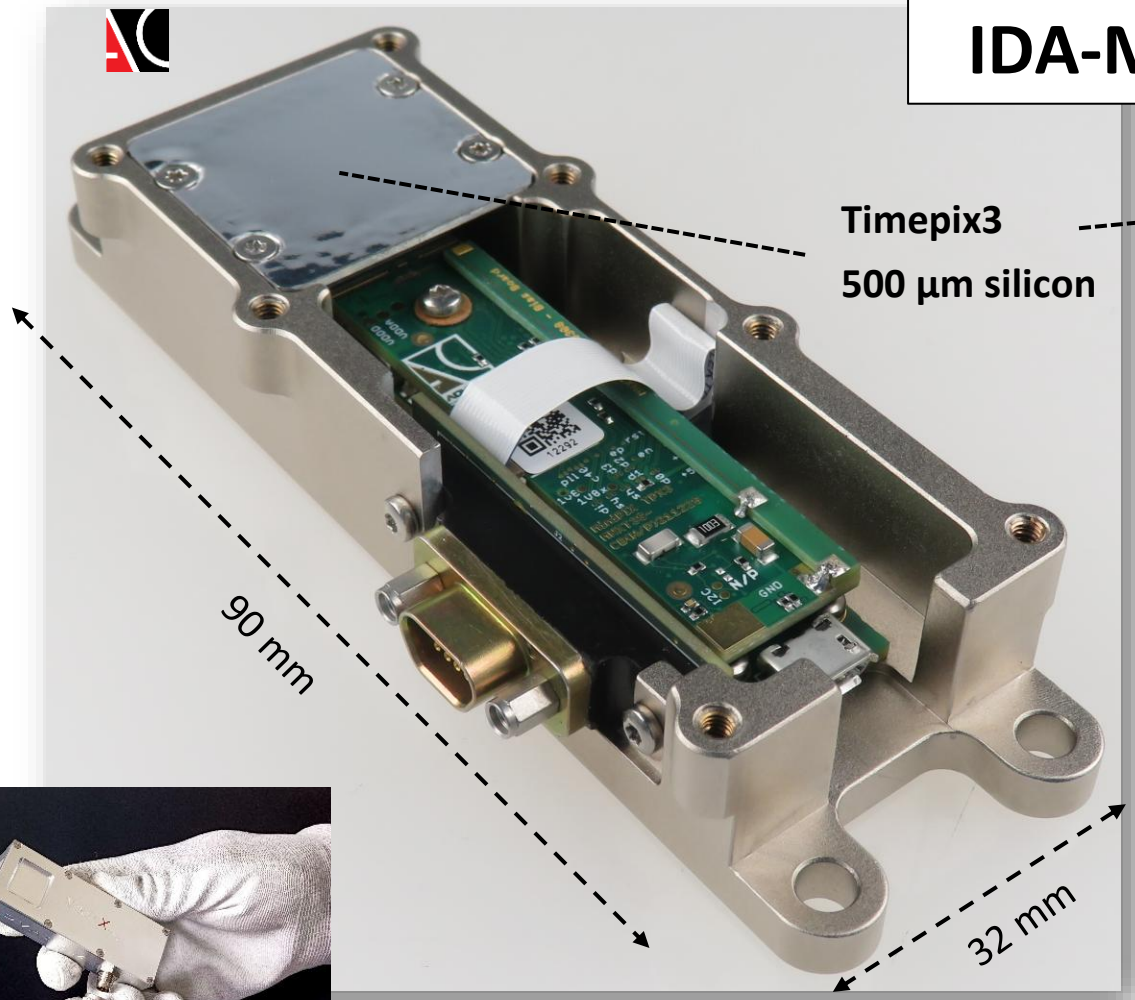
¼ of the px matrix active

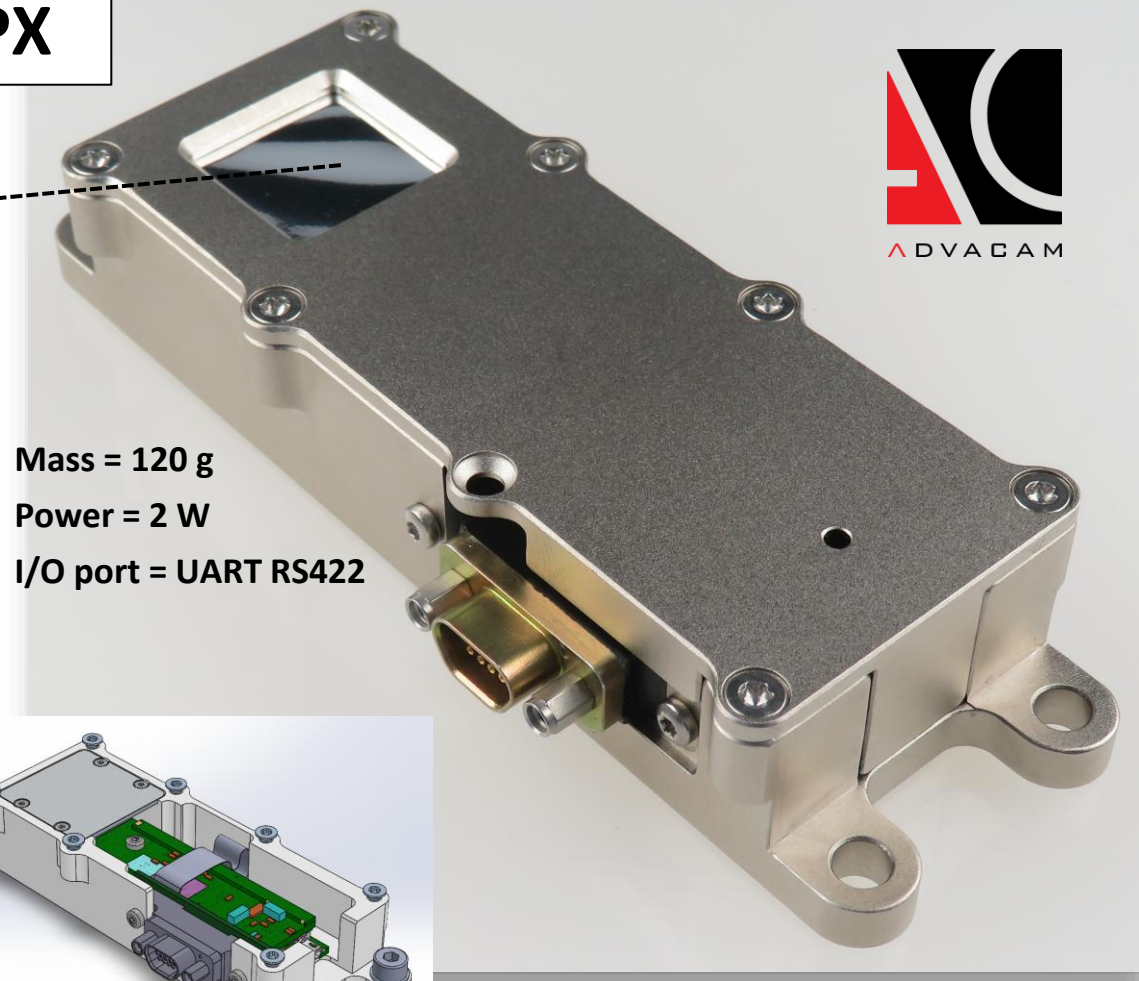
¾ masked/off

NASA-ESA Lunar Space Station Gateway

European Internal Dosimetry Array IDA: MiniPIX TPX3 SPACE → Payload IDA-MPX

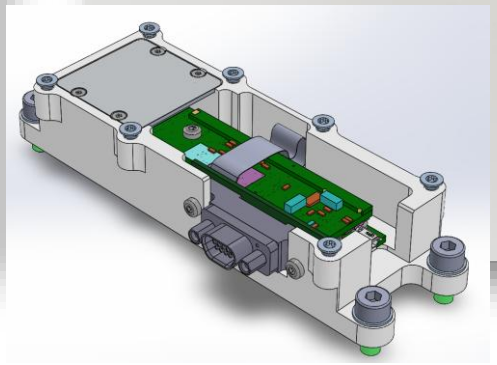
IDA-MPX





Mass = 120 g
Power = 2 W
I/O port = UART RS422

MiniPIX-Timepix3
Space



OneWeb Joeysat MPX data

MPX TPX3: high-res radiation data in wide range and high-discrimination

MPX physics data

- Radiation field composition: **3x broad classes**
  - Protons, ions
  - HE electrons + low-energy gammas
  - X rays, (partly) low-energy electrons
- Particle fluxes: total, partial (2x classes)
  - On detector, time plots
  - Along orbit, GPS maps
- Dose rates: total, partial (2x classes)
  - On detector, time plots
  - Along orbit, GPS maps
- LET spectra, dep energy spectra: total, partial
  - On detector, time plots
  - Along orbit, GPS maps
- Deposited dose, total, partial, detailed time-integrated
  - On detector, time plots
  - Along orbit, GPS maps
- Detection & track visualization of radiation field

MPX on JoeySat: radiation response

- Protons: above* ≈ 40 MeV
- Ions: above* ≈ 50 MeV/u
- Electrons: above* ≈ 3 MeV
- X rays, low-energy gammas*: 8 keV – 30 keV

* = 5 mm Al shield

TPX3 settings, MPX operation duty cycle

- TPX3 in frame mode, per-px ToT+CNT
- Measure the rad field at least once per minute
- 2x sampling frames → adjust frame acq time
- 1x radiation data frame
- Overall MPX duty factor TPX3 live time ≈ 20%

Raw data

- MPX TPX3 radiation data
- MPX meta (frame acq time, hit-px occupancy, temperature, ….)
- JoeySat navigation stamp (UTC, GPS, attitude)

Timepix3: data quality & quantity ← particle count rates

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MAXIMUM PARTICLE FLUXES ON DETECTOR [particle × cm^2 × sec^{-1}]

For single-particle detection, high-resolution spectrometry (energy loss) + particle tracking in wide FoV

→ particle-type resolving power, full data high-res wide-range physics products

Radiation/particle species	≈ 0° (perp)	≈ 45°	≈ 90° (parall)
Electrons, LE gamma rays	E6	E5	E5
Protons, ions	E5	E4	E3
X rays	E7	E7	E7

Integrated detection, limited counting, minimum/no tracking, good integrated dosimetry

Radiation/particle species	≈ 0° (perp)	≈ 45°	≈ 90° (parall)
Electrons, LE gamma rays	E8	E7	E6
Protons, ions	E7	E6	E5
X rays	E9	E9	E9

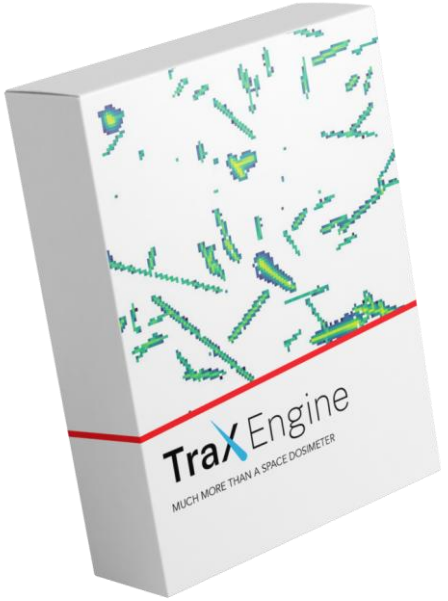
ADVACAM
Imaging the Unseen

DPE / TraX Egine = Data processing toolkit & experimental database for Timepix detectors:

TPX, TPX3, TPX2

- ❑ experimental in-beam calibrations
- ❑ Detector ASIC chip-sensor response matrices
- ❑ Preprocessing, pattern recog algort, AI/ML

Detector data processing



esa

ADVACAM

C. Granja, L. Marek
ADVACAM, 2024

Post-processing, satellite navigation, physics, …

L. Marek, C. Granja, ADV, 2024

MPX radiation monitor on JoeySat in LEO 600 km

Space radiation decomposition: particle-event types

Detection of space radiation in LEO 600 km

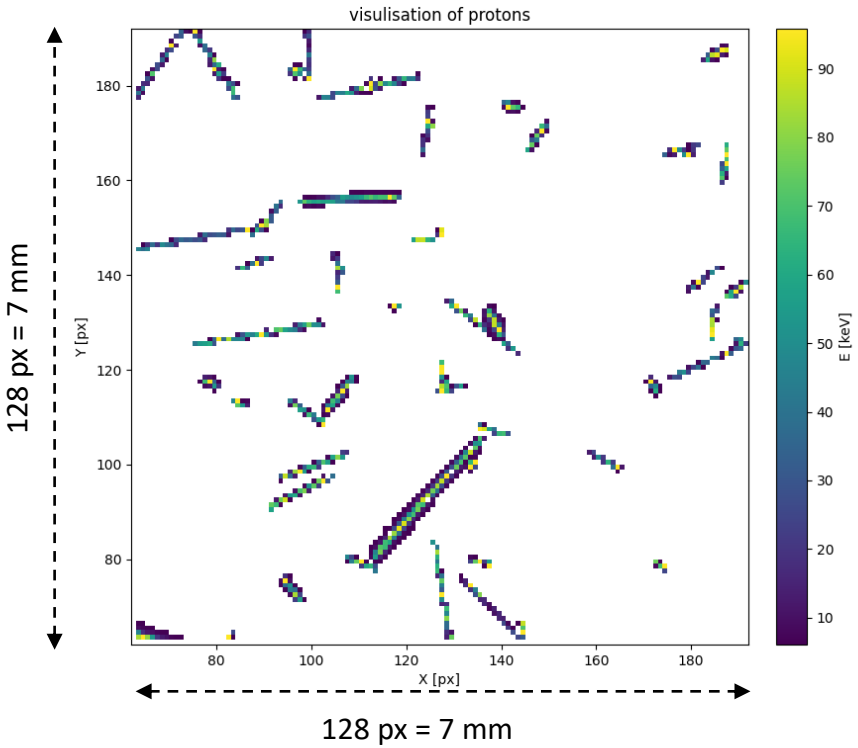
Spectral visualization of tracks by single particles

Timepix3 Silicon 500 µm

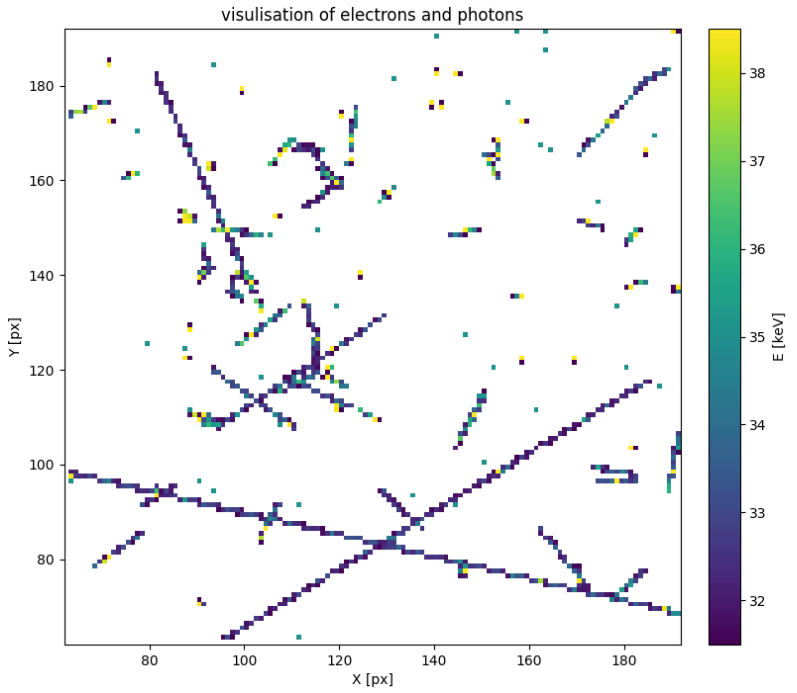
Data: Nov 2023

LEO 600 km

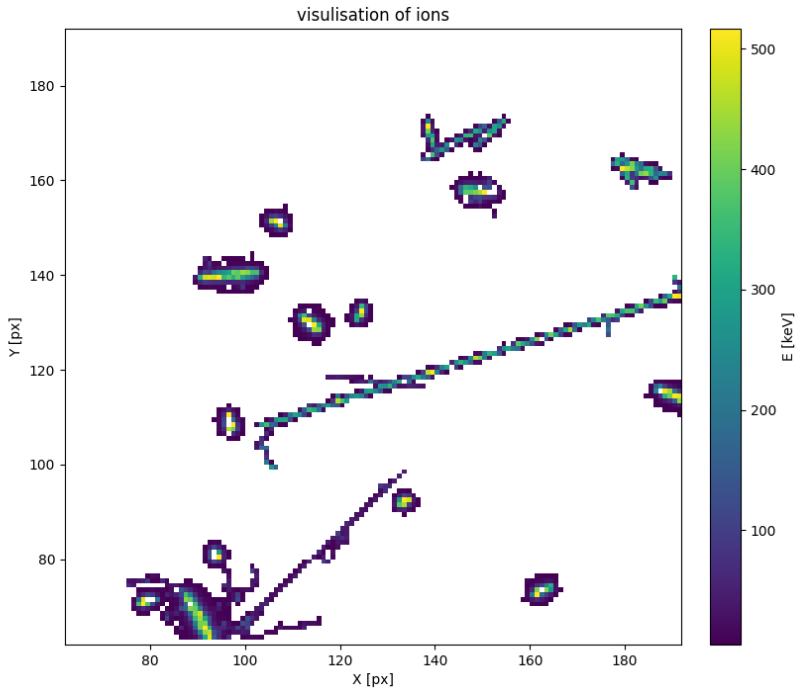
Mid-energy protons



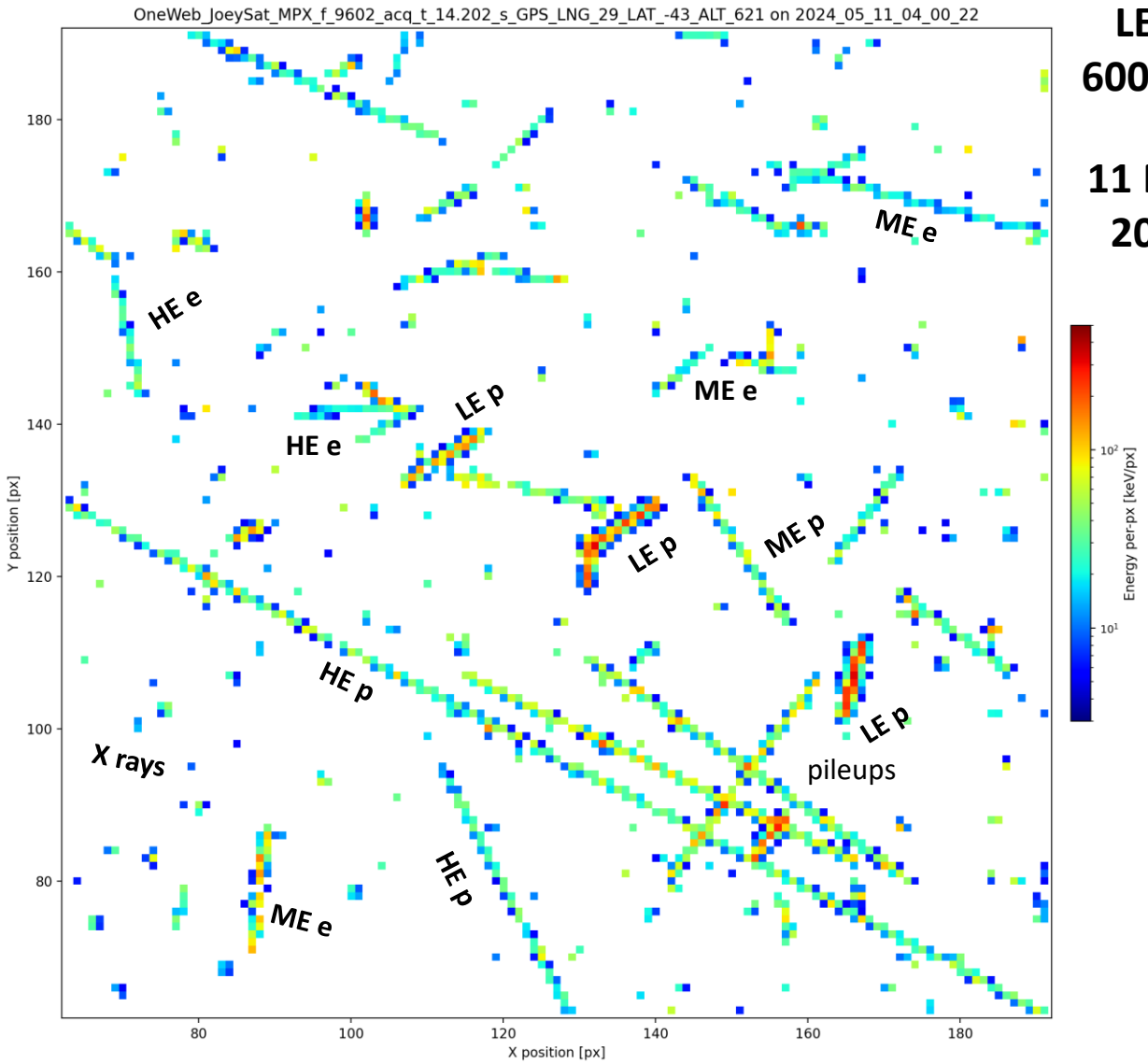
Electrons, X rays, LE gammas, HE/MIP protons



Low-energy protons, ions

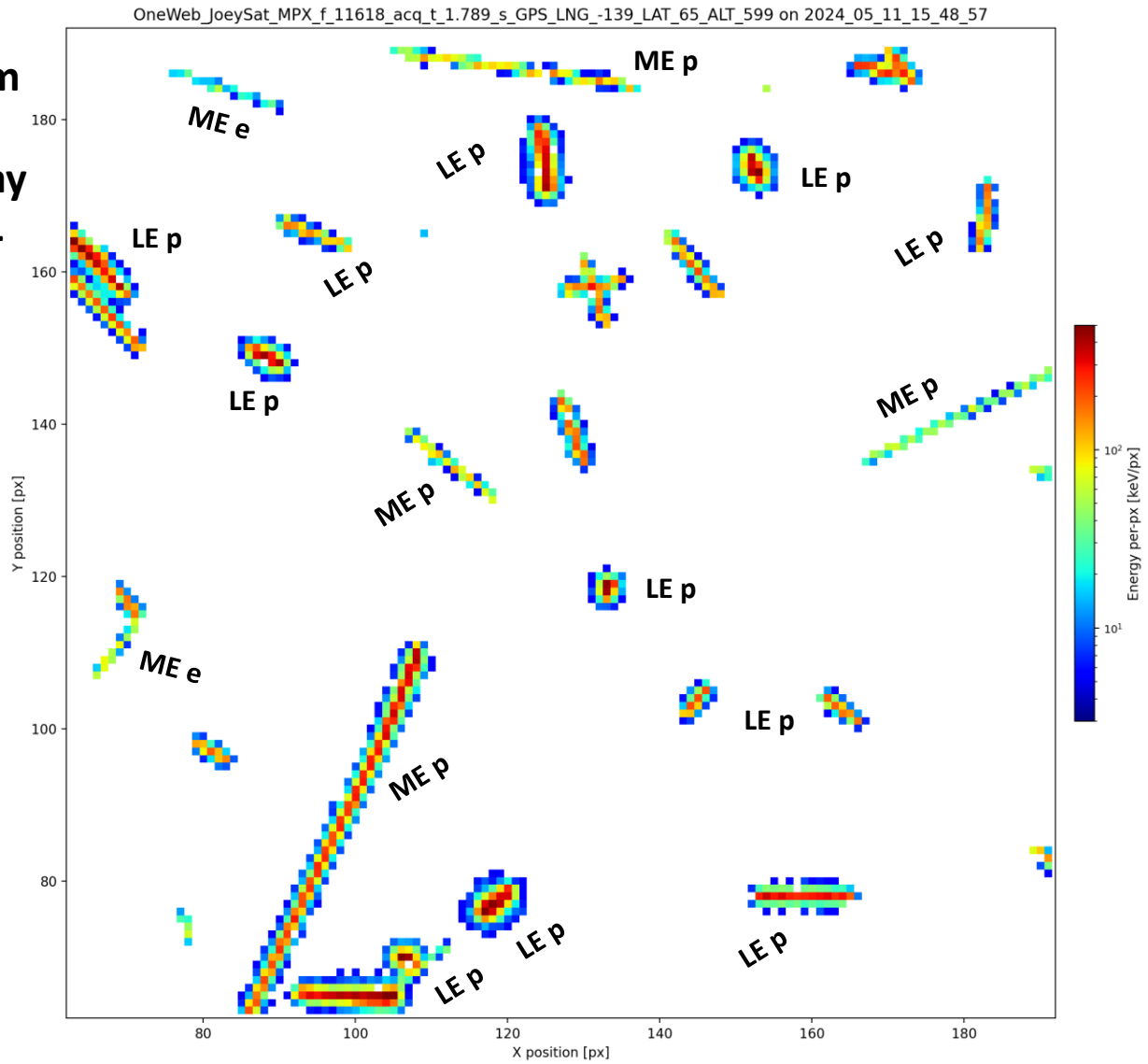


MiniPIX TPX3 Si: spectral-composition characterization: particle species, energy, direction



LEO
600 km

11 May
2024



Noiseless particle-counting sensitivity + spectrometry/energy loss + particle tracking + radiation field calibrations

→ Detector response functions, enhanced discrimination, wide-range particle-type resolving power

LEO 600 km

OneWeb JoeySat MPX

2024 May 02

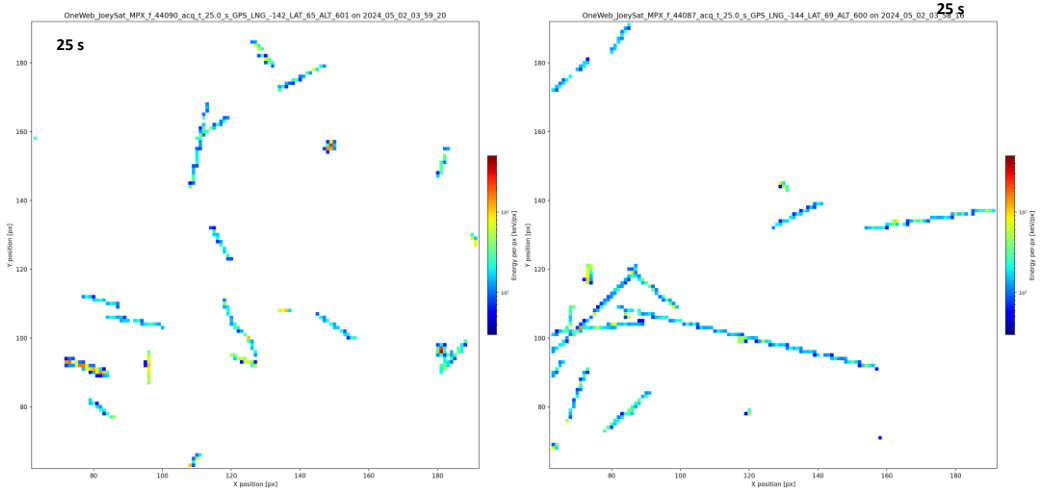
normal period

LEO 600 km

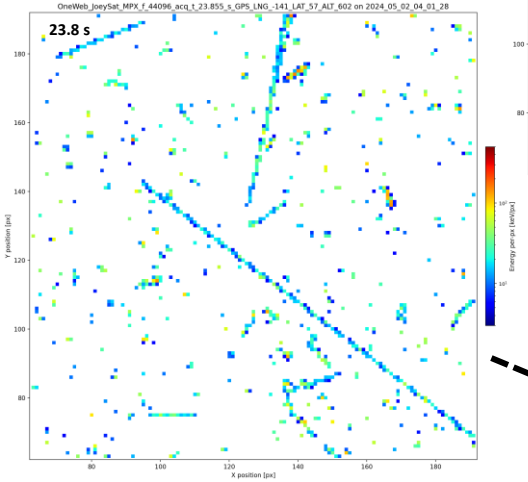
Quantum-imaging detection and track visualization of the radiation field in JoeySat
LEO 600 km
Timepix3 Si sensor

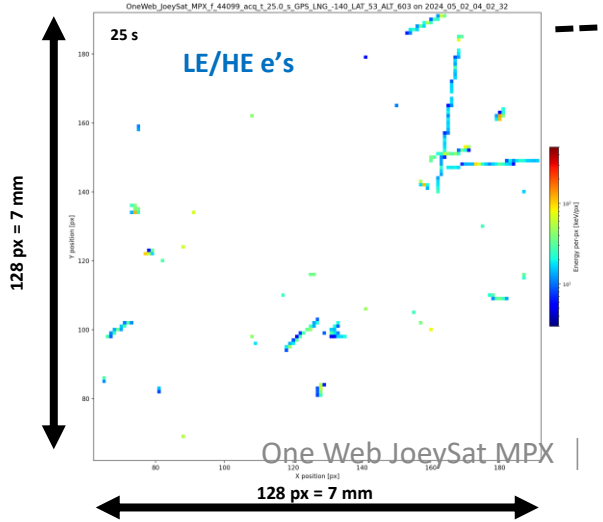
2D track visualization

LE/HE e's

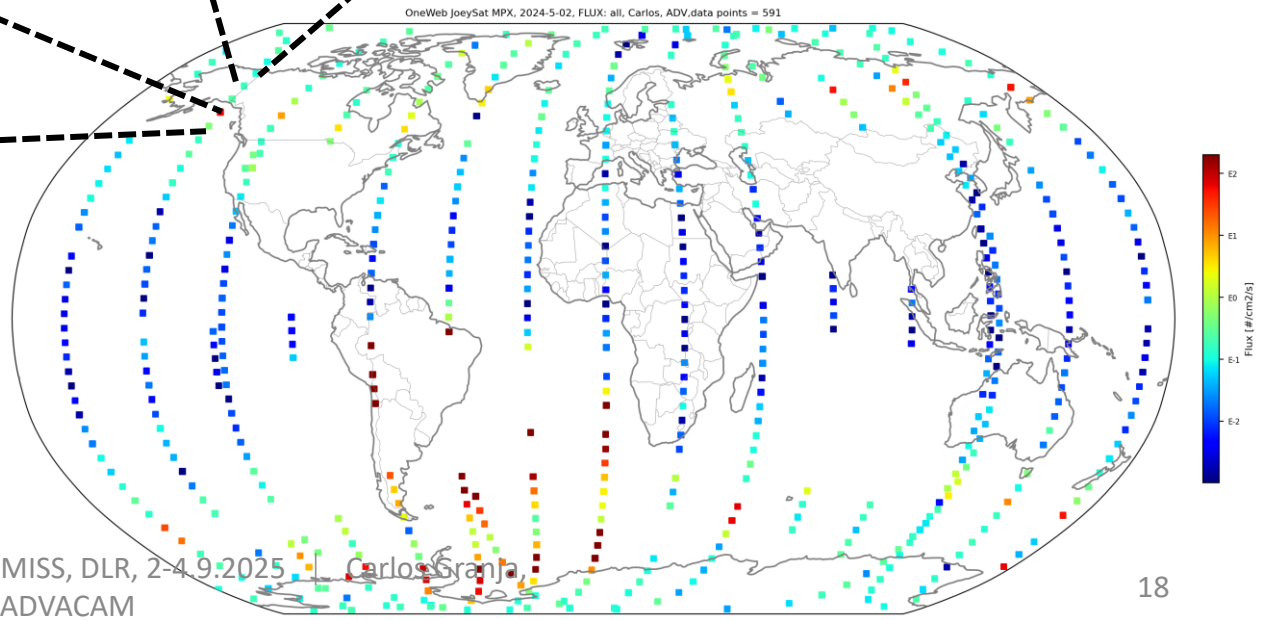


X rays + LE e's





Particle flux all particles



OneWeb JoeySat MPX

Carlos, ADV, Prague July 2024

2024 May 11

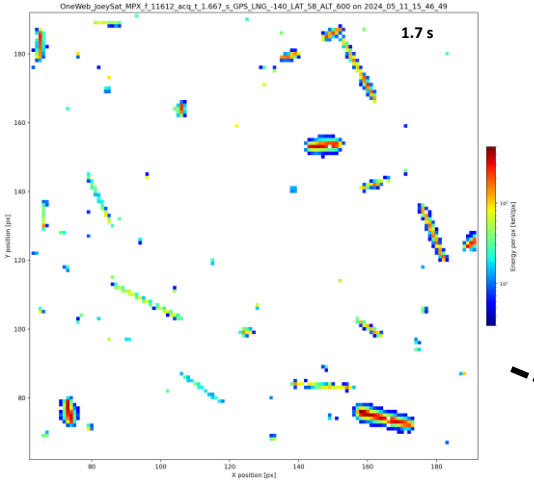
solar storm

LEO 600 km

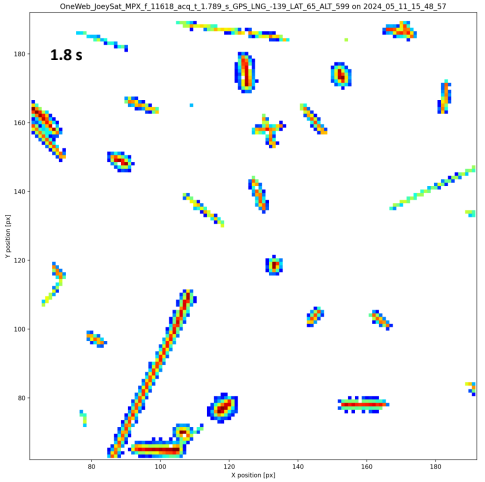
Quantum-imaging detection and track visualization of the radiation field in JoeySat
LEO 600 km
Timepix3 Si sensor

2D track visualization

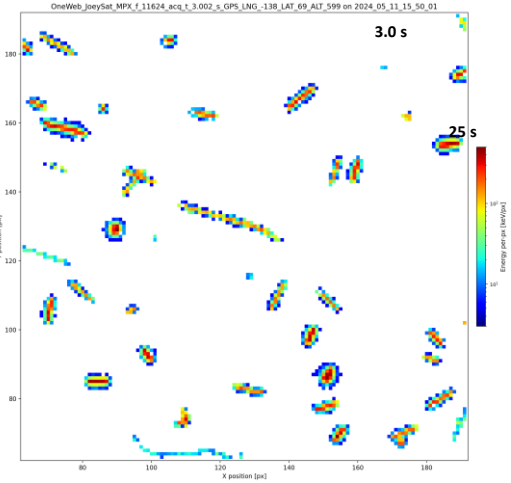
X rays + LE e's + LE/HE p's



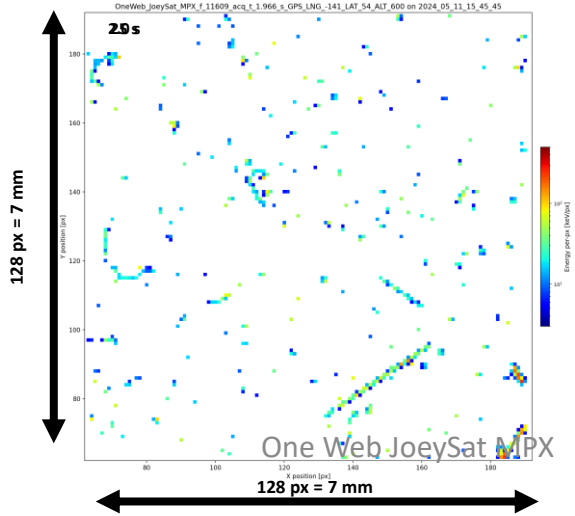
LE/HE p's



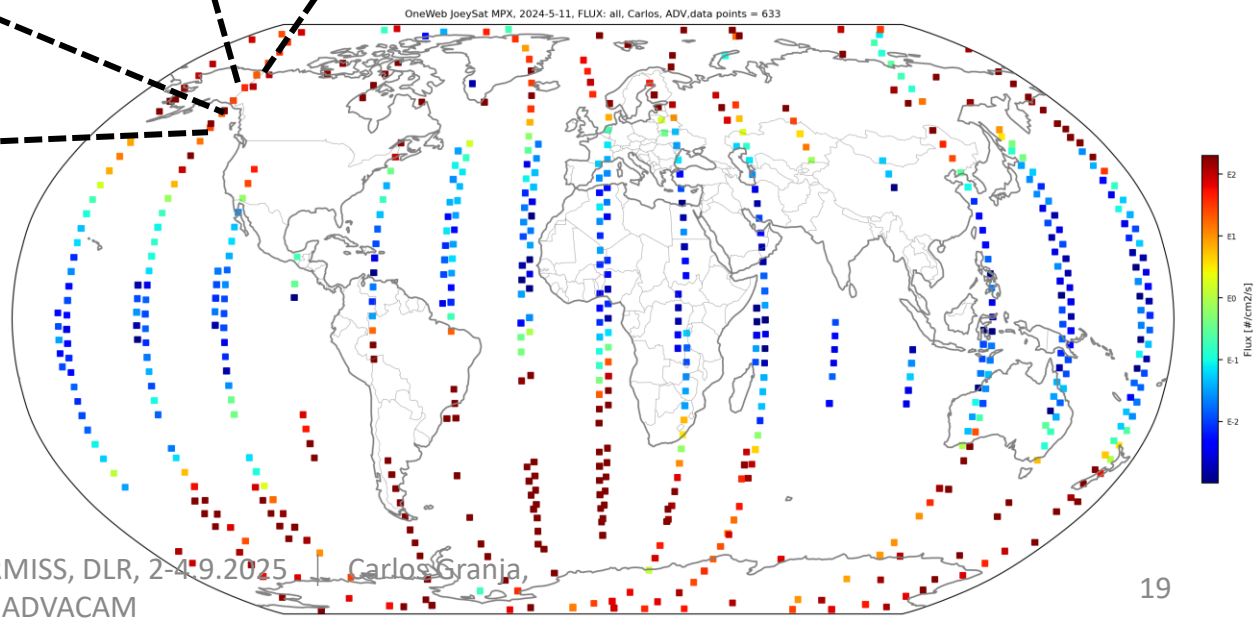
LE/HE p's



X rays + LE e's + HE p's



Particle flux all particles



OneWeb JoeySat MPX
2D track visualization

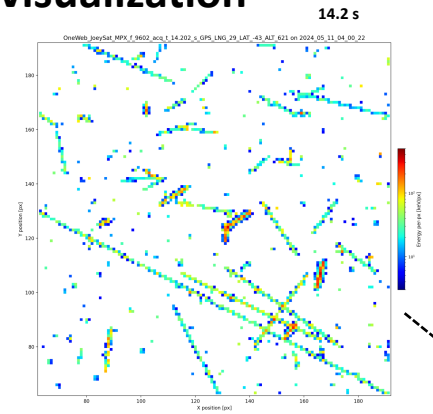
2024 May 11

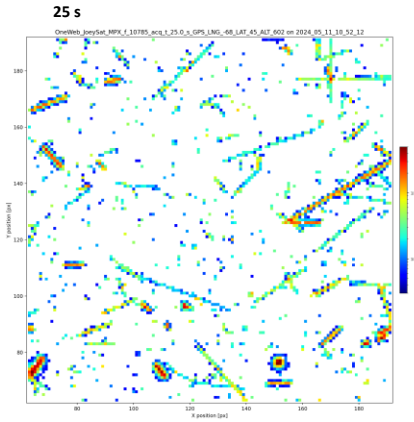
solar storm

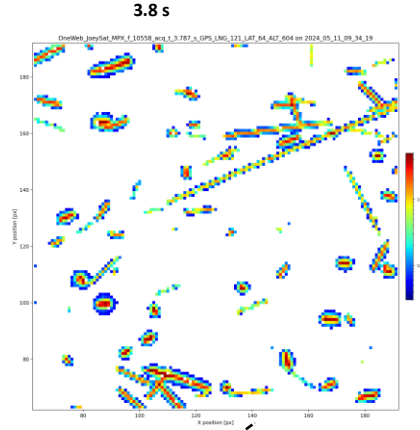
LEO 600 km

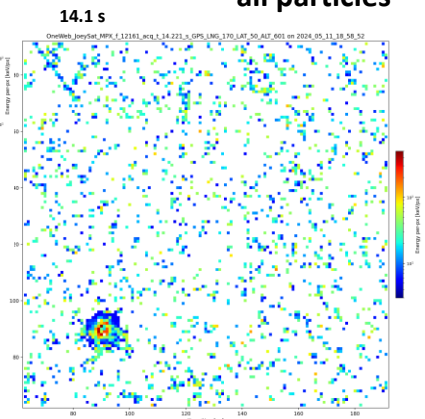
Quantum-imaging detection and track visualization of the radiation field in JoeySat LEO 600 km Timepix3 Si sensor

Particle flux
all particles

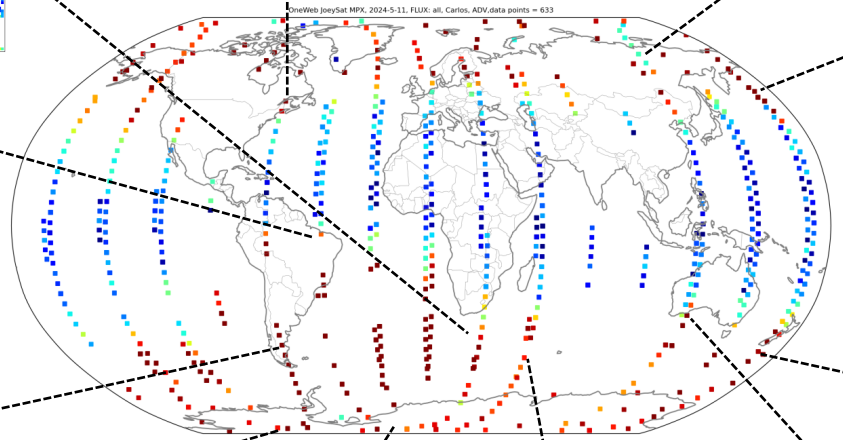


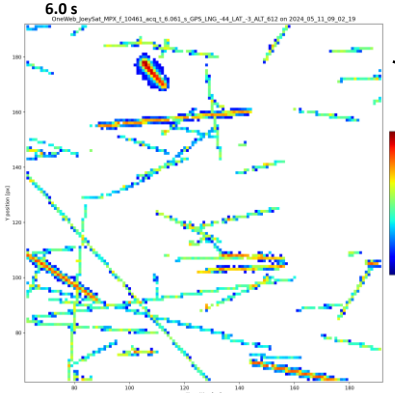


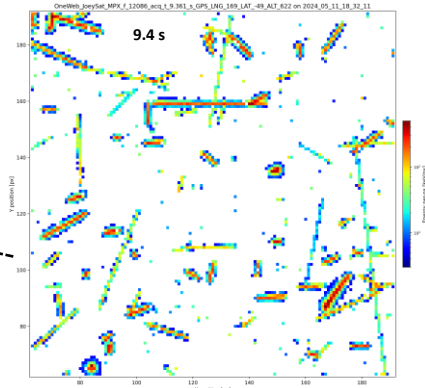




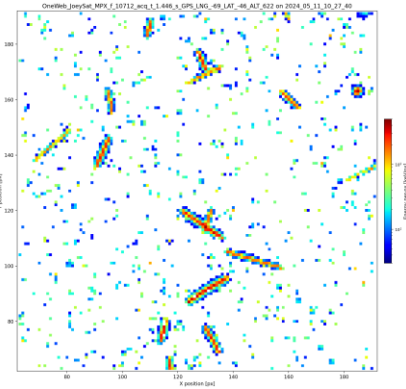
X rays
LE electrons

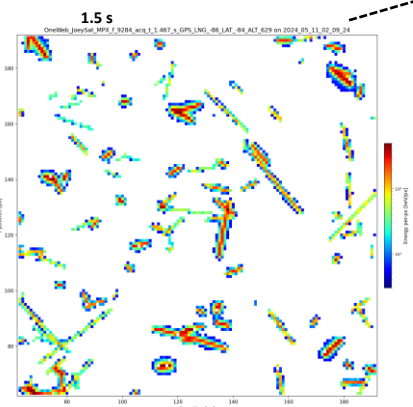


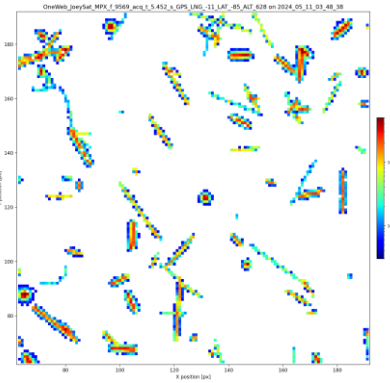


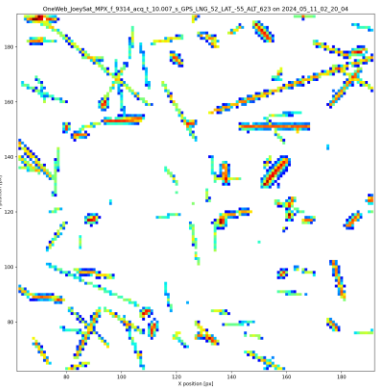


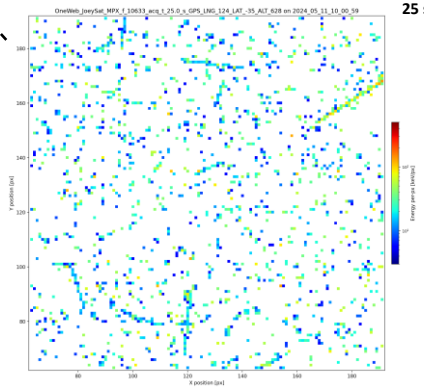
X rays
LE electrons











X rays
LE electrons

❑ Physics data products

- Particle fluxes
- Dose rates
- Time plots
- Earth-orbit maps

❑ Mother's Day Solar Storm

- 10-11 May 2024

LEO 600 km

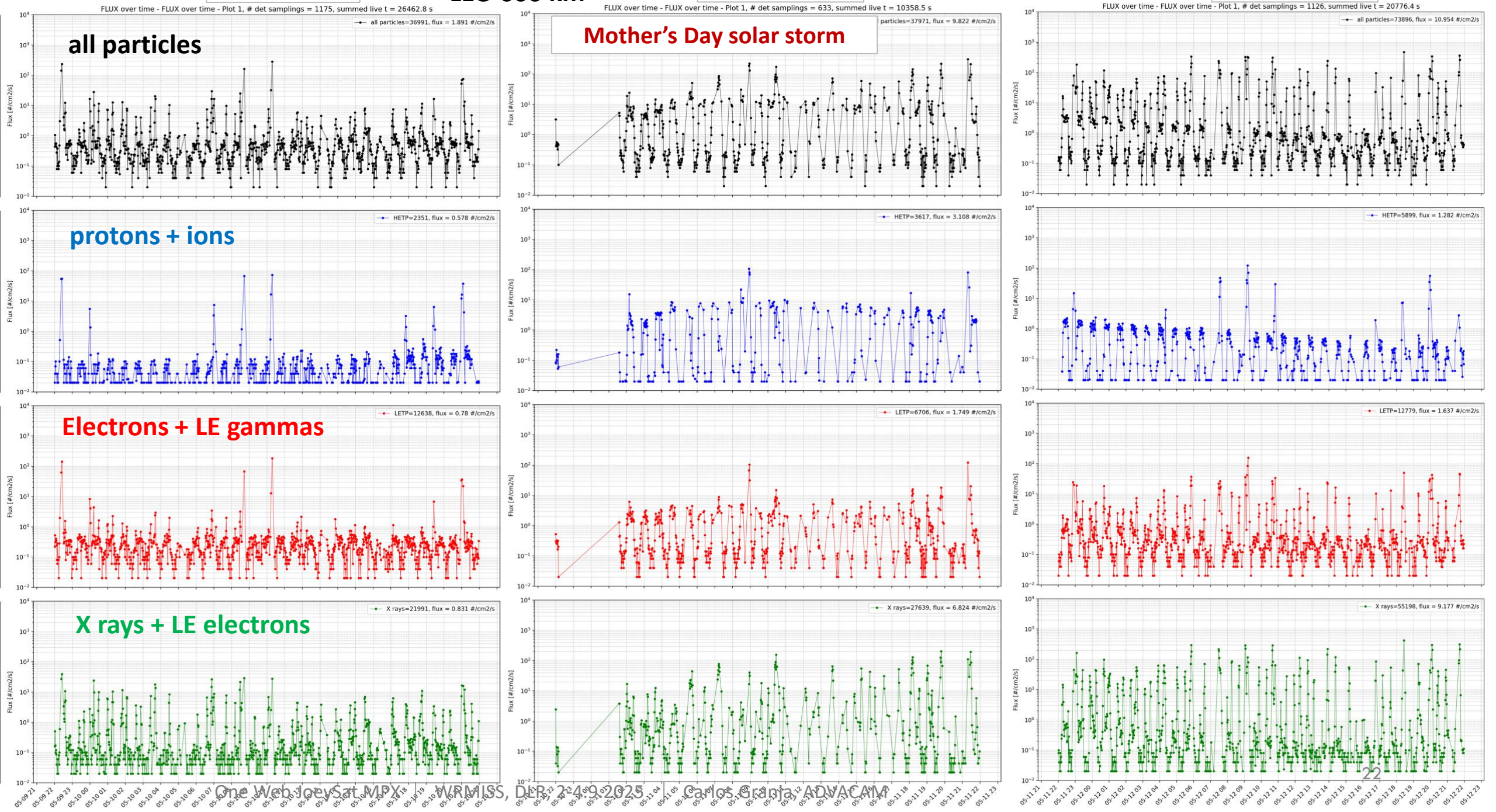
Particle flux

LEO 600 km

2024 May 10

2024 May 11

2024 May 12



MPX radiation monitor on JoeySat in LEO 600 km

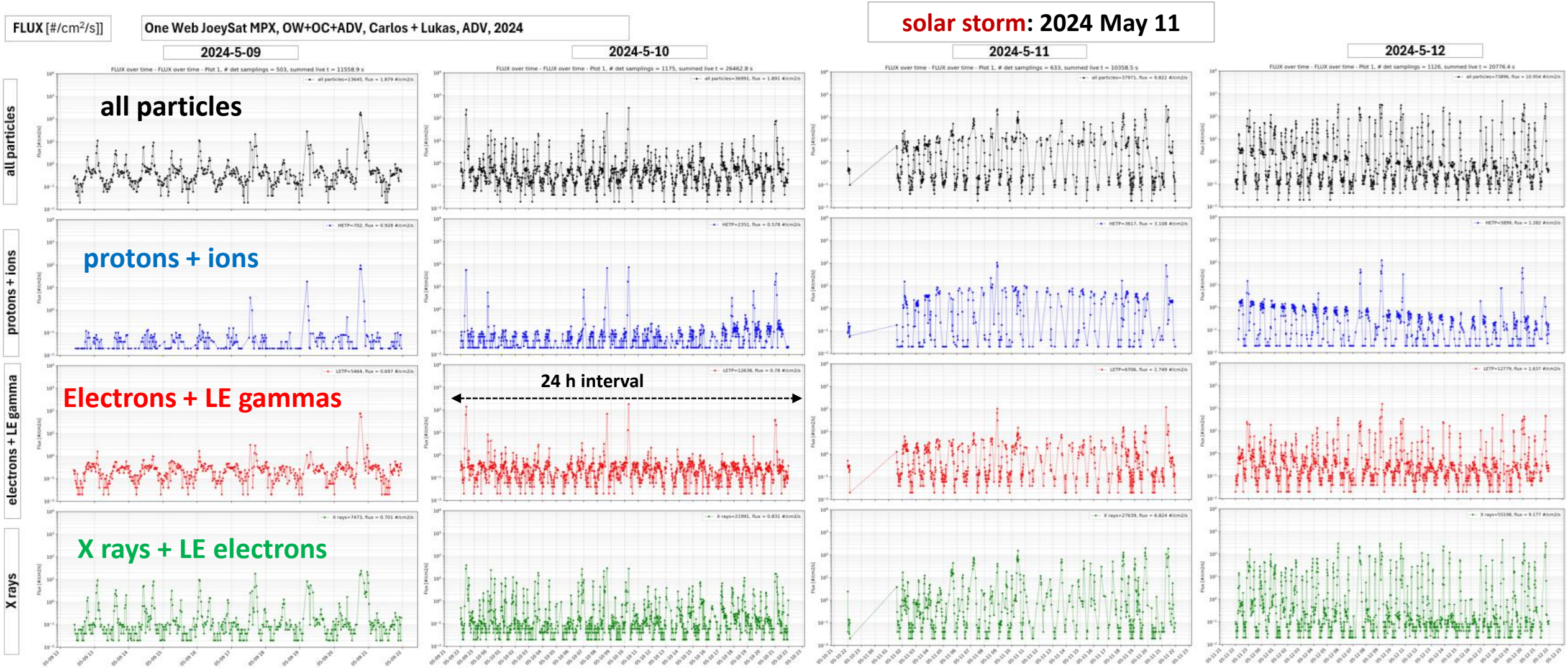
Space radiation decomposition: particle-event types

LEO 680 km

Timepix3
Si 500 µm

particle flux: all, protons, electrons/X rays ← 4 days

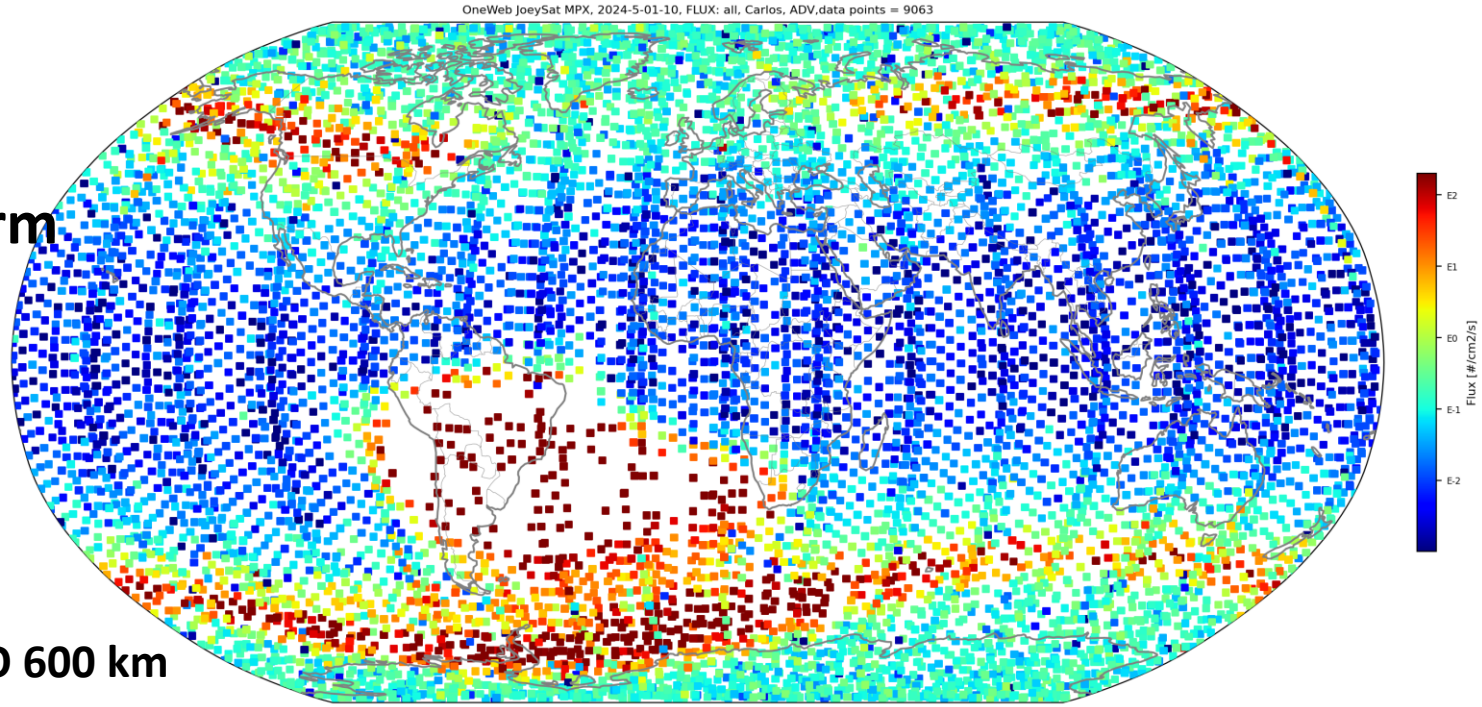
solar storm: 2024 May 11



Radiation Earth maps along JoeySat orbit: 9-day data periods prior and during/after solar-geomagnetic storm

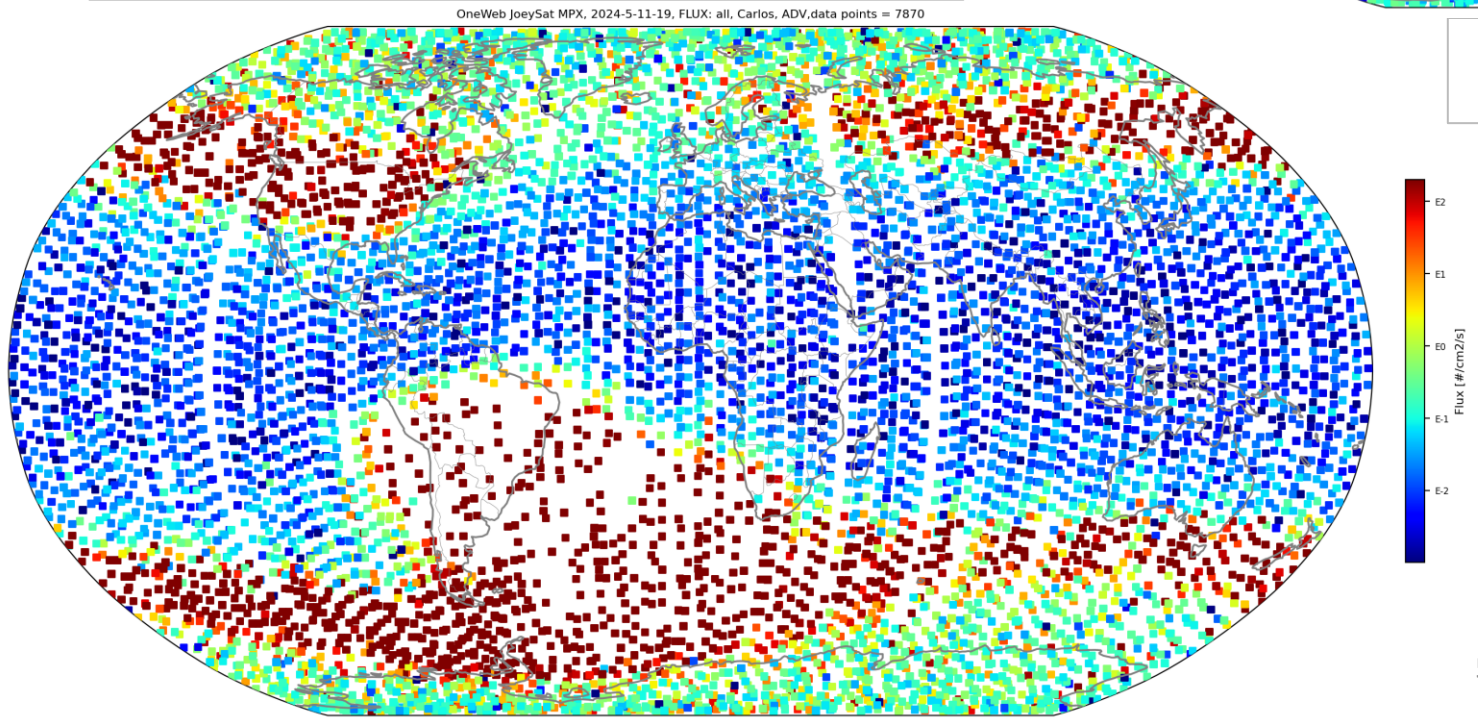
PARTICLE FLUX [#/cm^2/s]

all particles



solar storm: 2024 May 11-19

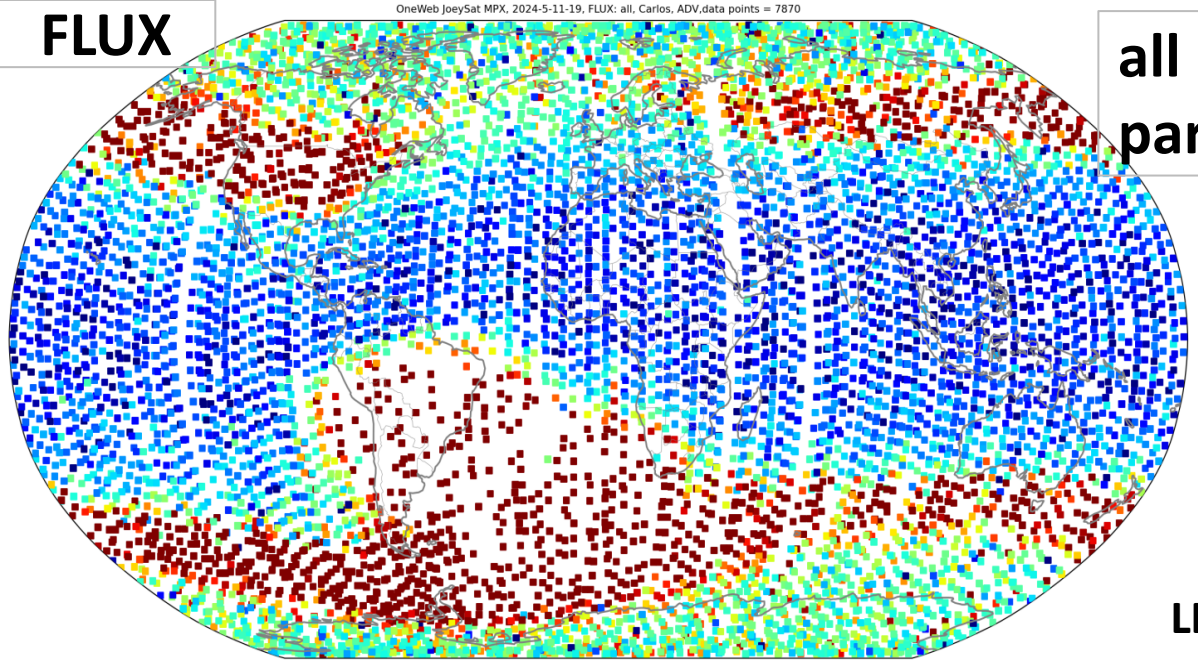
LEO 600 km



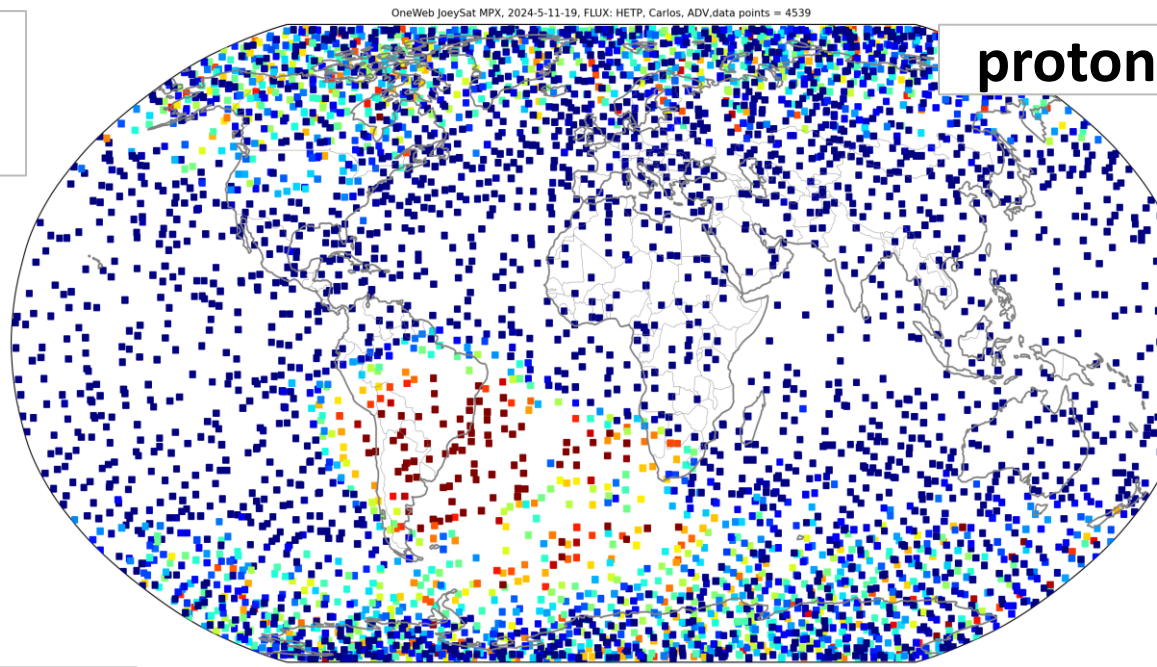
Normal period: 2024 May 1-10

One Web JoeySat MPX,
OW+OC+ADV,
Carlos + Lukas, ADV, 2024

FLUX



all particles

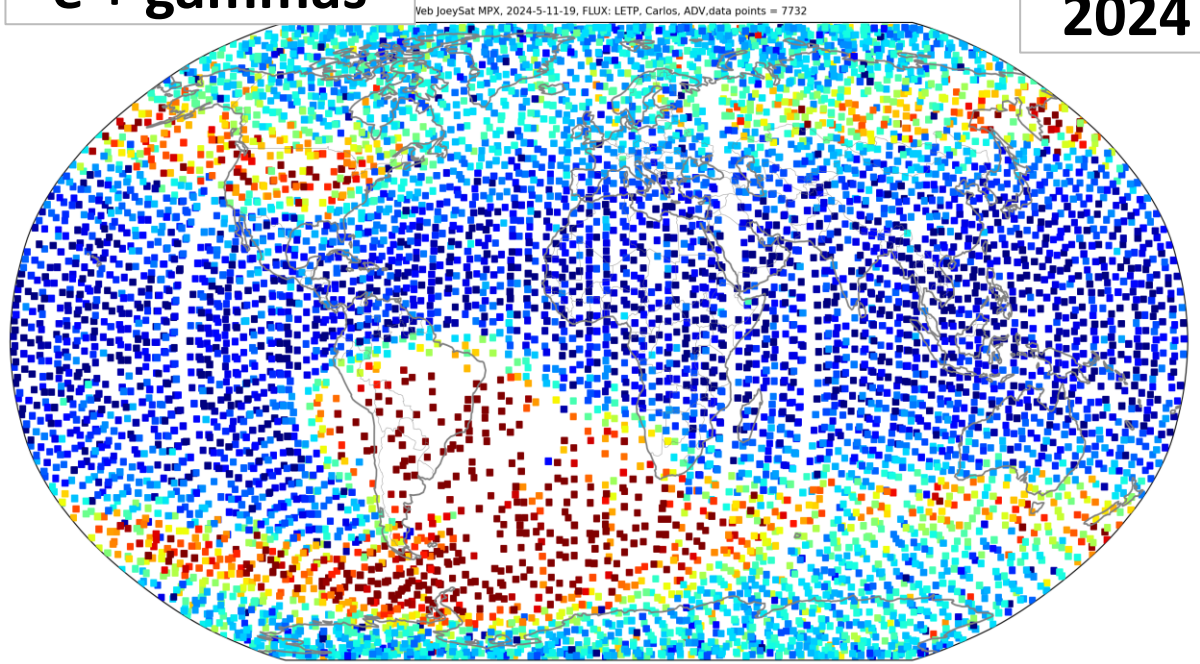


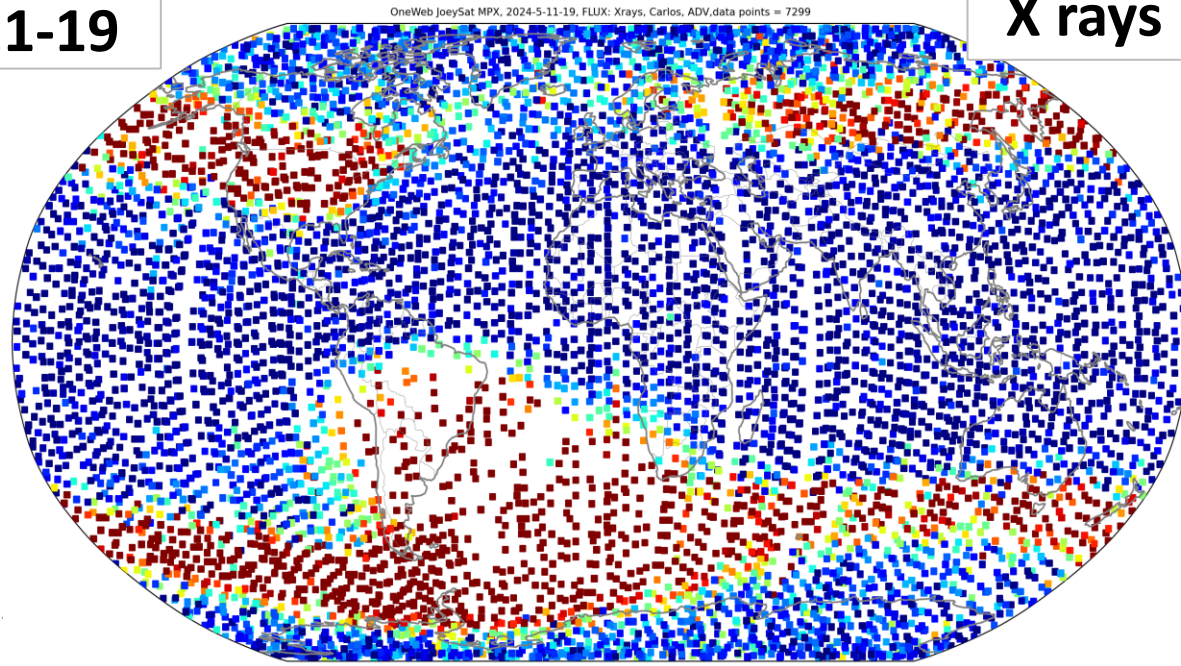
proton

LEO 600 km

solar storm: 2024 May 11-19

e + gammas





X rays

❑ Physics data products

- Particle fluxes
- Dose rates
- Time plots
- Earth-orbit maps

❑ Solar Storm

- 09-11 Oct 2024

LEO 600 km

Time plot

Particle flux omnidirectional

MiniPIX TPX3 Space

JoeySat One Web

LEO 610 km

solar storm

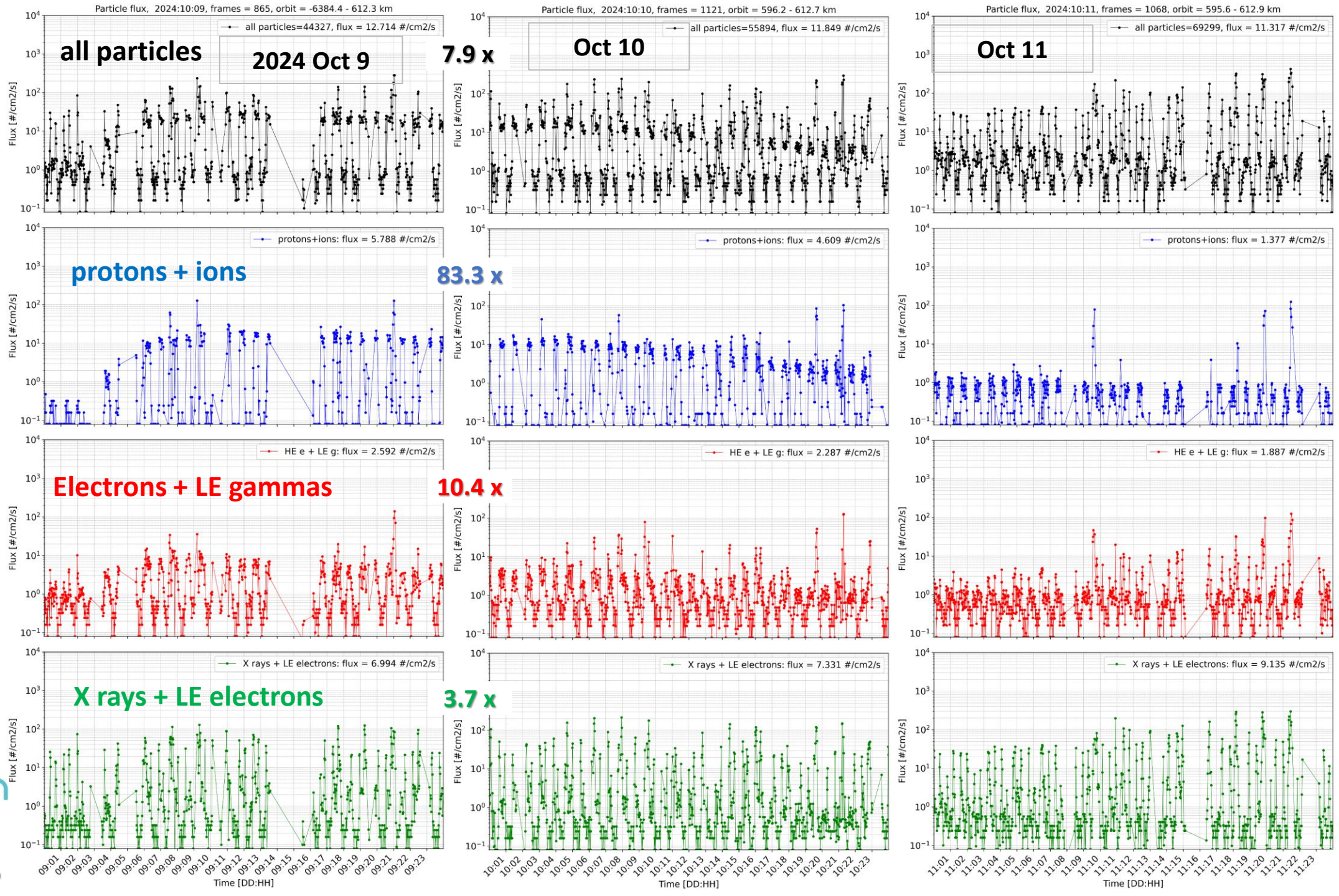
2024 Oct 9-11

esa

ADVACAM
Imaging the Unseen

OneWeb

oledcomm



Time plot

Dose rate (all particles)

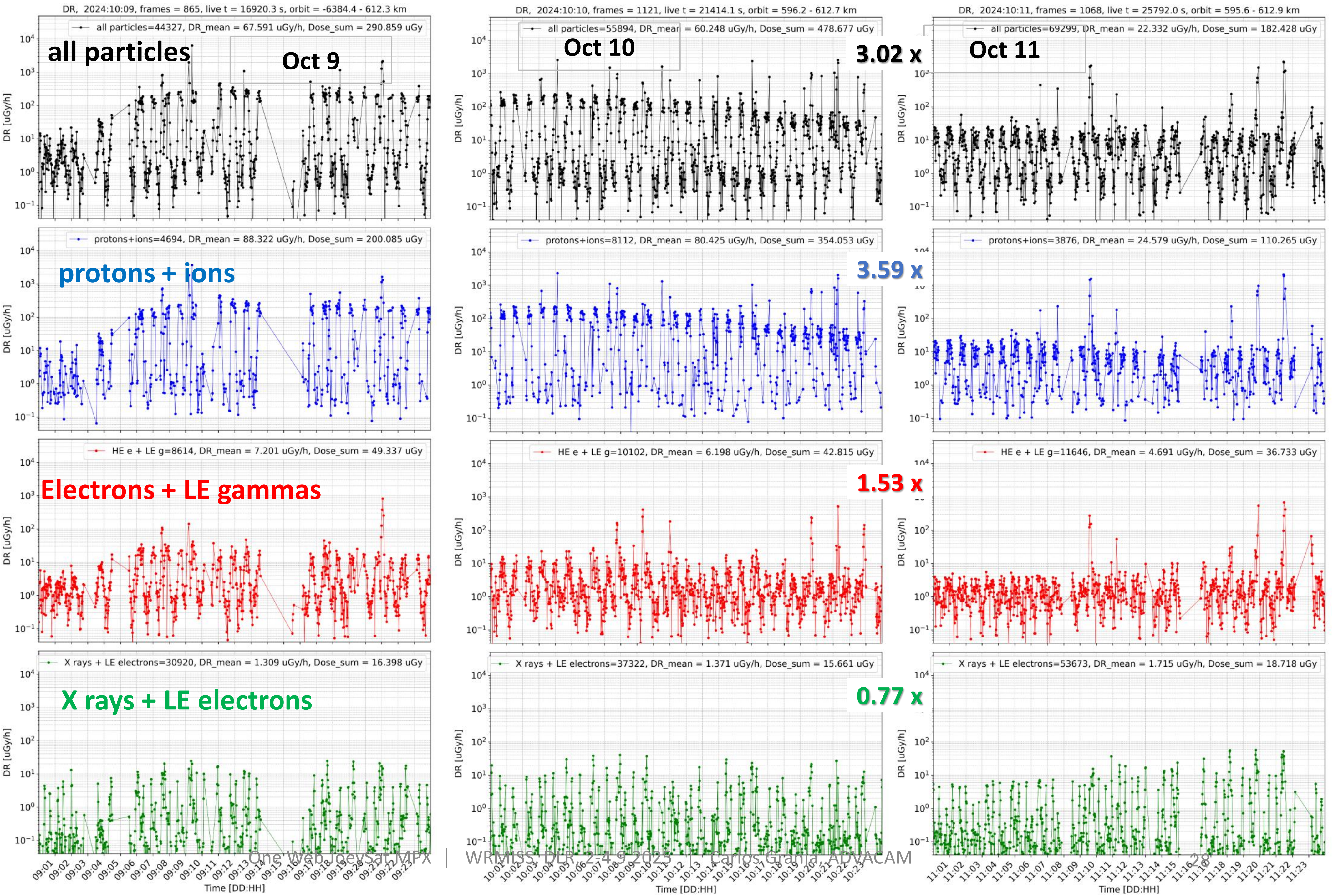
MiniPIX TPX3 Space

JoeySat One Web

LEO 610 km

solar storm

2024 Oct 9-11



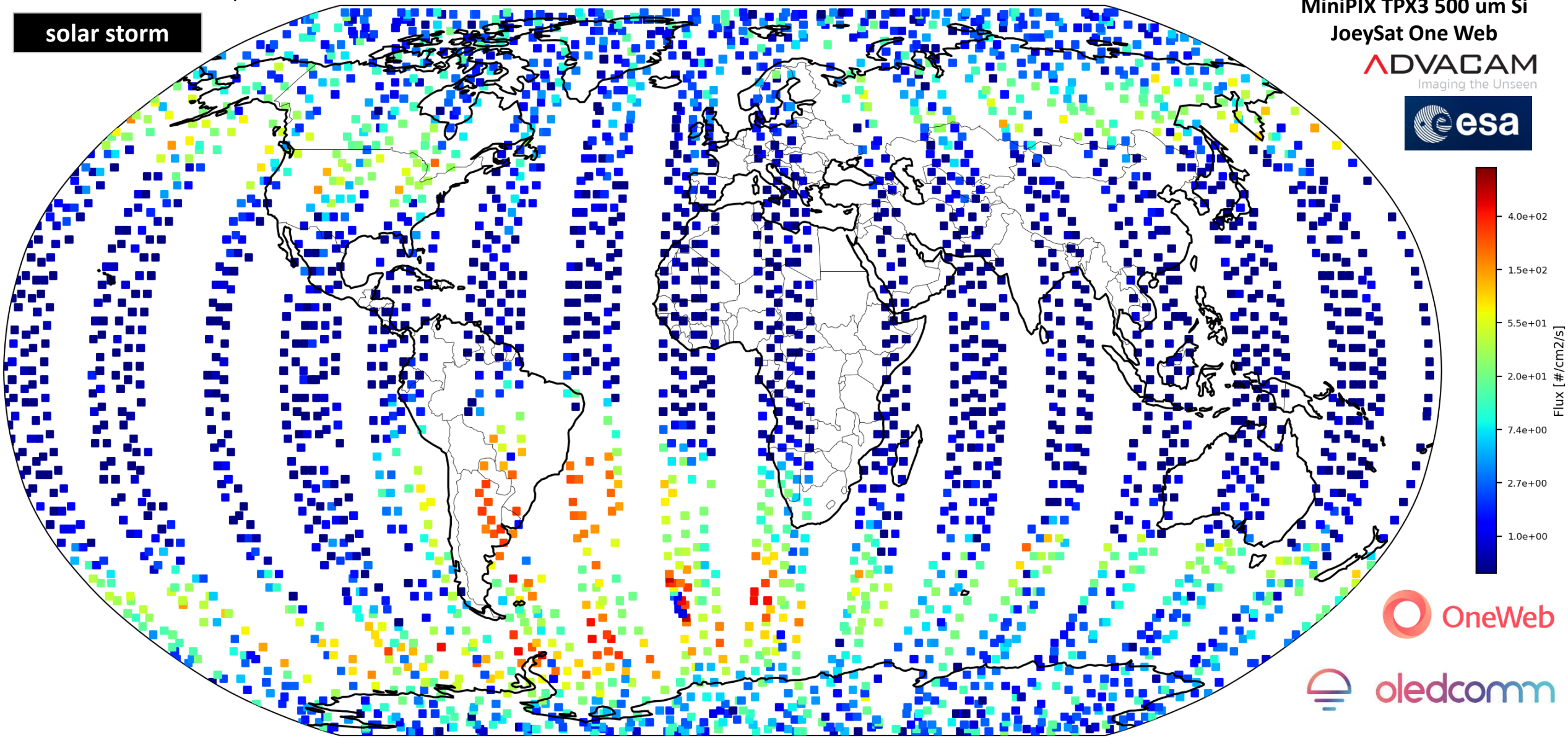
Particle flux: all particles, omnidirectional

LEO 680 km

3x days: 2024 Oct 09-11

Earth-orbit map

solar storm



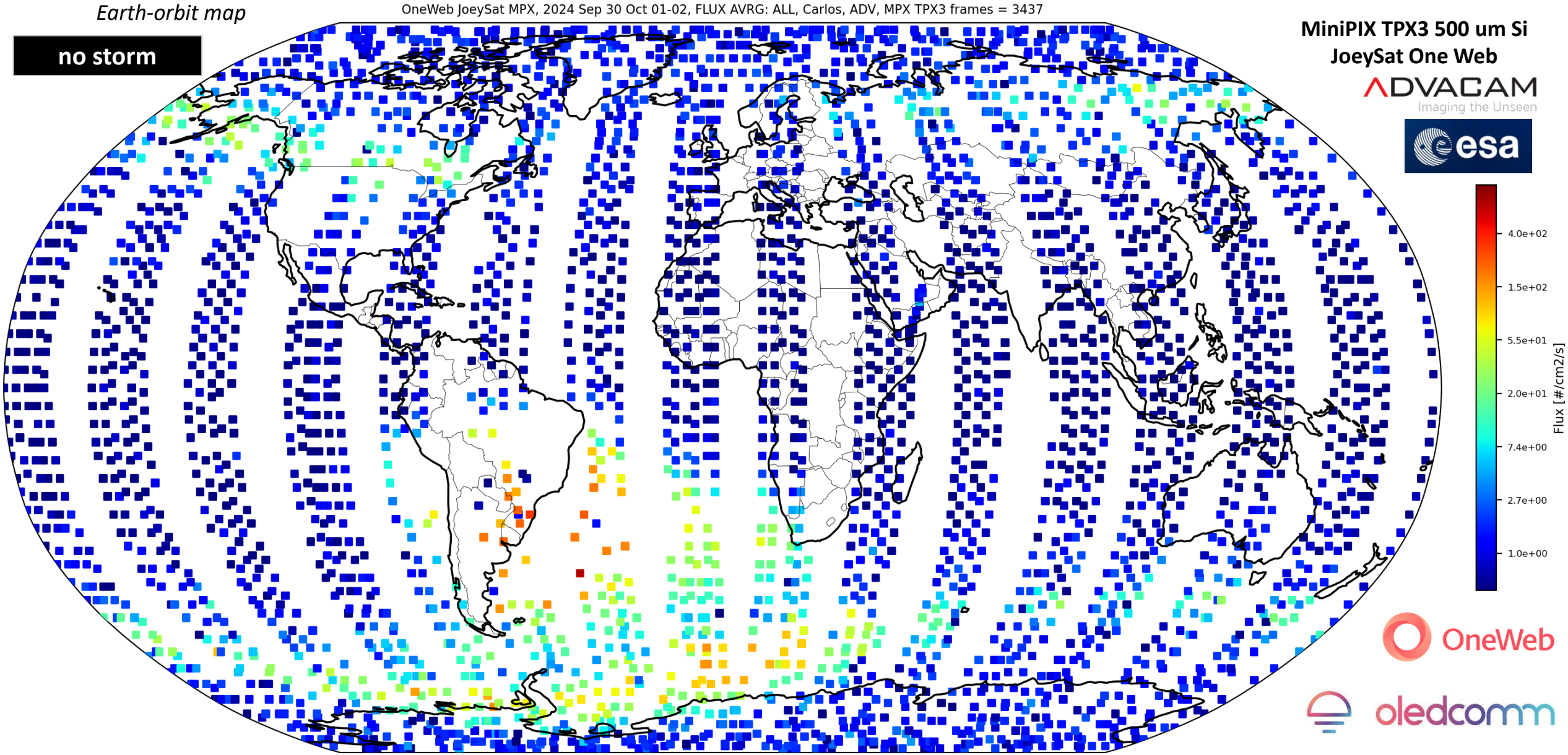
Particle flux: all particles, omnidirectional

LEO 680 km

3x days: 2024 Sept 30 Oct 01-02

Earth-orbit map

no storm



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❑ Physics data products

- Particle fluxes
- Dose rates
- Time plots
- Earth-orbit maps

❑ Higher orbit

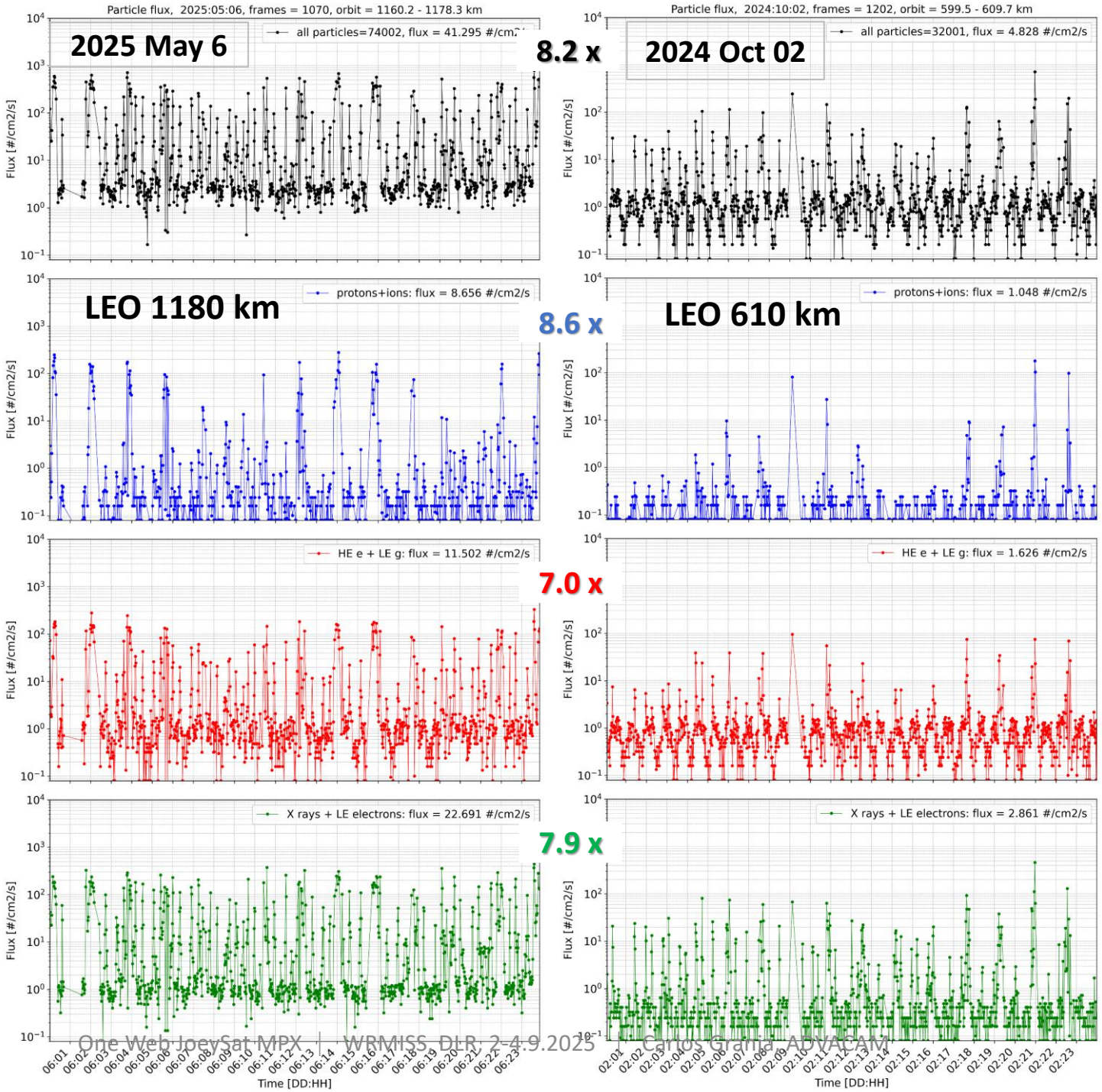
- 1200 km (2025)

Time plot

Particle flux omnidirectional

Timepix3
Si 500 µm

MPX
JoeySat
OneWeb

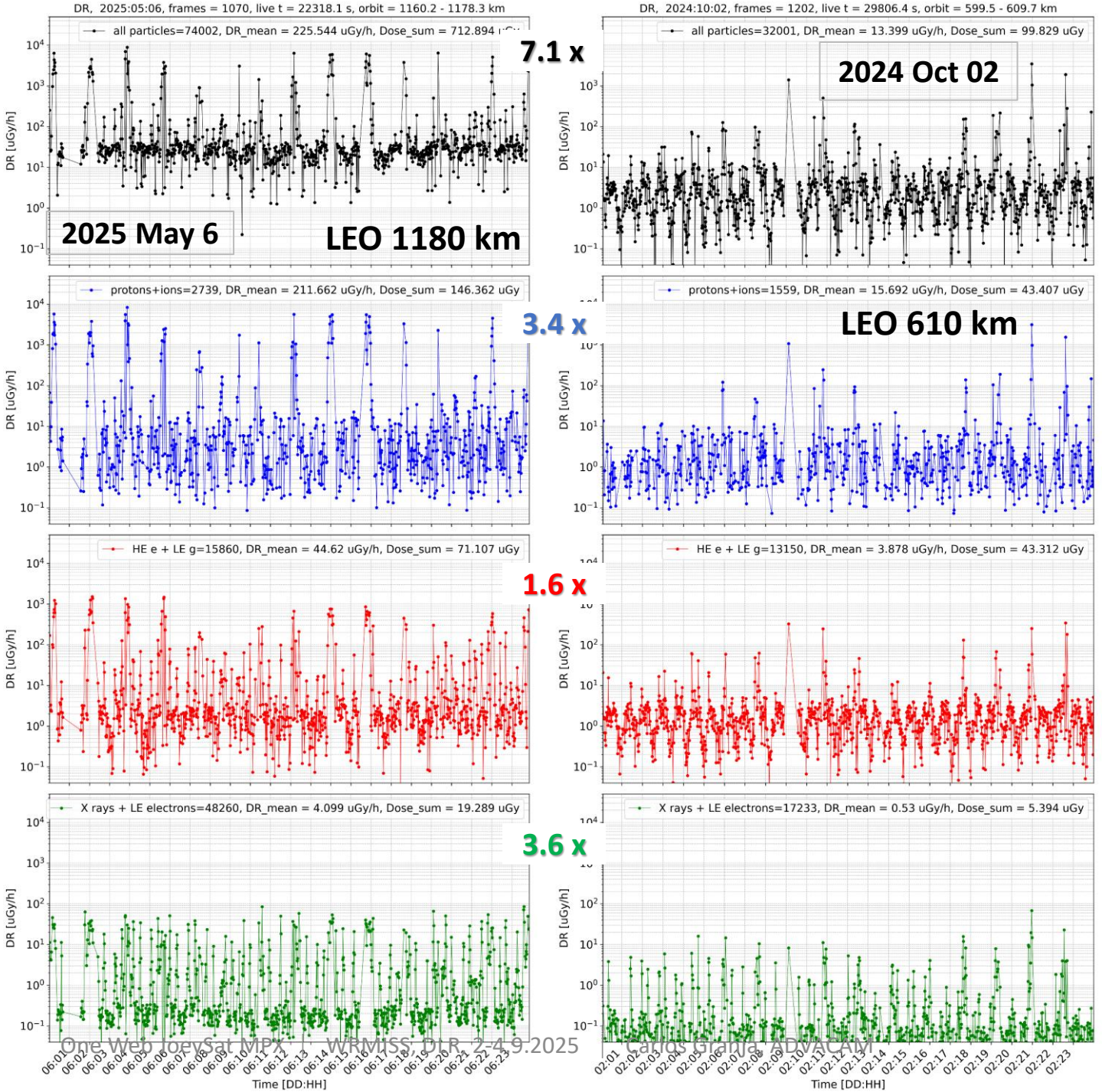


Time plot

Dose rate

Timepix3
Si 500 µm

MPX
JoeySat
OneWeb



In-orbit comparison with other radiation detectors / other missions

DLR RAMIS radiation detector, on Eu:CROPIS satellite, LEO 575 km

Eu:CROPIS mission— life-science satellite satellite by DLR— launched in Dec 2018 in LEO 575 km, SSO 98°

RAMIS: single-pad semiconductor/Si diode

RAMIS	FM	
Dimensions	140 x 140 x 35	mm^3
Mass	608	g
Supply voltage	28	V
Power consumption	1.82	W

RAMIS payload

Single Detector Data		
Radius	0,51	cm
Thickness	300	µm
Area	0,817	cm^2
Mass	57,11	mg
GF	5,133	$sr*cm^2$

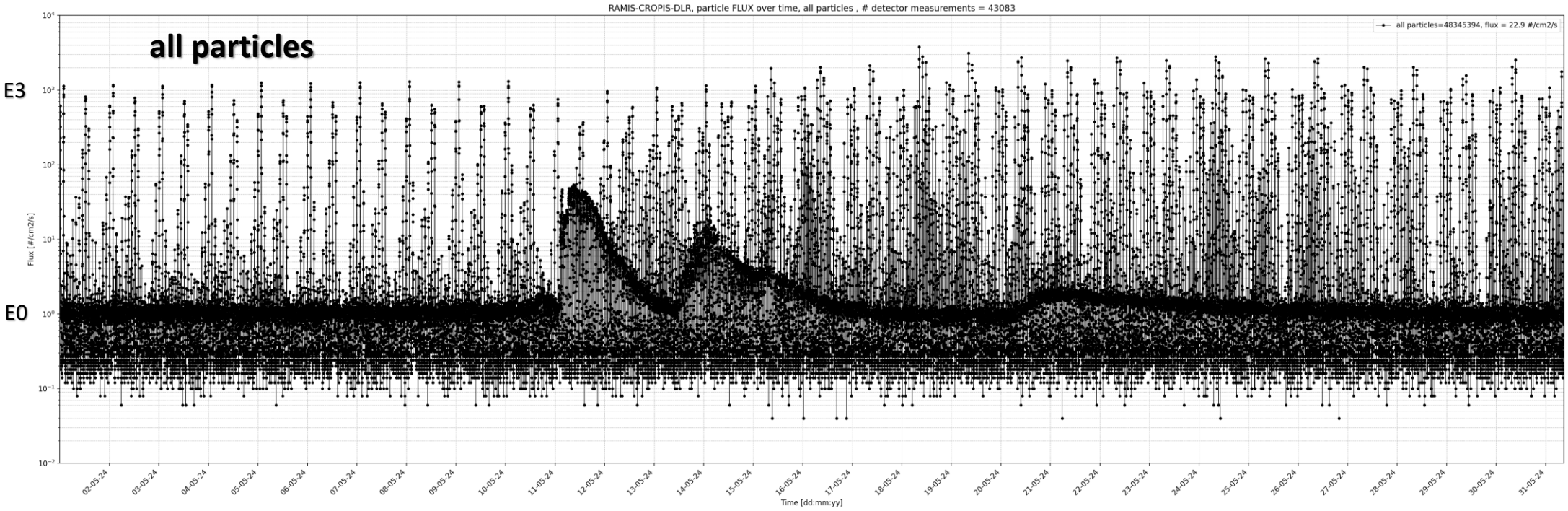
Telescope Data		
Distance between the diodes	0,73	cm
Opening angle	109	°
GF	1,423	$sr*cm^2$
Mean path length	335,85	µm

Ranges		
Energy range (in Si)	0.09 – 145	MeV
LET Range (in H2O)	0.15 – 228	keV/µm

Particle flux
omnidirectional
1 month: May 2024

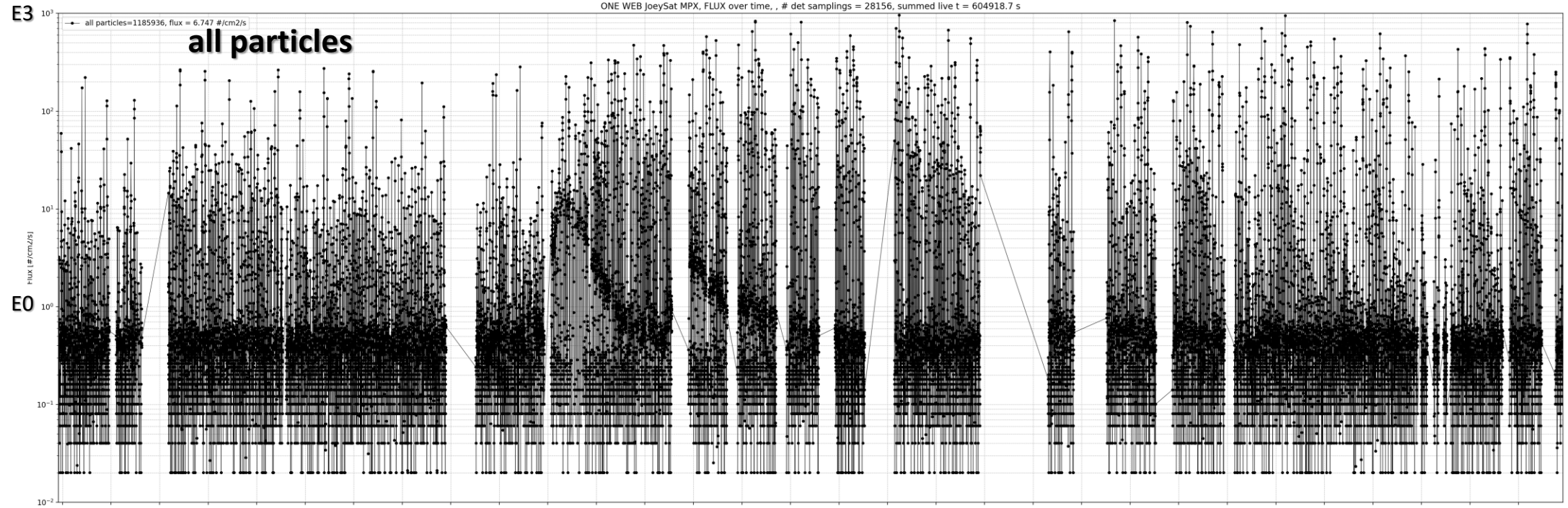
RAMIS DLR
CROPIS Mission

Th Berger/DLR



OneWeb Joeysat
MPX: LEO 600 km

Carlos/ADVACAM

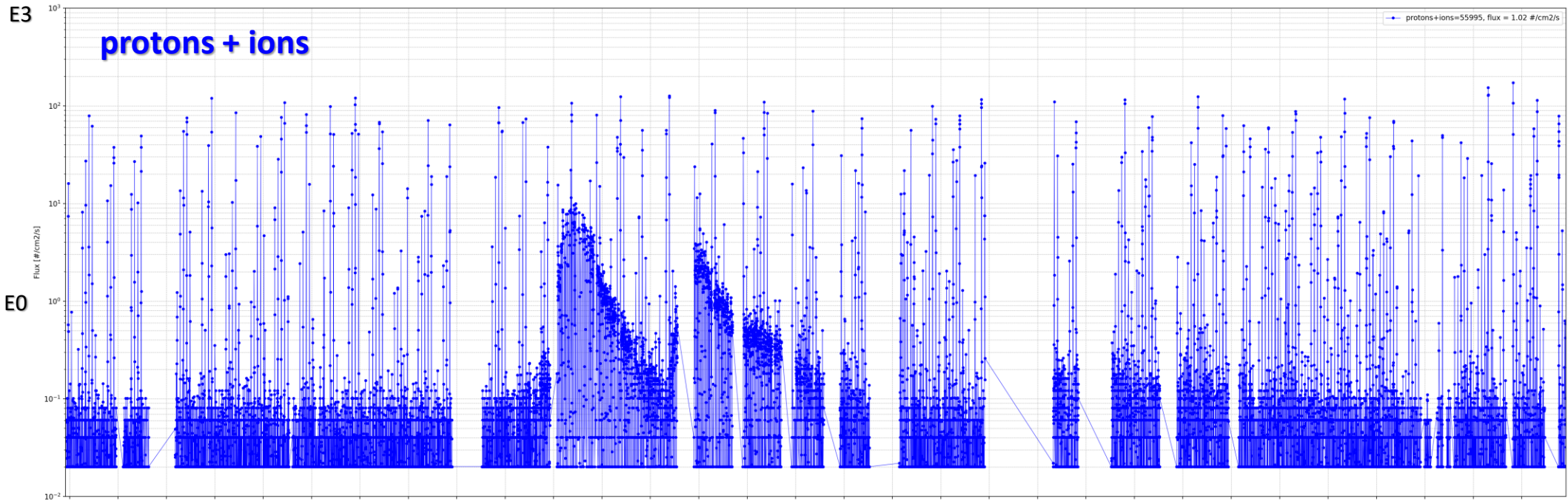


Particle flux

omnidirectional

1 month: May 2024

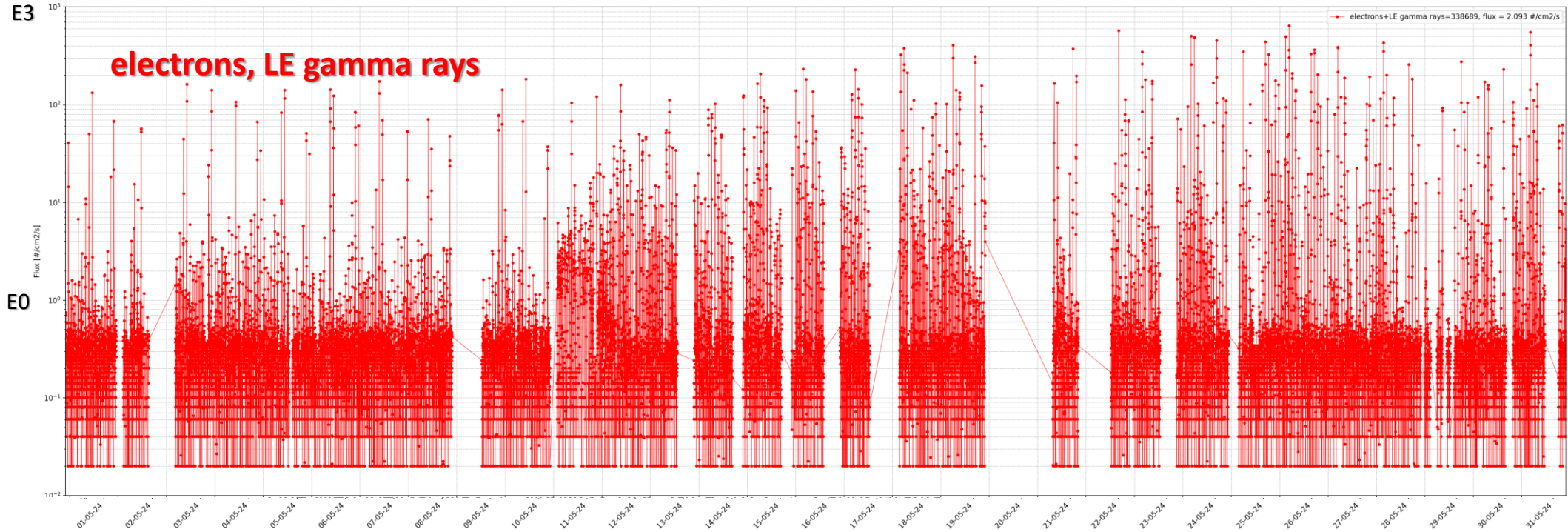
Carlos/ADVACAM



OneWeb Joeysat

MPX: LEO 600 km

Carlos/ADVACAM

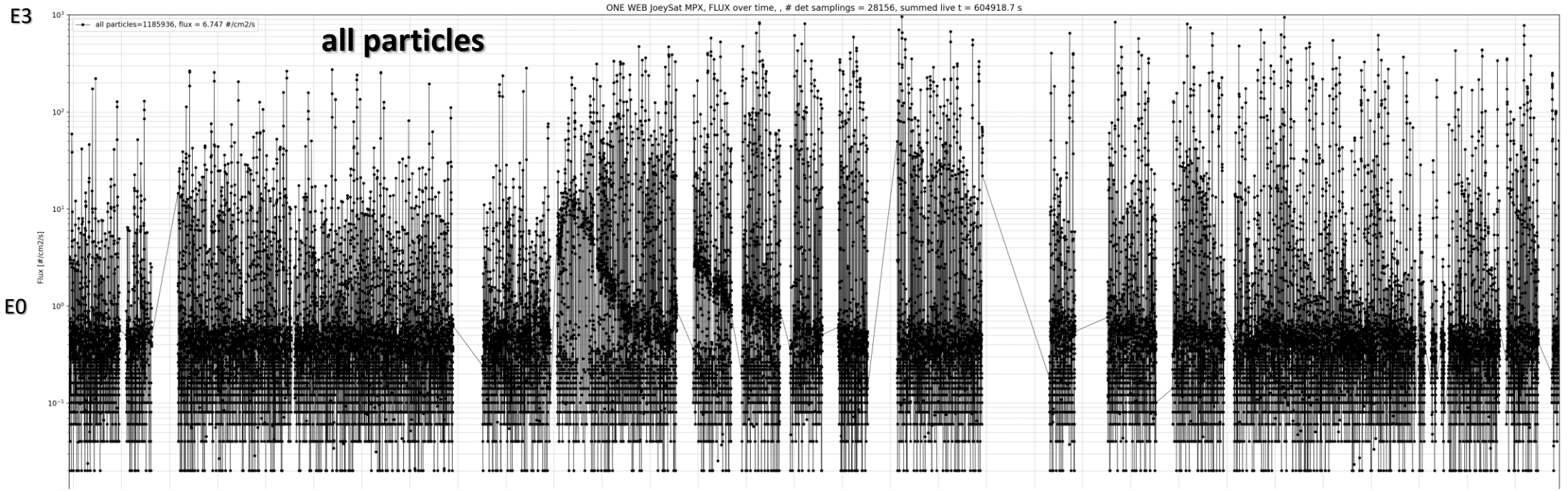


Particle flux

omnidirectional

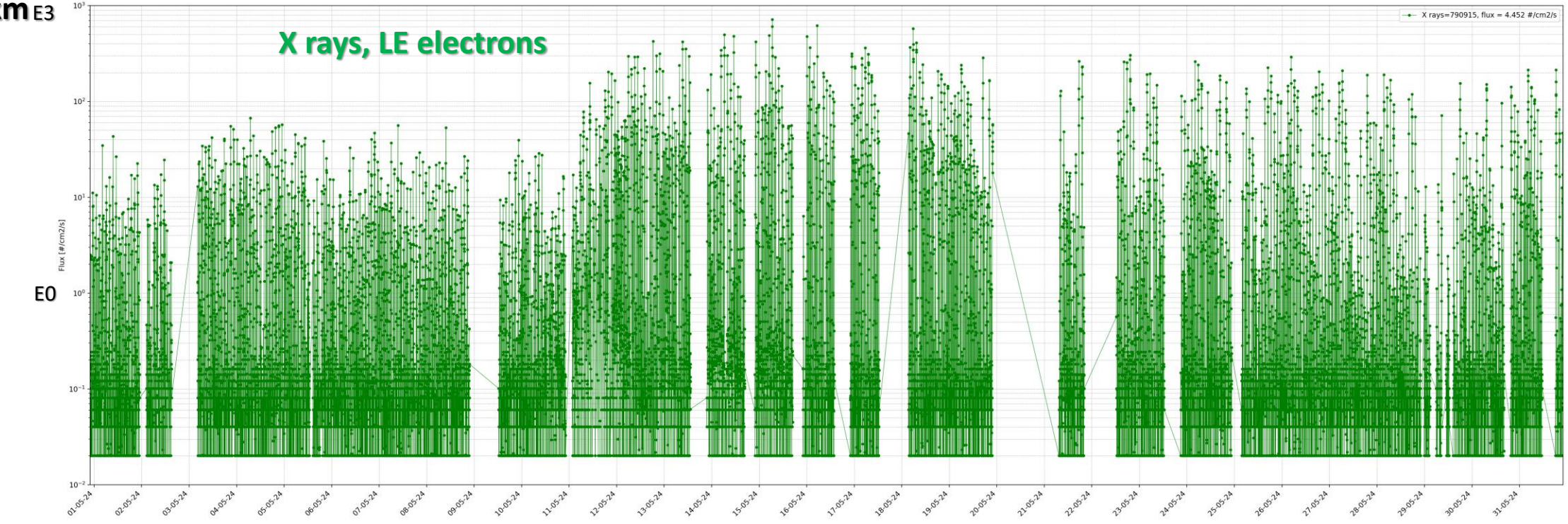
1 month: May 2024

Carlos/ADVACAM



OneWeb Joeysat

MPX: LEO 600 km



Carlos/ADVACAM

One Web JoeySat microsatellite: radiation environment characterization

High-resolution radiation monitor, particle tracker: ADV MPX TPX3 Space

Ongoing work/next steps

- ❑ Processing of spectrometry data
  - LET spectra: total, partial
  - Deposited energy spectra: total, partial
- ❑ Correction for shielding (Al 5 mm), MC SIM+ model + exp in-beam calibrations
- ❑ Correction for event-track pile-ups
- ❑ Processing of tracking-directional data, pitch angle, satellite attitude
- ❑ Higher-resolution particle-type classification
  - Protons: 2-3 spectral groups
  - Electrons: 2 spectral groups
  - Neutrons (fast), limited detection efficiency (< 1%): challenge to discriminate in mixed-unknown radiation field with single-chip detector

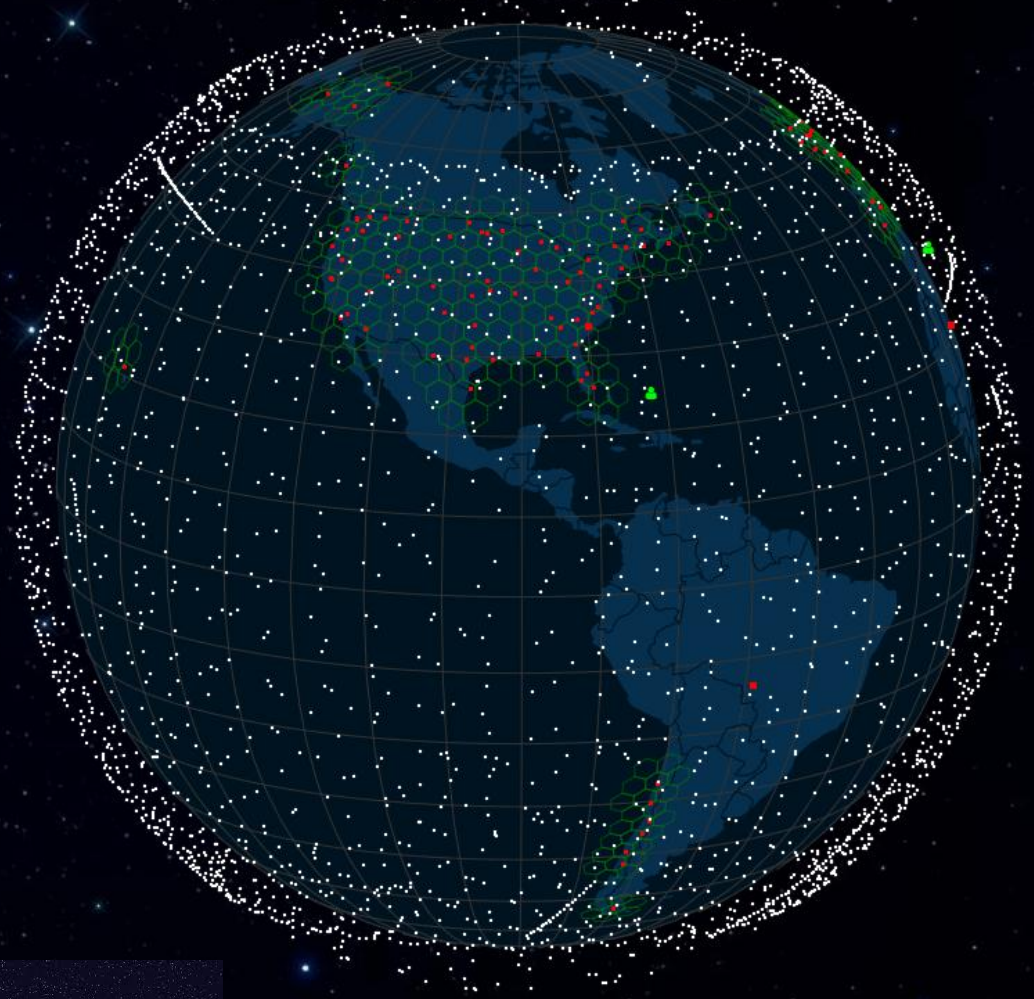
MSc Thesis, Delft Univ,
Onno v.d.S. / A. Menicucci

Back-up material

Satellite constellations: Telecommunication/internet from orbit

7,875 Starlink satellites in orbit, LEO 550 km

Starlink

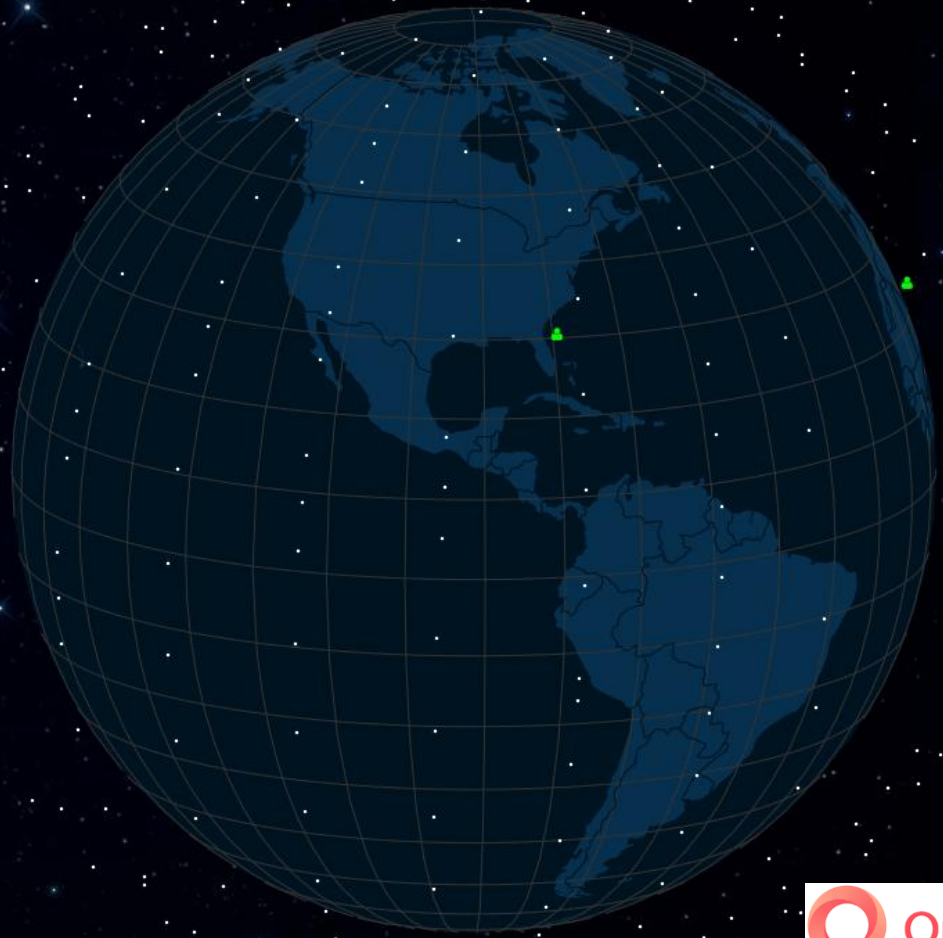


SPACEX

Microsatellites 260 kg – 1250 kg

648 satellites, LEO 600 – 1200 km, full polar orbit

OneWeb



OneWeb

Microsatellites 150 kg

eutelsat

Radiation effects

On satellites, components, electric-electronic components

Single Event Effects (SEEs)

- A single-event effect (SEE) is a disturbance to the normal operation of a circuit caused by the passage of a single ion (proton or heavy ion) through or near a sensitive node in a circuit.
- SEEs can be either destructive or non-destructive.

Non-Destructive	Destructive
Single-Event Upset (SEU)	Single-Event Latchup (SEL)
Multiple-Bit Upset (MBU)	Single-Event Burnout (SEB)
Single-Event Transient (SET)	Single-Event Gate Rupture (SEGR)
Single-Event Functional Interrupt (SEFI)	

Specific, sensitive to
- Type of particle
- Energy
- Intensity

Hybrid semiconductor pixel detector Timepix3
Per–pixel signal readout electronics

Medipix Collaboration based at CERN

www.cern.ch/medipix

ADVACAM

Hybrid architecture

Hybrid architecture: sensor is bump-bonded to the **Timepix readout ASIC chip**. Different semiconductor sensors can be used:

- material (Si, CdTe, GaAs)
- thickness (e.g. 100, 300, 500, 700, 1000, 1500 µm).

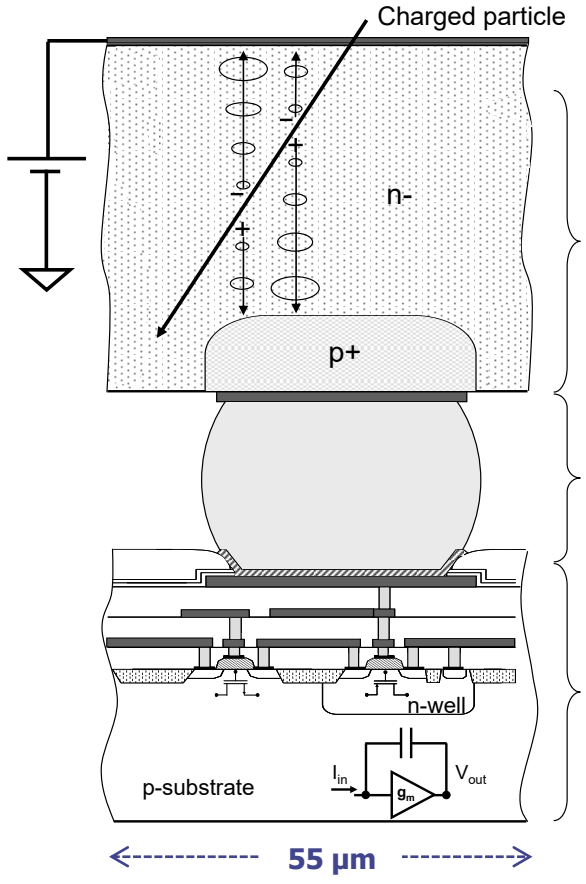
High signal electronics integration

High integration, 1-2 k transistors per pixel

Quantum imaging detection

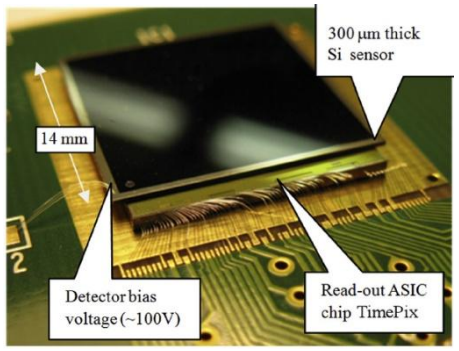
- Hybrid architecture
- Per-pixel signal processing electronics

- dark-current free detection
- threshold ~ 4 keV
- track visualization of single particles



per-pixel signal electronics

Pixel detector Timepix



256 x 256 pixels (pitch 55 µm)
14 mm x 14 mm = 2 cm²

Miniaturized radiation camera MiniPIX-TPX

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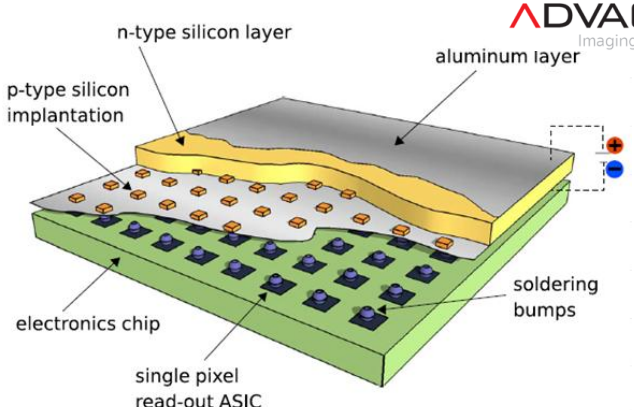

Integrated per-pixel signal readout electronics
MPX/TPX ASIC chip-sensor assembly

On line radiation camera

Digital spectral nuclear track emulsion