Overview of the Mini-EUSO μs trigger logic performance

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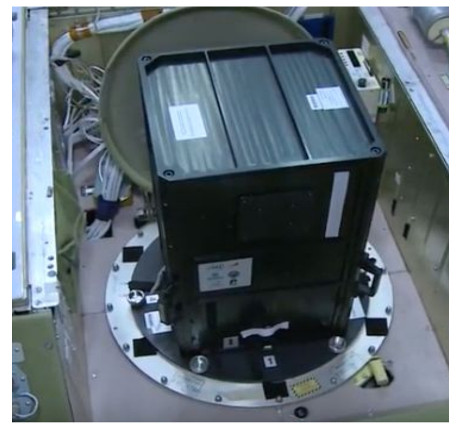
Mini-EUSO is a small telescope currently operating from the International Space Station. Its data acquisition system allows to store data with different timescales, the shortest being the 2.5 μs time resolution. This timescale, called D1, features a dedicated trigger system (L1) designed to detects Extensive Air Showers (EAS) induced by EECRs. An overview of the general performance of the trigger system, with a particular focus on the identification of classes of events, is presented

Mini-EUSO telescope



Mini-EUSO during a data acquisition session onboard the International Space Station, installed on the UV transparent window of the Zvezda module [1]

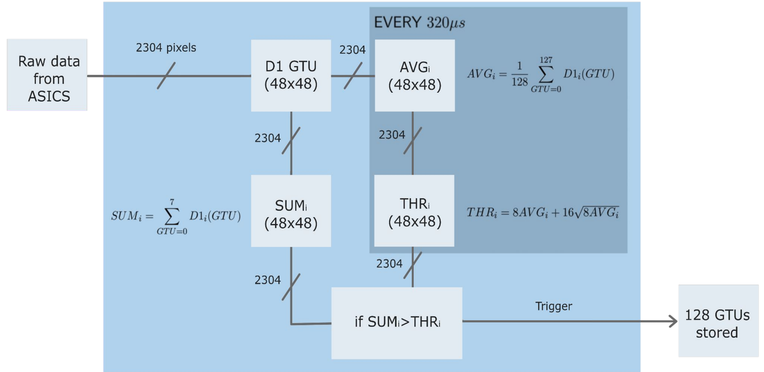
- Focal surface: **1 PDM** [Photo Detection Module]
  - PDM = 6×6 Multi-Anode PMTs (MAPMTs)
  - MAPMT = 8×8 pixels, side 2.88 mm each
  - 1 PDM = 36 MAPMTs = **2304 pixels** arranged in a **48x48 matrix**
- Optical system: **2 Fresnel lenses** of **25 cm diameter** each
  - The size of the lenses is constrained by the size of the UV transparent window
    - Energy threshold E>10^{21}eV (due to lenses dimension)
- **Single photon counting**
- Pixels coated with 2 mm thick BG3 filter
- Peak Sensitivity ~**390-430 nm**
- **Total efficiency ~ 10%**
- Time resolution **2.5 μs = 1 GTU** (Gate Time Unit)
  - double pulse resolution ~6 ns
- **Pixel size on ground** (assuming flight altitude of 400 km): **6.3 km**
- Total **field of view**: **44° × 44°**

Multi-level data acquisition and μs trigger system

- **D3** timescale → **40.96 ms** resolution
  - data taken continuously, without trigger
    - monitor UV emission, cloud coverage...
- D2 timescale → 320 μs resolution
  - L2 trigger, dedicated to atmospheric events
- **D1** timescale → **2.5 μs** resolution
  - L1 trigger dedicated to very fast events
    - **EAS-like events, elves, flashers**

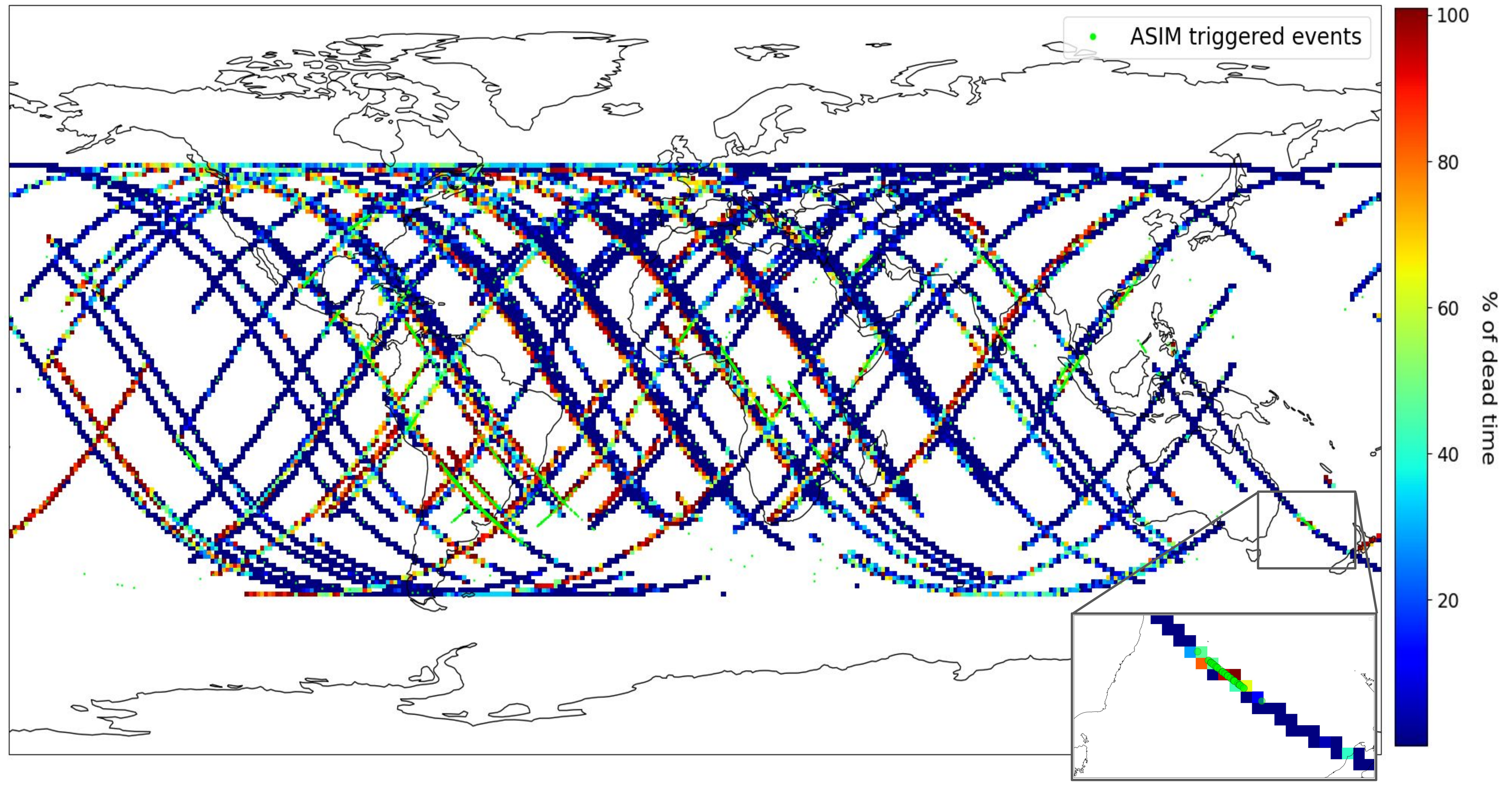
- Upon a L1 trigger, **128 D1 GTUs are stored**, 64 GTUs before and 64 GTUs after the triggered event
- Up to **4 consecutive events** within the same slot of 128 D3 GTUs (5.24 seconds) can be stored
- **After** the **fourth** triggered **event** the system is in **dead time** and can not store any other data. The ability to save data is restored at the start of the next slot of 128 D3 GTUs [2]
- **Border pixels** and two entire MAPMTs are **prevented from triggering** in the first orbit (from the switch-on moment until the first sunrise)
  - a few border pixels are more prone to generate fake triggers

- An **upgrade** of the firmware is currently under testing
  - store **up to 8 triggers** every 5.24 seconds,
  - implement the **pixel mask** also for other orbits



***Mini-EUSO trigger logic**: Each pixel is independent, a pixel over threshold issue a trigger. Every 320 μs the thresholds for each pixel are updated, according to the formulas in the darker box. In parallel, every GTU, the integral over the last 8 GTUs is compared with the threshold for each pixel. If the sum is higher a trigger is issued*

Dead time

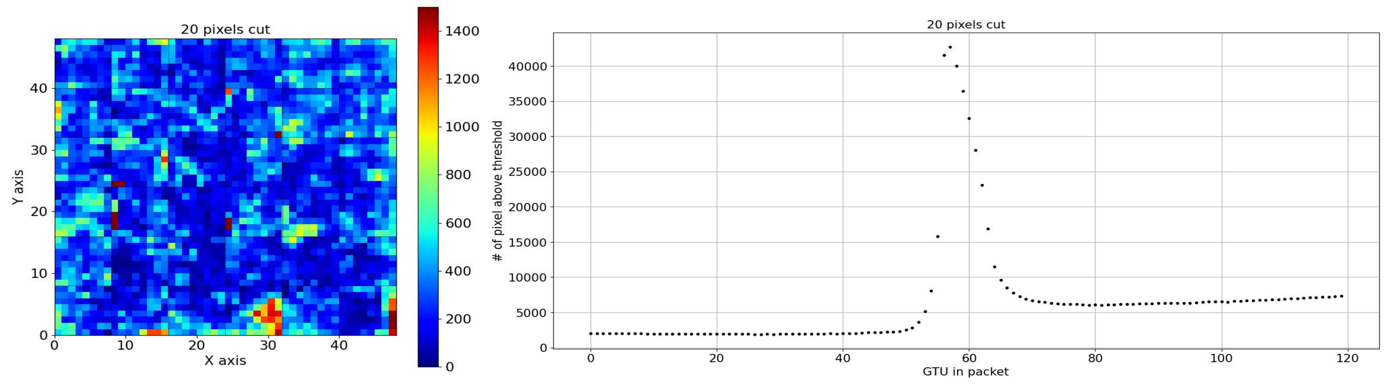


Fraction of dead time. The globe has been divided into a 1°×1° grid, the color represent the relative amount of dead time in each cell. The green circles are triggers form ASIM detector [3], mainly lightning strikes. The average dead time is ~25%. In the inset, an example of the increase of dead time caused by thunderstorms

- Average dead time in the firsts orbits: 11%
- Average dead time in the other orbits: 29%
  - Difference due to masked border pixels
  - High dead time orbits are often caused by a few border pixels
- Dead time does not increase over cities
  - adaptive threshold is fast enough and prevent triggering from static sources
- The upcoming firmware update should decrease the dead time considerably

Distribution of pixels over threshold

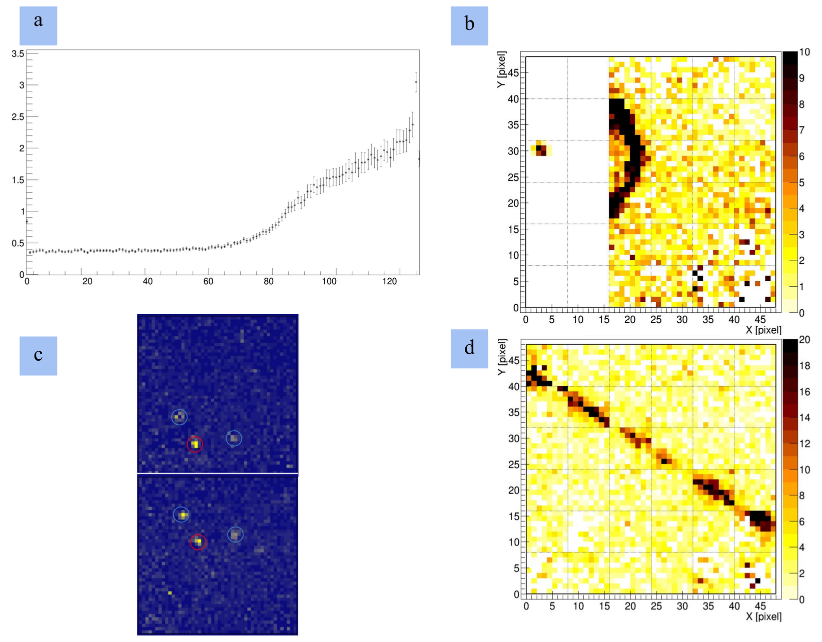
The distribution of pixels over threshold presents a few hot spots, corresponding to border pixels more prone to generate fake triggers, but is overall quite uniform



***Left**: the number of GTUs over threshold for each pixel, considering only the packet with less than 20 pixels over threshold (46180 events, 88% of the dataset). 12 border pixels (0.52% of the pixels) account for 13.2% of the total amount of pixels over threshold.*
***Right**: the time position of the pixels over threshold inside the packet of 128 GTUs, each point is the sum over 8 consecutive GTUs: the huge peak centered at GTU 57 shows that the algorithm used in the analysis correctly recognises the events that issued the trigger, which are positioned at the center of the packet. A few long lasting events produce the tail, while almost no trigger are recognised before GTU 50*

Categories of D1 triggered events

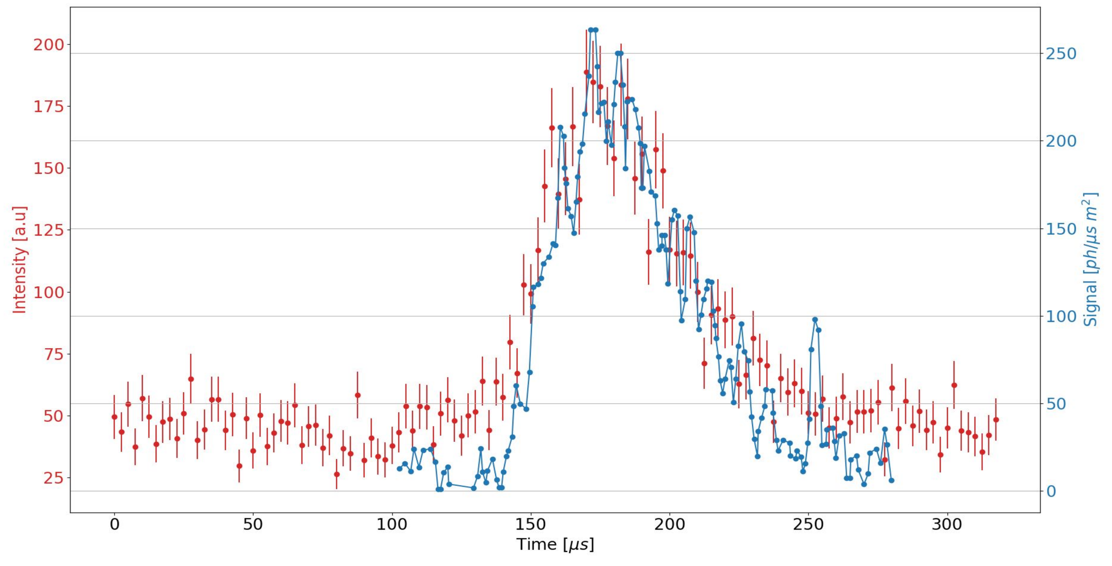
- **Atmospheric events,** mainly lightning strikes. The signal appears over a large area of the focal plane where the brightness increases constantly, until the end of the 128 saved GTUs
- **Elves** are horizontally expanding, fast donut-shaped light emissions at the bottom ionosphere. Mini-EUSO can provide high-speed UV imaging of elves. So far 17 elves have been detected
- **Ground flashers**: several triggers come from ground sources and present a light profile that lasts for tens on μs. These events are usually found near airports, and are probably produced by warning lights
- **Direct cosmic rays** are low energy cosmic rays directly impinging on the detector. They are usually characterized by a signal that reaches the maximum in only 1 GTU and then presents an exponential decay



***a)**: Lightcurve of a lightning event*
***b)**: The bright disk of an elve. Mini-EUSO can observe the elve development as the ring expands in the field of view.*
***c)**: Two frames from two different events: the light sources inside the blue circles are static (cities) while the source inside the red circle is flashing and caused the trigger.*
***d)**: Footprint of a direct cosmic ray leaving a track in the focal plane*

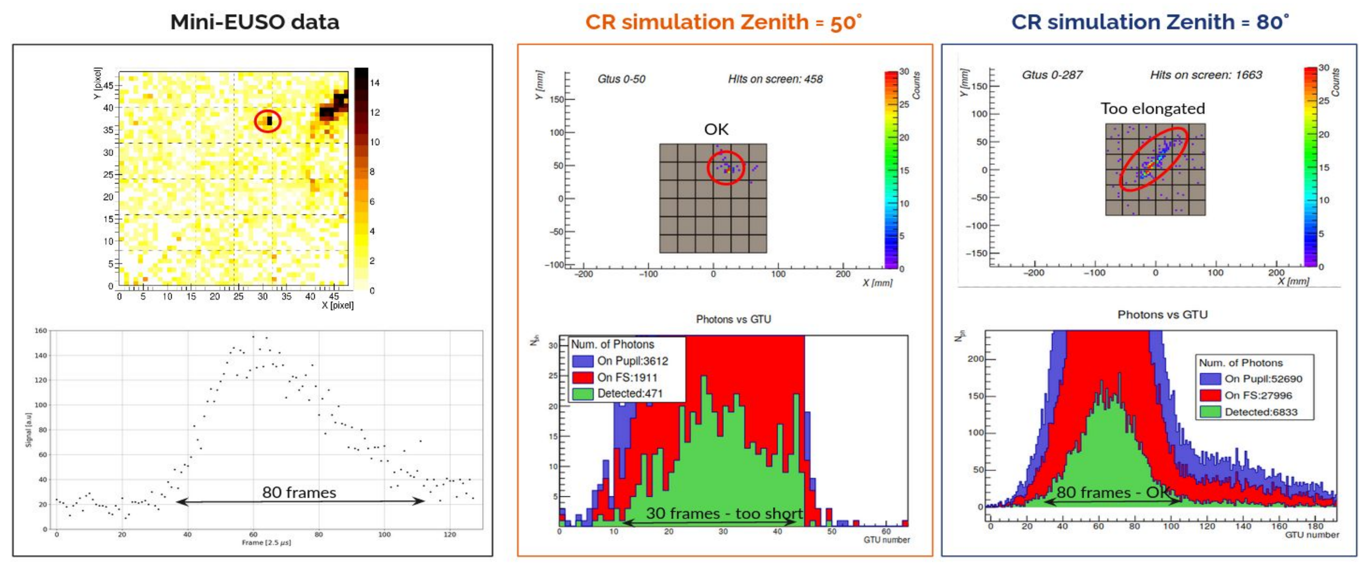
EAS-like events

The TUS detector [4] has found several events with the shape and characteristics that resemble the ones expected from EASs [5], the most interesting being event TUS161003, over Minnesota [6].



***Blue**: Lightcurve of TUS161003 event as seen by TUS. Even though the event has probably an anthropogenic origin, it presents all the features of an EAS signal.*
***Red**: An event detected by Mini-EUSO near lake Michigan. It presents the same time profile of the event seen by TUS even though it is ~ 10 times brighter. It is triggered four times by Mini-EUSO, it is therefore produced by a ground source. The signal appears in an area near three small airports*

In Mini-EUSO data there are several events with time profiles that match the bi-gaussian shape expected from an EAS and with the signals being confined in one or few neighbouring pixels. The vast majority of these events are detected near the location of airports and are triggered many times while moving in the focal plane. One event has been found over the ocean, the cosmic origin has been excluded via a comparison with the simulations.



***Left**: Mini-EUSO event detected over the ocean, off the coast of Sri Lanka .*
***Center and Right**: EAS simulated through ESAF [7] with different energy and zenith angle. The simulation with Z = 50° and energy 5×10^{21} eV produce a footprint on the focal plane similar to the event but the lightcurve is too short, while the event at Z = 80° and energy 2×10^{22} eV correctly reproduces the lightcurve but has a different shape.*

References

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Acknowledgments

This work was supported by State Space Corporation ROSCOSMOS, by the Italian Space Agency through the ASI INFN agreement n. 2020-26-HH.0 and contract n. 2016-1-U.0, by the French space agency CNES, National Science Centre in Poland grant 2017/27/B/ST9/02162.
This research has been supported by the Interdisciplinary Scientific and Educational School of Moscow University "Fundamental and Applied Space Research". The article has been prepared based on research materials carried out in the space experiment "UV atmosphere"