BSc Thesis in Physics

A classification of Mini-EUSO triggered events at microsecond time scale

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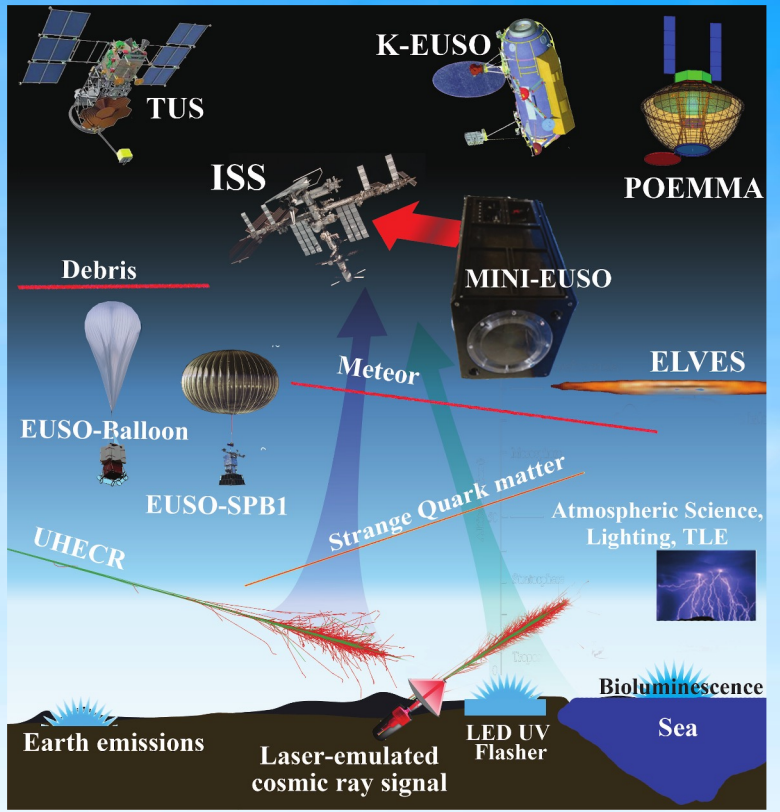
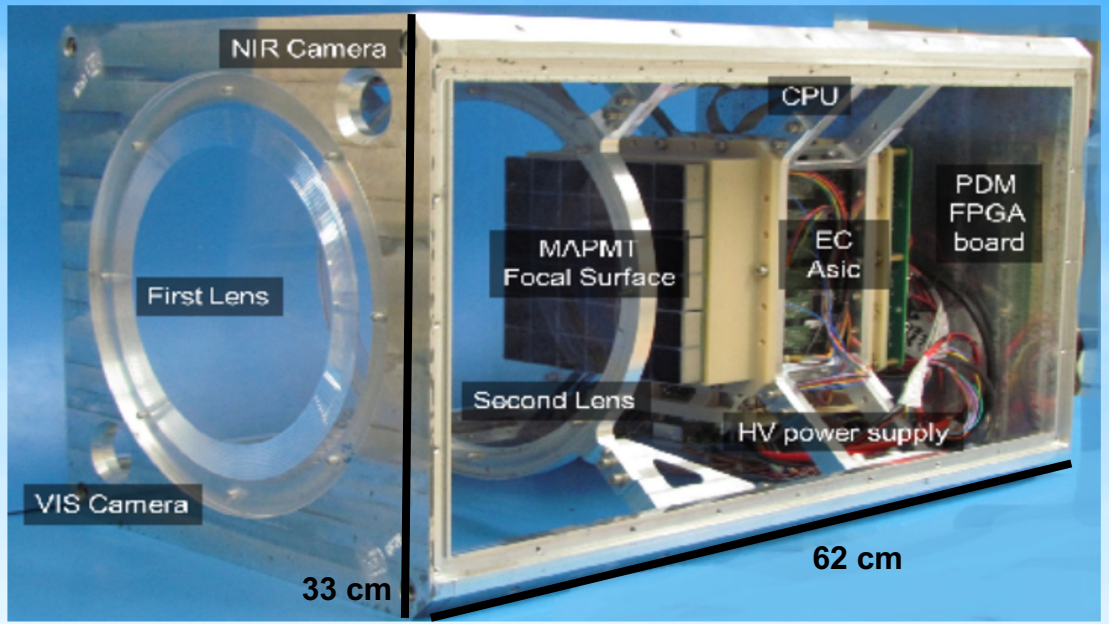
JEM-EUSO program

- Joint Experiment Missions for Extreme Universe Space Observatory (JEM-EUSO)
- Study of Ultra High Energy Cosmic Rays (UHECRs): 10^{19} eV
- UHECRs impact on Earth's atmosphere:
  - Extensive Air Showers (EAS)
  - isotropic fluorescence light emission
  - Cherenkov light
- Different types of experiments:
  - space telescopes
  - balloons
  - ground detectors



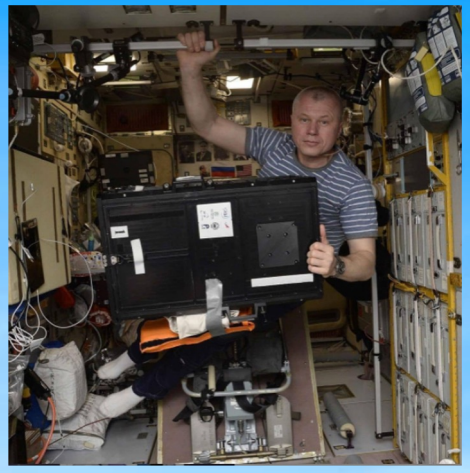
JEM-EUSO and Mini-EUSO telescopes

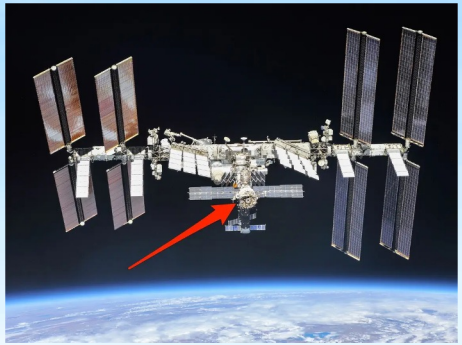
- Japan Experiment Module for the Extreme Universe Space Observatory (JEM-EUSO)
- Mini-EUSO is a scale model of the original JEM-EUSO telescope
- Similar components



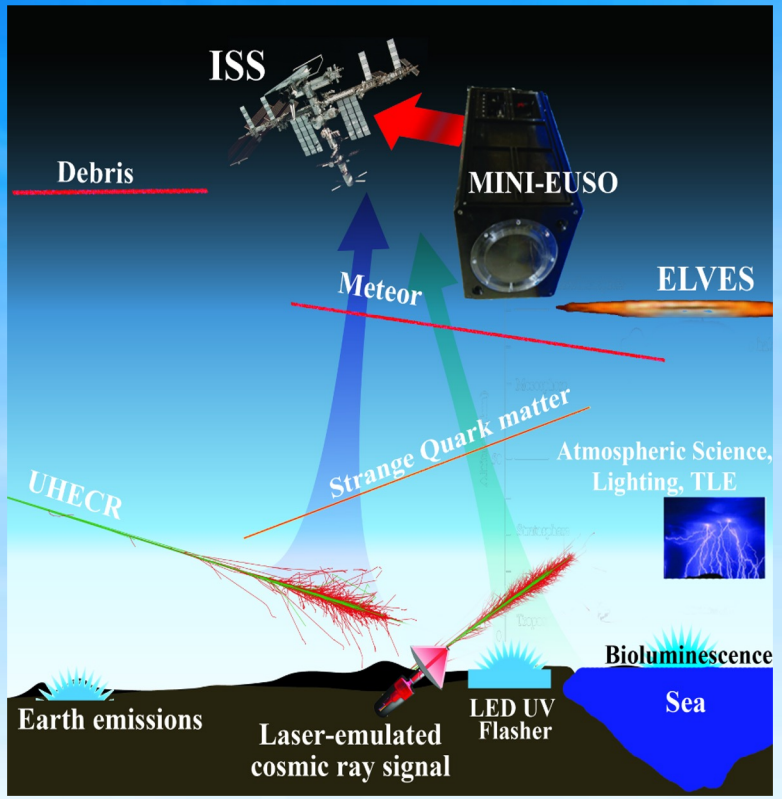
Mini-EUSO experiment

- Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory (Mini-EUSO)
- Installed in the Russian Zvezda module of the ISS
- Manually prepared for data taking by astronauts
- First detector of the JEM-EUSO program that observes Earth from ISS creating an UV map
- 82 data sessions since first operation (October 2019)

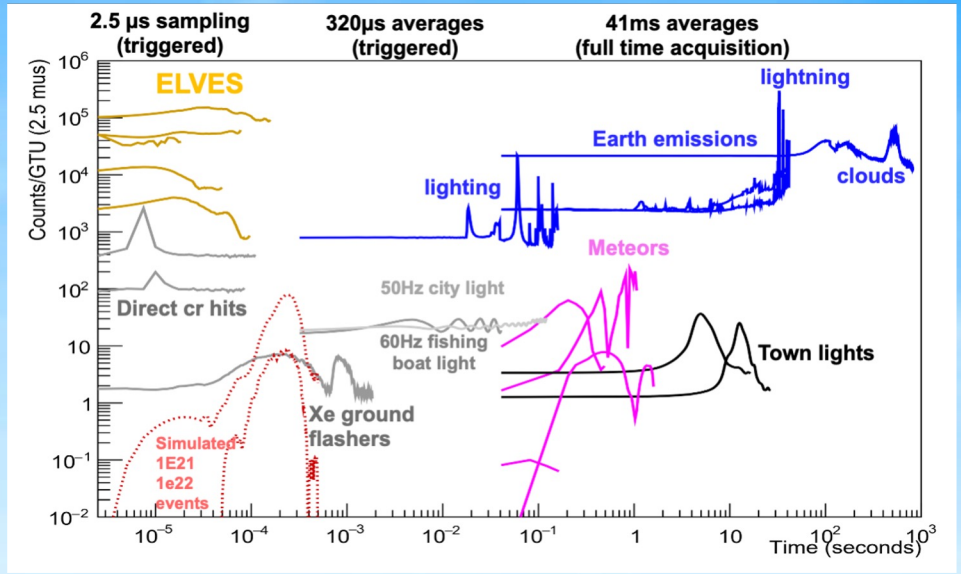




Mini-EUSO scientific objectives

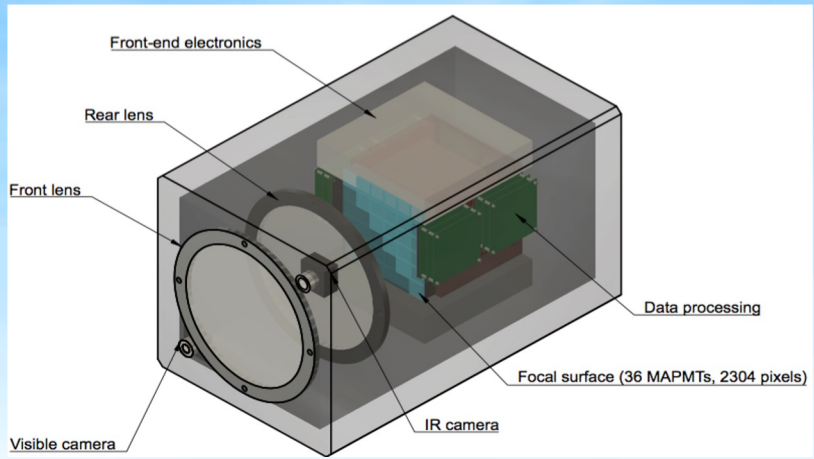


Types of detected events:



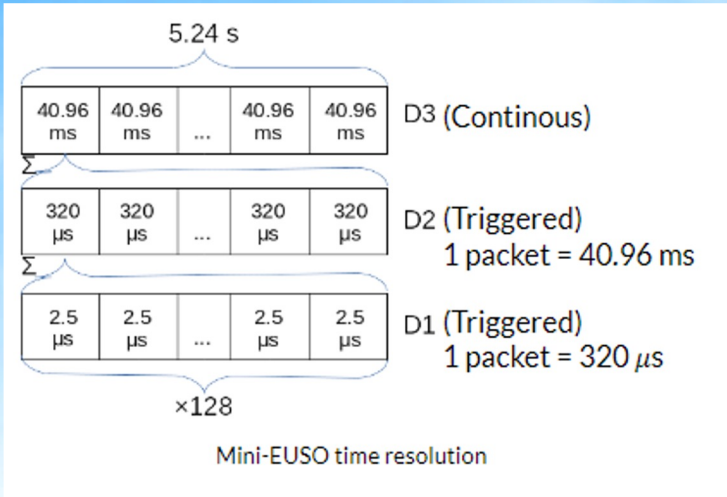
Mini-EUSO detector

- Optical system: two Fresnel Lens of 25 cm of diameter
- PDM (Photo-Detection Module): matrix of 36 MAPMTs (Multi-Anode Photomultipliers) of 64 pixel each and electronic components
- Sensitivity: single photon in the UV band between 290 nm and 430 nm
- Field of view: 44°x44° (350x350 km^2 on the ground)
- ISS average height: 400 km



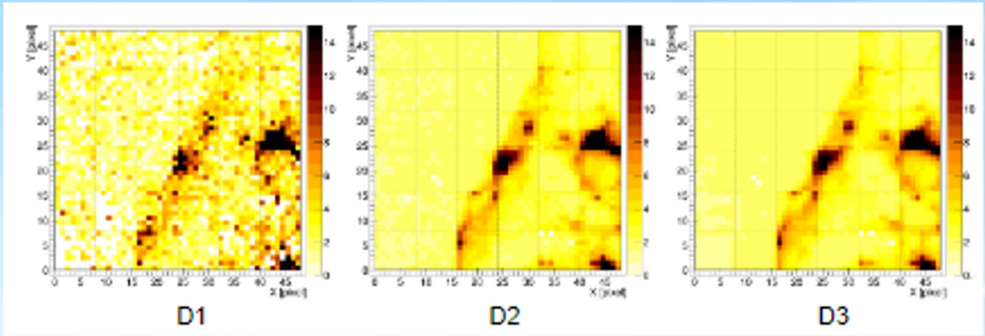
Mini-EUSO data acquisition system

- Mini-EUSO stores data in three different time resolutions - Gate Time Unit (GTU):
  - D1 GTU: 2.5 μs, fast events, L1 trigger
  - D2 GTU: 320 μs, atmospheric events, L2 trigger
  - D3 GTU: 40.96 ms, slow events and UV maps, continuous data taking
- 1 packet contains 128 GTUs



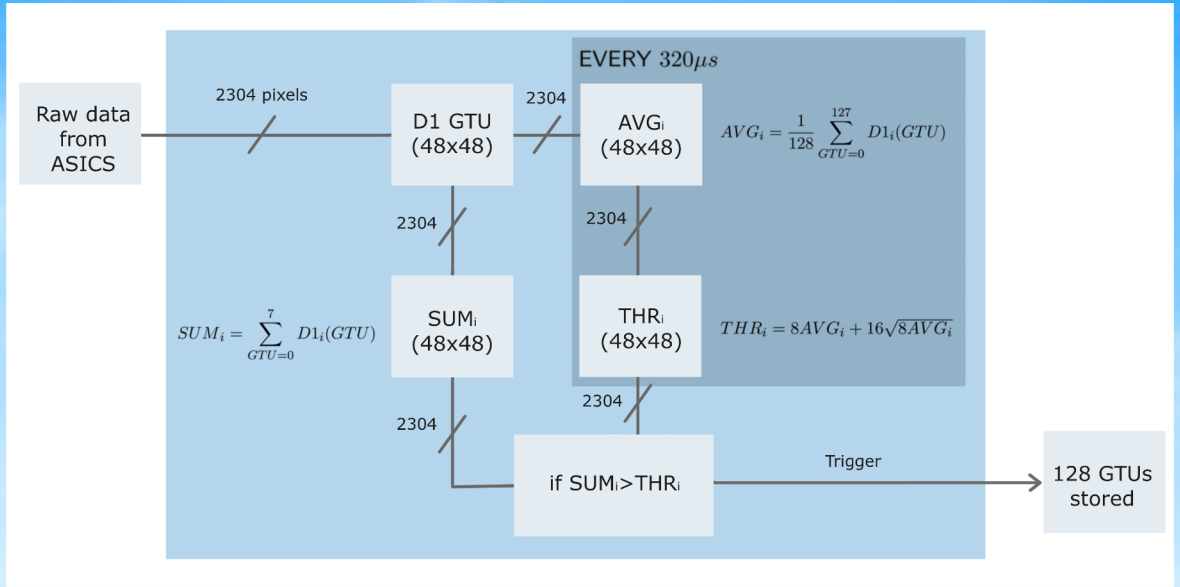
Mini-EUSO time resolution

Examples of data views: (spatial resolution of 6.3 km)



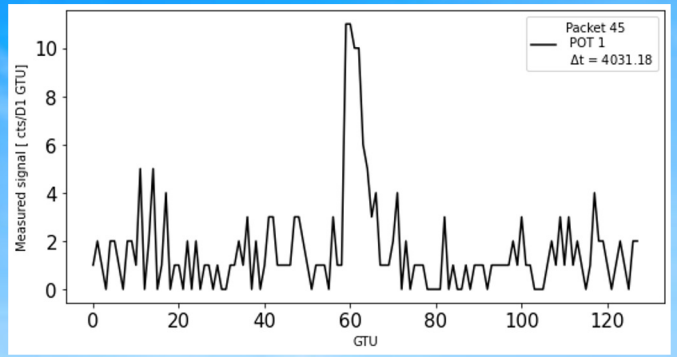
D1 trigger logic

- Analysis focused on D1 data
- Each pixel works independently
- Signal from each pixel is integrated over 8 consecutive GTUs
- Event triggers if the signal is 16σ over the average value of the pixel computed over 128 GTUs
- Maximum 4 events every 5.24 s

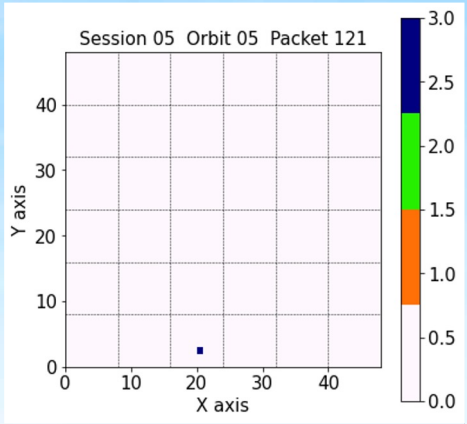


D1 common detected events

Direct Cosmic Rays (DCRs)

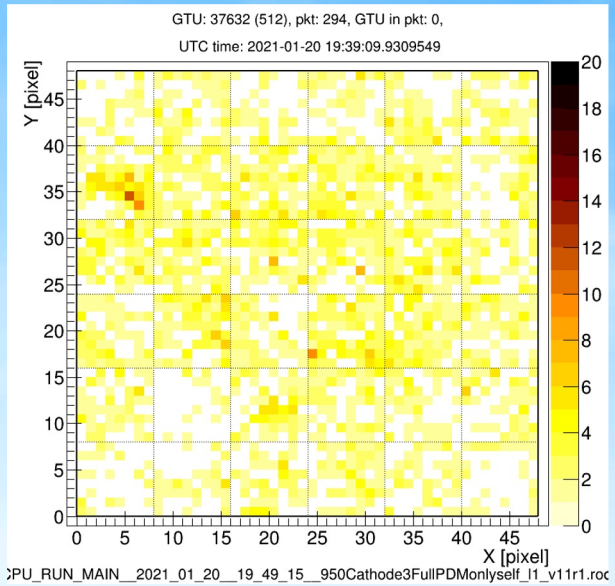


Flashers



Atmospheric events:

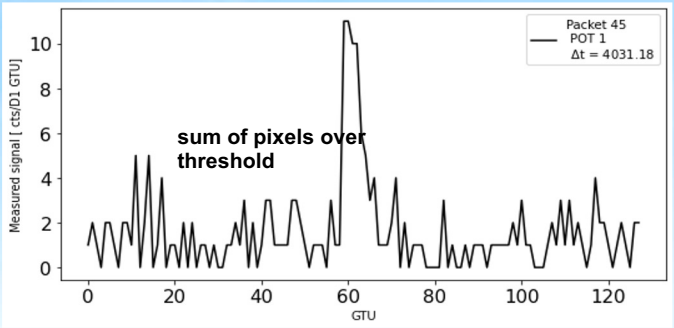
- lightnings
- Transient Luminous Events (TLEs)



Classification of not DCRs events

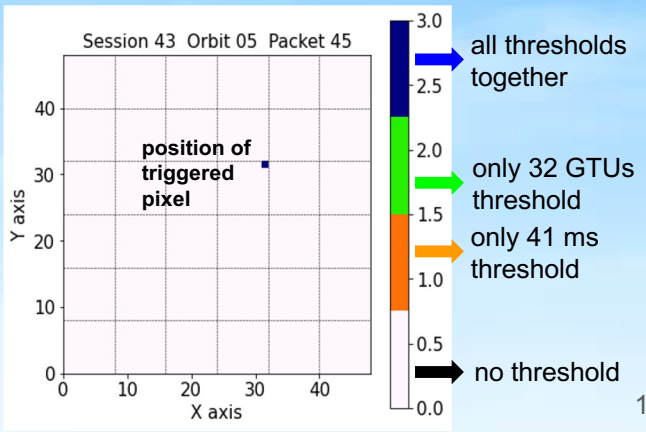
A python code analyzes root files session by session and orbit by orbit:

- Apply offline the D1 trigger logic: threshold is estimated in two different ways
  - average over the first 32 GTUs of each D1 packet (32 GTUs)
  - corresponding values of D3 GTU (41 ms)
- Triggers from noisy pixels are excluded (12 out of 2304)
- Packets without identified offline trigger are rejected (called empty packets)



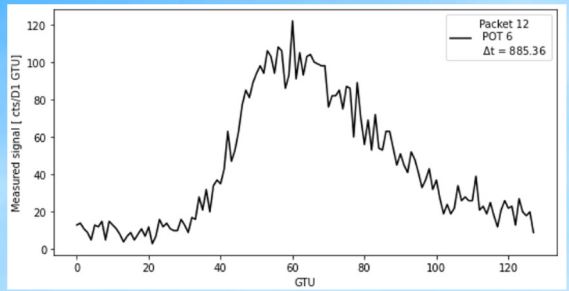
example of light curve

example of trigger plot

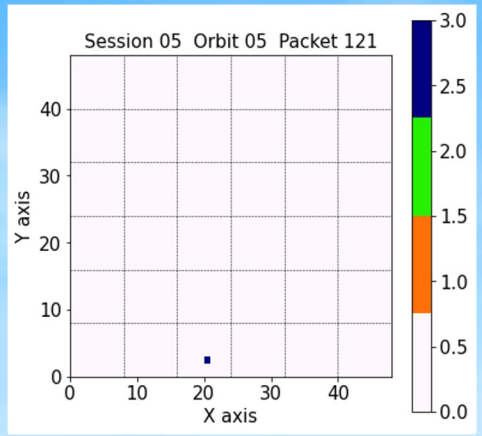


Visual analysis

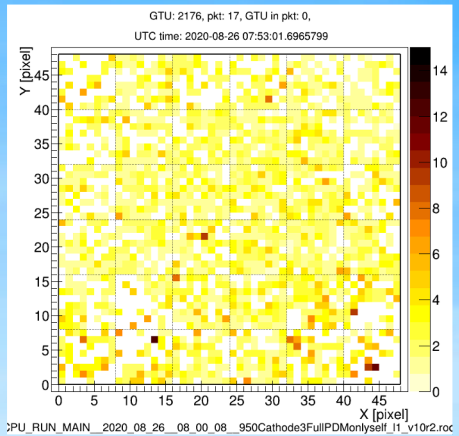
- Different types of interesting events are searched:
  - flashers
  - EAS-like
  - ELVES



EAS-like



flasher

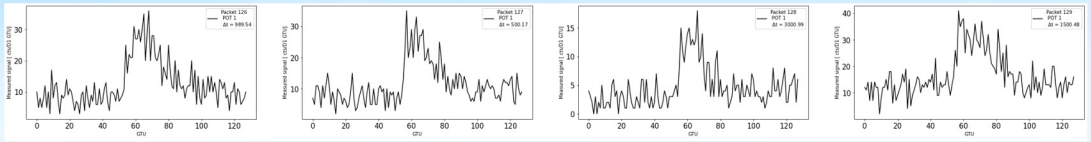


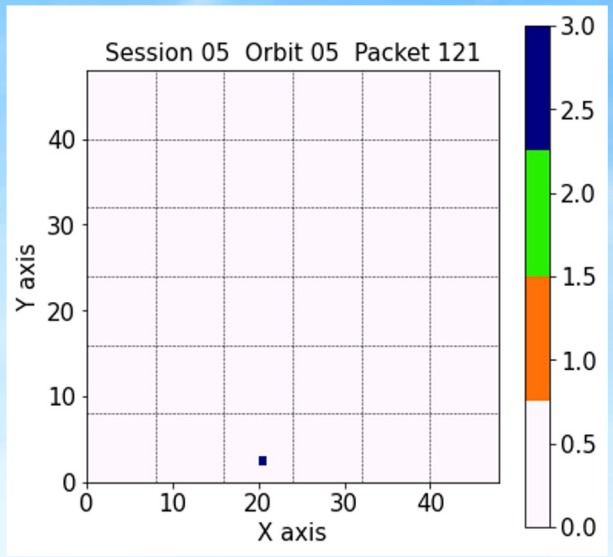
ELVES

- Also other types of particular events have been considered
- 33 data sessions analysed containing 606 interesting events
- 123000 D1 packets: 60% DCRs, 30% not DCRs, 10% empty

Flashers

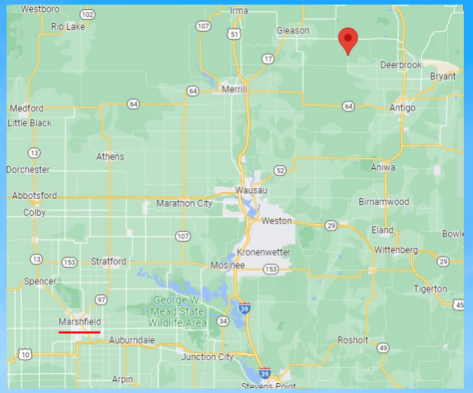
- Anthropic lights with a constant repetition time
- Flashers in data:
  - three or more almost consecutive packets show similar light curves
  - trigger plots show a pixel moving along a straight line
  - only one or few pixels over threshold
- Normally localised near airports, cities and towns
- 561 flashers found
- There are different types of flashers light curves:
  - shorter peaks
  - longer peaks
  - mixed peaks

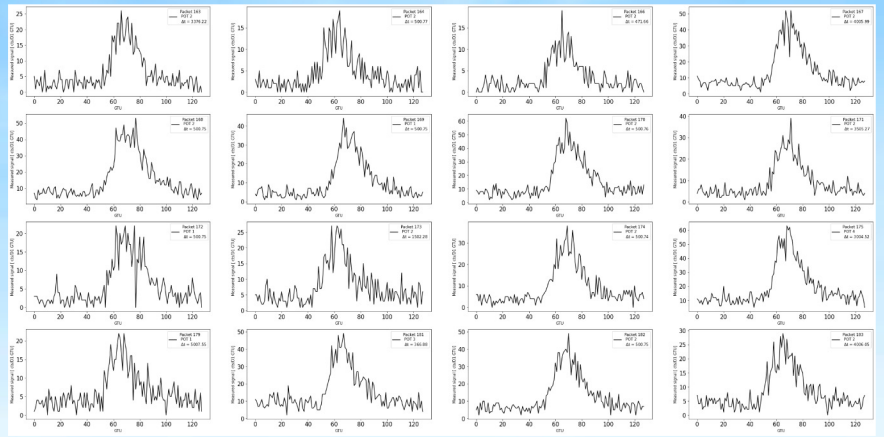


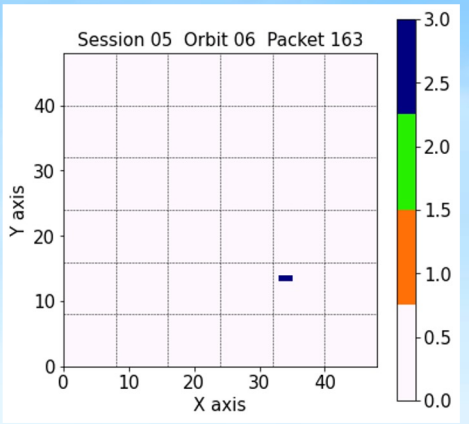


Example of shorter peaks

- Short and intense enough well defined peaks
- Fully contained in one packet
- Localised in Wisconsin (USA) near Marshfield

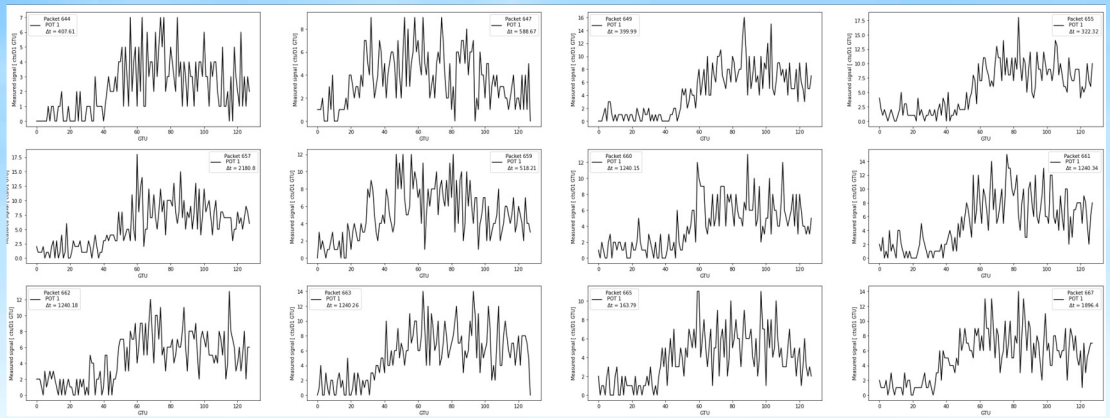


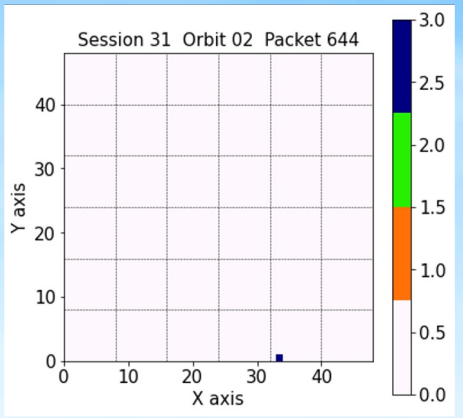




Example of longer peaks

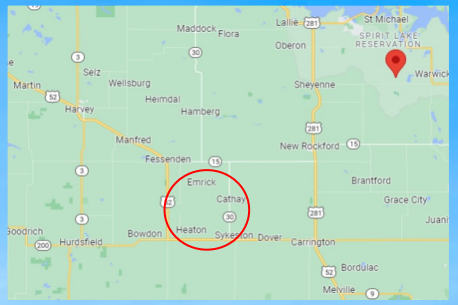
- Long and not intense bad defined peaks
- Not fully contained in one packet
- Localised in Mongolia near small towns

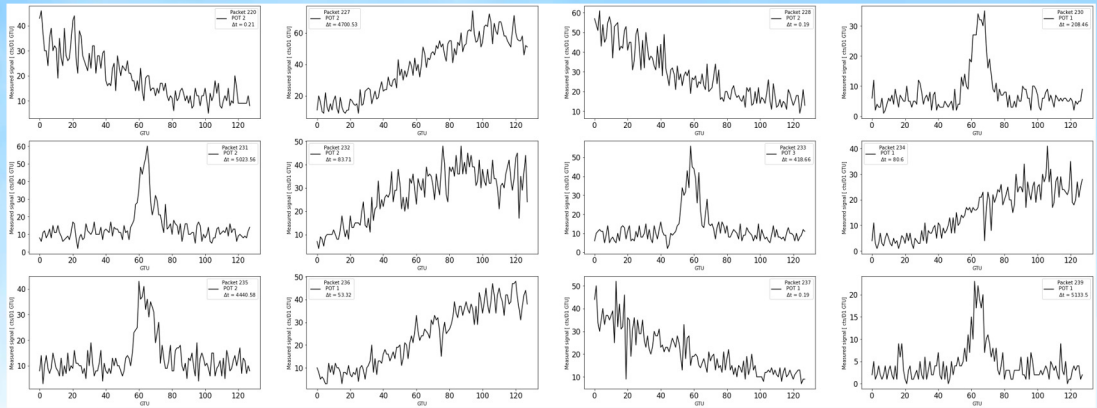


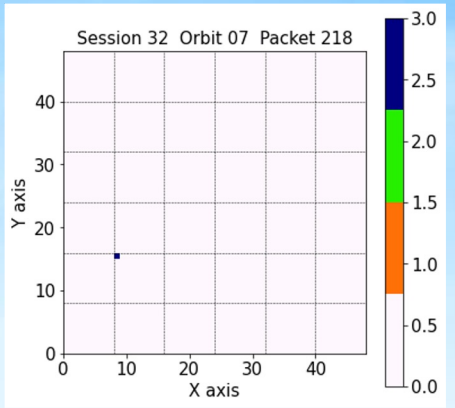


Example of mixed peaks

- Mixed types of peaks
- Same flasher or two different ones
- Localised in North Dakota (USA) near small towns

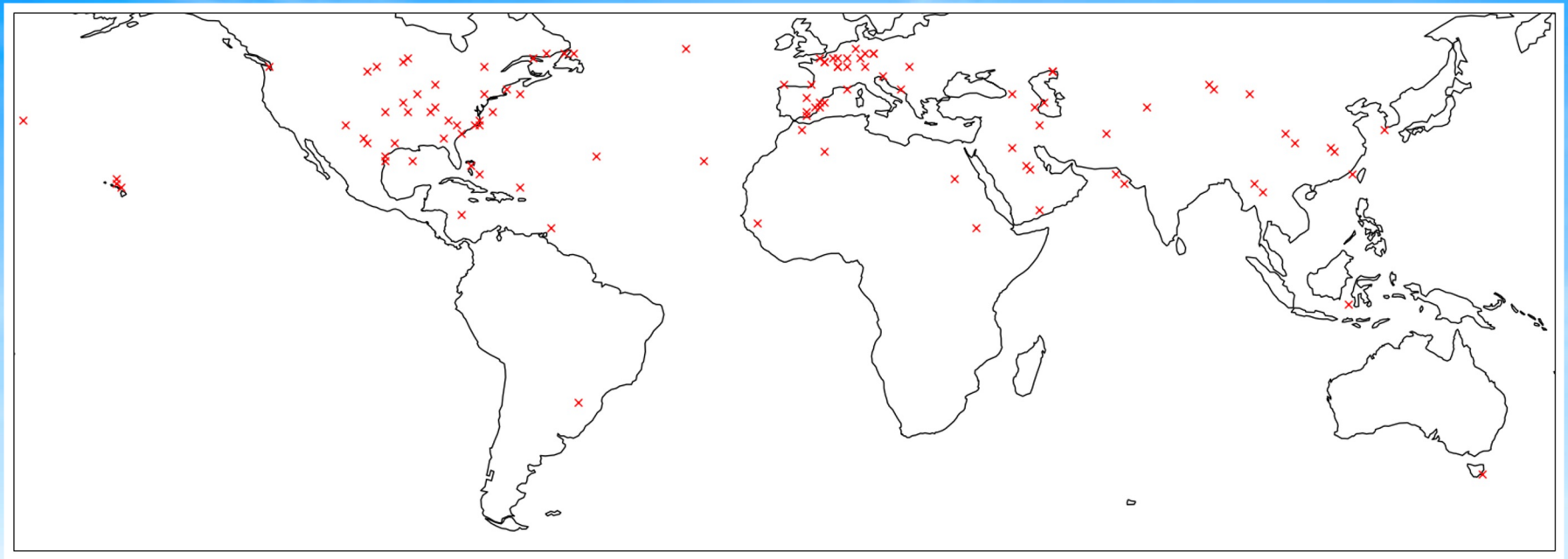






Flashers map

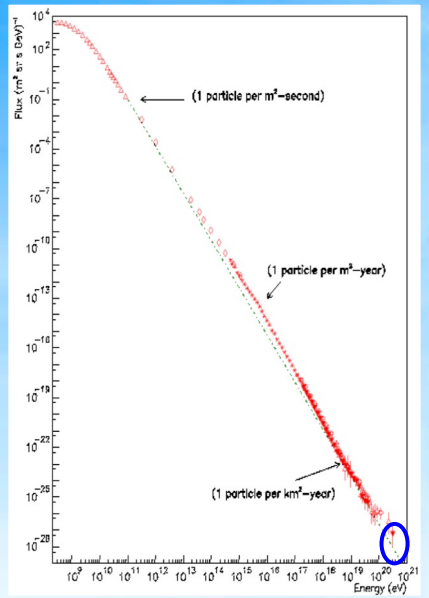
Sample of 108 flashers contained in 32 orbits of 8 sessions



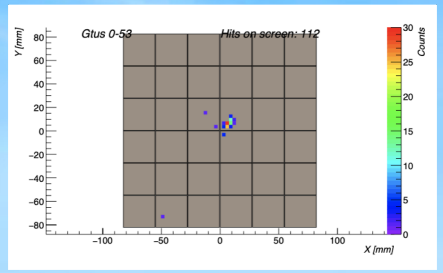
EAS simulations

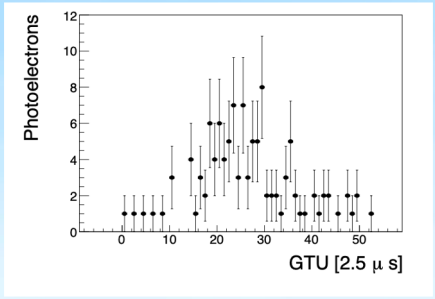
EAS can not be detected by Mini-EUSO because its threshold energy is 10^{21} eV

cosmic rays energy spectrum

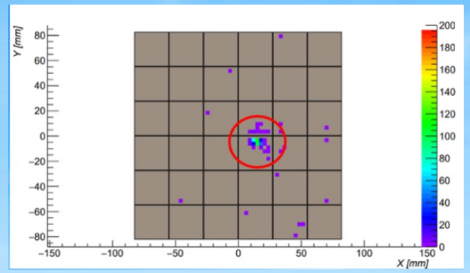


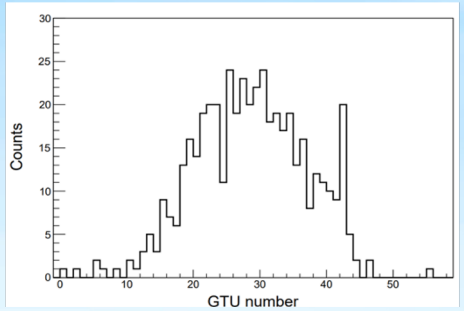
Zenith = 60°
E = 10^{21} eV



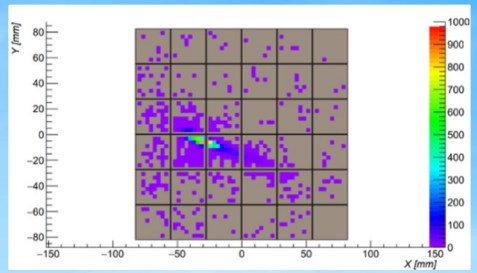


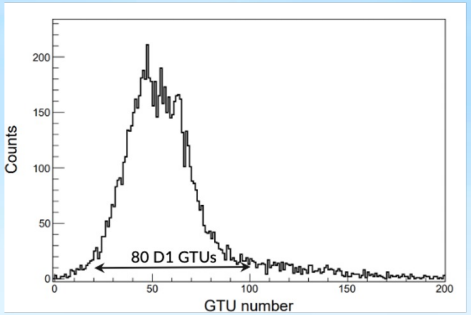
Zenith = 50°
E = 5 x 10^{21} eV





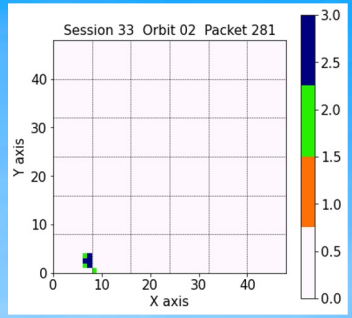
Zenith = 80°
E = 2 x 10^{22} eV

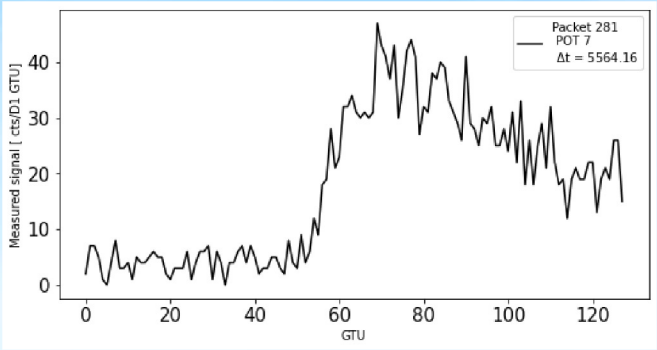




EAS-like events

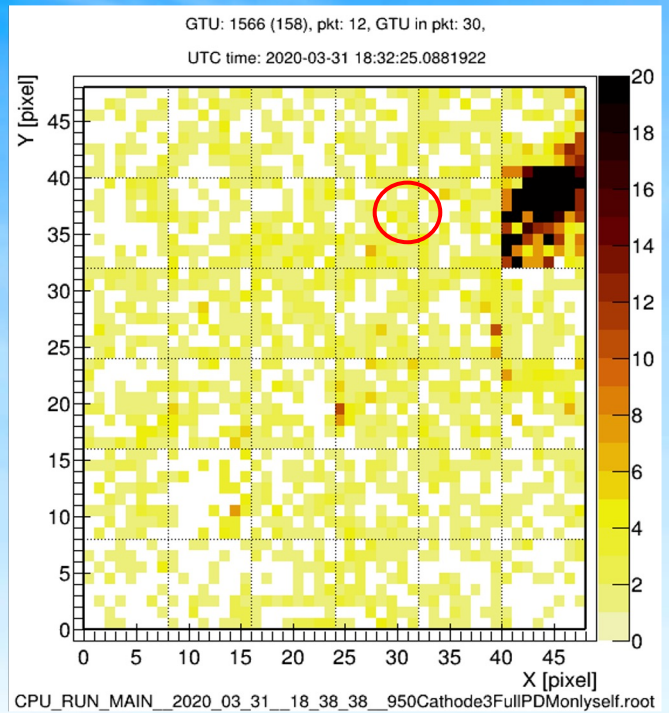
- Is it possible to find EAS in Mini-EUSO D1 data?
- Search for light curves similar to EAS
- EAS-like events in data:
  - light curves show an about 60 GTUs long asymmetrical peak
  - trigger plots show a compact shape of no more than 10 pixels
- Normally localised in tropical places
- Light profiles combined with images on focal surface do not match with simulated EAS
- 15 EAS-like events found, two different cases:
  - single events (9/15)
  - precursors of an atmospheric event (6/15)

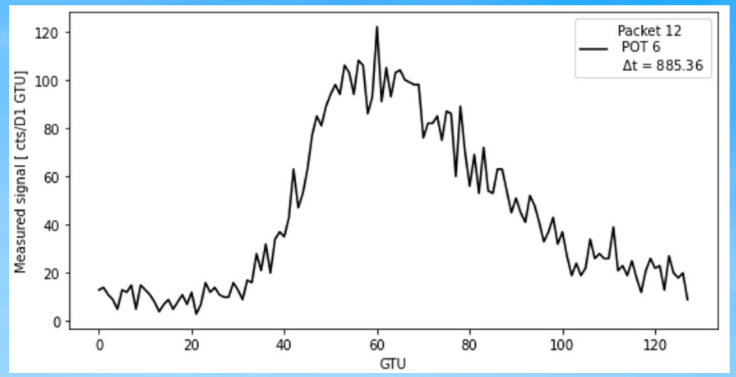


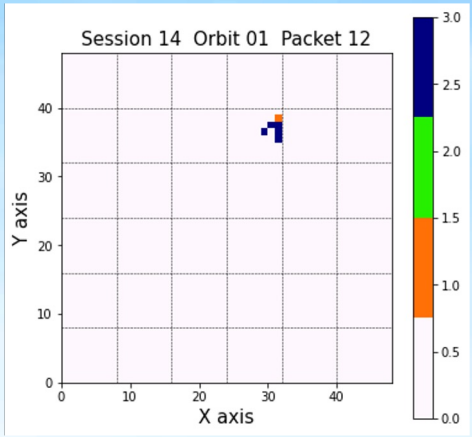


Example of single EAS-like

Localised in Sri Lanka

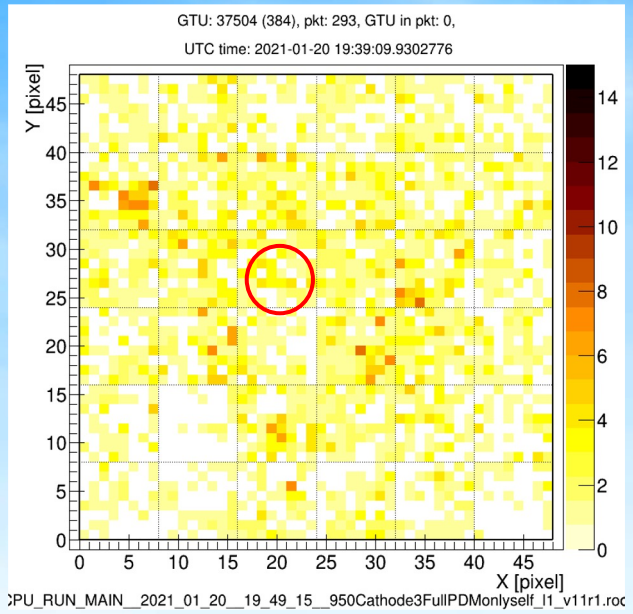


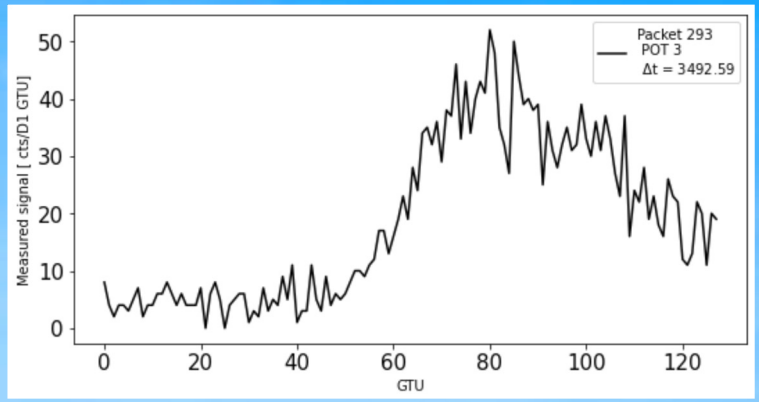


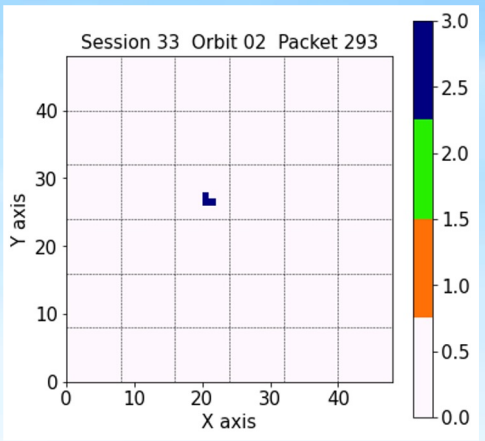


Example of precursor EAS-like

- Localised in India
- Precursor of an atmospheric event

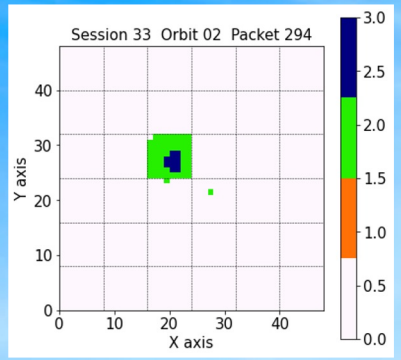


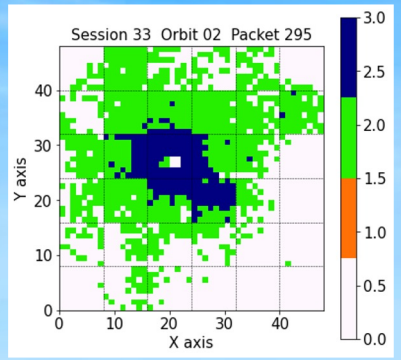


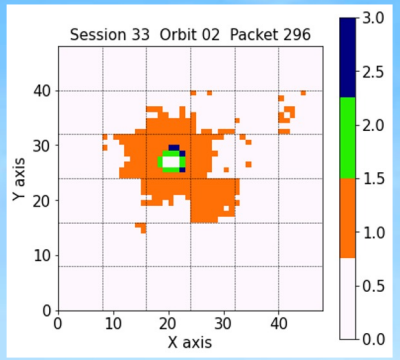


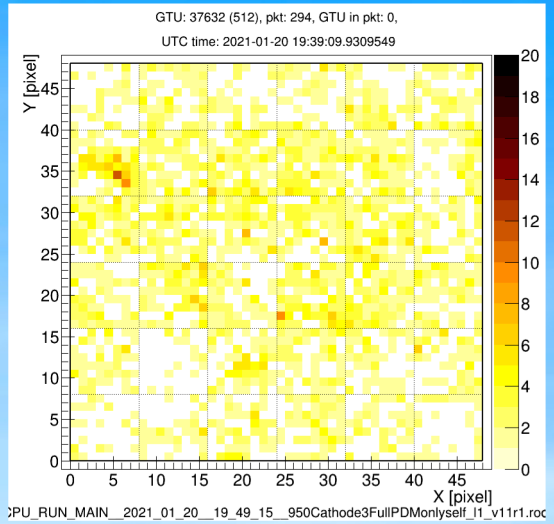
Atmospheric event after the EAS-like

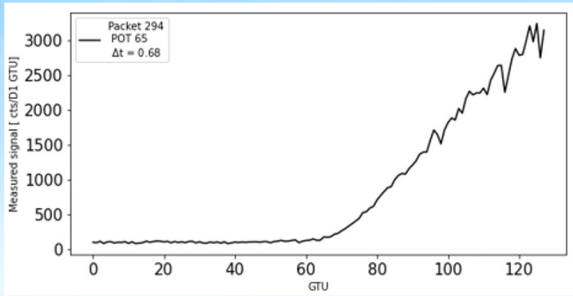
- 680 µs after the EAS-like event
- Starts at the same position

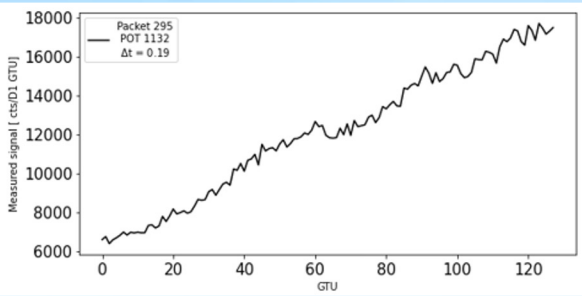


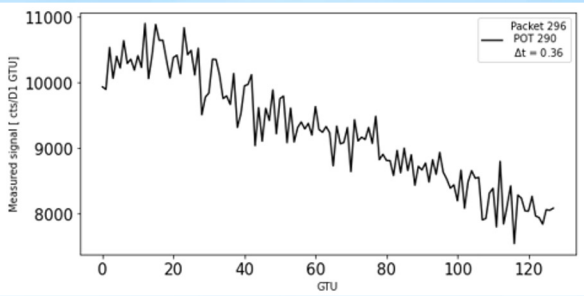




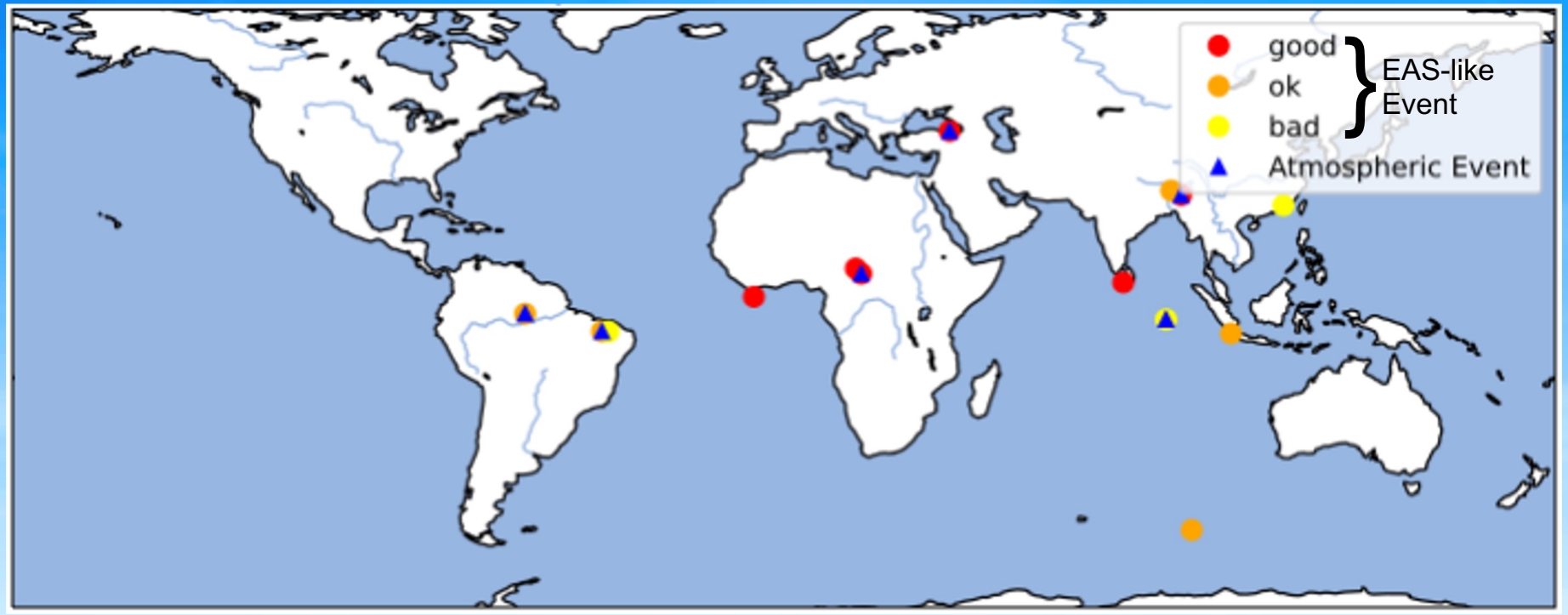








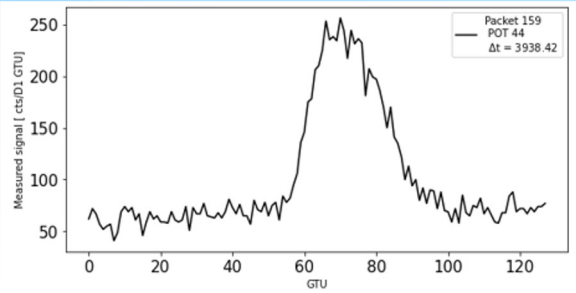
EAS-like events map

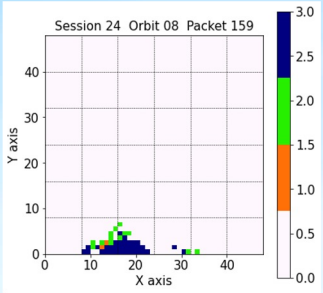


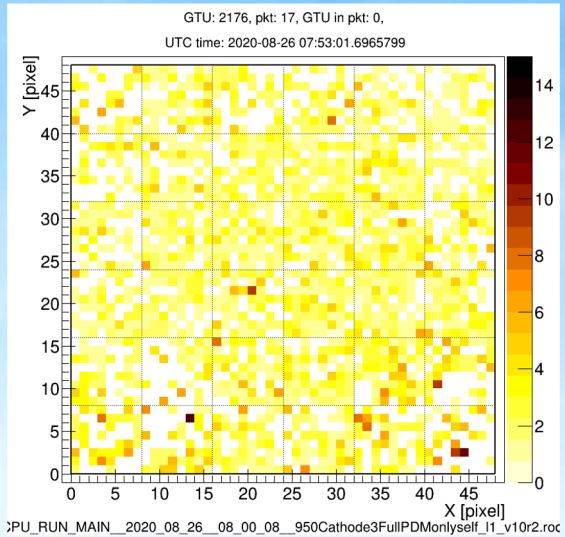
Colours represent the estimation of how much the EAS-like light curve is similar to a true EAS

ELVES events

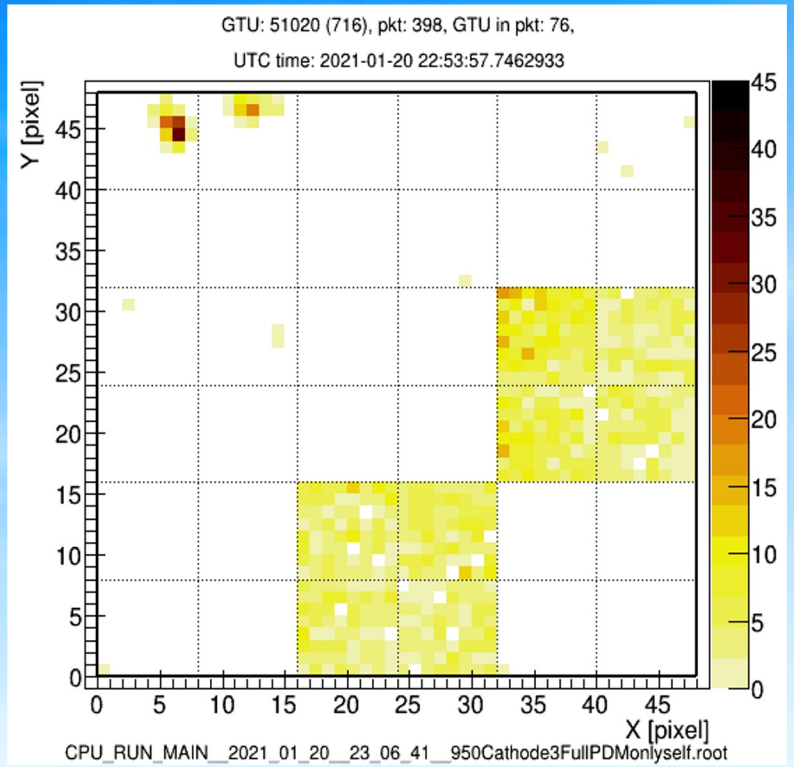
- Upper atmospheric lightnings: Emission of Light and Very low frequency perturbations due to Electromagnetic pulse Sources (ELVES)
- Visual analysis is not focused on them:
  - only evident enough semi-circular shaped trigger plots can be found
  - already exist better types of analysis to find ELVES
- ELVES events in data:
  - one or two expanding rings
  - tens or hundreds of pixels over threshold
- 4 ELVES found out of 27 already known

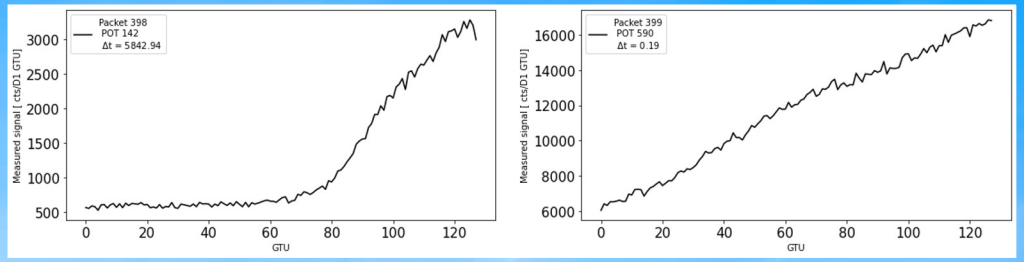


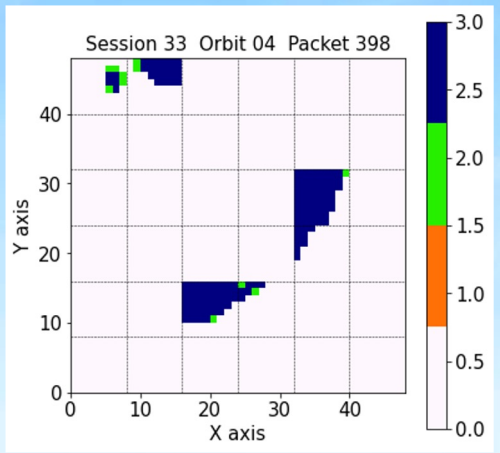


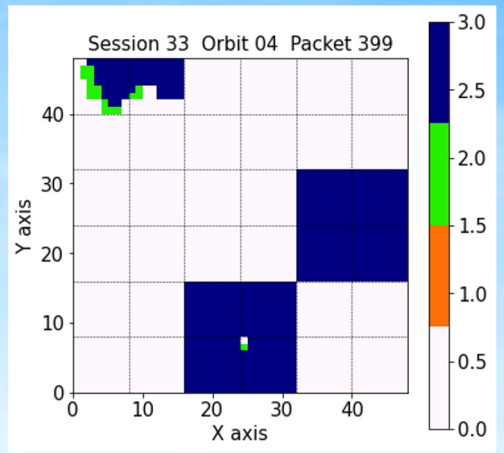


Example of unrecognised ELVES



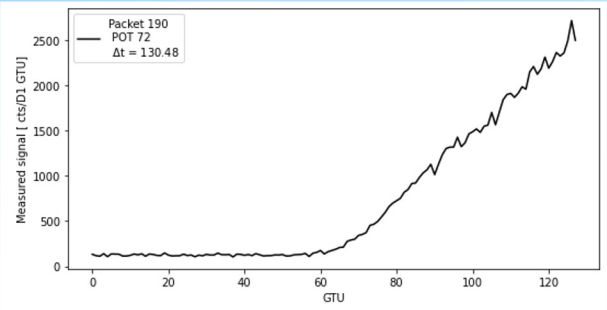


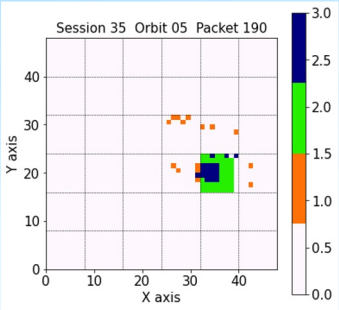


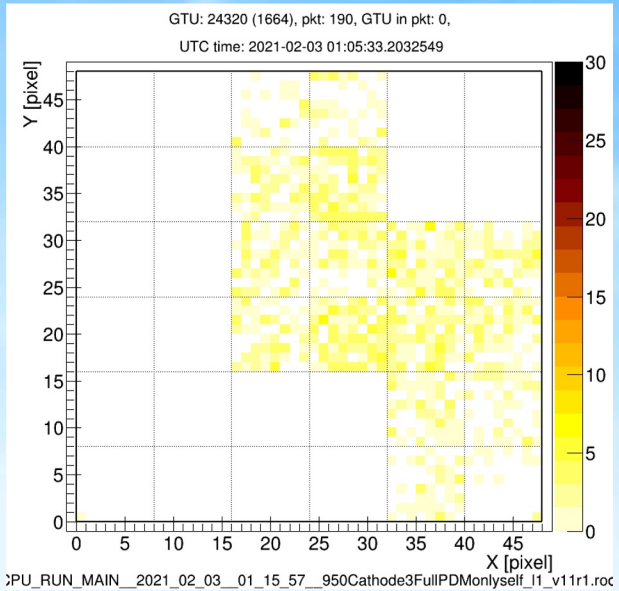


Other atmospheric events

- Bright events in atmosphere: lightnings and TLEs
- Visual analysis is not focused on them:
  - only particular shaped trigger plots can be selected
  - already exist better types of analysis to find atmospheric events
- Light curves show a growing trend
- Tens or hundreds of pixels over threshold
- Tens or hundreds of events in D1 data
- 21 events selected
- A future analysis will categorise these events

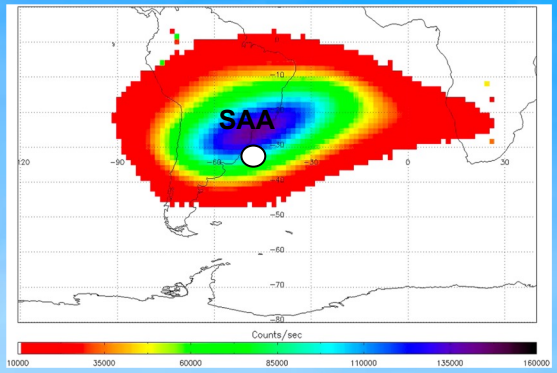


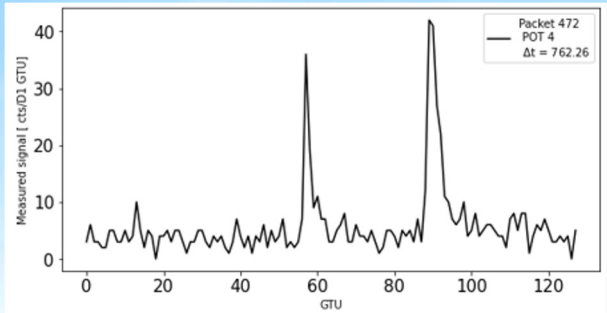


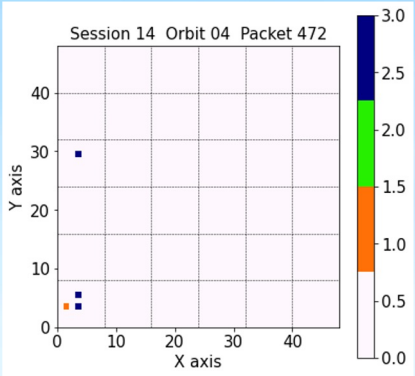


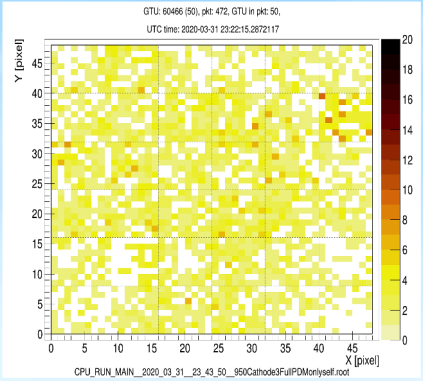
Double direct cosmic ray

- 2 double DCR packets expected in D1 data
- 1 isolated packet observed in South-Africa
- 4 packets into the same orbit observed in Brazil
- It can be explained considering the South-Atlantic Anomaly (SAA):
  - lower intensity of Earth's magnetic field
  - increasing of DCRs rate









Conclusions and research developments

36900 not DCRs packets analysed in 33 data sessions, 606 interesting events found:

FLASHERS (561 flashers found)

- visual analysis can find all of them
- the knowledge of their position and lighting characteristics can help next calibrations?

EAS-LIKE EVENTS (15 EAS-like found: 9 single events and 6 precursors of an atmospheric event)

- visual analysis can find all of them
- are they atmospheric events?

ELVES EVENTS (4 ELVES found out of 27 already known)

- visual analysis can not find all of them
- only evident enough trigger plots can be selected

ATMOSPHERIC EVENTS (21 atmospheric events selected)

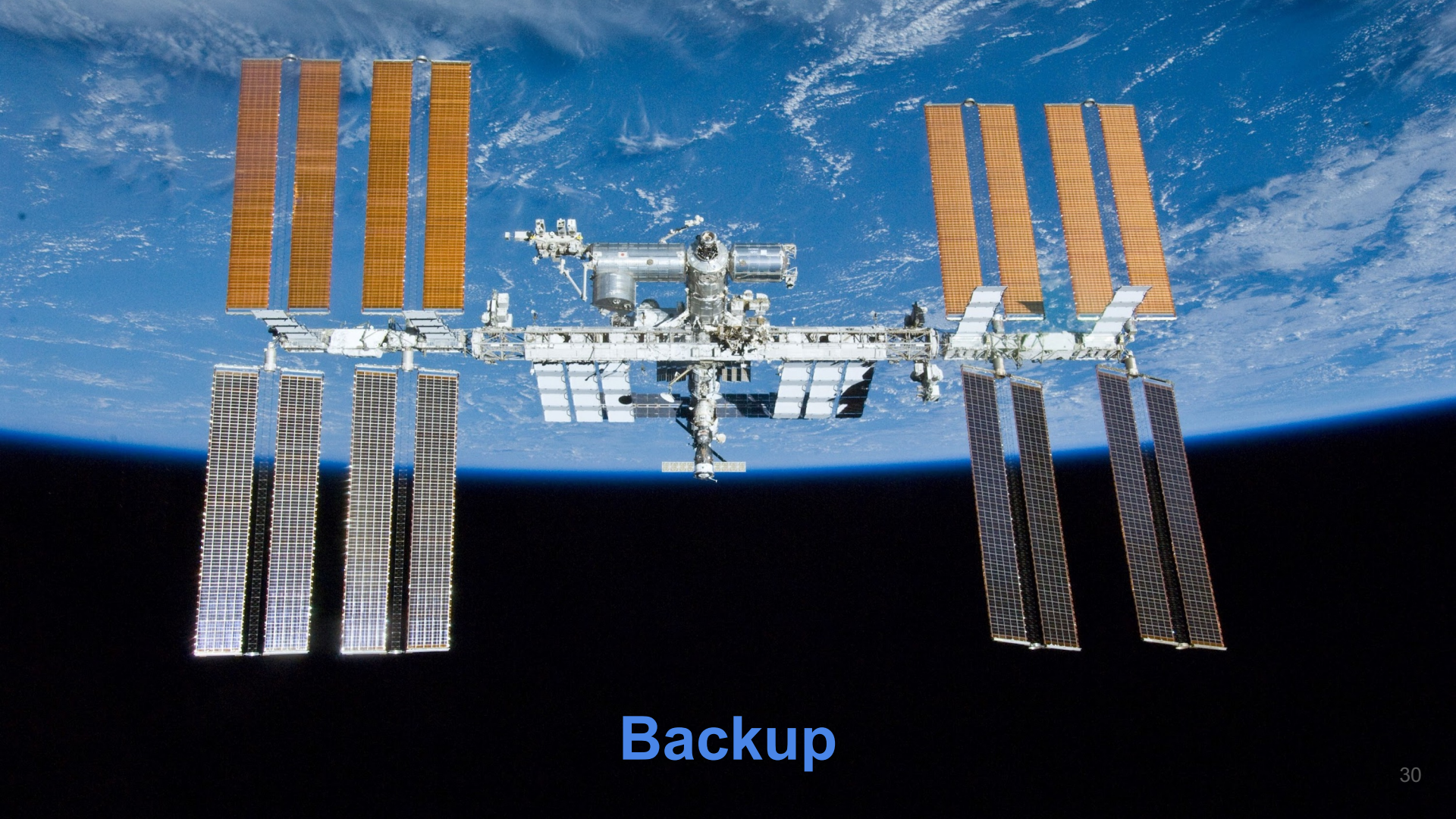
- Focus of forthcoming researches

Events counts	
flashers	561
EAS-like	15
ELVES	4
atmospheric	21
double DCR	5

References

- JEM-EUSO Program website, *“Missions: Mini-EUSO”*
- M. E. Bertaina website, *“Research activity and other projects”*
- M. E. Bertaina, *“An overview of the JEM-EUSO program and results”*
- S. Bacholle *et al*, *“Mini-EUSO mission to study Earth UV emissions on board the ISS”*
- M. Battisti *et al*, *“The onboard performance of the Level 1 trigger of Mini-EUSO telescope”*

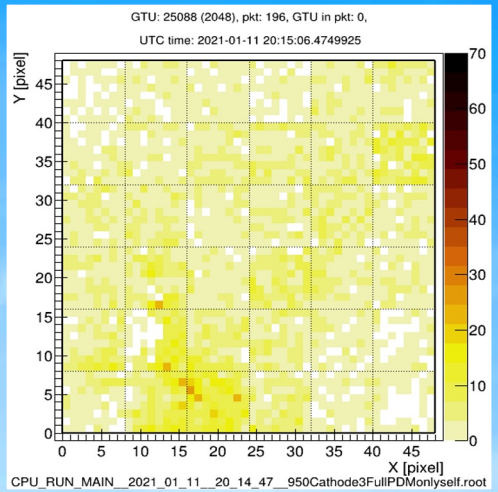
Thank you all for your attention

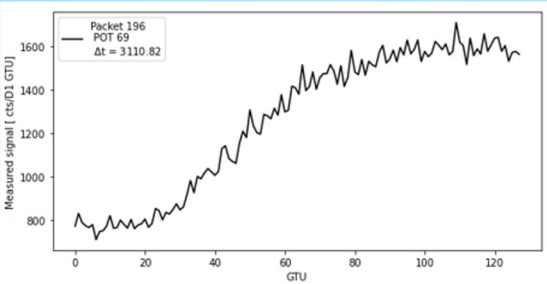


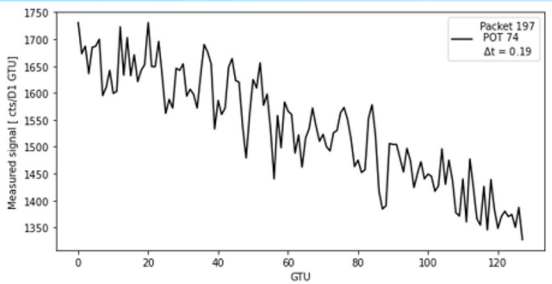
Backup

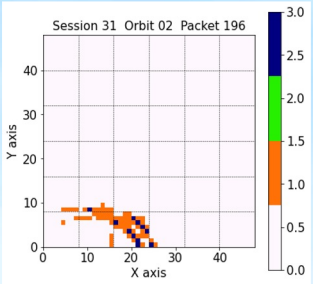
Ring shaped events

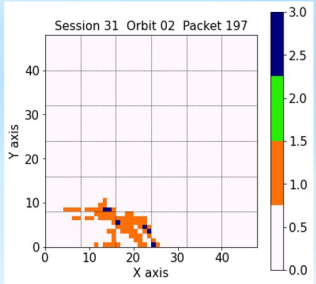
- Common events
- Ring shaped events in data:
  - double ring shaped trigger plots
  - two packets long light curves
- Not moving double ring caused by the optical system of the detector
- Events caused by very intense light out of the field of view, such as lightnings











Two curious events

- Almost near packets
- Identified as borderline EAS-like events
- Localised in Washington State (USA)
- It could be the same event or not
- EAS-like, atmospheric or flasher?