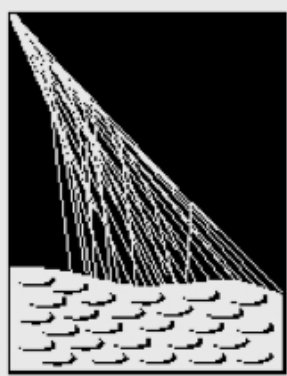


Recent observations of Transient Luminous Events above Central Argentina from the Pierre Auger Observatory

Roberto Mussa



**PIERRE
AUGER**
OBSERVATORY

AtmoHEAD 2026

28 - 30 . 7 . 2026

Olomouc - Czechia



Outline

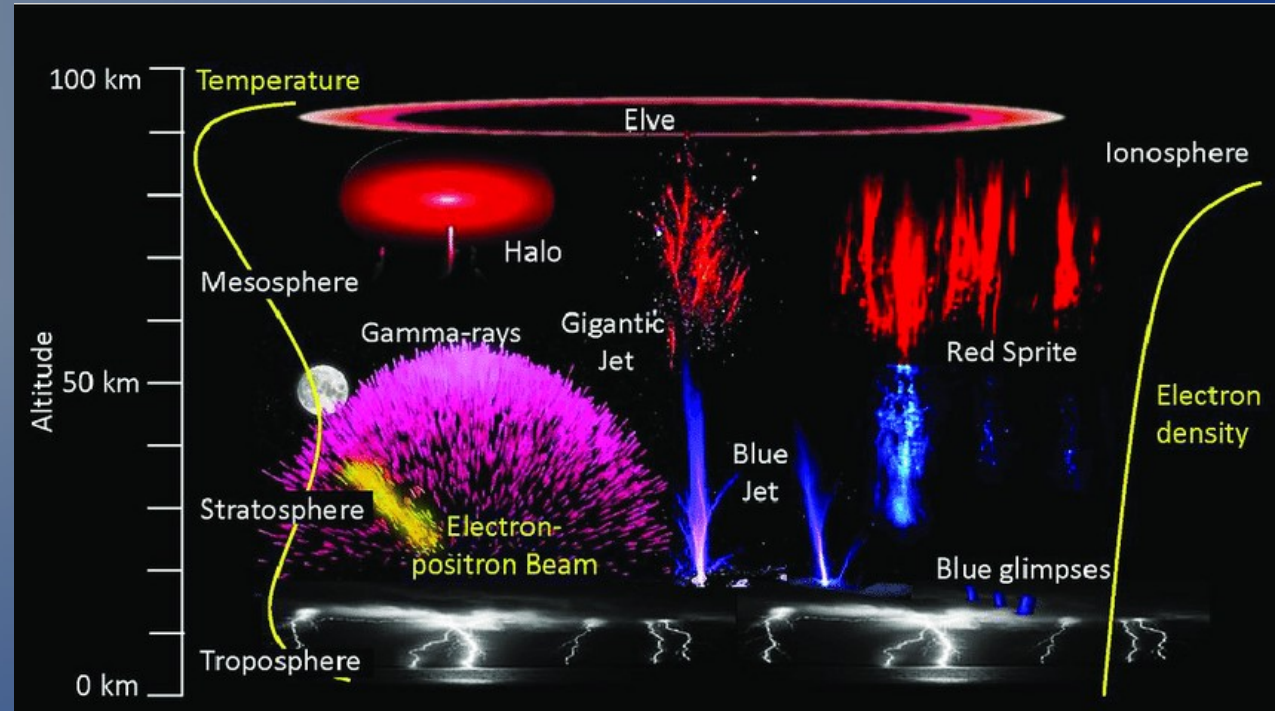
ELVES triggering and DAQ

Halos after ELVES

The new TLE cameras

A standalone trigger for
SPRITES

Using FD for precision timing
of SPRITES



TLE: Transient Luminous Events in upper atmosphere



Observation of ELVES at the Auger Observatory

24(+3) telescopes in 4 eyes

FD camera: 440 PMTs / telescope

Mirror area: 11m²

Field of View: 6x30°x30° for each FD

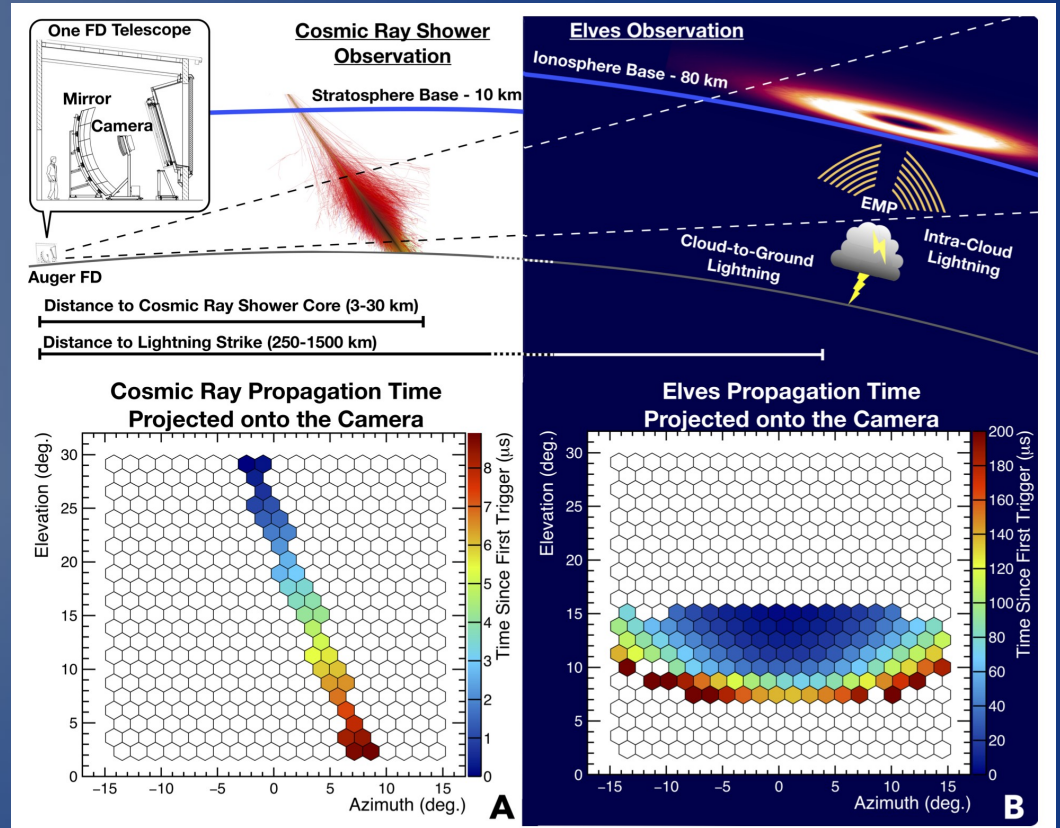
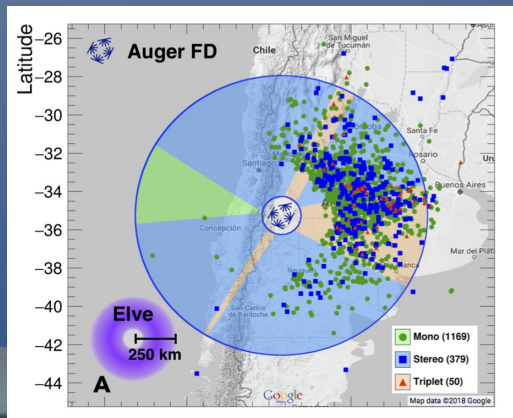
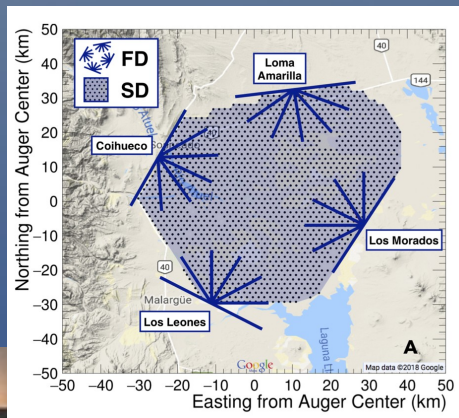
UV filter: 300-420 nm

A 10 Mfps camera, with 0.9ms trace length

Duty cycle ~12% (1/2 moon cycle)

Angular resolution ~ 0.6°

Dedicated ELVES trigger operating since 2014



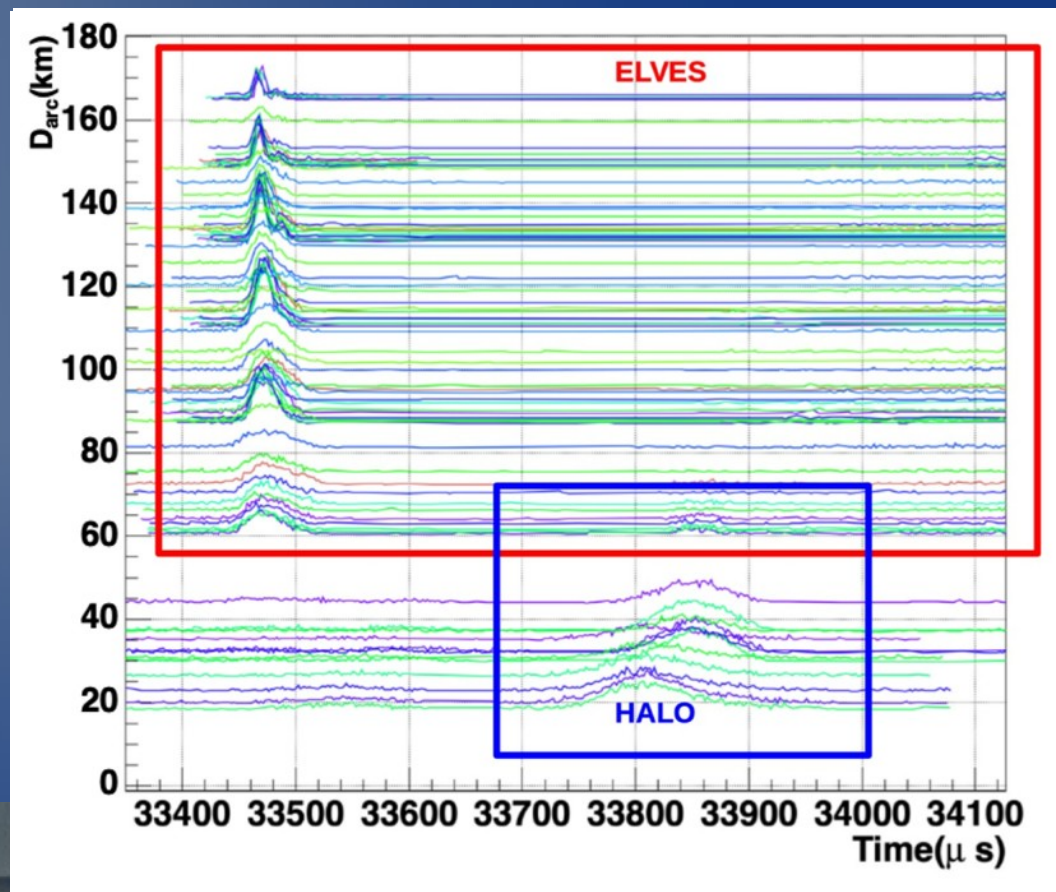
Observation of halos in Auger

PoS(ICRC2023)372

The extended Readout has allowed to read traces from ELVES triggers up to 0.9 ms long.

This allowed to see *halos* few hundred μ s after ELVES

Halos are disks of 100 km diameter, at 70-80 km altitude, lasting longer than ELVES.



Observation of halos in Auger

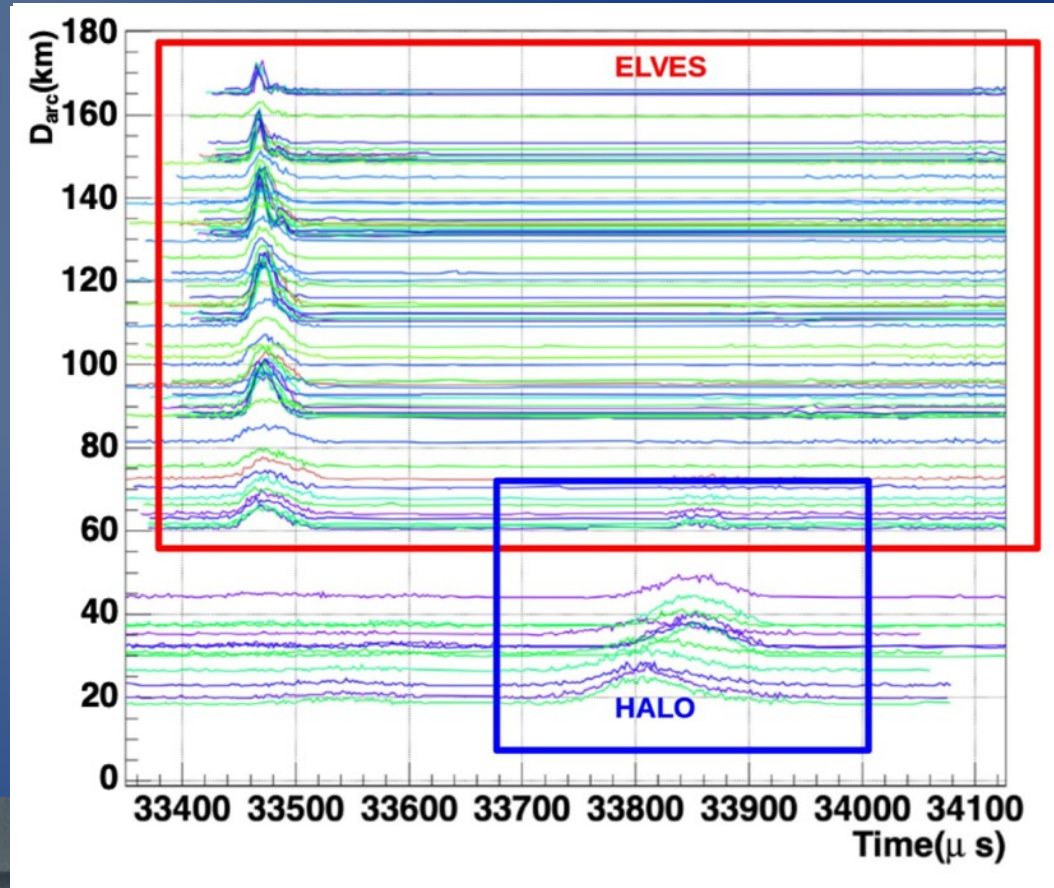
PoS(ICRC2023)372

The extended Readout has allowed to read traces from ELVES triggers up to 0.9 ms long.

This allowed to see *halos* few hundred μ s after ELVES

Halos are disks of 100 km diameter, at 70-80 km altitude, lasting longer than ELVES (sure?)

Halos are frequently associated to SPRITES



A new instrument to study more TLEs

To complement the FD images of ELVES (high time resolution but poor space resolution) and study correlation with other TLEs such as sprites and blue jets, we installed two new instruments, in the proximity of Coihueco FD site:

TLEcam-1 (dec.2023) :

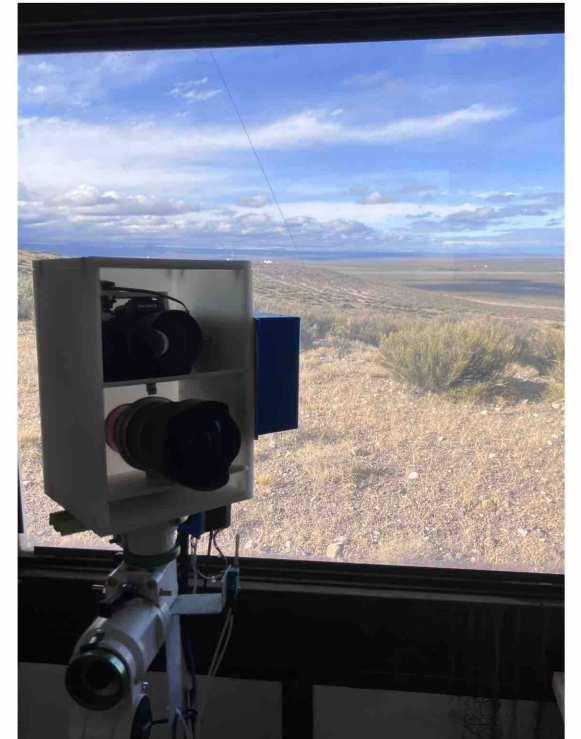
- Sony $\alpha 7$ -III camera
- 7artisans 50mm f/0.95

TLEcam-2 (apr.2024):

- ZWO ASI294MC
- Sigma 20mm f/1.4

Arduino microprocessor controls:

- Azimuth motion
- Power on/off Sony
- Light sensor
- Motorized curtain



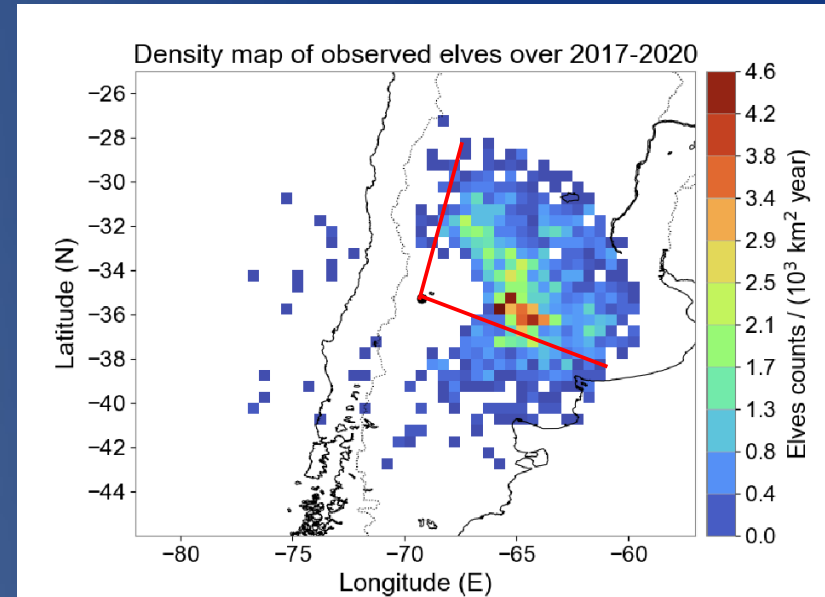
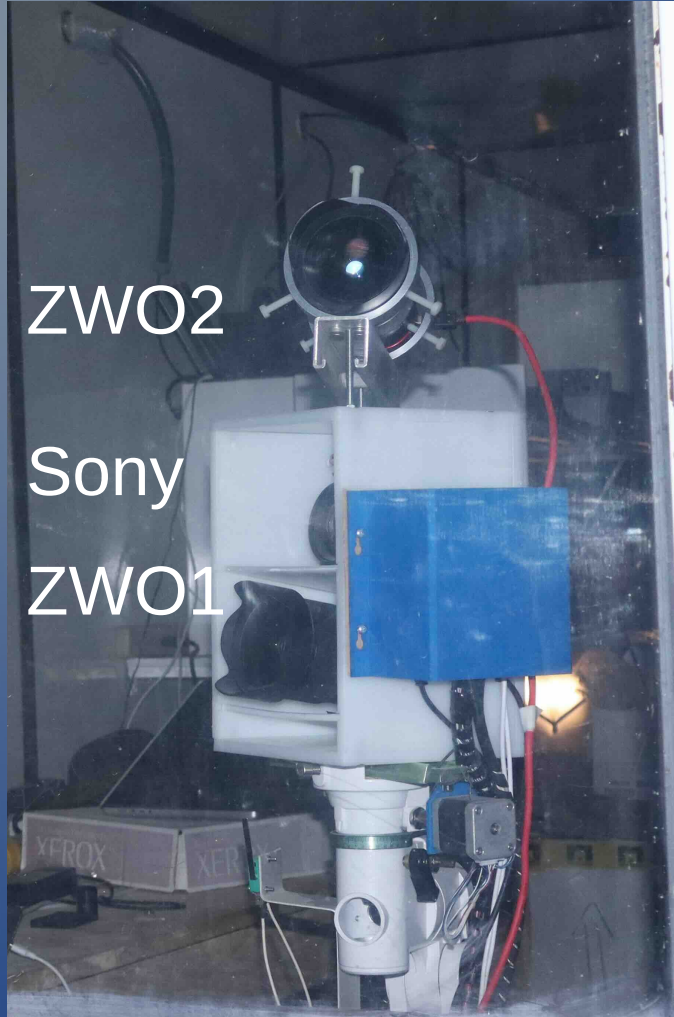
... and then there were three ...

Until Nov 2025, the cameras were manually operated pointing to the same Field of View (FoV), following the evolution of the storm.

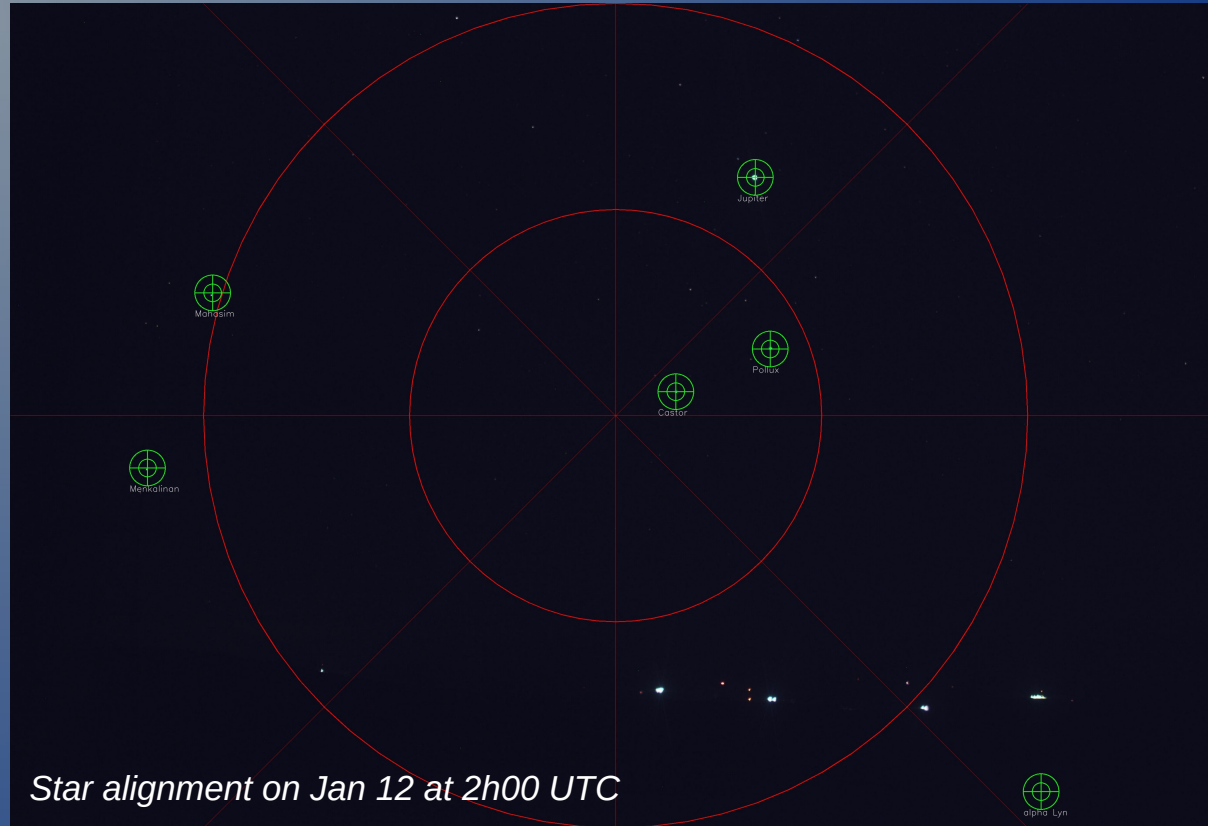
In May 2025, a motorized curtain was installed to protect the TLEcams from sunlight during the day.

Since Nov.2025:
A second ZWO camera, to fully cover more than 90 degrees in Azimuth with a static setup.

Currently the Sony is not operated, but we plan :
- to change optics
- to keep it on a movable frame, AI controlled



Left Camera alignment

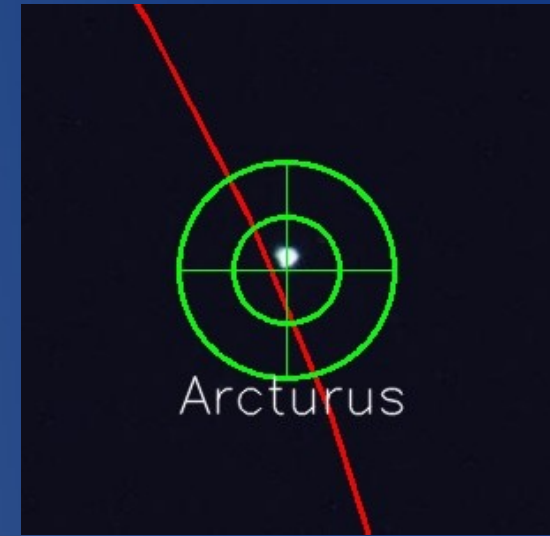
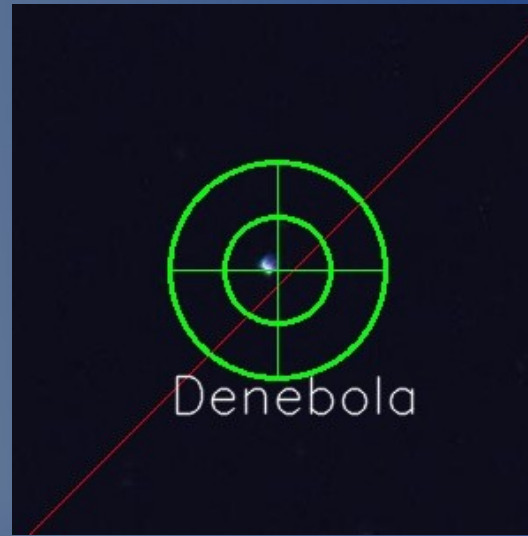


Python code uses astropy packages to get stars' coordinates and planets' ephemeridis.



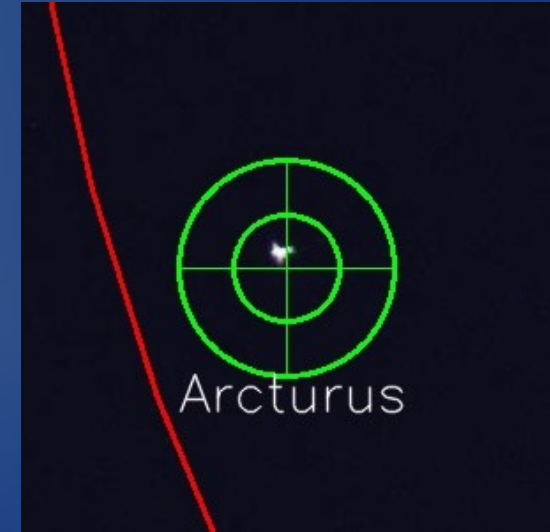
Stars' PSF

Left camera



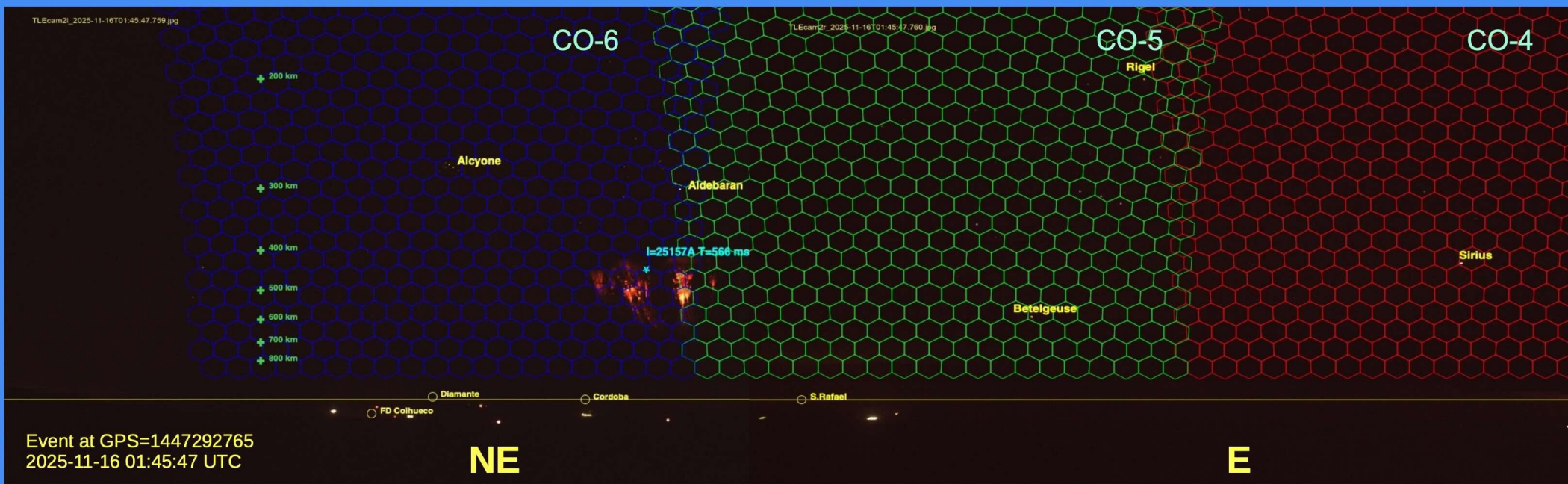
Right
Camera
(ZWO-1)

Lenses
misaligned?



First SPRITES seen with the new setup

The map and the picture below show the FoV of the new setup, covering almost 3 FD Telescopes (CO-4,5,6). The timing of the TLEcam images is given by the Unixtime of the PC: its time resolution is not accurate enough to compare with the lightning networks (WWLLN, ENTLN, GLM) provided in real time via the GeoRayos platform. The event shown in the picture has been observed on Nov.16, 2025. The blue star in the figure shows the point on the vertical of the lightning detected by ENTLN at an altitude of 90 km, correlated with the SPRITE event.



Many SPRITES come without ELVES triggers ...

March 9, 2024: SIX SPRITES in less than 30' ! NONE with an ELVES trigger!

01:07:45



01:09:29



01:22:52



01:25:33



01:30:14



01:35:24



Can we write a stand alone trigger for SPRITES?

TLEcam-2 can fill a 2TB disk in one week of data taking. Challenge: process all data taken during the night in the following day, saving only TLEs

In order to reduce significantly the data set we need to save only periods with TLEs, and reject:

- car headlights below the horizon
- close thunderstorms with high lightning frequency
- bright stars

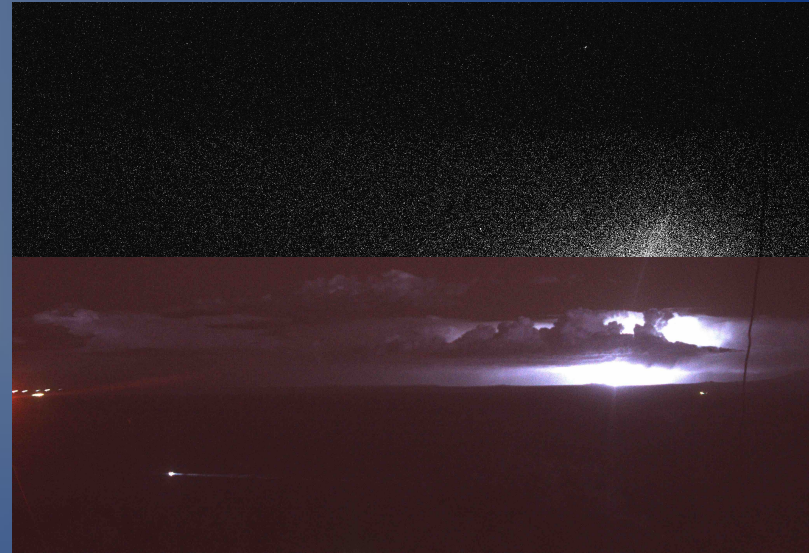


Python code for SPRITEs

Crop the upper part of the image with
an adjustable virtual horizon (YMIN)

Grey convert images

Subtract two consecutive images



YMIN



Python code for SPRITEs

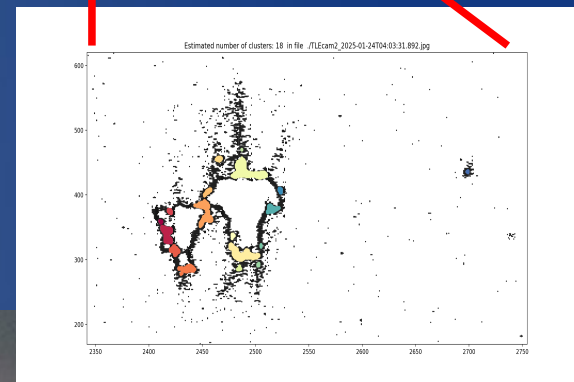
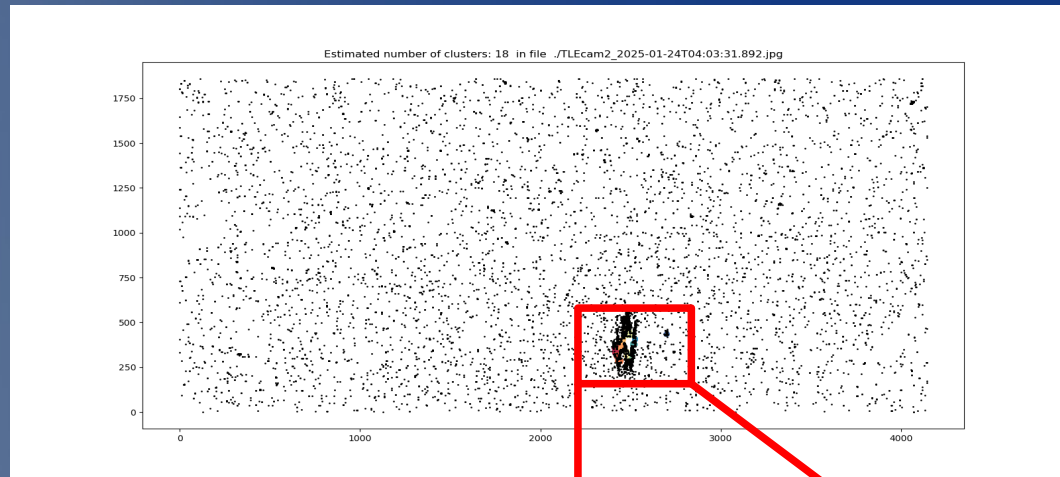
Crop the upper part of the image with an adjustable virtual horizon (YMIN)

Grey convert images

Subtract two consecutive images

Discriminate pixels above a given threshold

Check for clusters of pixels (DBSCAN)



Python code for SPRITEs

Crop the upper part of the image with an adjustable virtual horizon (YMIN)

Grey convert images

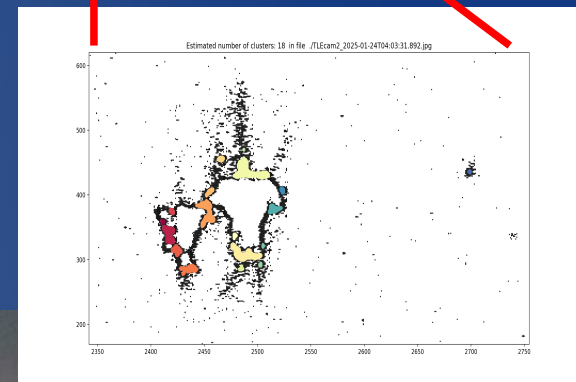
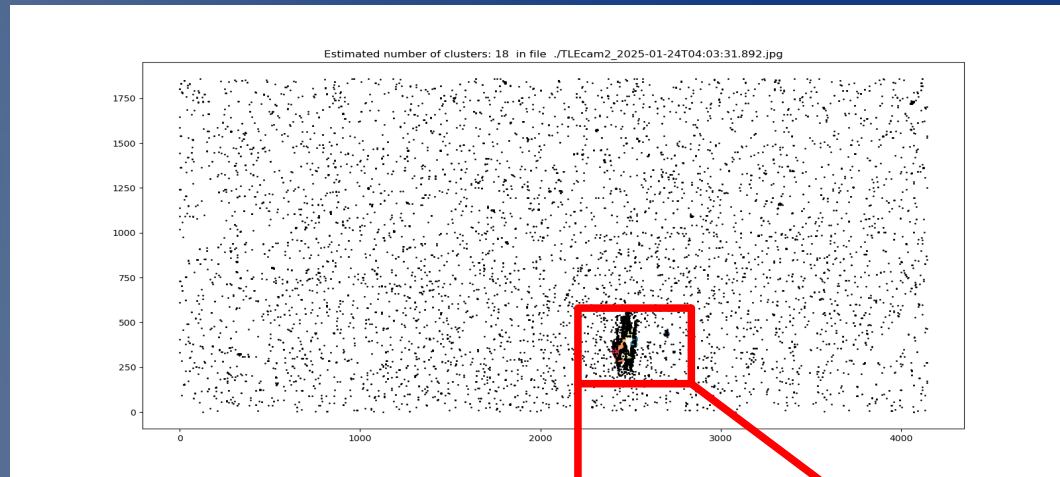
Subtract two consecutive images

Discriminate pixels above a given threshold

Check for clusters of pixels (DBSCAN)

Residual backgrounds: meteors, strong lightning, bright stars ...

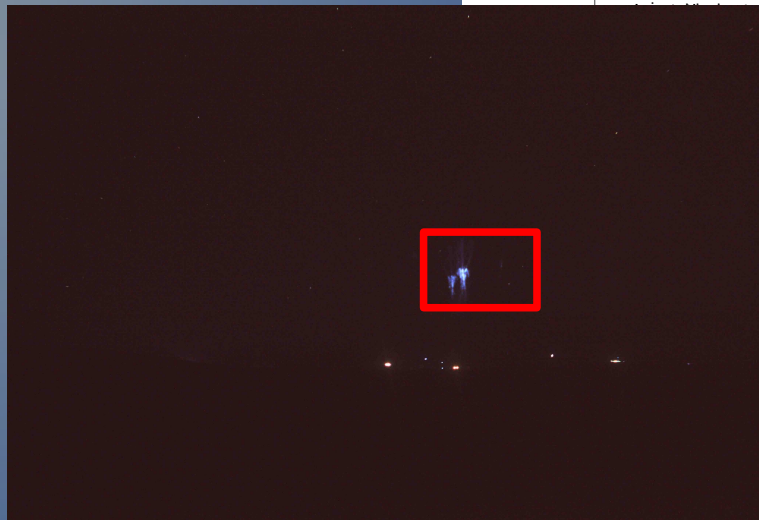
Suppression factor up to 1:1000 !!!



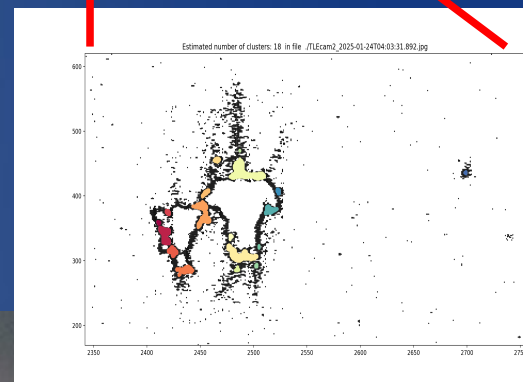
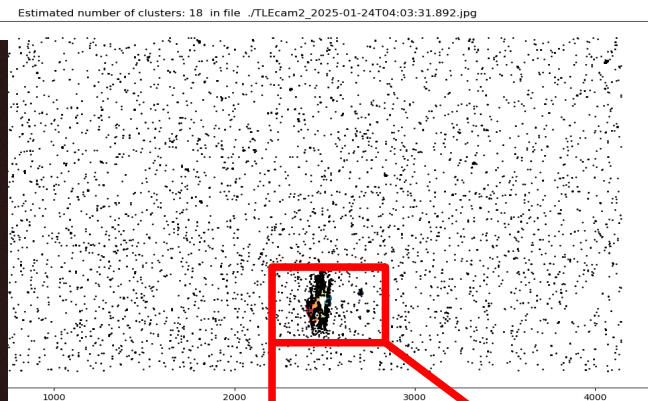
Python code for SPRITEs



Sony



ZWO



All night time lapse

The first second of each minute (the sum of ~15 frames, 60 ms long) is saved on disk and checked to set YMIN for the SPRITE finder.

A meteor is visible at 5:30 UTC: the gaps show the deadtime fraction.



*Nov 27, 2025
Right camera*

All night time lapse

The first second of each minute (the sum of ~15 frames, 60 ms long) is saved on disk and checked to set YMIN for the SPRITE finder.

A SPRITE is visible at
2:47:00 UTC

*Nov 27, 2025
Left camera*



SPRITES on Nov.27 2025

The first second of each minute (the sum of ~15 frames, 60 ms long) is saved on disk and checked to set YMIN for the SPRITE finder.

A SPRITE is visible at 2:47:00 UTC: the single frame at 602 ms shows a very faint one



*Nov 27, 2025
Left camera*

SPRITES on Nov.27 2025

TLEcam2l_2025-11-27T02:35:46.755_1448246164.jpg



The SPRITE at
2:35:46.755 UTC is
much brighter, almost in
the same location:
ENTLN hit: 24.725 kA
Lat: -32.7715
Long: -66.5751
MilliTime: 527

*Nov 27, 2025
Left camera*

SPRITES on Nov.27 2025

TLEcam2l_2025-11-27T02:45:19.446_1448246737.jpg



Also the SPRITE at
2:45:19.446 UTC is
much brighter, almost in
the same location
ENTLN hit: 84.595 kA
Lat: -32.8053
Long: -66.4975
MilliTime: 300

*Nov 27, 2025
Left camera*

SPRITES on Nov.27 2025



SPRITES on Nov.27 2025



SPRITES on Nov.27 2025



SPRITES on Nov.27 2025



SPRITES on Nov.27 2025



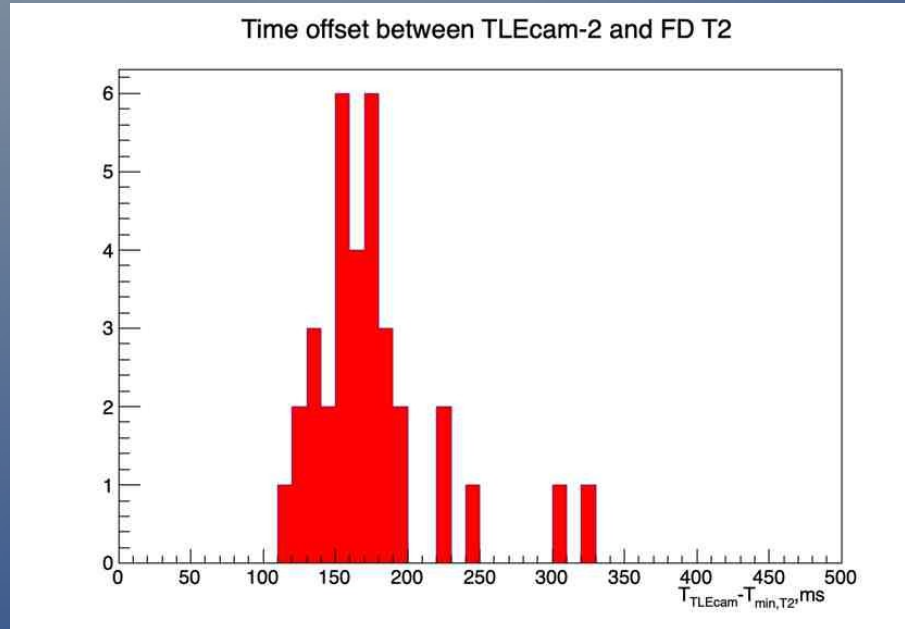
SPRITES on Nov.27 2025



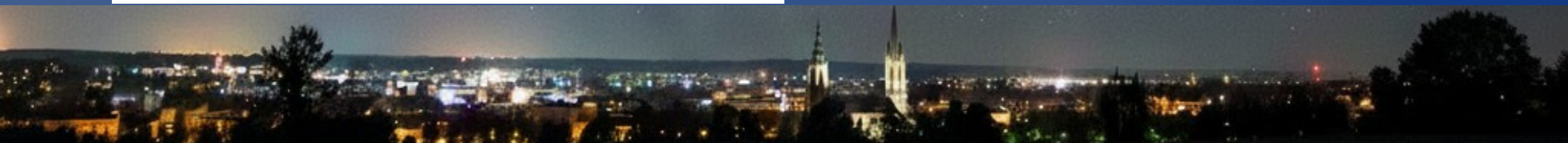
TLEcam – FD time synchronisation

Can we use FD to provide SPRITE timing information without ELVES triggers? YES

Using 2nd level FD Trigger we can time tag sudden bursts of light in each telescope with a precision of $\sim 1 \mu\text{s}$, and record the number of hit pixels every 100 μs .



Typically the T2s from SPRITES come in bursts, and the time of the first T2 can be compared to the UNIX time which identifies the frame (60 ms wide) which contains the SPRITE.



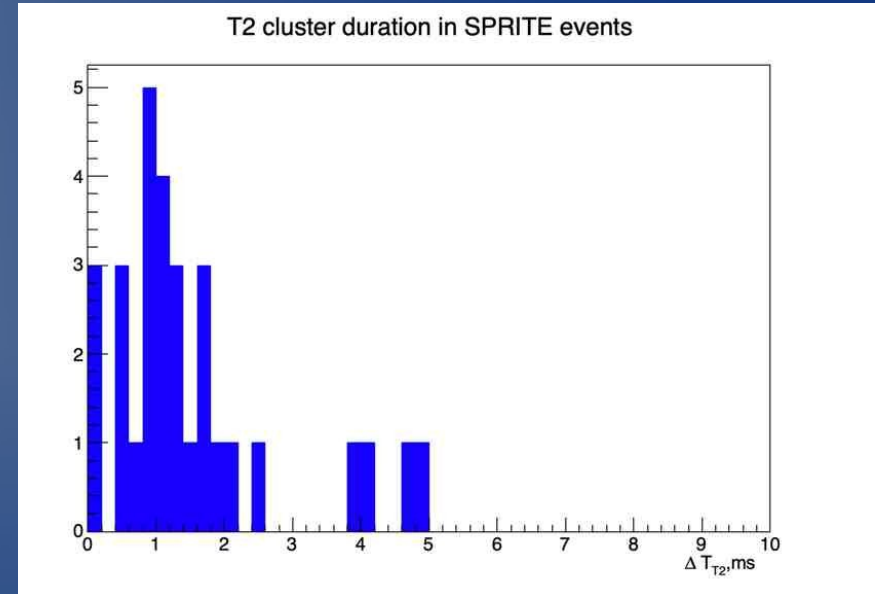
TLEcam – FD time synchronisation

Can we use FD to provide SPRITE timing information without ELVES triggers? YES

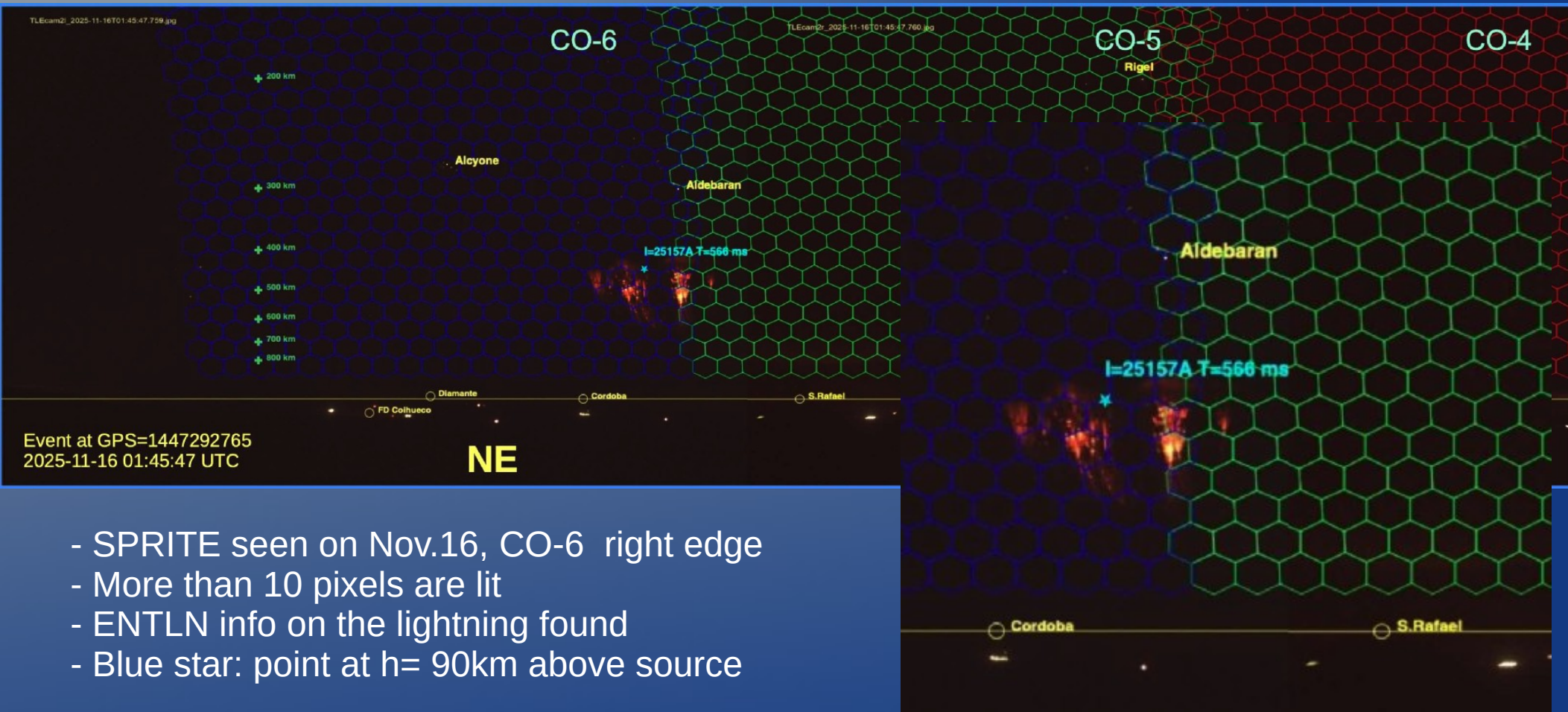
Using 2nd level FD Trigger we can time tag sudden bursts of light in each telescope with a precision of $\sim 1 \mu\text{s}$, and record the number of hit pixels every $100 \mu\text{s}$.

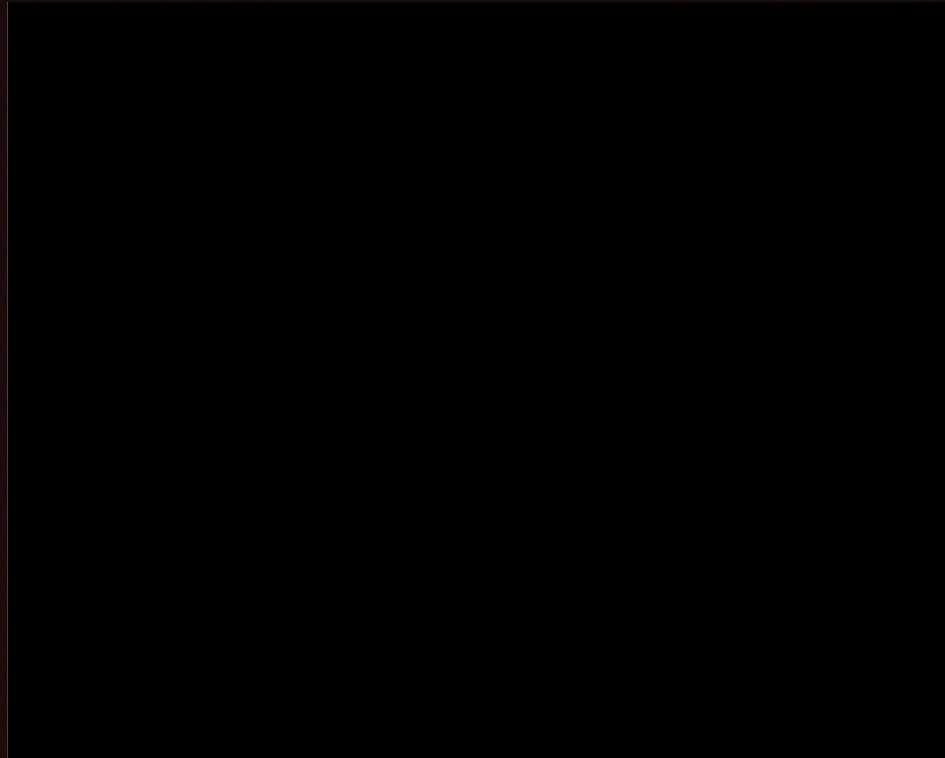
The T2 buffer depth is only 6.4 ms, but allows to measure the duration of most SPRITES.

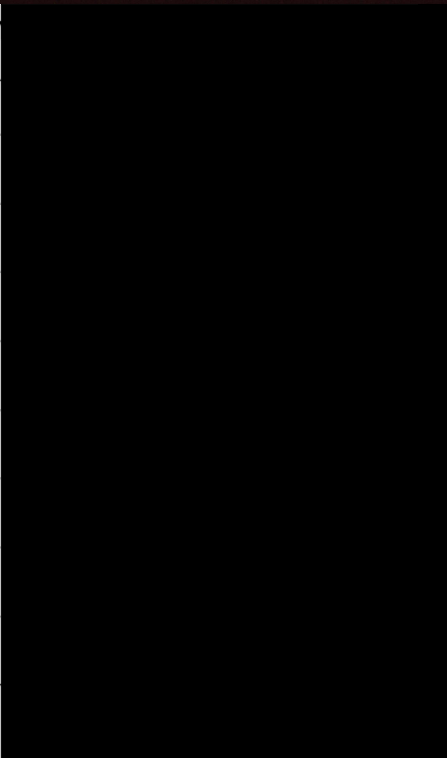
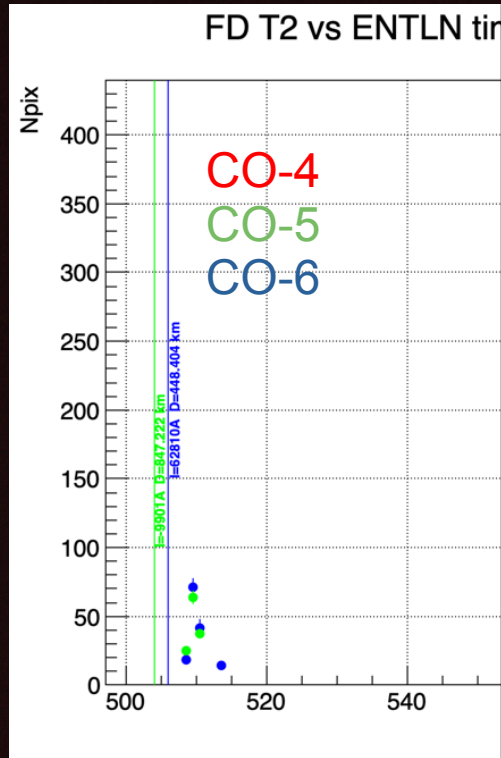
The number of consecutive, adjacent T2s in a burst allow to have an estimate of the time duration of the brightest part of a SPRITE, if its light emission covers at least 4 adjacent pixels.

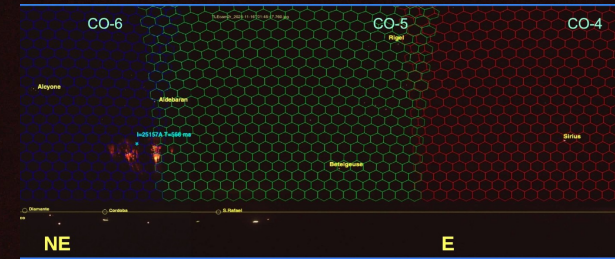
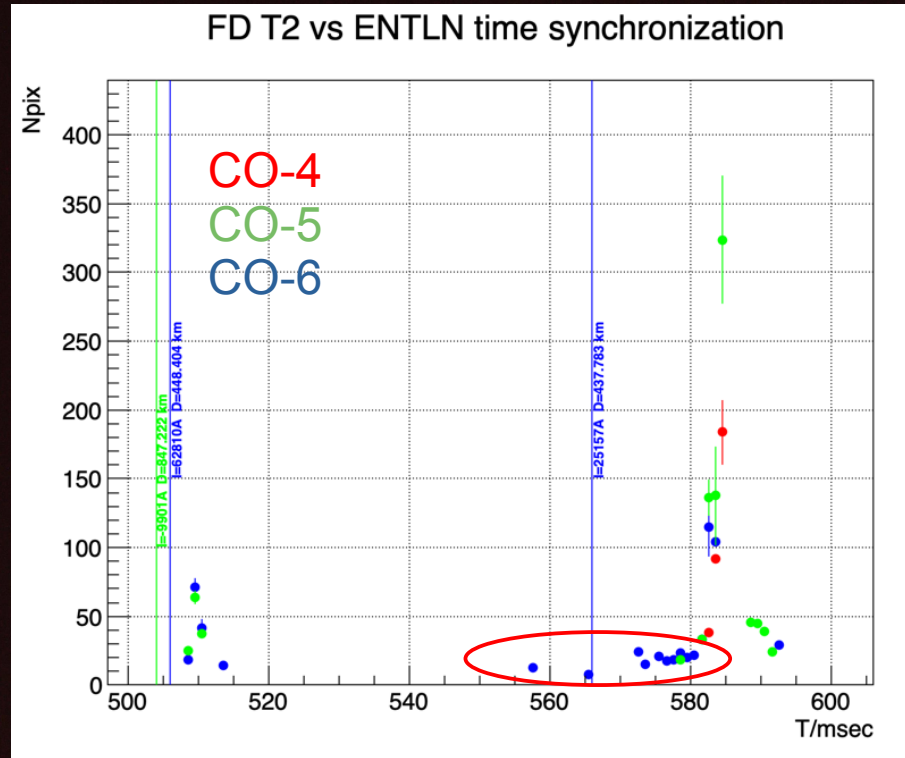


TLEcam – FD in GPS 1447292765 event



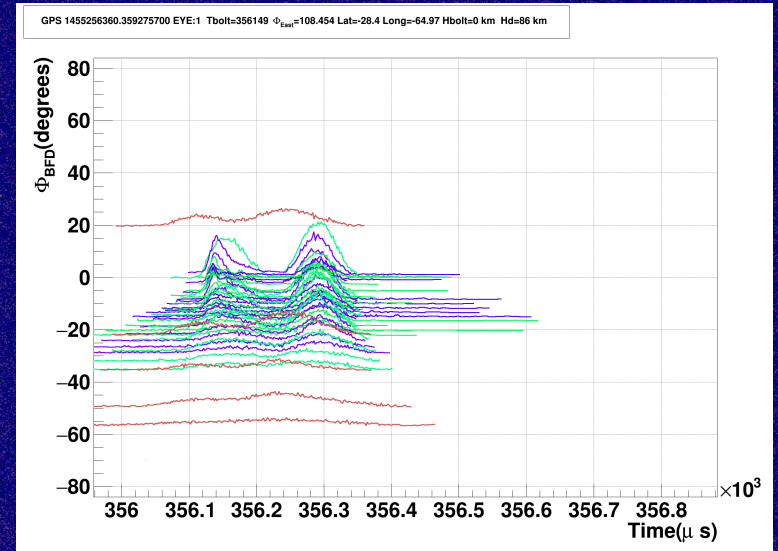
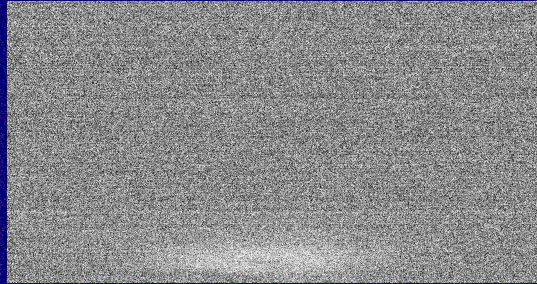






SPRITES are recognized as sequences of many T2's with 10-30 pixels lit; the lightning glow (or a faint ELVES?) can last much less, and is seen by 2 or 3 telescopes

More ELVES in ZWO cameras!



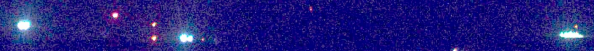
GPS=1455256360

DOUBLE ELVES at ~920km

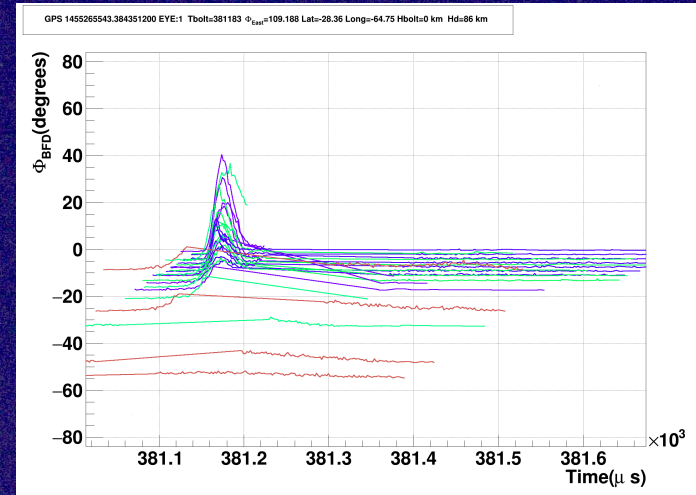
ENTLN: -135kA

Lat=-28.40, Long=-64.97, T=356.13 ms

Seen by LL



More ELVES in ZWO cameras!



GPS=1455265543

ELVES at ~930km

ENTLN -211.7kA
 Lat=-28.36 Long=-64.76 T=381.165ms

Seen by LL



More ELVES in ZWO cameras!

ELVES at ~660km



ENTLN -33.143kA

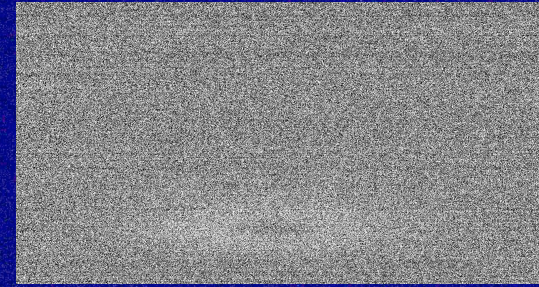
Lat= -31.10, Long=-66.15,

T=385.967ms, Hb=19.2 km

Seen by LL



More ELVES in ZWO cameras!!



GPS=1455782903

ELVES at ~660km

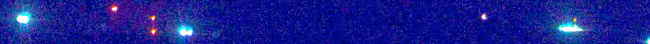


ENTLN -33.143kA

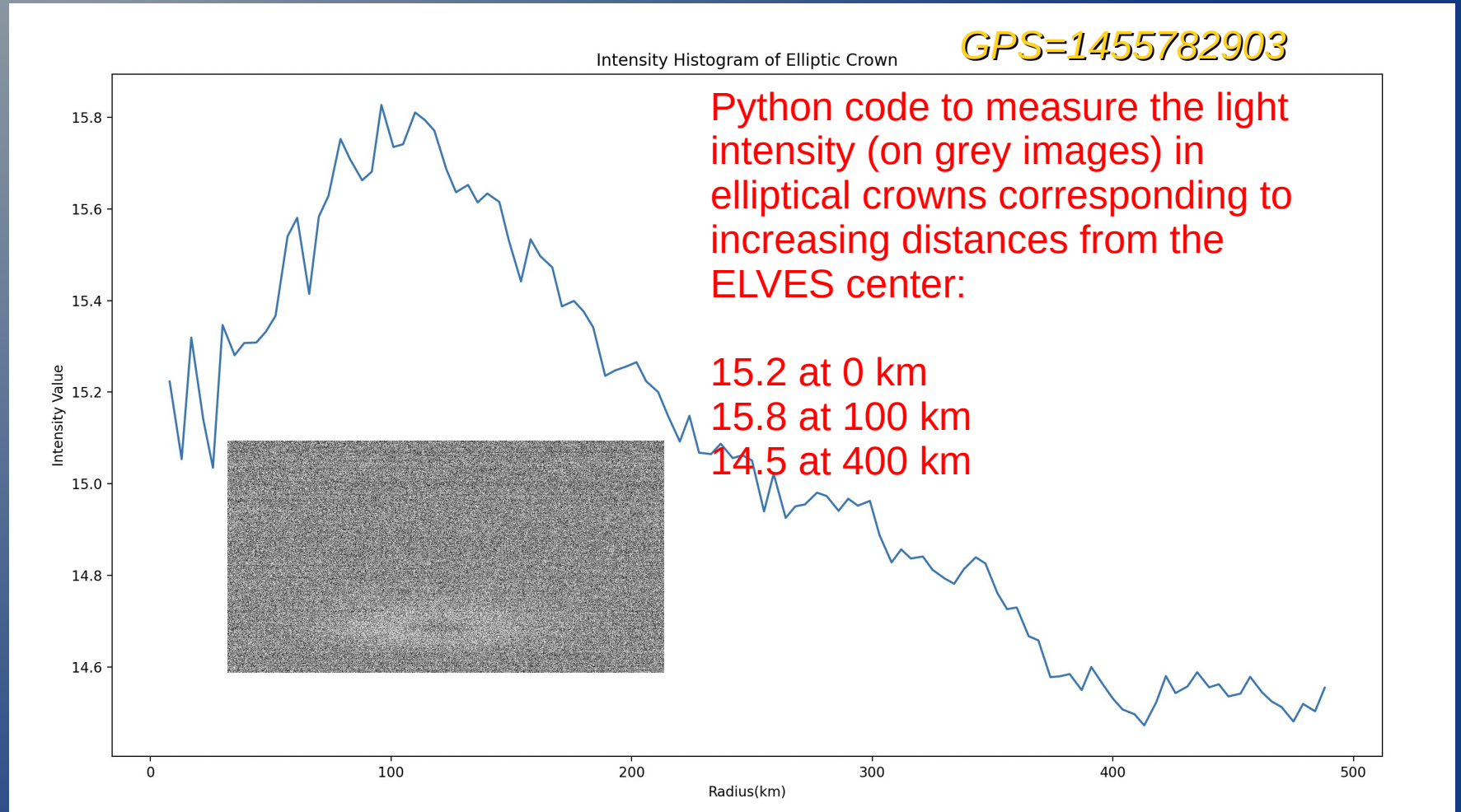
Lat= -31.10, Long=-66.15,

T=385.967ms, Hb=19.2 km

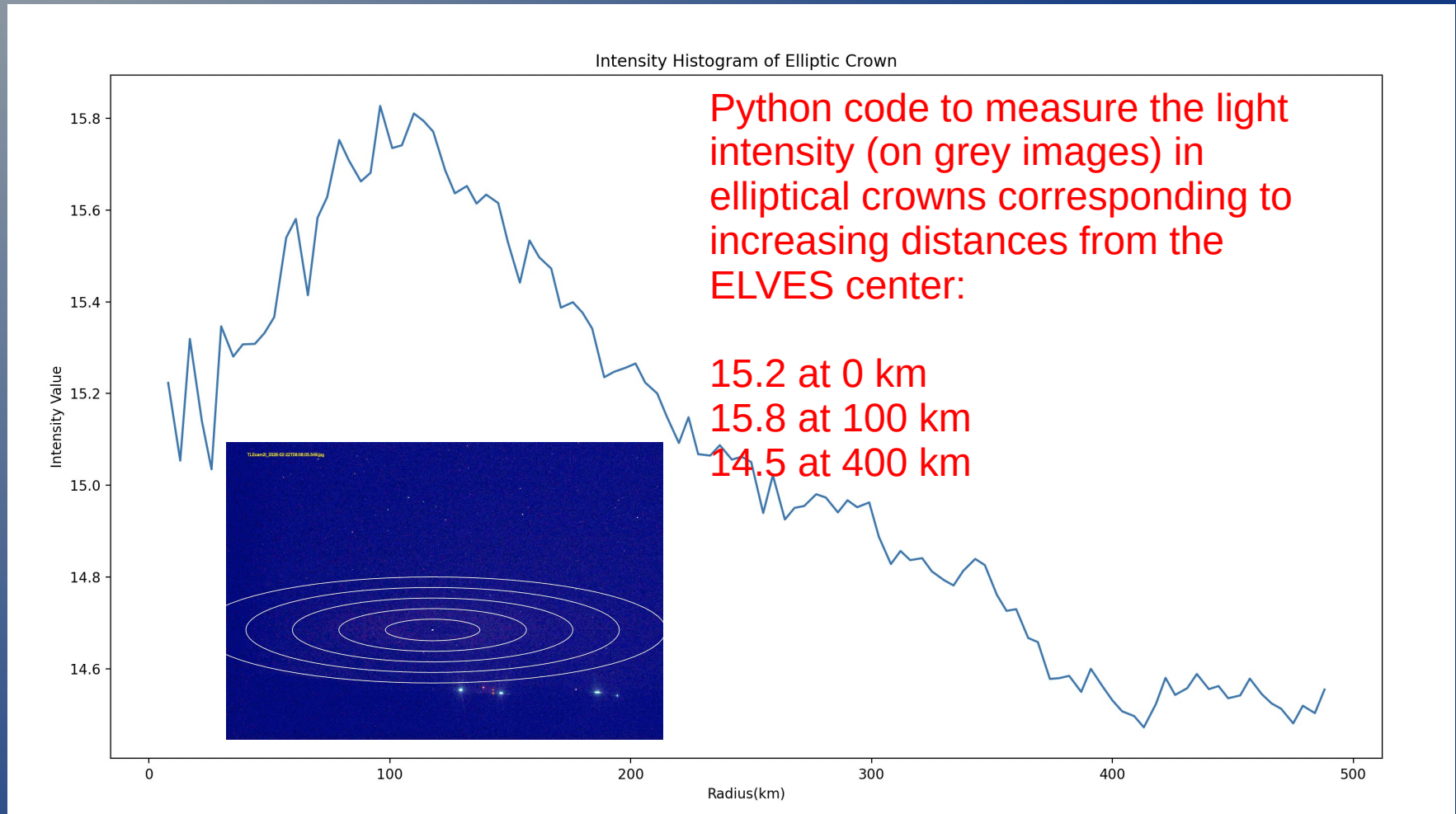
Seen by LL



Quantifying light emission

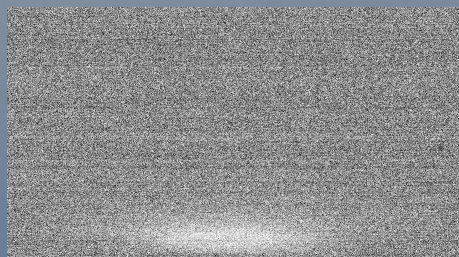


Quantifying light emission

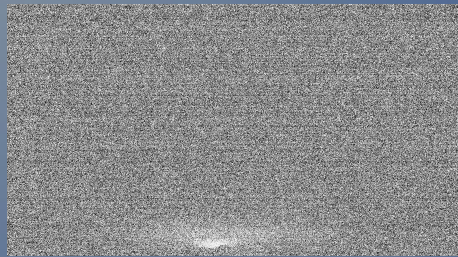


Learning to see ELVES in the TLEcams ...

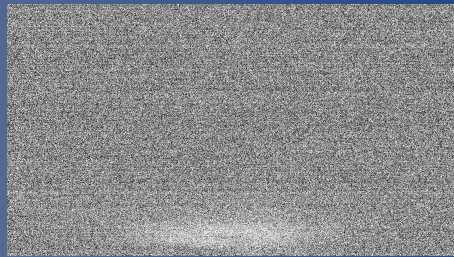
February 16 events (distance about 920 km)



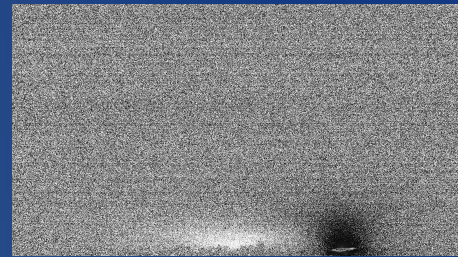
GPS1455253995



GPS1455255808

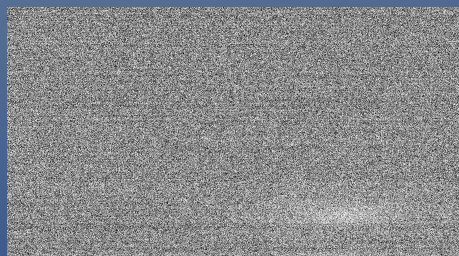


GPS1455256360

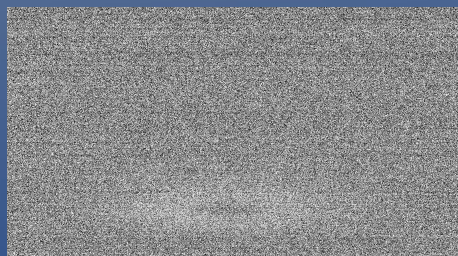


GPS1455265543

February 22 events (distance about 660 km)



GPS1455782756



GPS1455782903

Images obtained

- converting RGB to gray

- differentiating frames:

$$\text{Diff} = [2F_0 - F_{-1} - F_{+1}] / 2$$

Summary and prospects

- The setup with Sony $\alpha 7$ -III and a ZWO ASI294MC with a movable frame costed me a countless number of sleepless nights ... and many misses: multiple storms in Argentina frequently develop on a very wide front
- The ZWO1+2 static setup is up and running, taking data every night, and cleaning the disk the day after.
- Scripts have been optimized to automatize operations
- Python code with astropy allows precise star alignment of all images
- Finally we learned to see ELVES in the TLE cameras... but it's very hard with the current rate: 15 fps. Working out a way to run the Sony not continuously at 100 fps.
- Python code is being developed to improve ELVES detection by ZWO
- Work in progress :
 - finalize analysis on light ratios in double and triple ELVES
 - correlate light intensity of FD images with TLE images
 - automatize multiple ELVES reconstruction
- Wish: detect a gigantic jet

Photo taken by Valter Binotto on Nov.26,2025
from Treviso : ELVES at 350 km distance above
Adriatic sea from a 387 kA lightning

