



IFAE SUMMER FELLOWSHIP 2026

Search for anomalous events in LST-1 observations

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under the supervision of Abelardo Moralejo

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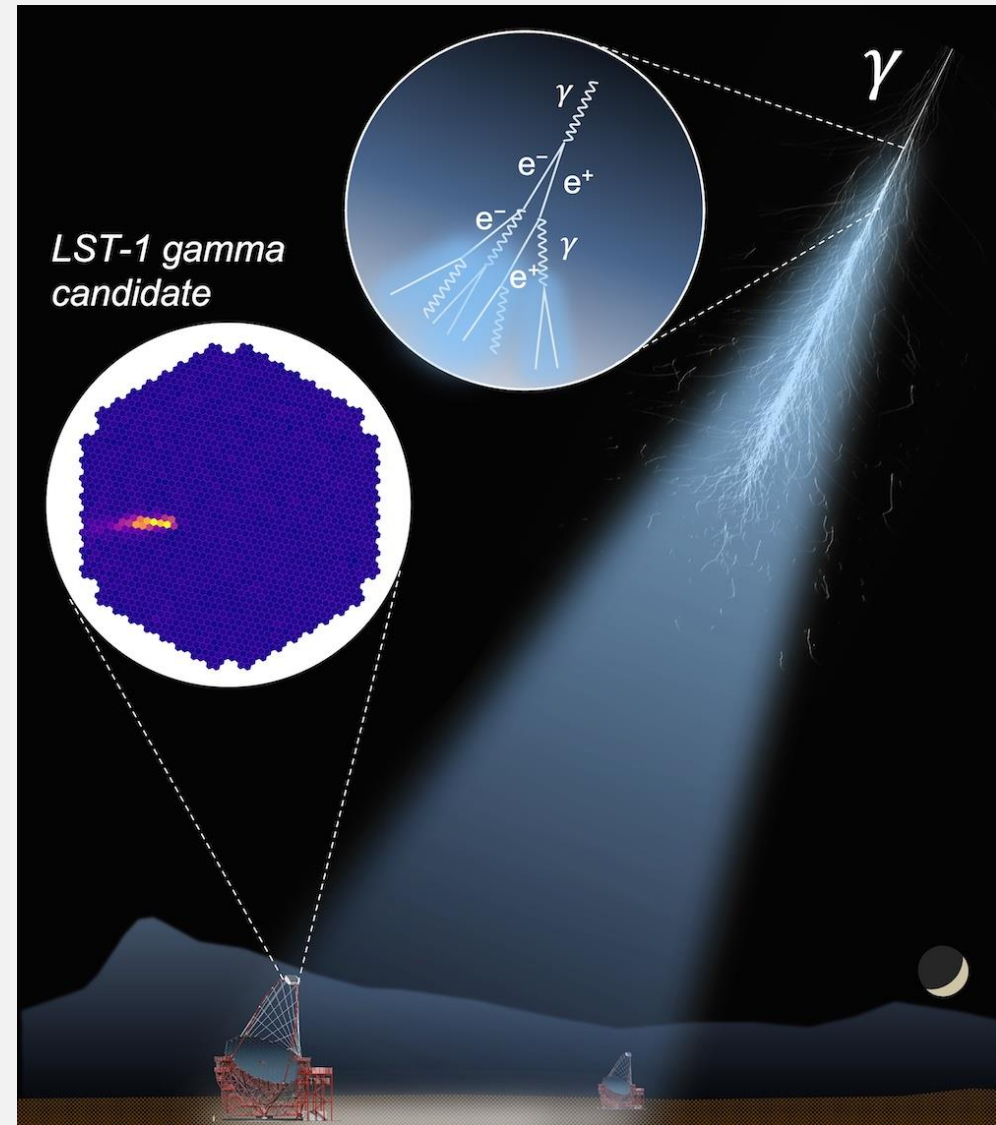
✦ Brief introduction to IACTs

Imaging Atmospheric Cherenkov Telescopes

Used for the **detection of Cherenkov light** produced by the ultra-relativistic **particle shower** induced when a VHE **photon** (γ -ray) is absorbed in the atmosphere.

We can reconstruct the **direction and energy** of the primary photon.

Most of the recorded events are cosmic rays (air showers produced by protons or other nuclei).



Credit: SEA

LST-1 Telescope



Credit: Otger Ballester, IFAE

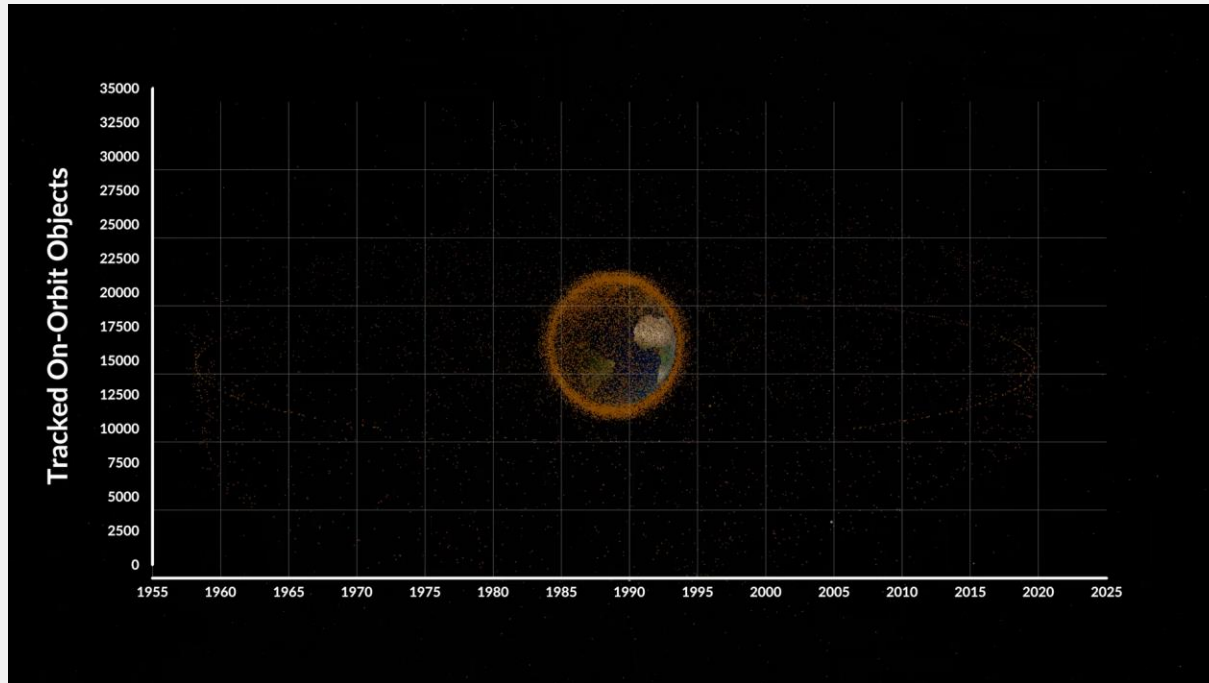
Working since 2019 at CTAO-North (La Palma, ES)

Could our observations be affected by the recording of undesired events?

Could we detect some unidentified interesting phenomenon by characterizing all anomalies?

✦ Motivation

- Significant increase in the launching of objects that stay orbiting the Earth over the past few years.
- No previous study on the matter had been carried out with LST-1.



Credit: NASA's Scientific Visualization Studio

Impact of satellite trails on H.E.S.S. astronomical observations★

T. Lang¹, S.T. Spencer^{1,2}, and A.M.W. Mitchell¹

¹ Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen Centre for Astroparticle Physics, Nikolaus-Fiebiger-Str. 2, D 91058 Erlangen, Germany

² Department of Physics, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, United Kingdom

September 22, 2023



Credit: H.E.S.S.

✦ Anomaly detection method

Goal: software able to detect which of our observations ('runs') may contain an anomalous event.

We consider an **anomaly** any event recorded by the camera that is not a cosmic ray.

IN OR FROM SPACE

Satellites

Space debris

Meteorites

TERRESTRIAL

Car-flashes

Flashlights

Telescope

malfunctions

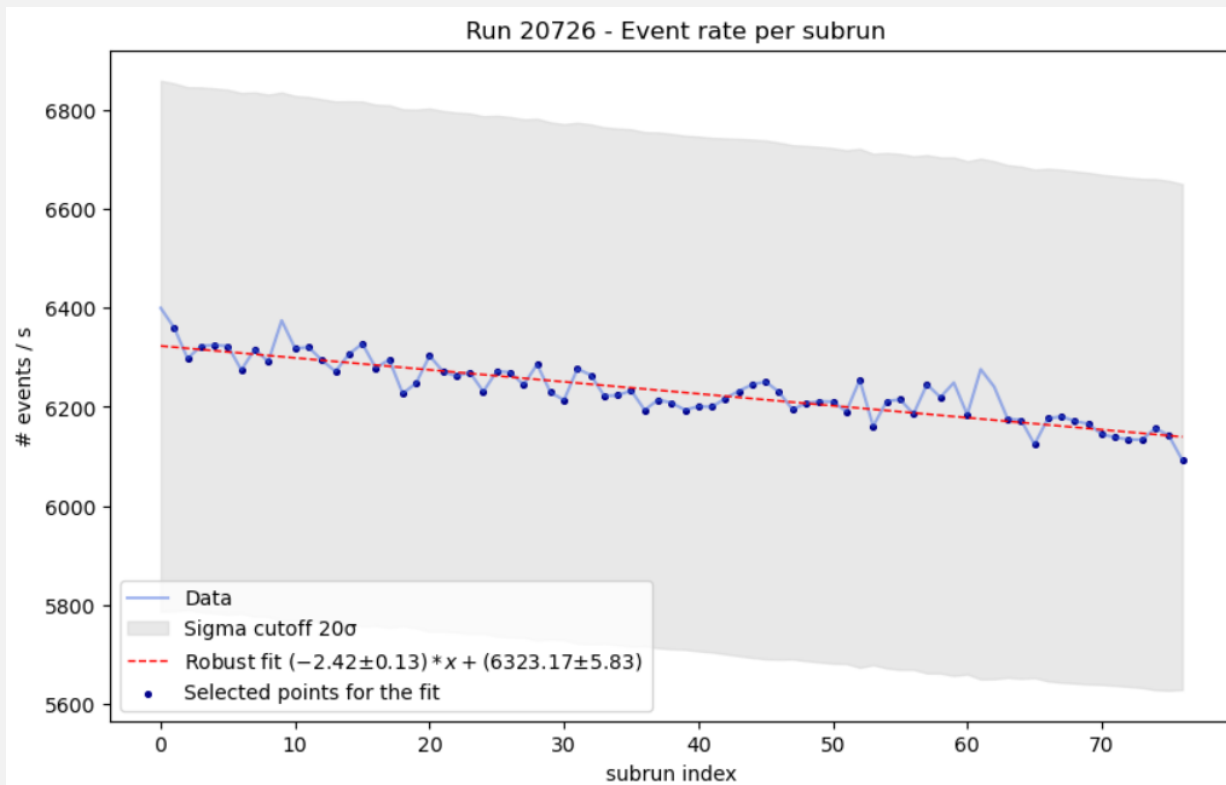
+ OTHERS

-> Look into **datacheck summary files** to look for hints of anomalies.

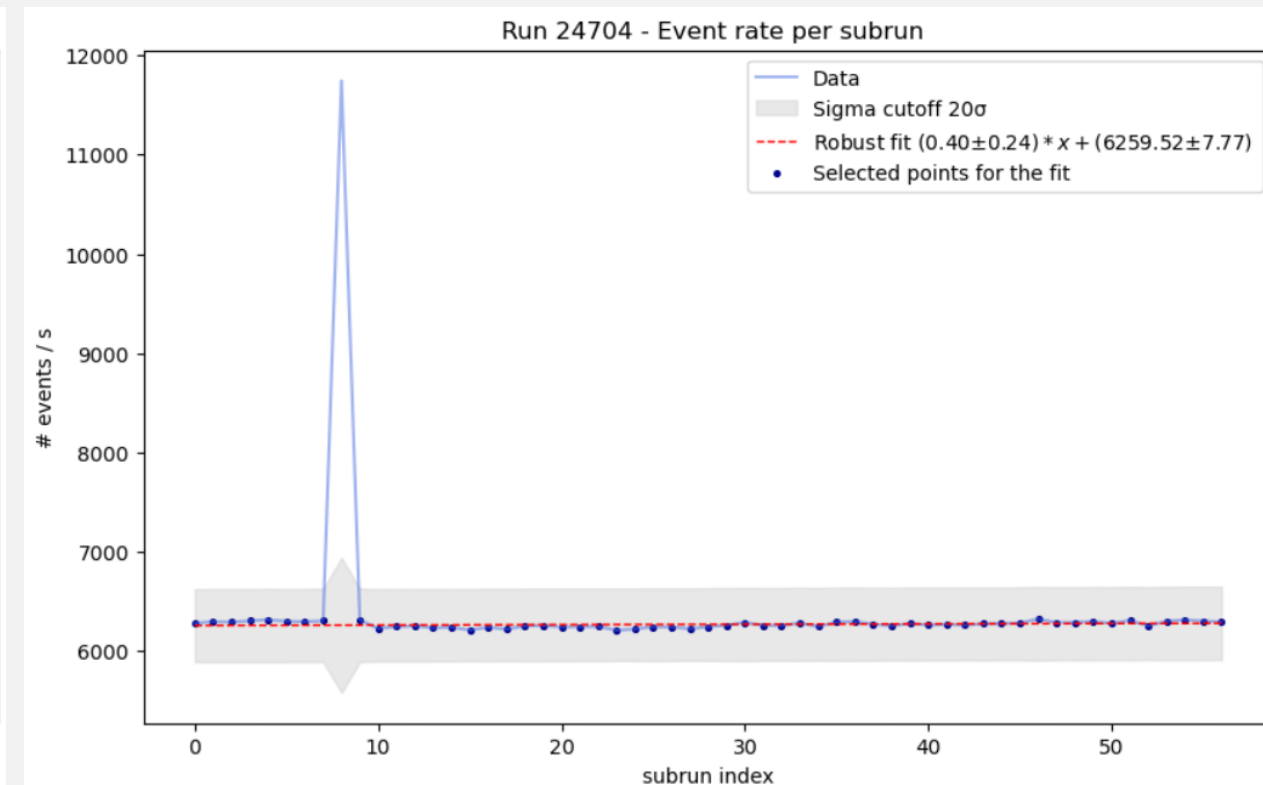
✦ Anomaly detection method

Filter 1: Event rate per subrun

The event rate is expected to vary slowly during a run, because of the change of the telescope pointing direction while tracking sources -> **Look for large deviations from a linear fit of the Rate VS subrun index.**



Normal run



Anomalous run

✦ Anomaly detection method

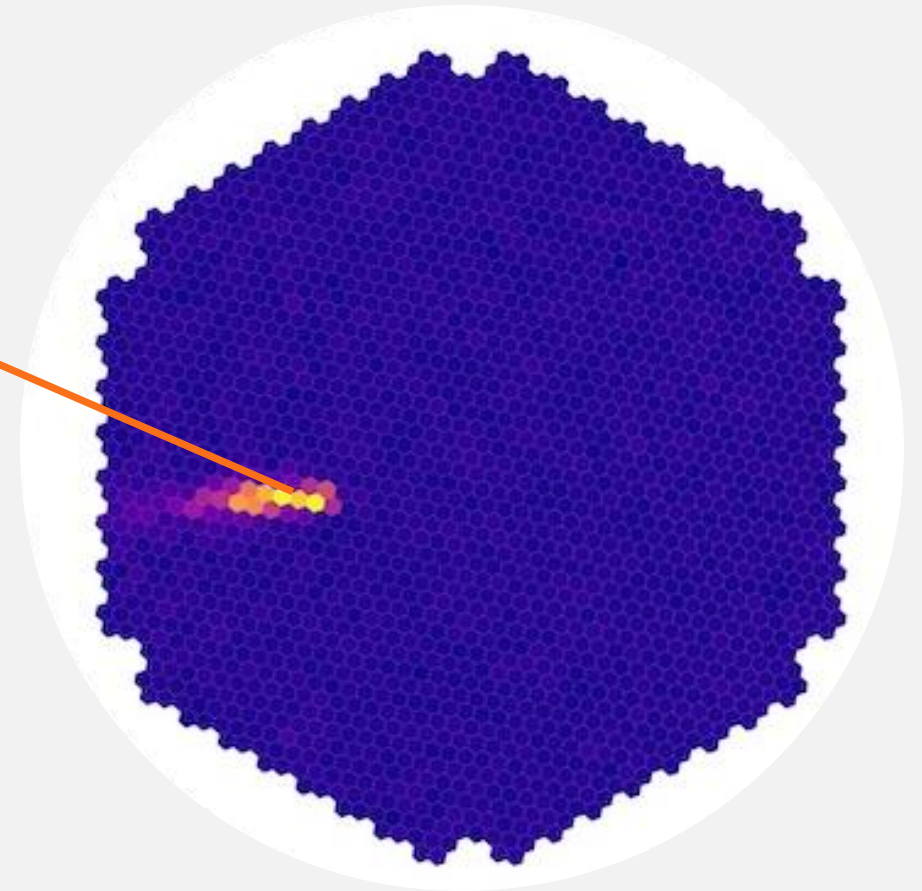
Center of Gravity (CoG) of an event

First-order spatial moments of the camera's pixel charge distribution.

Intensity of an event

Sum of the charge in all pixels with a significant signal.

-> Search for anomalies in the CoG and intensity distributions relative to those expected from a **constant and isotropic** cosmic ray flux.

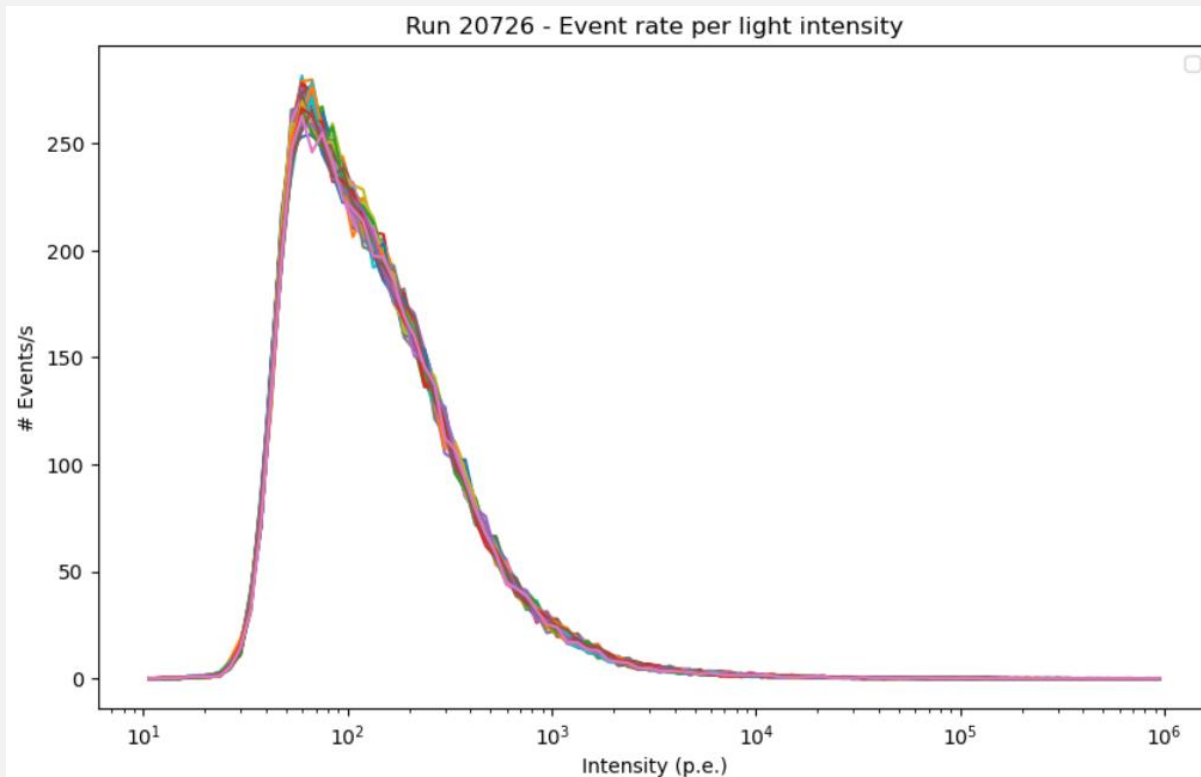


Cosmic ray recorded in LST-1 camera

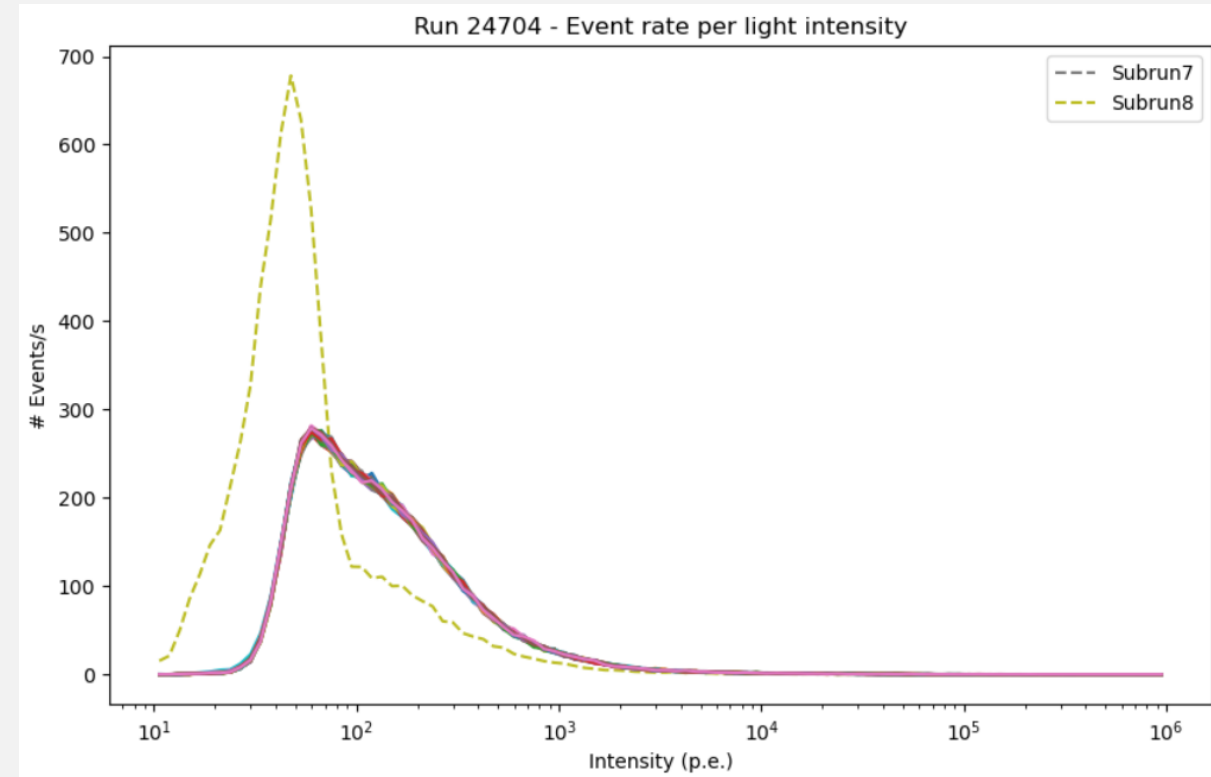
✦ Anomaly detection method

Filter 2: Intensity histogram per subrun

It is expected that the histogram of intensities registered by the camera will vary slowly from one subrun to the next due to the short duration of the runs -> **KS Test of the histograms** with their neighbouring ones.



Normal run

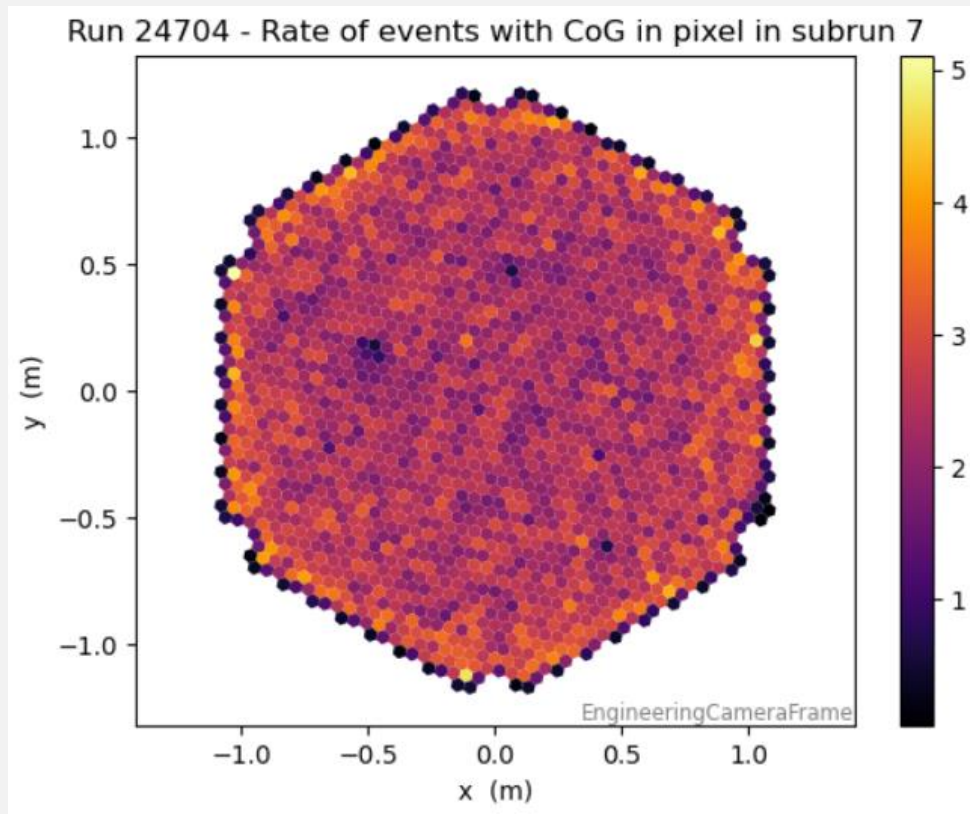


Anomalous run

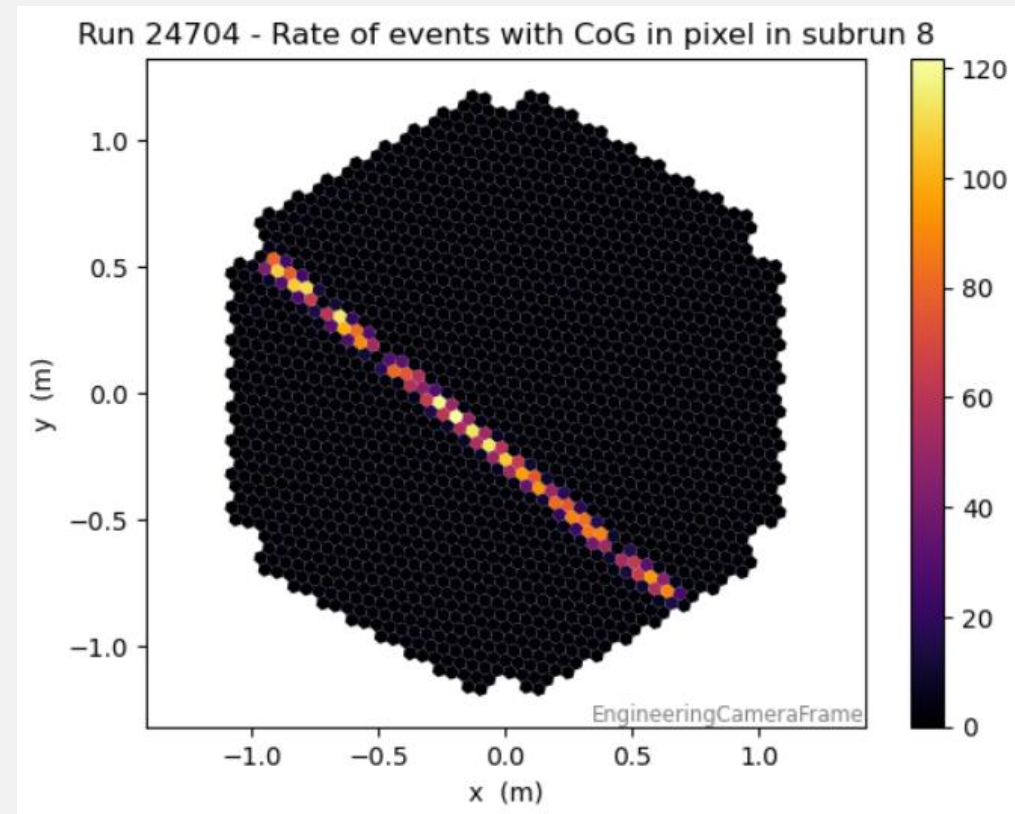
✦ Anomaly detection method

Filter 3: Search for tracks in the anomalous subruns

Now, let's focus on **satellites**. Within the subruns marked as 'anomalous', are there any straight-like traces?
-> χ^2 Test on the position of the affected pixels of the camera.



Cosmic rays



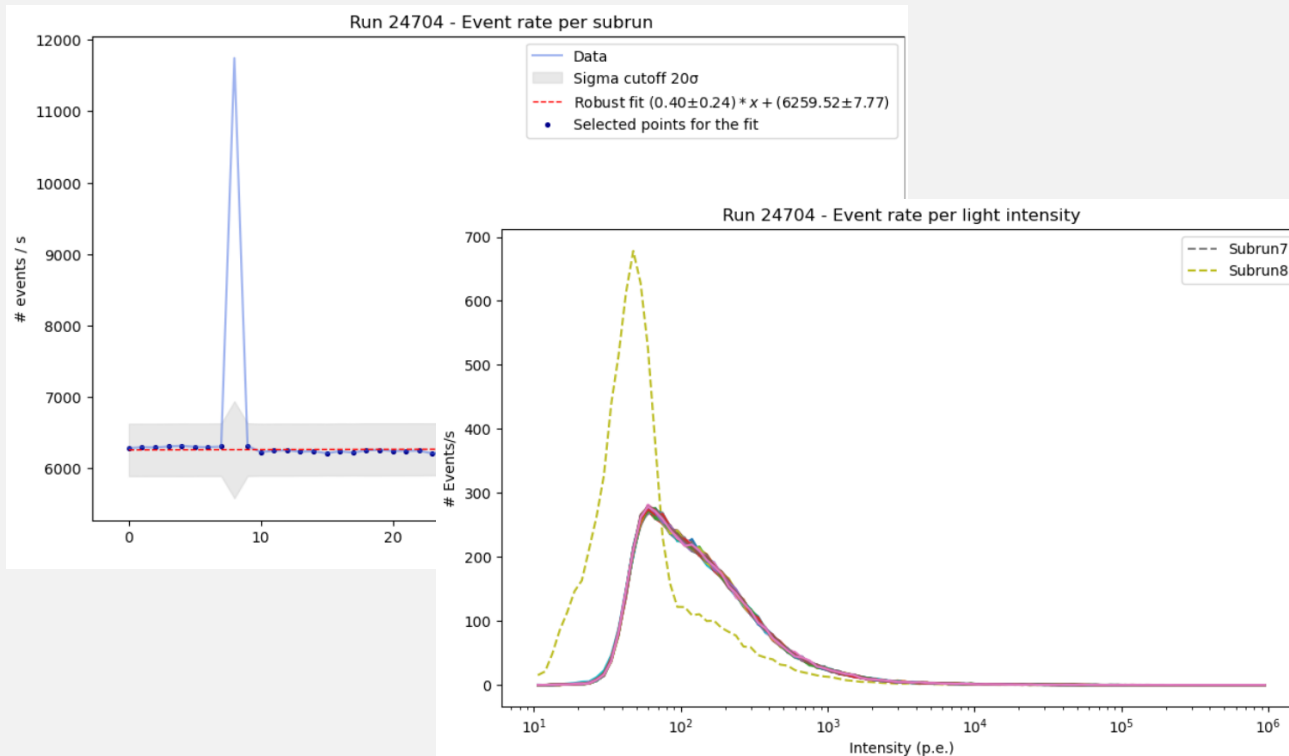
Satellite

✦ Anomaly detection method

Satellite identification

Given the coordinates of the telescope and the time of observation, we can obtain a list of candidates for the object we are observing.

SatChecker API, a satellite position prediction tool from the IAU CPS (IAU Centre for the Protection of the Dark and Quiet Sky).

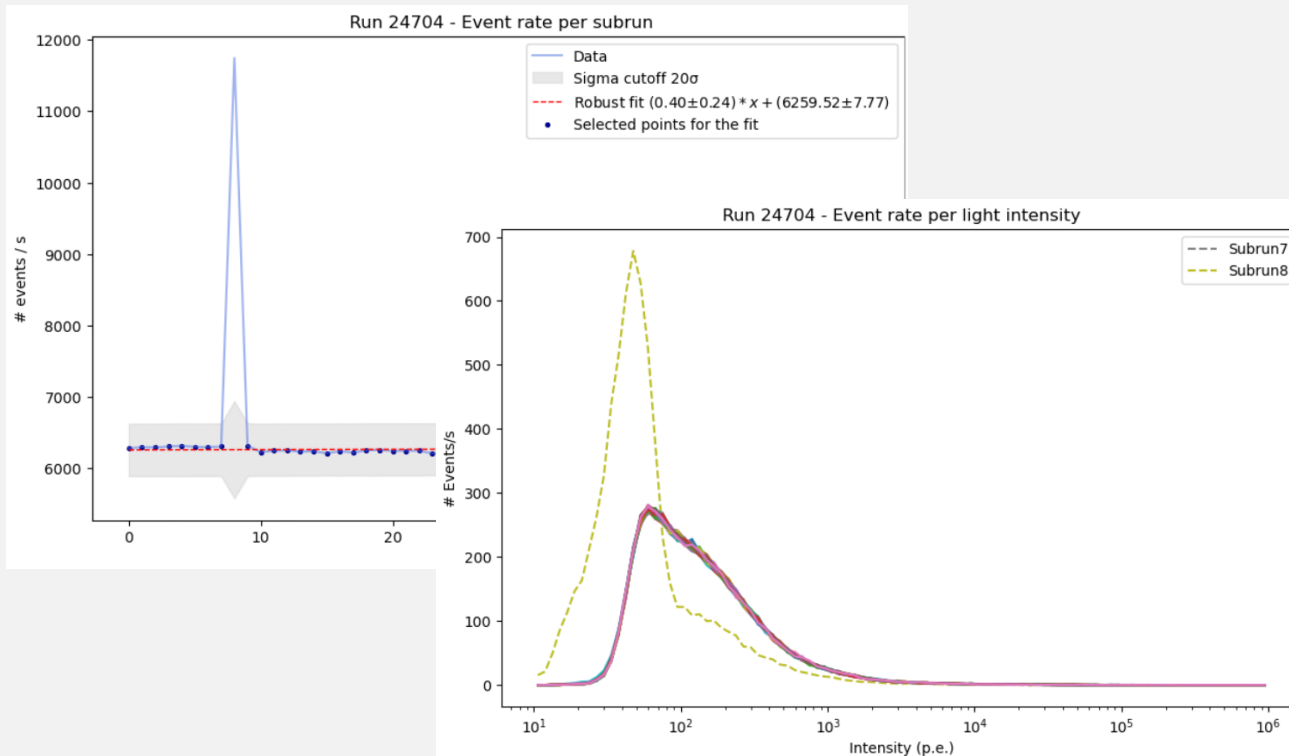


✦ Anomaly detection method

Satellite identification

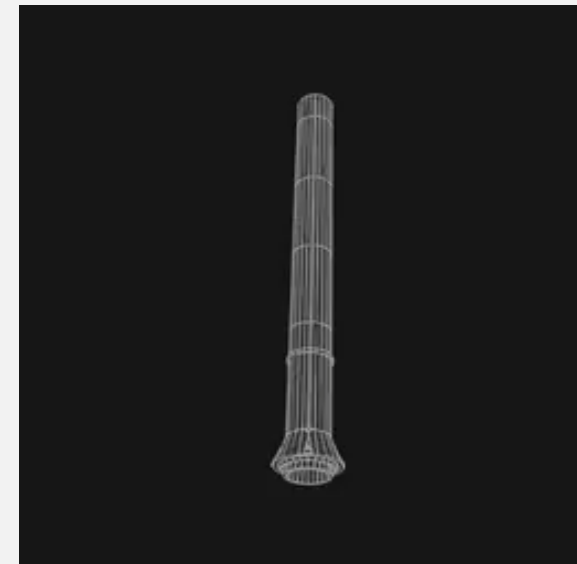
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NORAD ID: 31793

Name: SL-16 R/B

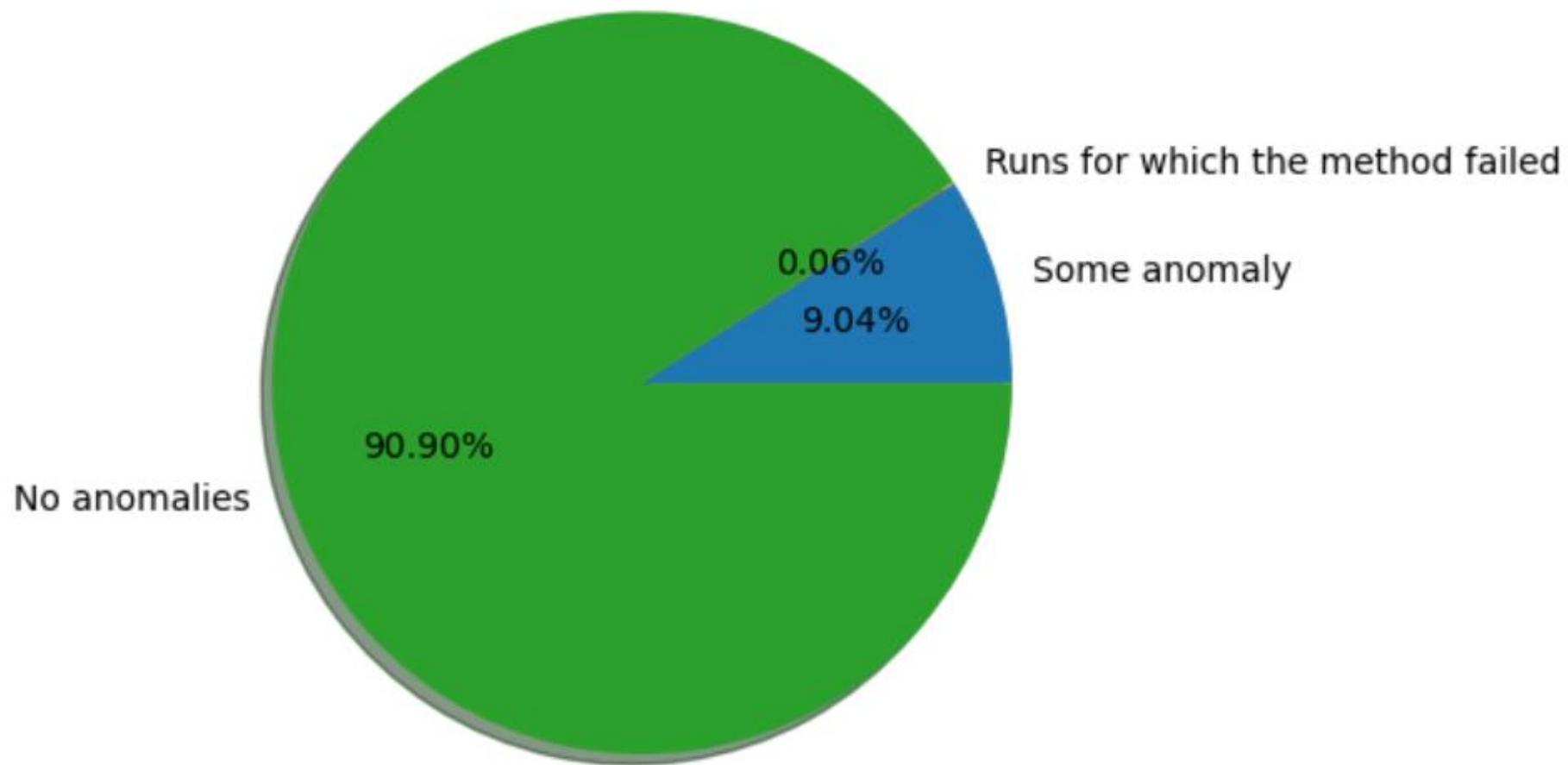


Credit: Satcat



Results

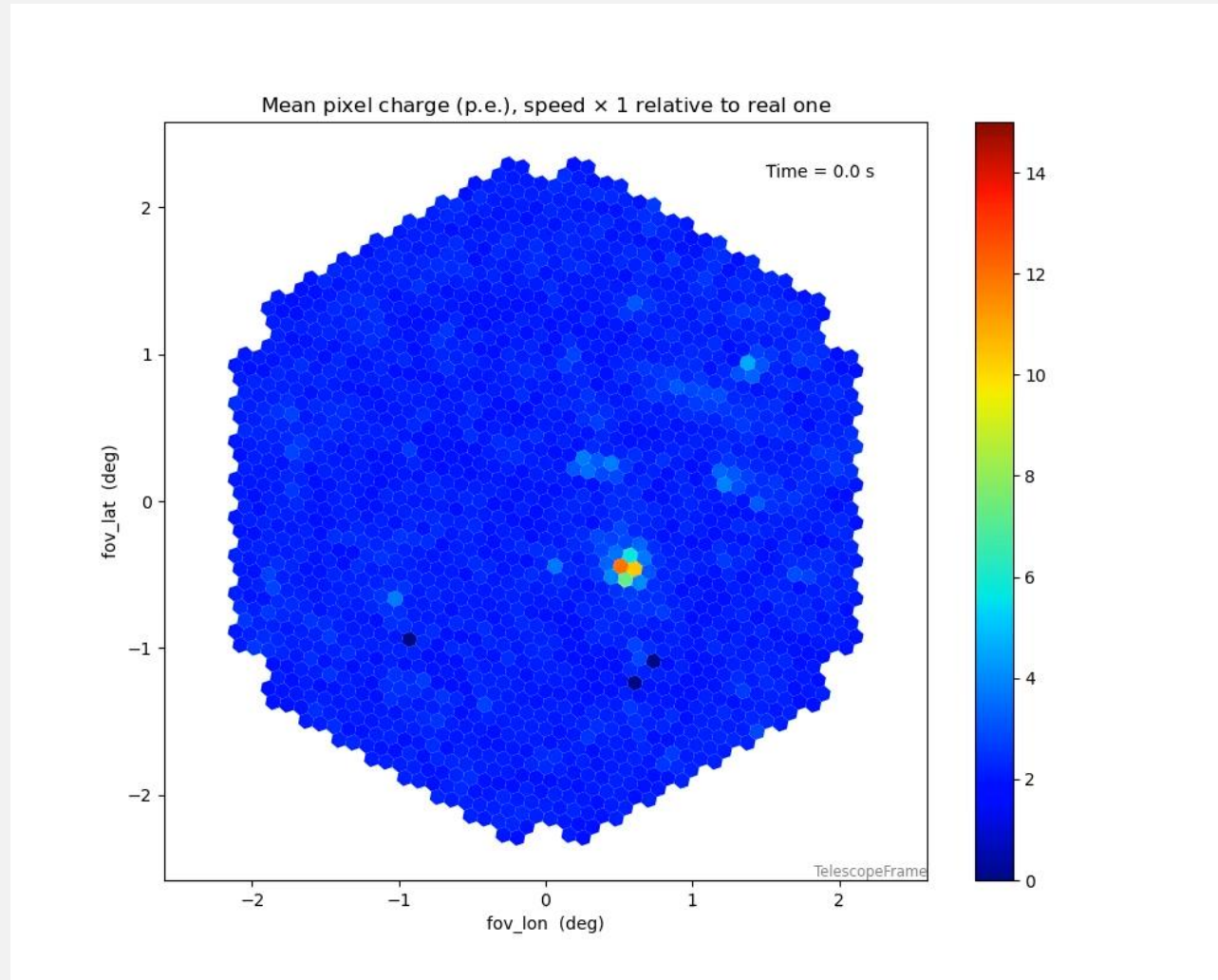
Observation time distribution in 3407.02 hours of observation





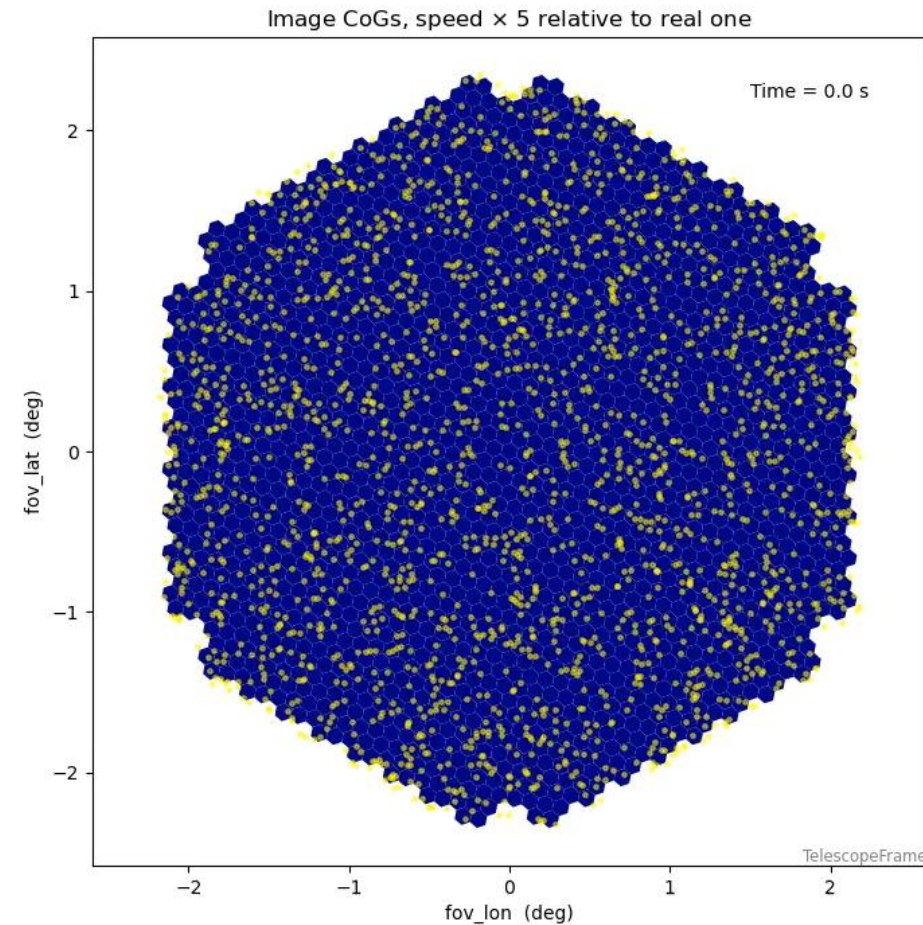
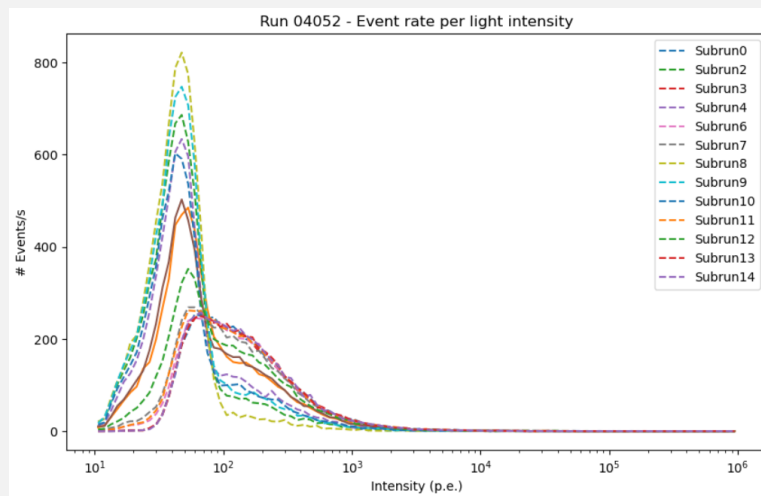
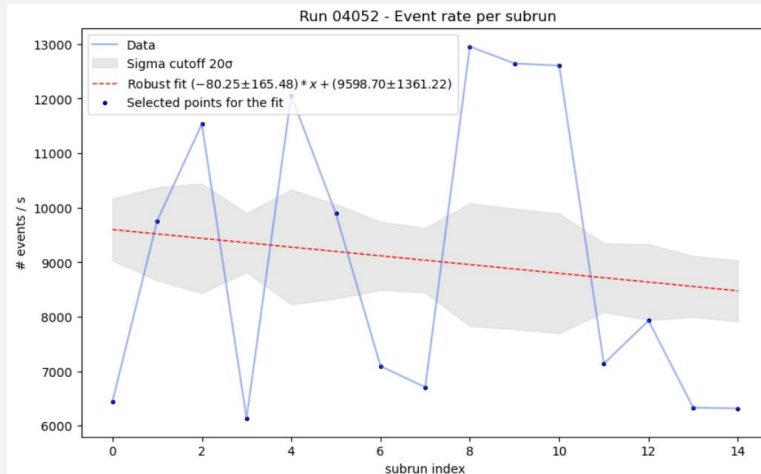
Results – The effects of bright objects

The image analysis can easily **reject these anomalous events**: their shape is quite different from the one expected for showers. However, bright objects may **saturate the DAQ**, resulting in a loss of efficiency.



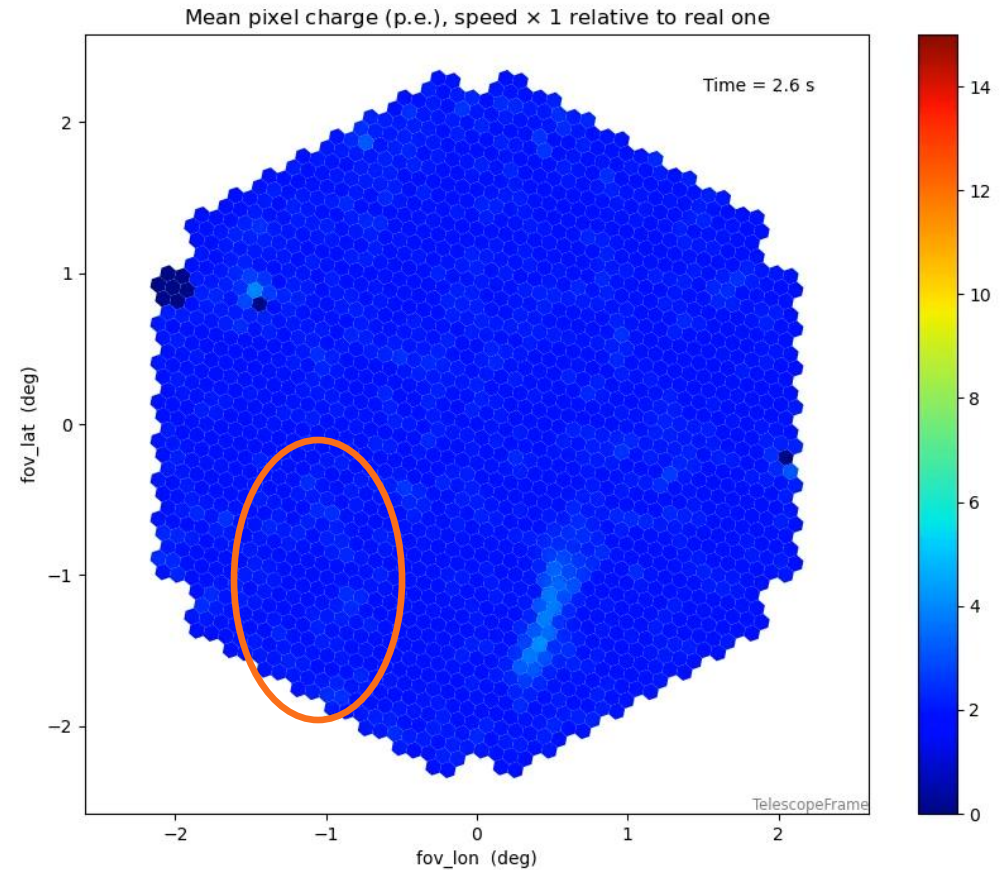
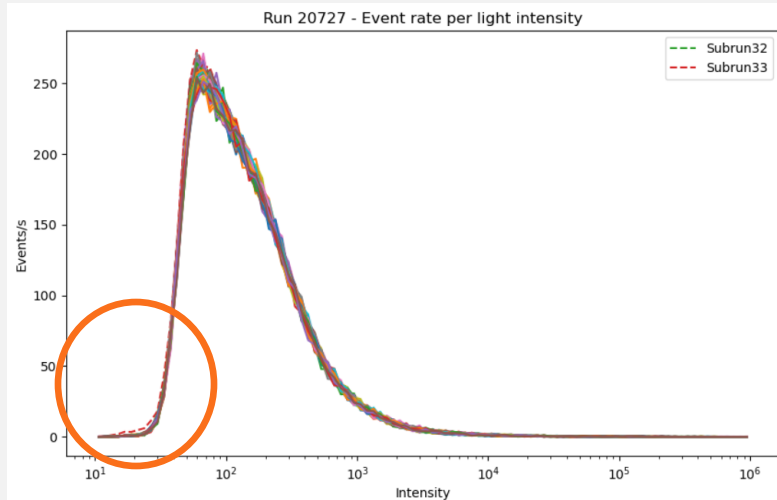
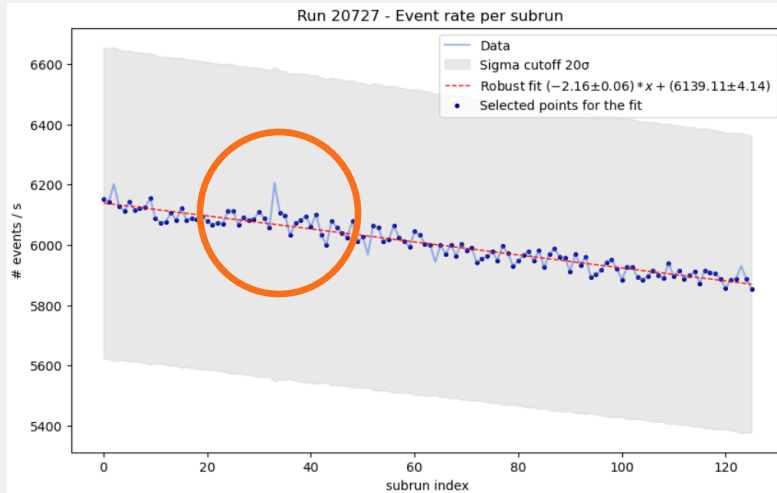
Results – Satellites (~0 – 100 p.e.)

CoGs of the recorded events in the run



Results – Meteorites (~0 – 100 p.e.)

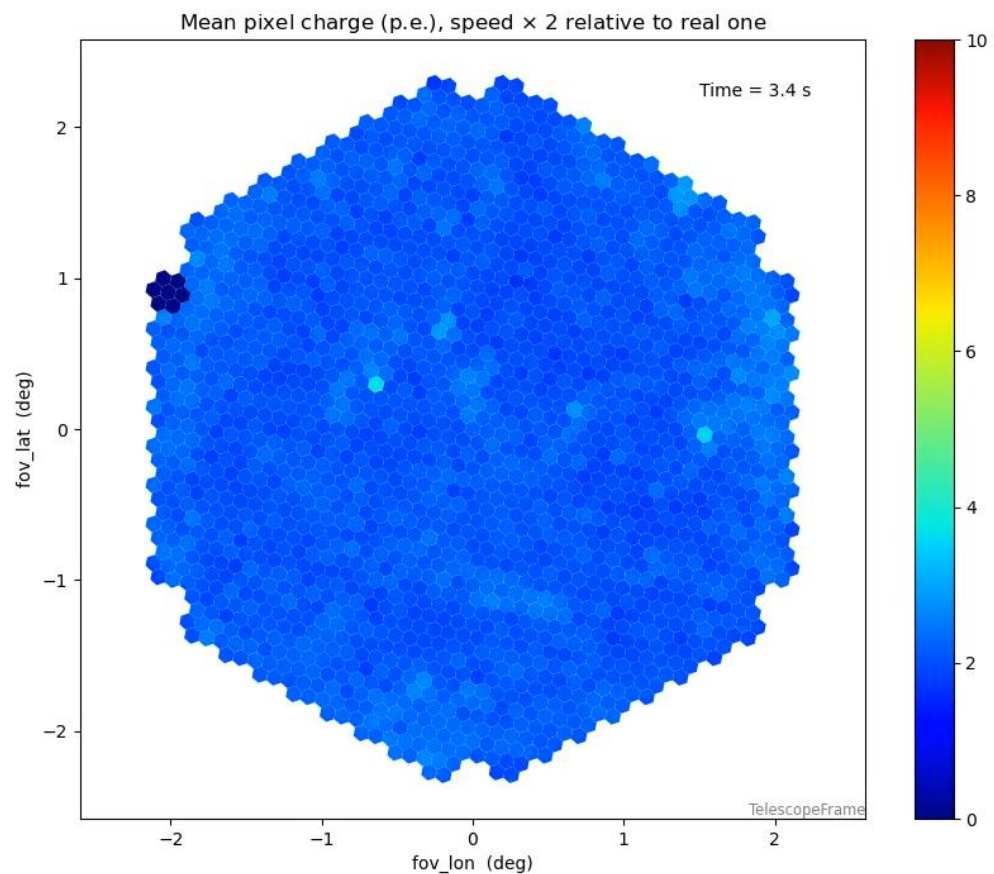
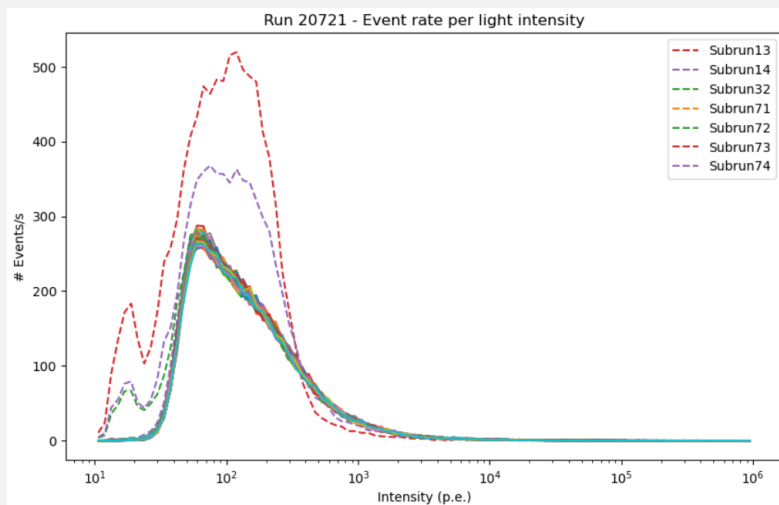
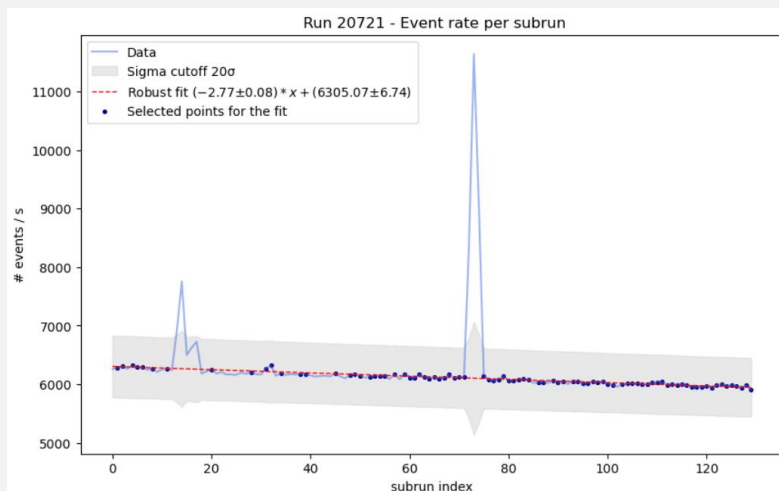
Mean pixel charge of the recorded events in the run





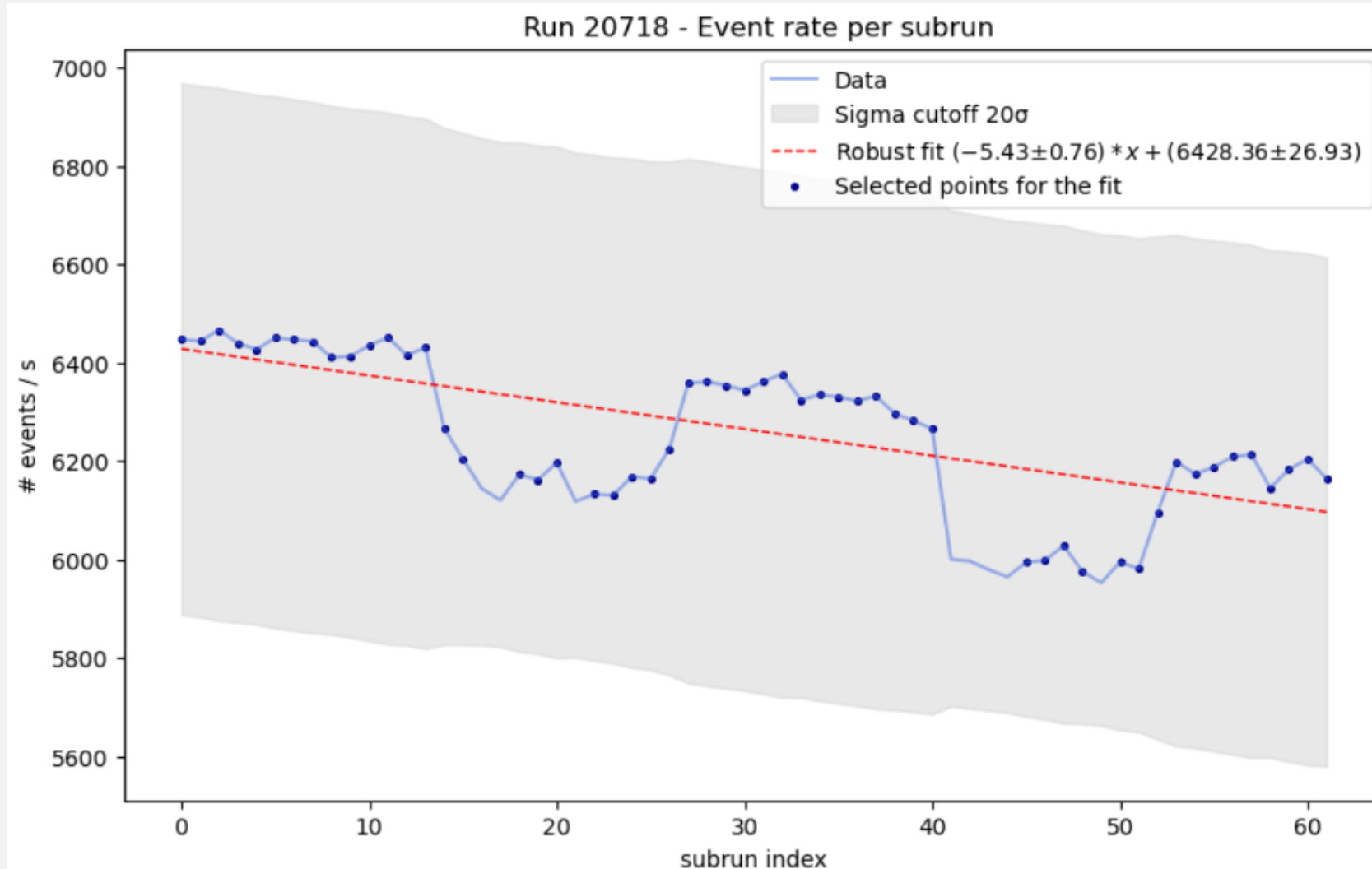
Results – Terrestrial anomalies (~0 – 1.000 p.e.)

Mean pixel charge of the recorded events in the run



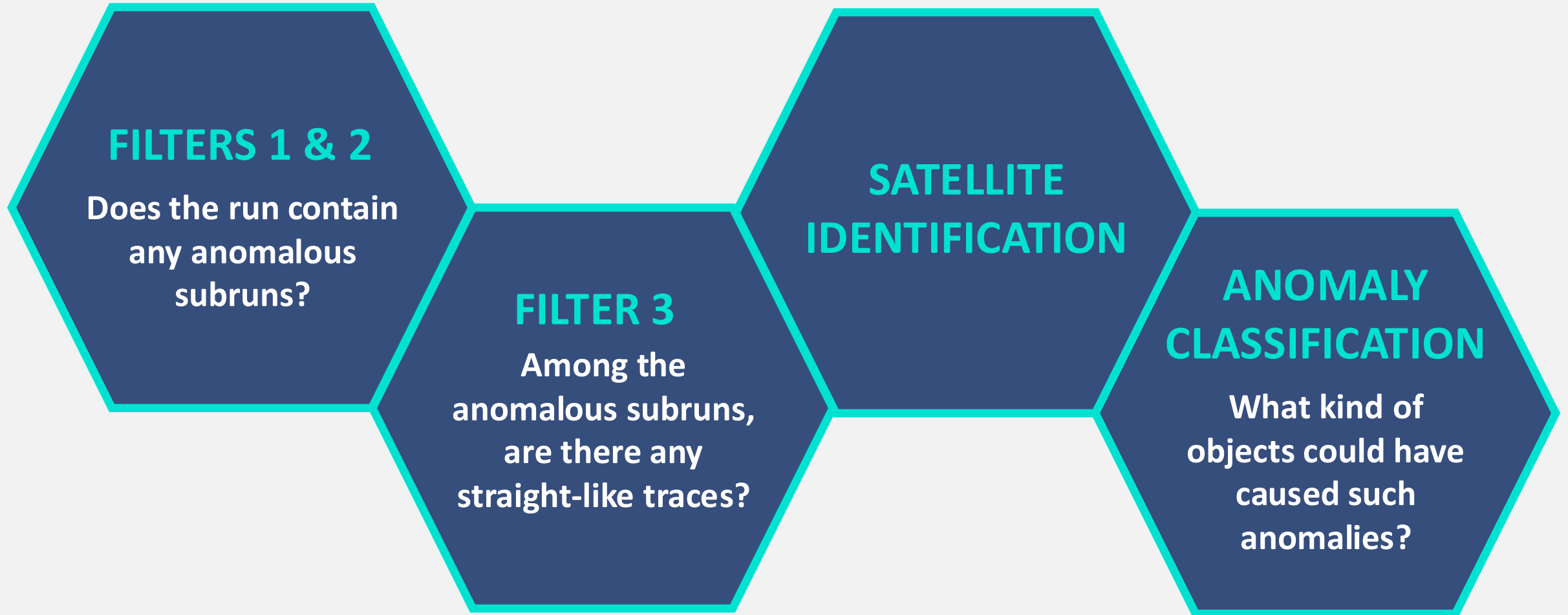


Results – MAGIC's LIDAR ($O(1.000)$ p.e.)



✦ Summary and future improvements

Anomaly detection *pipeline*



FILTERS 1 & 2

Does the run contain
any anomalous
subruns?

FILTER 3

Among the
anomalous subruns,
are there any
straight-like traces?

SATELLITE IDENTIFICATION

ANOMALY CLASSIFICATION

What kind of
objects could have
caused such
anomalies?

Thanks!

Acknowledgments:

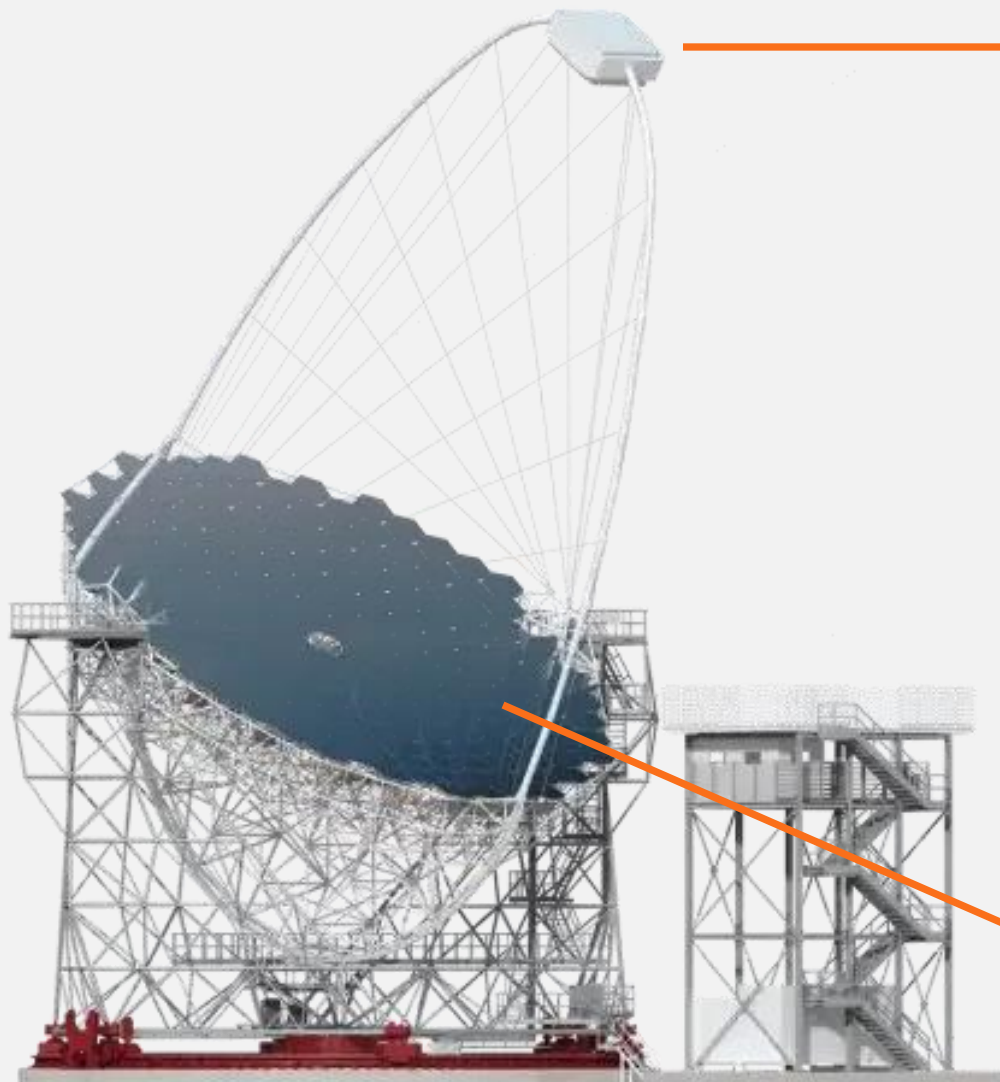
IFAE
Gamma-ray Group
Abelardo Moralejo

GitHub: [andreaprogram](#)

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A. Guerrieri

Brief introduction to IACTs



Camera

Time duration of Cherenkov light flashes: $\sim \text{ns}$

The camera starts recording once the **trigger** is fired:

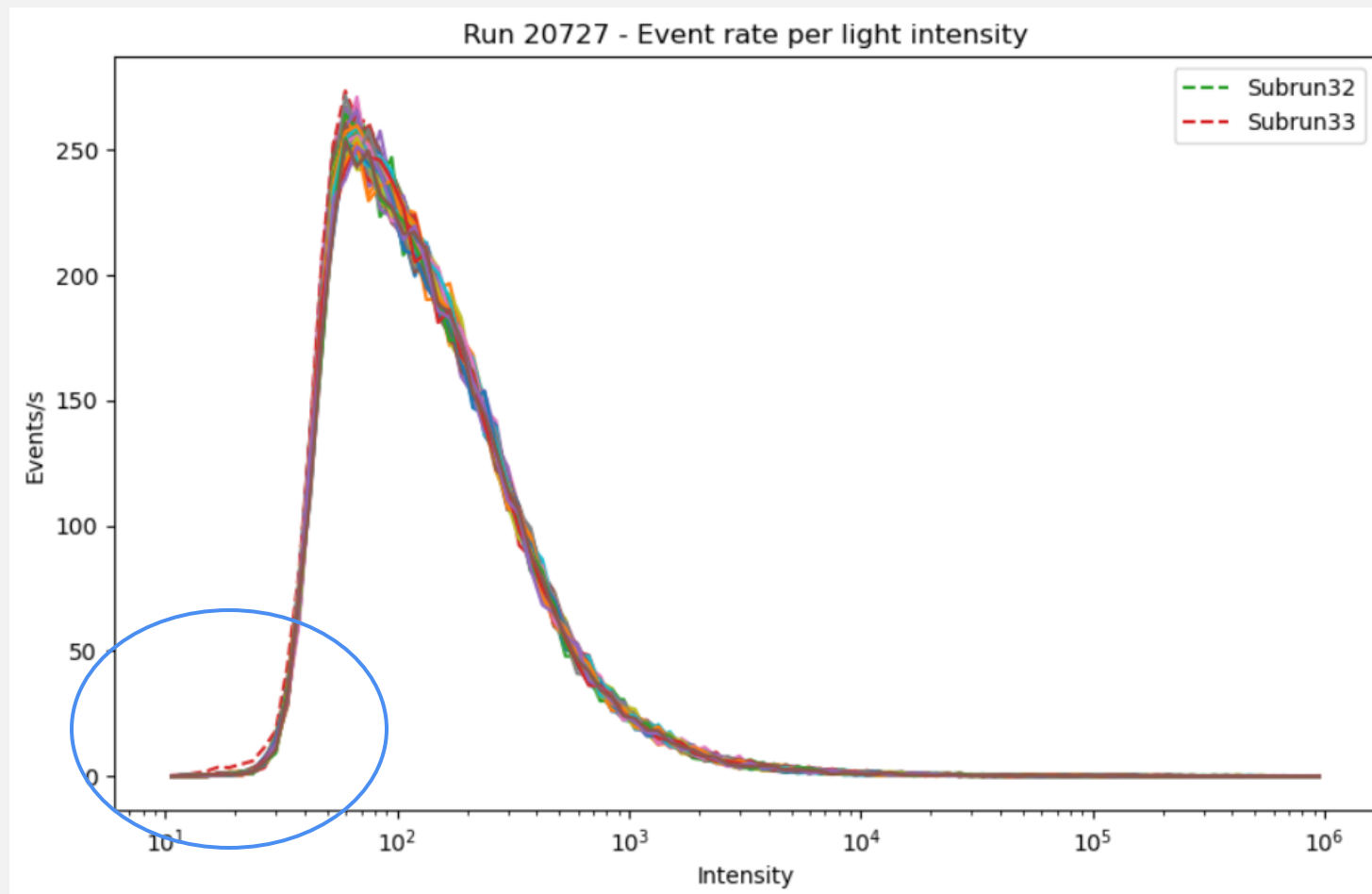
- Photons must arrive within a narrow time window ($\sim \text{ns}$).
- Multiple adjacent pixels must be activated, forming a compact cluster characteristic of gamma-rays.
- The combined light of the pixel group must be brighter than the background night-sky noise.

Mirror

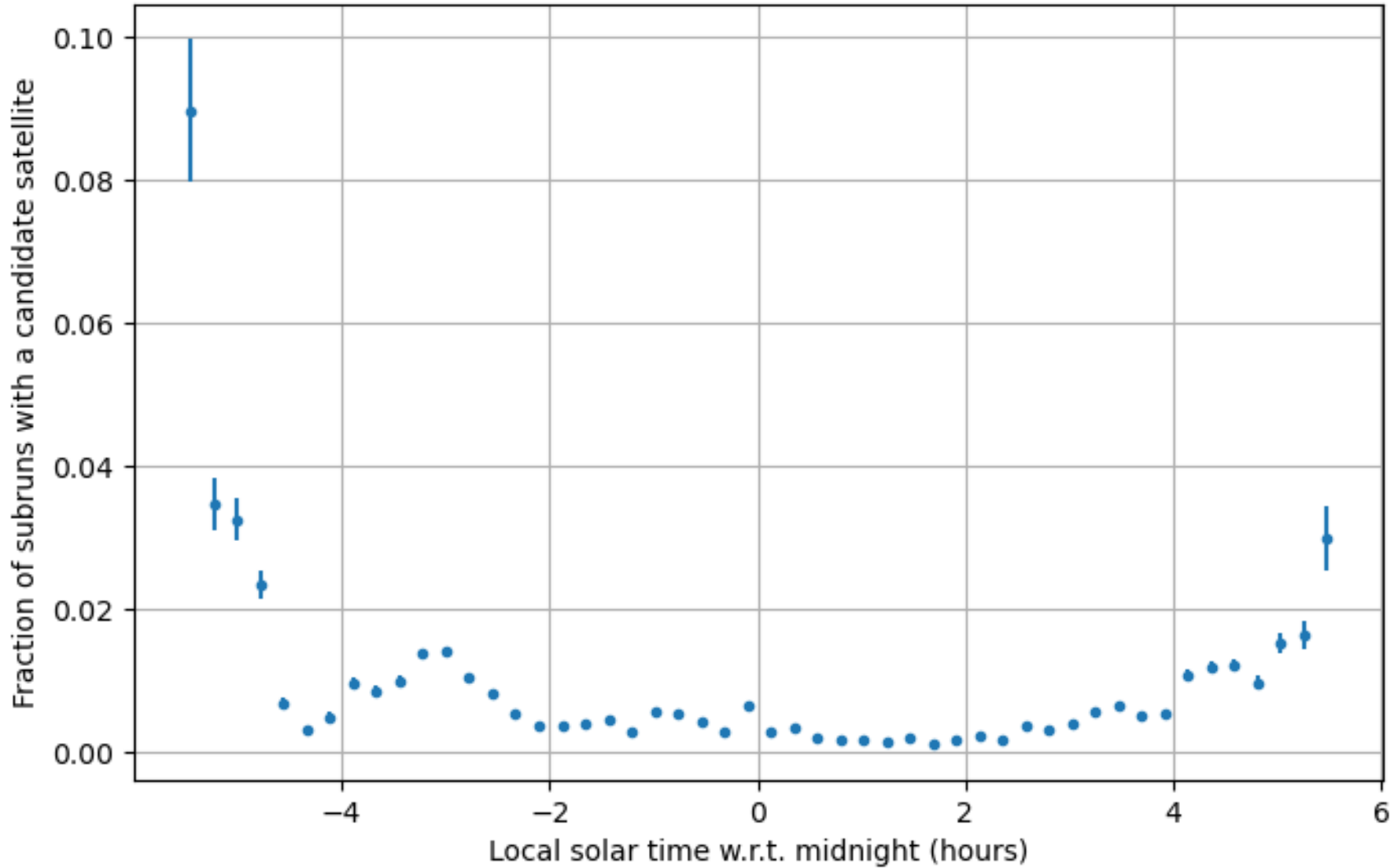
Anomaly detection method

Filter 2: Intensity histogram per subrun

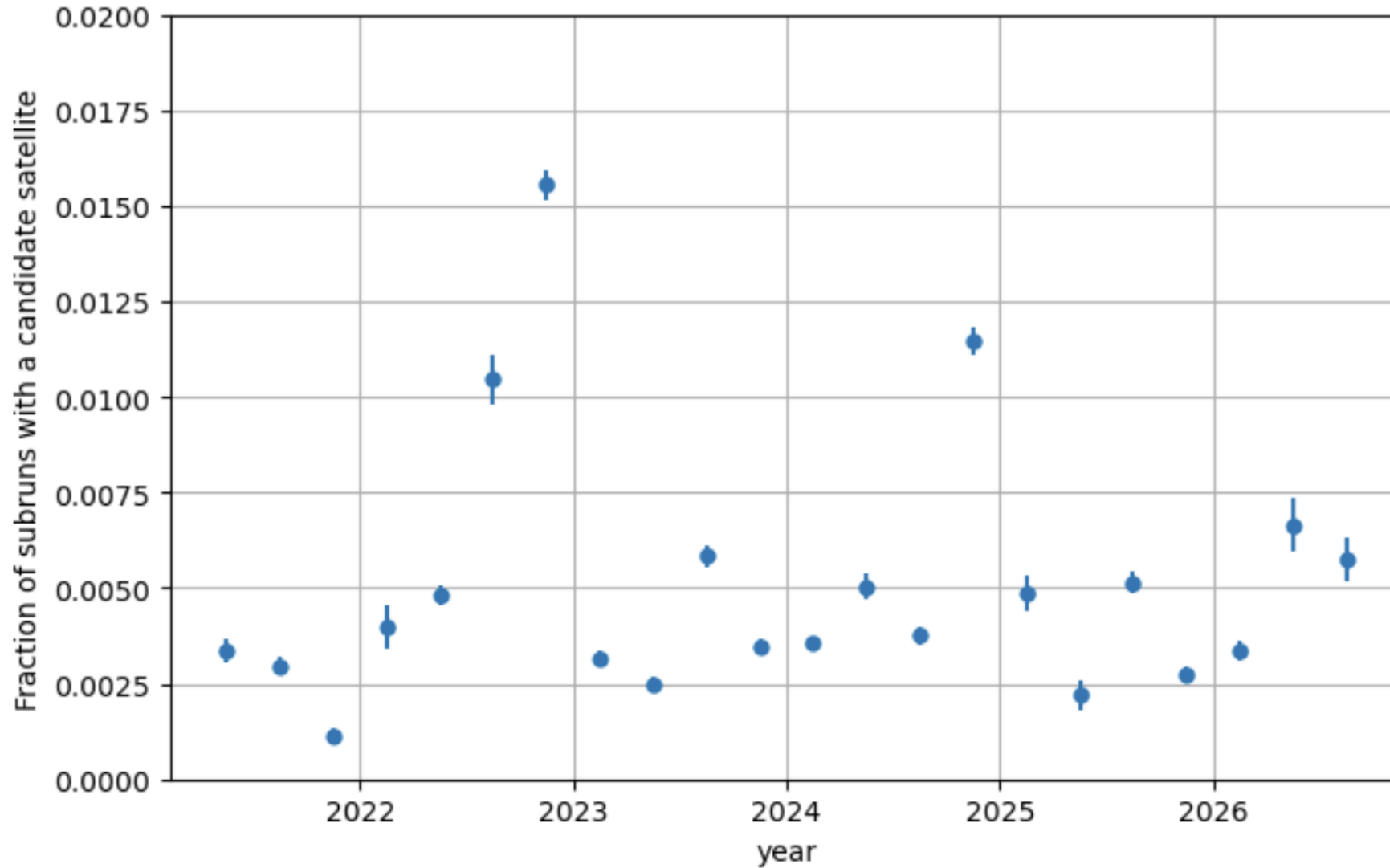
Different kinds of anomalies will appear at different intensity ranges; therefore, the filter has been applied across the intervals: **0-100 p.e.** , **100-1.000 p.e.** and **>1.000 p.e.** (as well as the full intensity range).



Satellites



Satellites



Summary



A study on the search for anomalous events in LST-1 observations has now begun.



We are now able to (roughly) detect and identify such anomalies from the data using a simple method.



By now, we have encountered (possible) satellites, meteorites, terrestrial anomalies and LIDARs.

Summary



A study on the search for anomalous events in LST-1 observations has now begun.



We are now able to (roughly) detect and identify such anomalies from the data using a simple method.



By now, we have encountered (possible) satellites, meteorites, terrestrial anomalies and LIDARs.

But this research
has just started...

Future improvements



A study on the search for anomalous events in LST-1 observations has now begun.



It is yet to determine to what measure these events affect our observations.



We are now able to (roughly) detect and identify such anomalies from the data using a simple method.



The method is up to revision and improvement.



By now, we have encountered (possible) satellites, meteorites, terrestrial anomalies and LIDARs.



The possibility of observing two or more traces is not yet contained, and the identification is not unique.



We cannot ensure the nature of those anomalies, a further analysis in a more detailed data level, as well as human revision is needed.

Brief introduction to IACTs

CTAO

Cherenkov
Telescope
Array
Observatory

