Multiple ELVES and more TLEs at the Pierre Auger Observatory

PIERRE AUGER OBSERVATORY

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AtmoHEAD

Outline

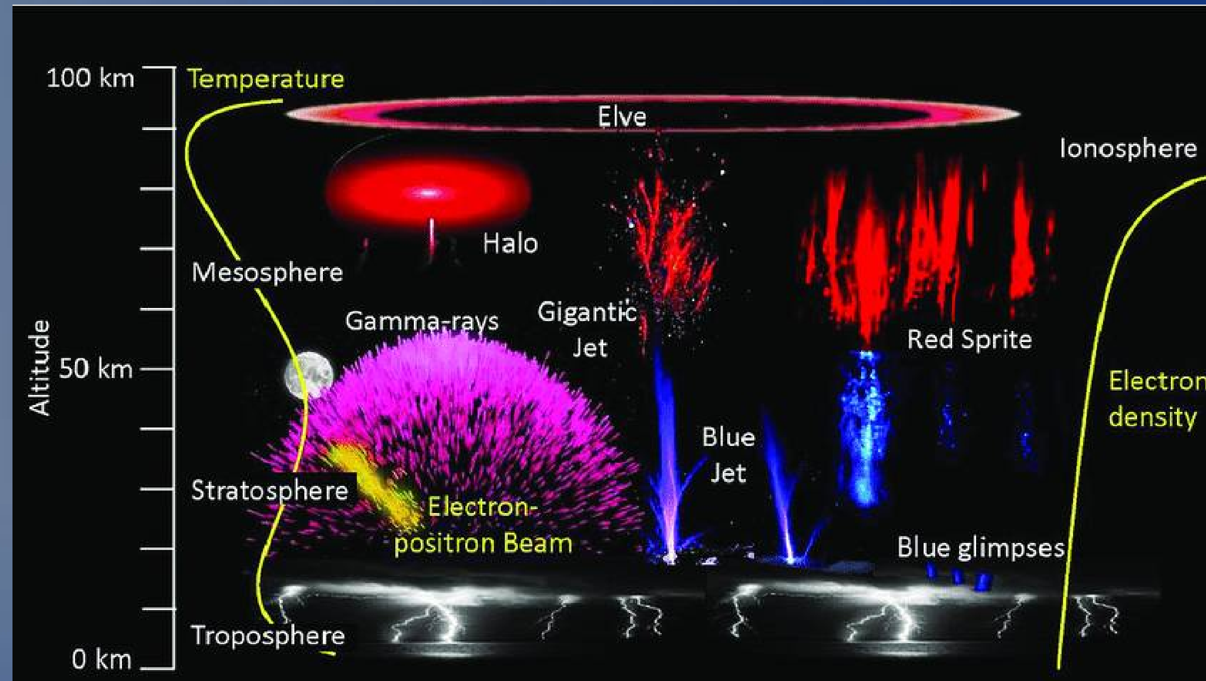
Auger FD triggers:

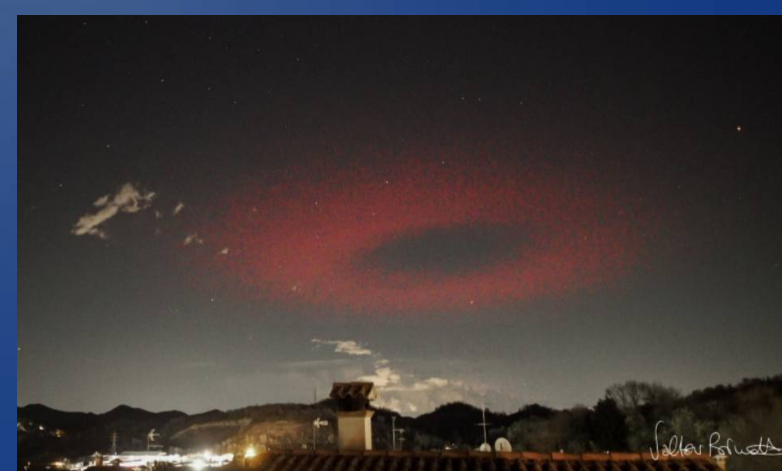
- Double/Triple ELVES

- Halos after ELVES

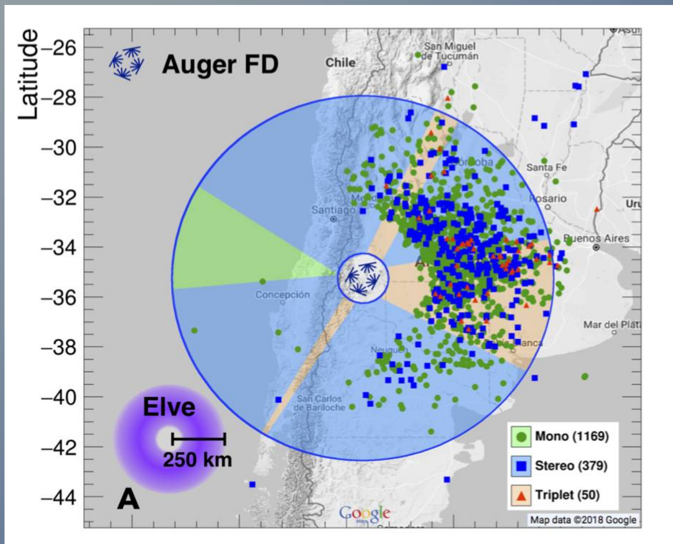
The new TLECams in Auger:

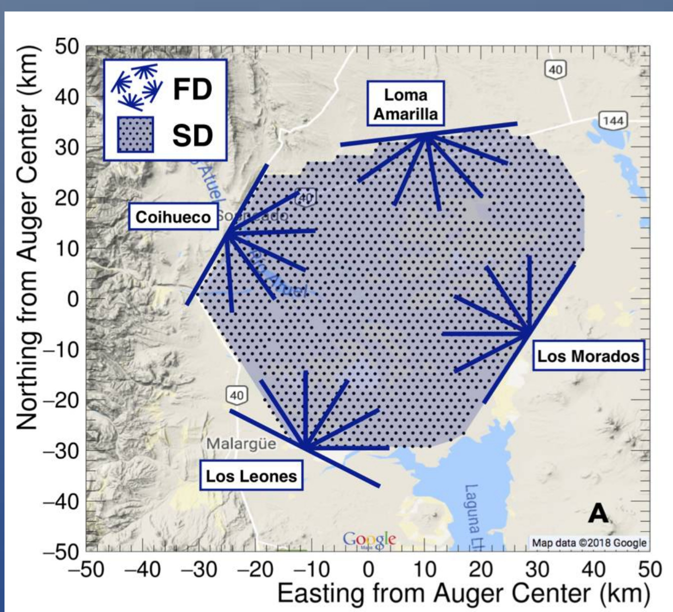
- First SPRITES in Auger

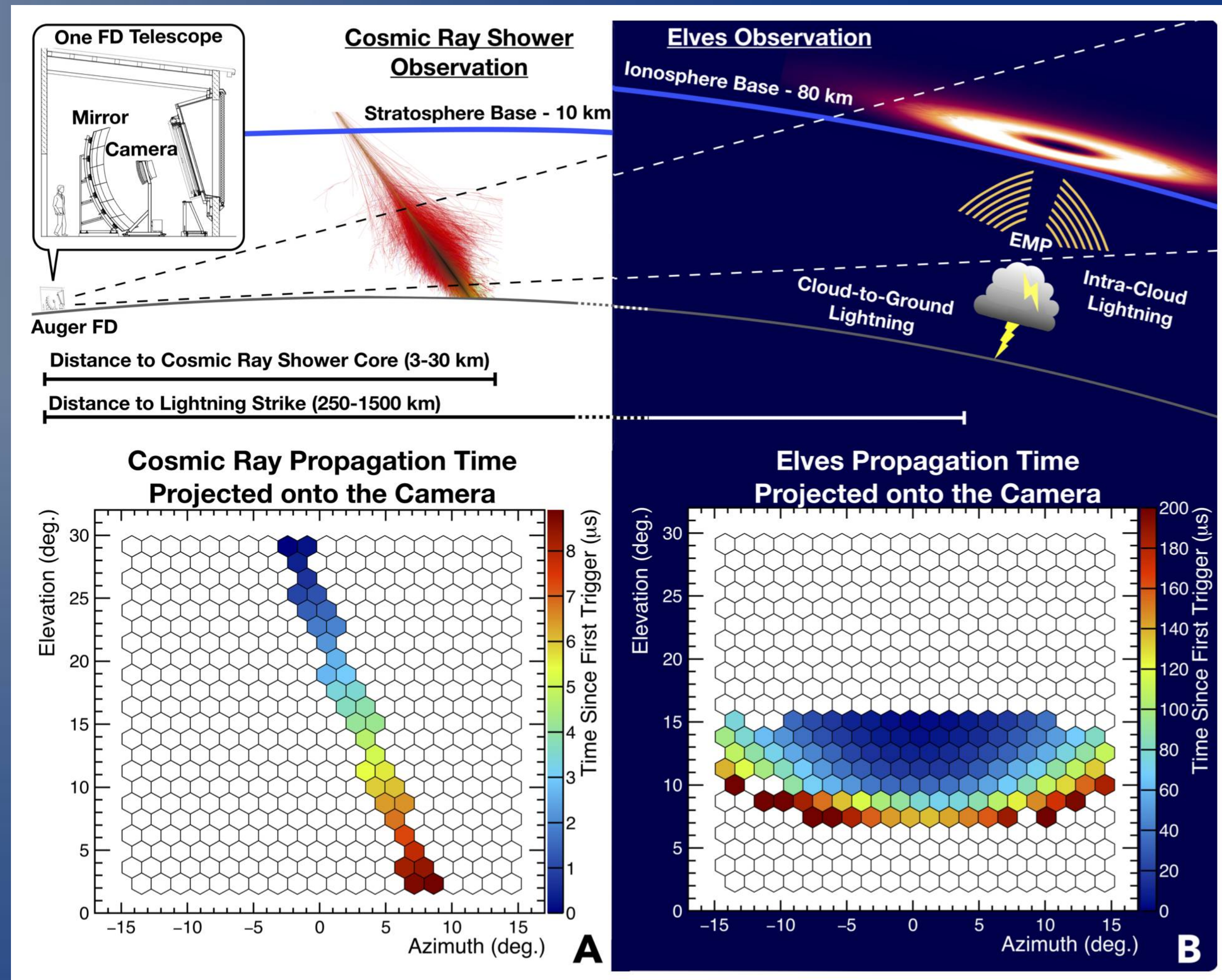




Observation of ELVES at the Auger Observatory



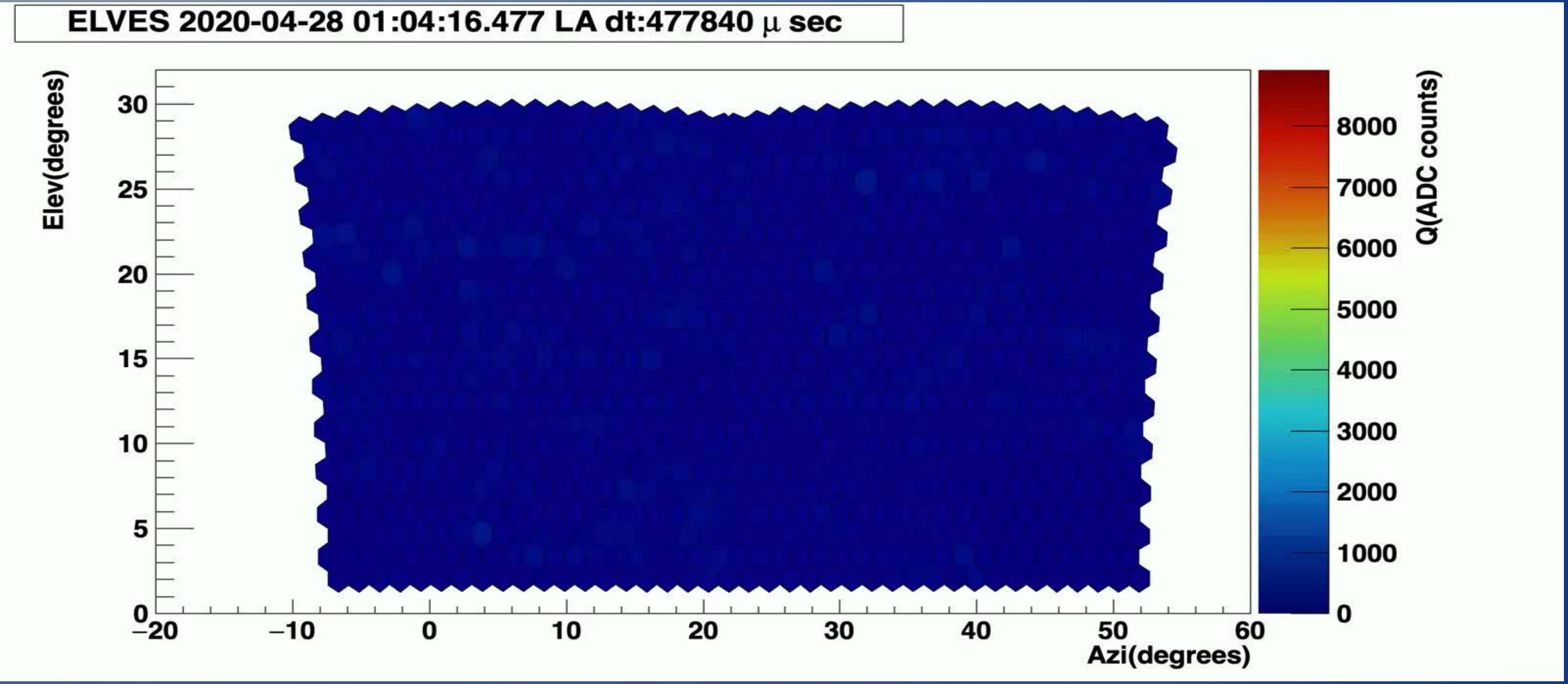




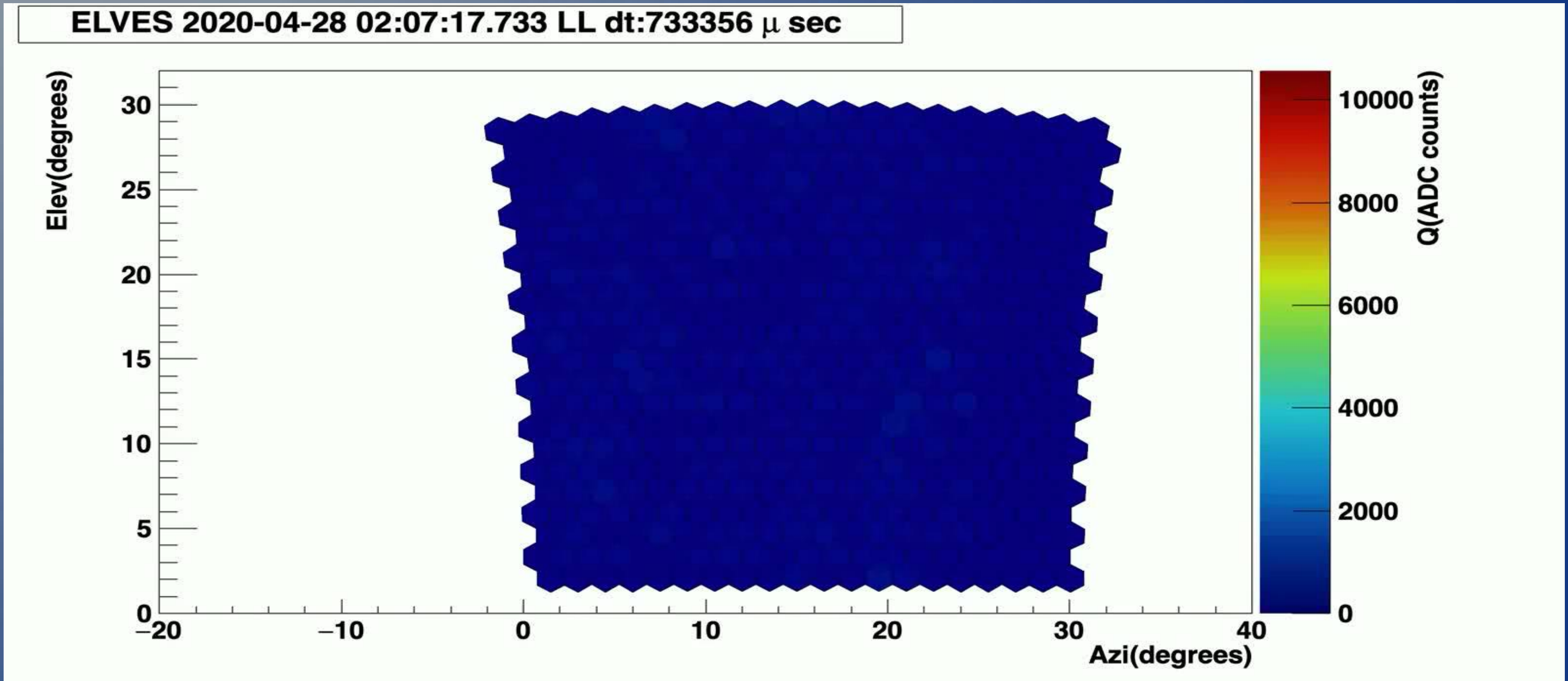
A.Aab et al,Earth Space Sci. 7 (2020) 4

DAQ: 100(x9) µs traces, 100(x20) ns bins

Double ELVES

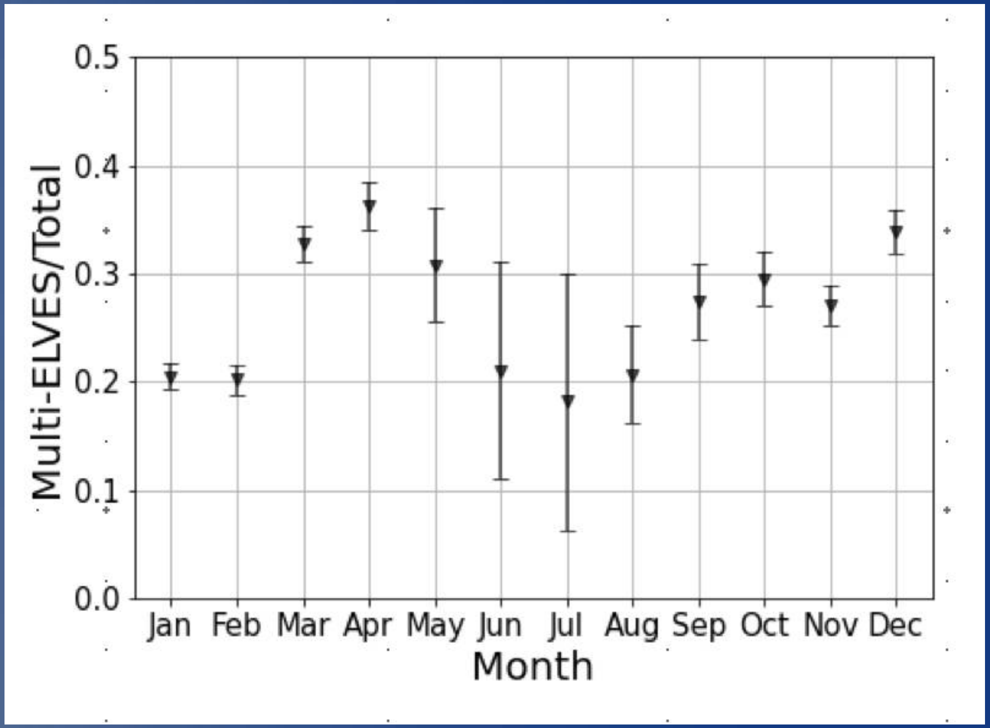


Triple ELVES

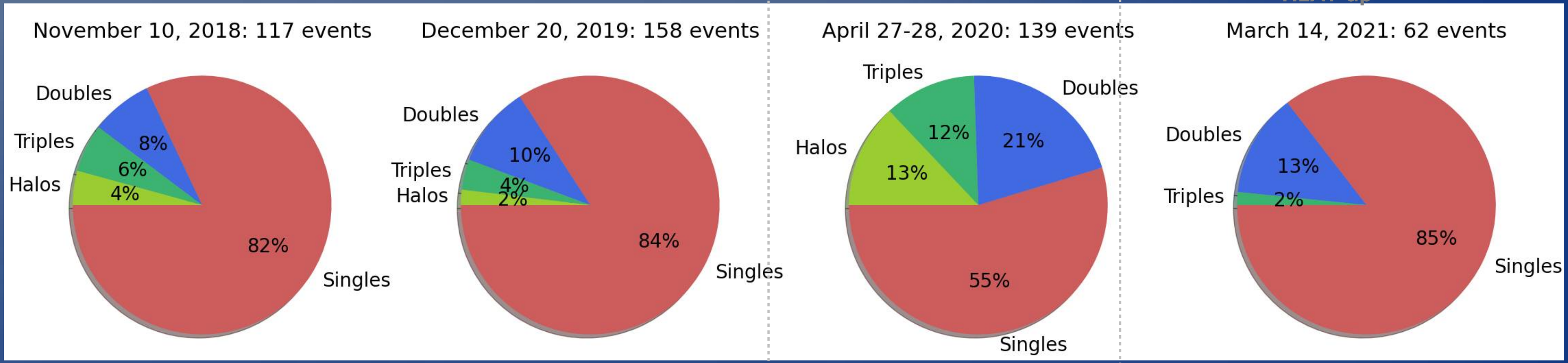


Multiple ELVES in four storms

- the fraction of events with multiple elves is higher in April and December
  → nature of multiple elves may be related to the type of storm
- beside double elves, we see a significant number of triple elves ...
- ... and halos (a different type of TLE)
- Auger published the first evidence of triple ELVES, in this analysis we will discuss more than 30 triple ELVES



HEAT-up



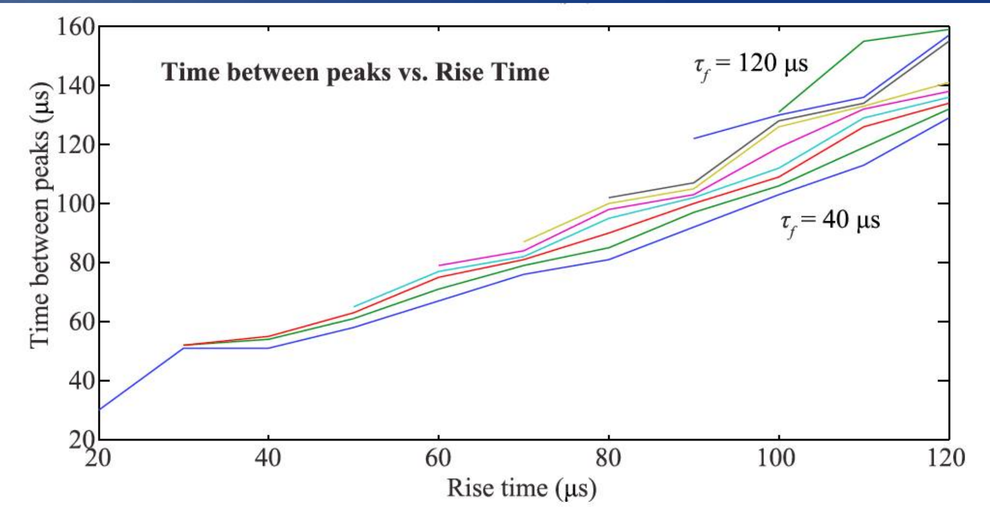
Storm with the most multi-elves between 2014 and 2020

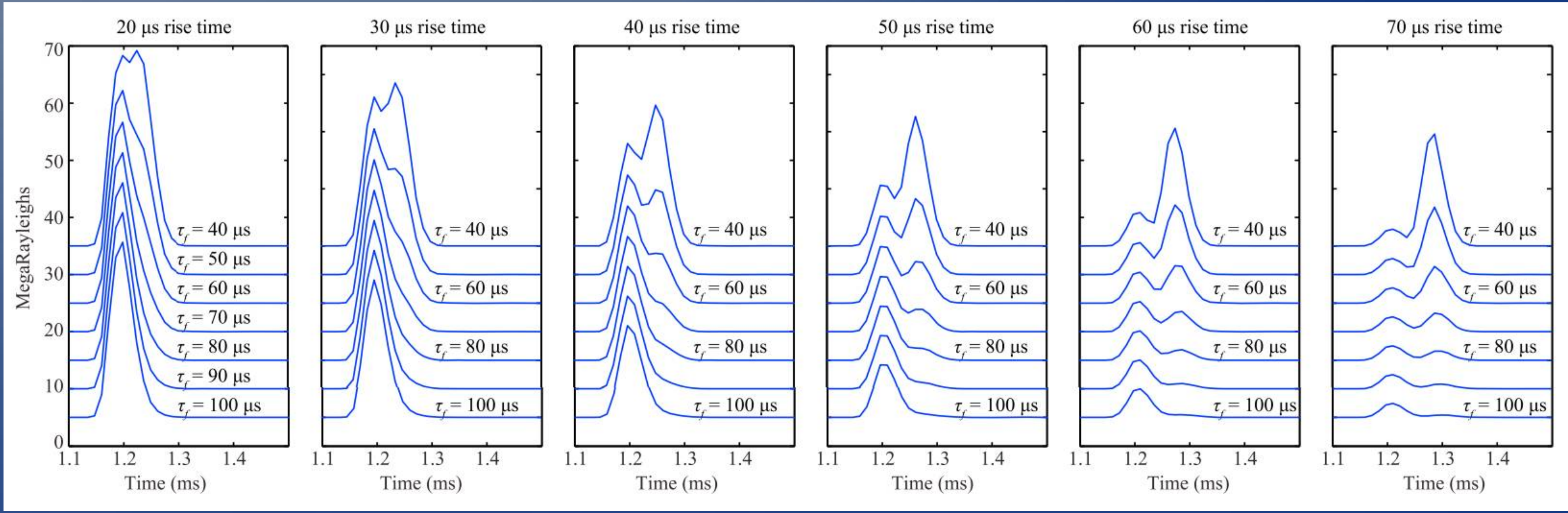
What causes

Time gap and peak ratio give insights on the source current.
The EMP source current is modeled as:

$$J_s(t) = \begin{cases} J_0 t/\tau_r & t < \tau_r \\ J_0 e^{-(t-\tau_r)^2/\tau_f^2} & t \geq \tau_r \end{cases}$$

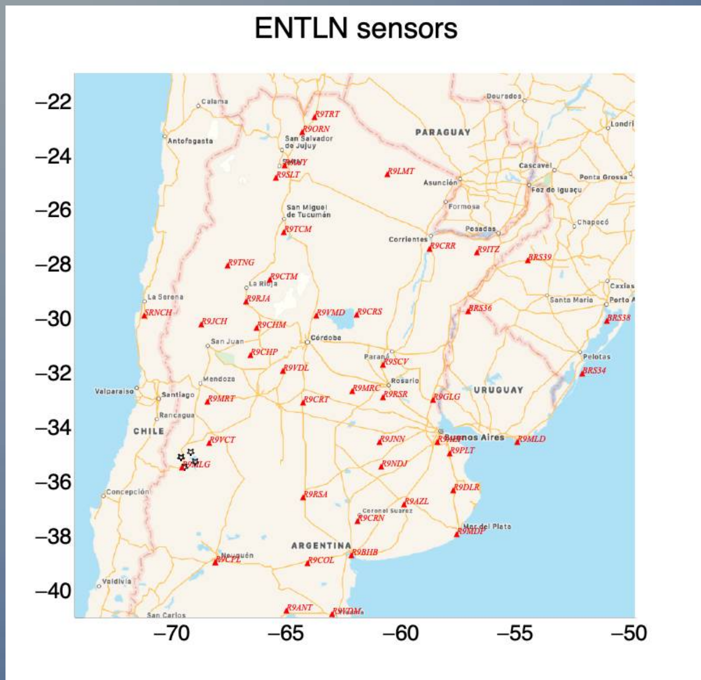
Time gaps depend almost linearly from risetime tr and more weakly from falltime tf

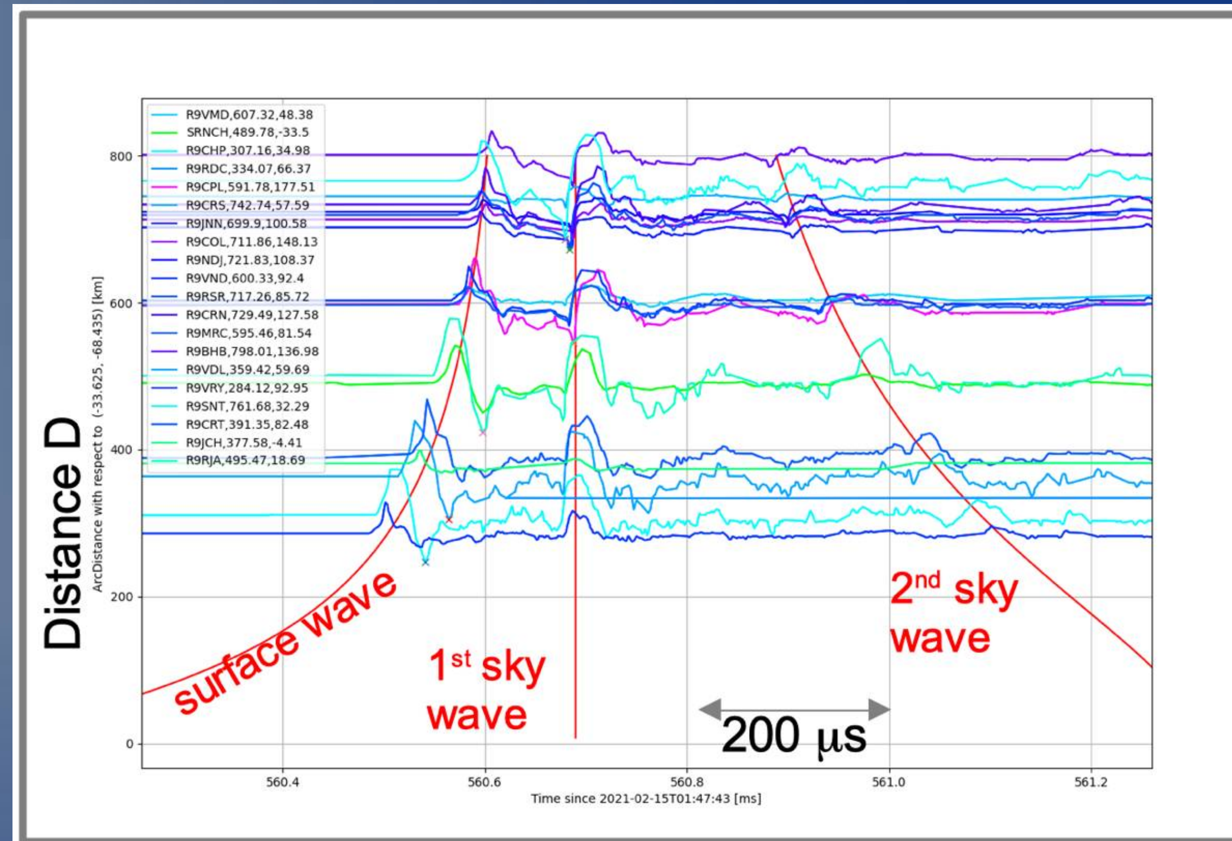




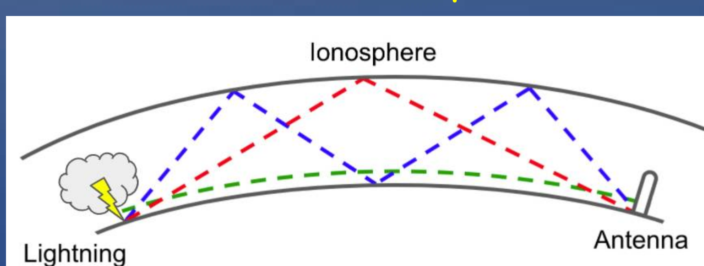
Marshall,RA (2012) , J.Geophys.Res.,117(A3)

ENTLN Network





- >35 antennas in ARG
- installed in (austral) Summer 2018-2019
- bandwidth: 1 Hz – 1.2 Mhz
- time resolution <1 μs



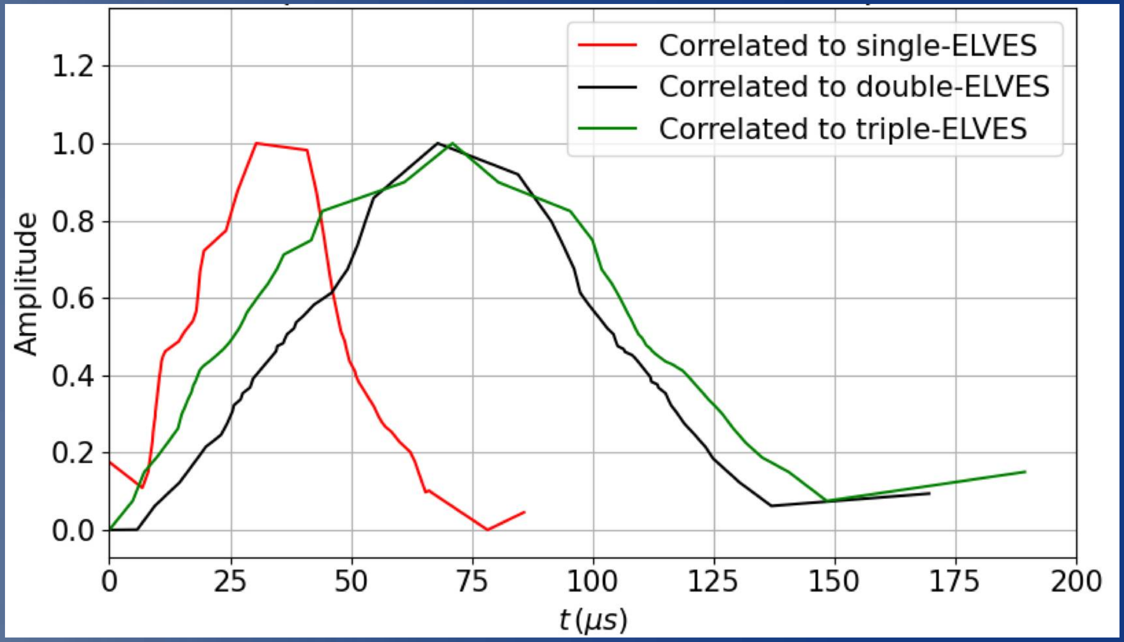
Using Long-Lat of the source from ELVES reconstruction, time delays are corrected and waveforms are aligned .

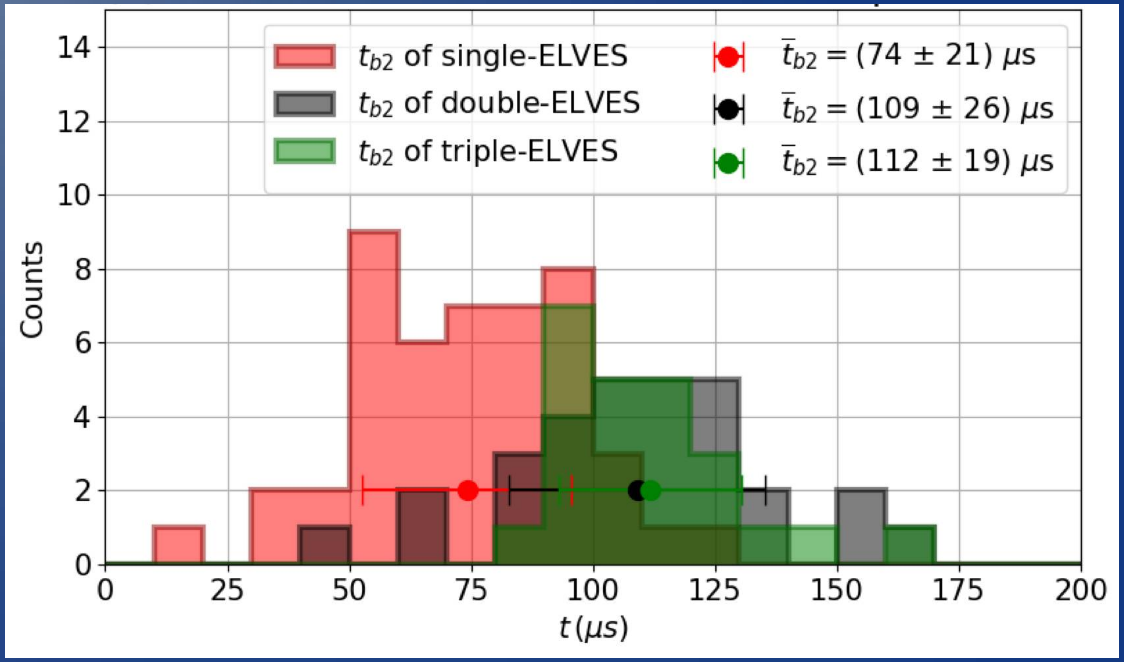
Sorting as functions of distance D from the source we can identify the 3 components. The 1st sky wave in the range D=(300,400) km is used to determine waveform parameters.

Multiple ELVES vs ENTLN waveforms

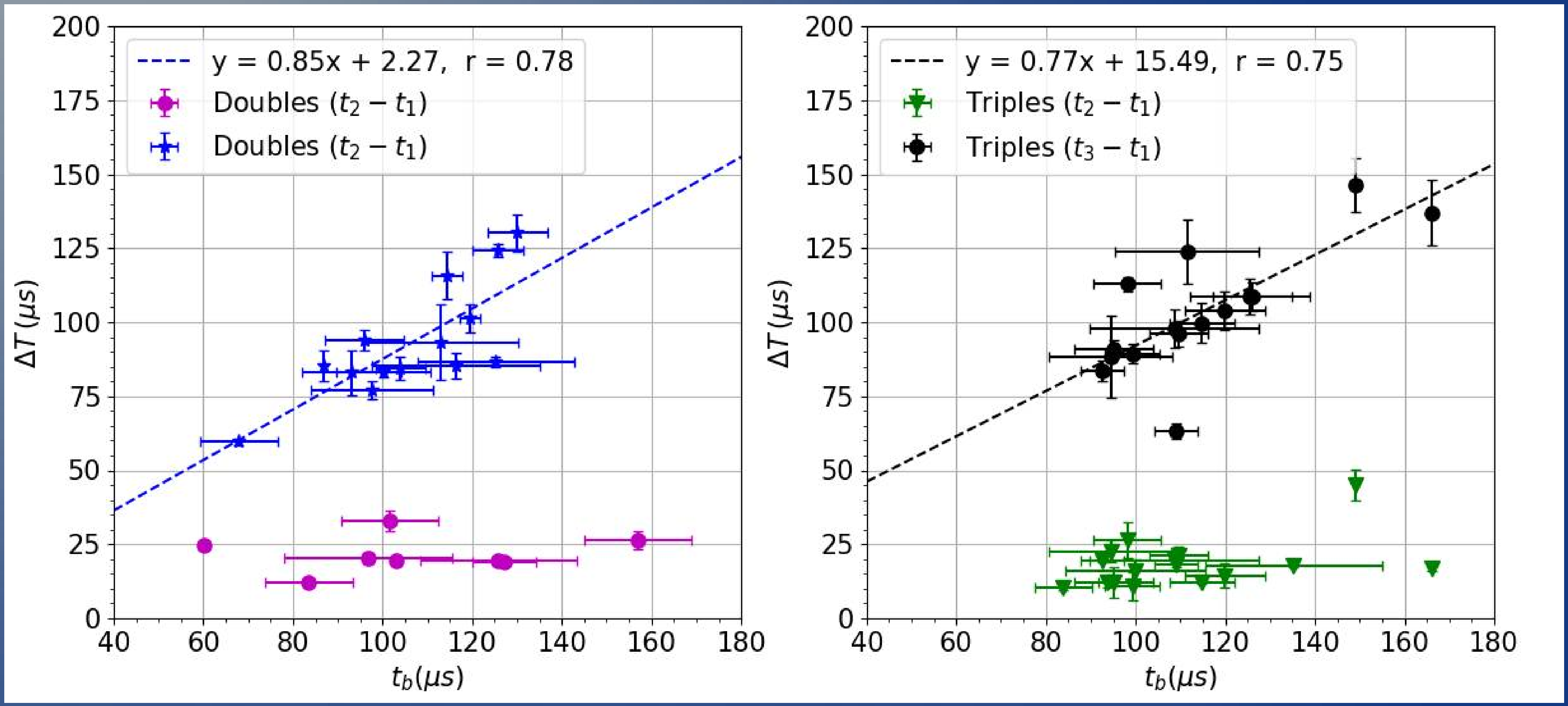
As waveform signals often saturate, calculation of risetimes and fall times is altered, therefore we use basetimes . In any case the difference between single and multiple elves is significant.

Double and triple elves show similar behavior.



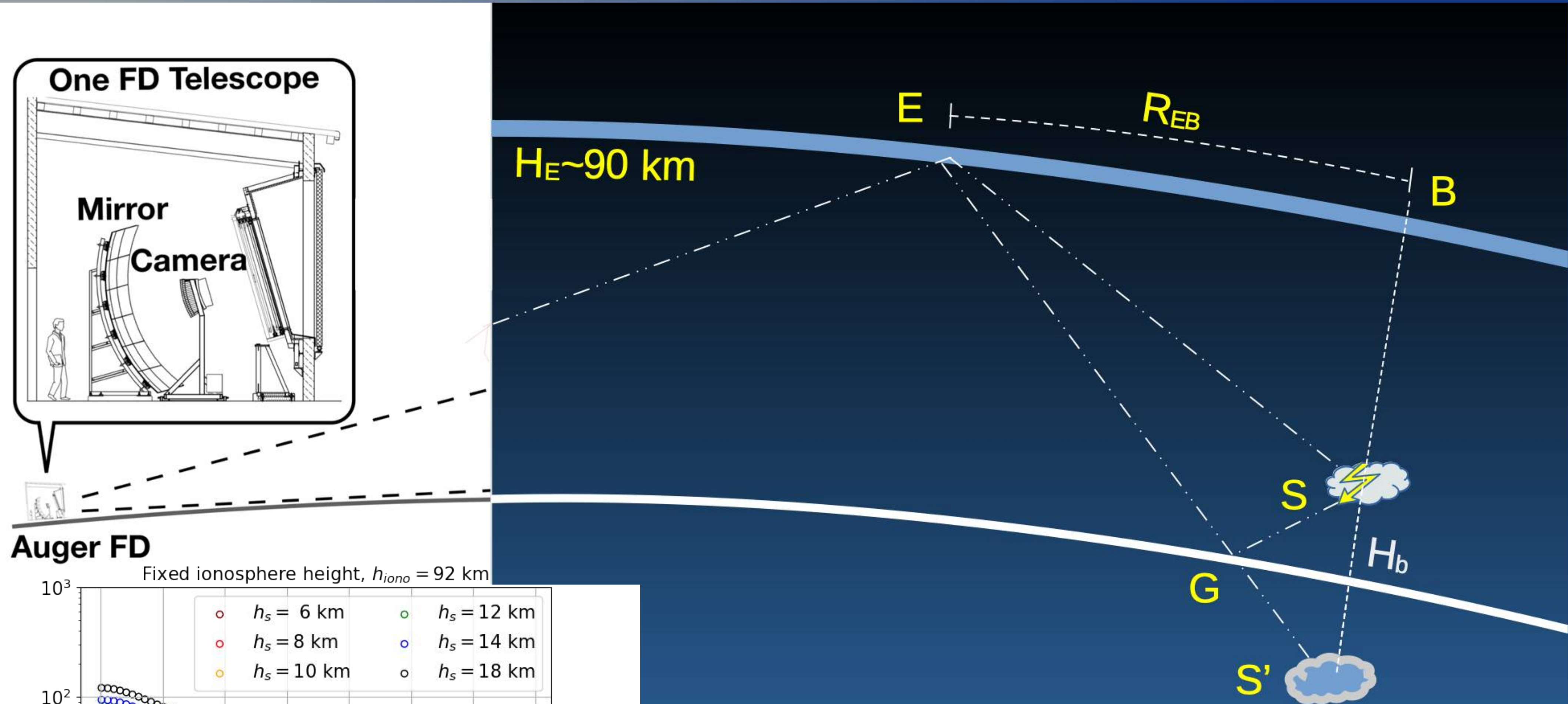


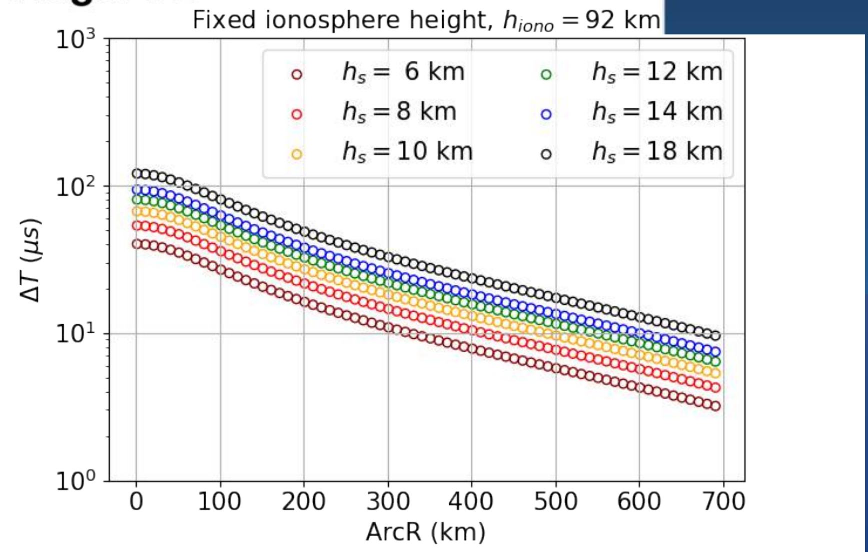
ELVES time gaps vs ENTLN waveform basetime



Auger time resolution allows us to measure time gaps well below 40 us.
These are not correlated with waveform basetimes and seem to originate from a different mechanism.

Ground reflection in multiple ELVES





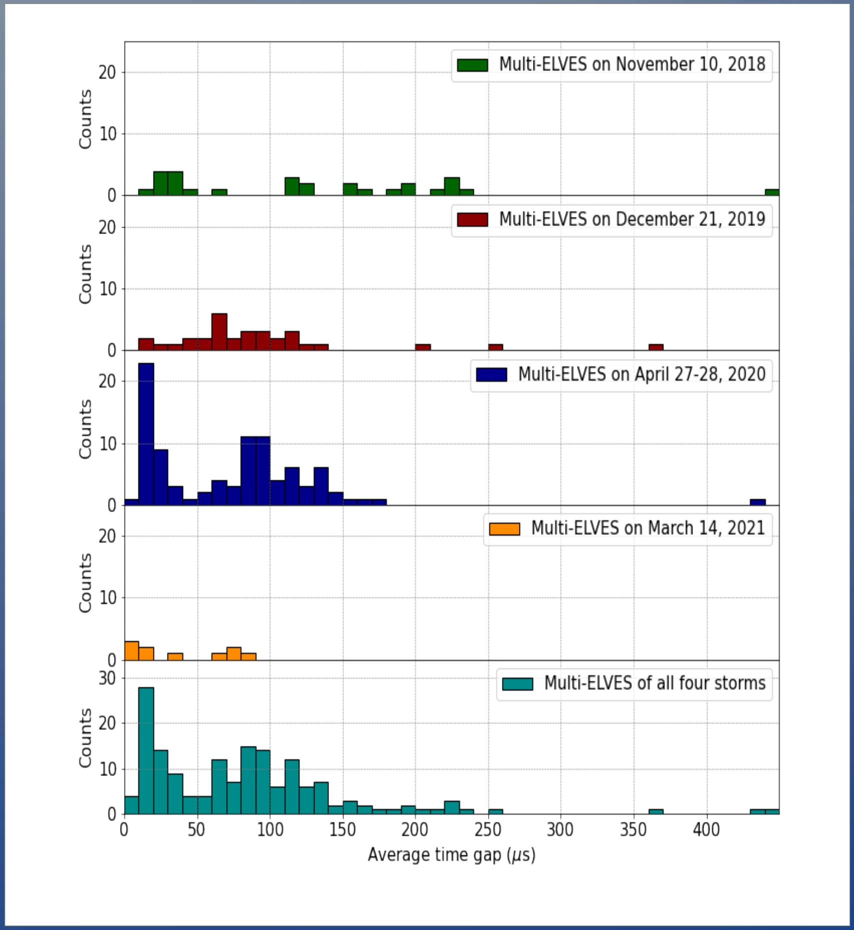
The Time difference between flashes:

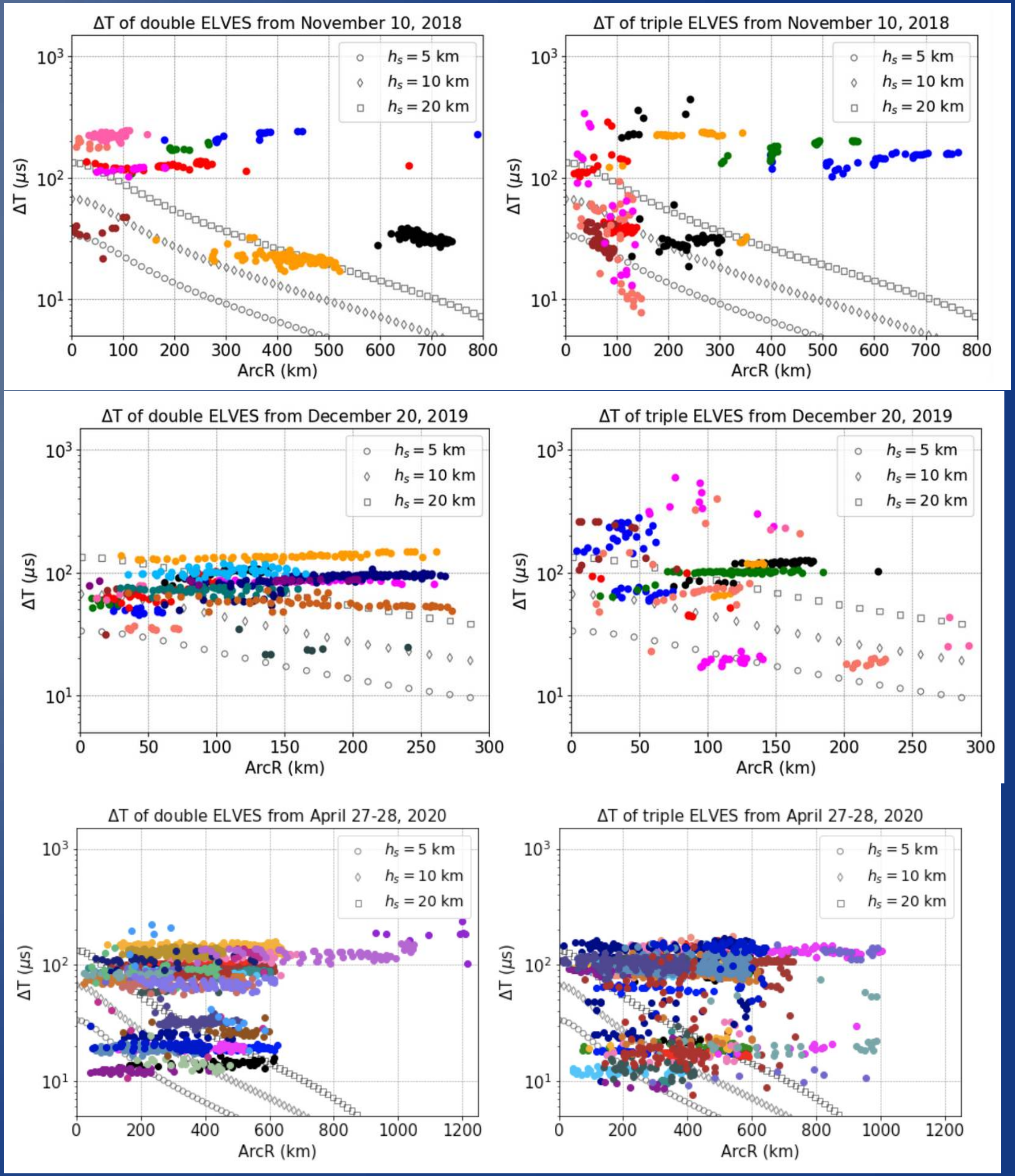
- is given from $(\overline{S'E}-\overline{SE})/c$
- depends from $H_b=h_s$
- decreases with ArcR = R_{EB}

Time gaps from double and triple ELVES

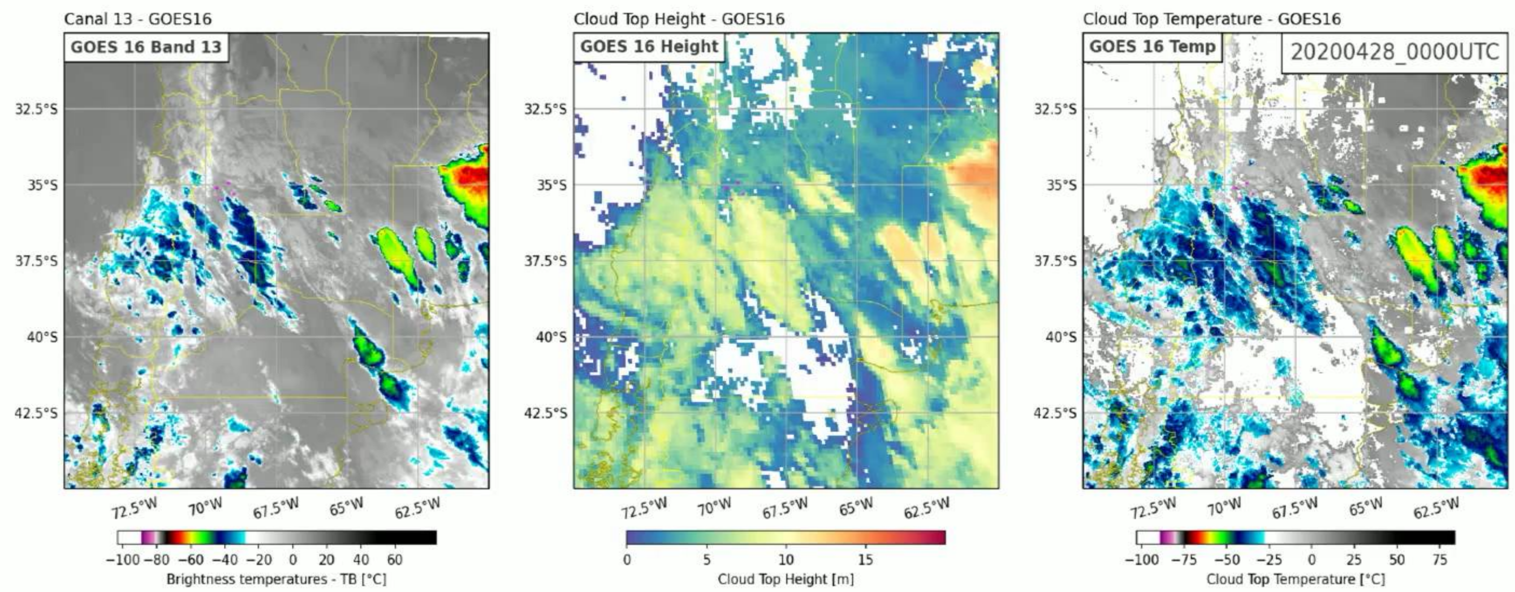
Auger can see time gaps down to 10us but very few follow the ArcR dependence expected from bounces.

In triple elves, one time gap is large, the other is short.





ELVES sources locations vs cloud height

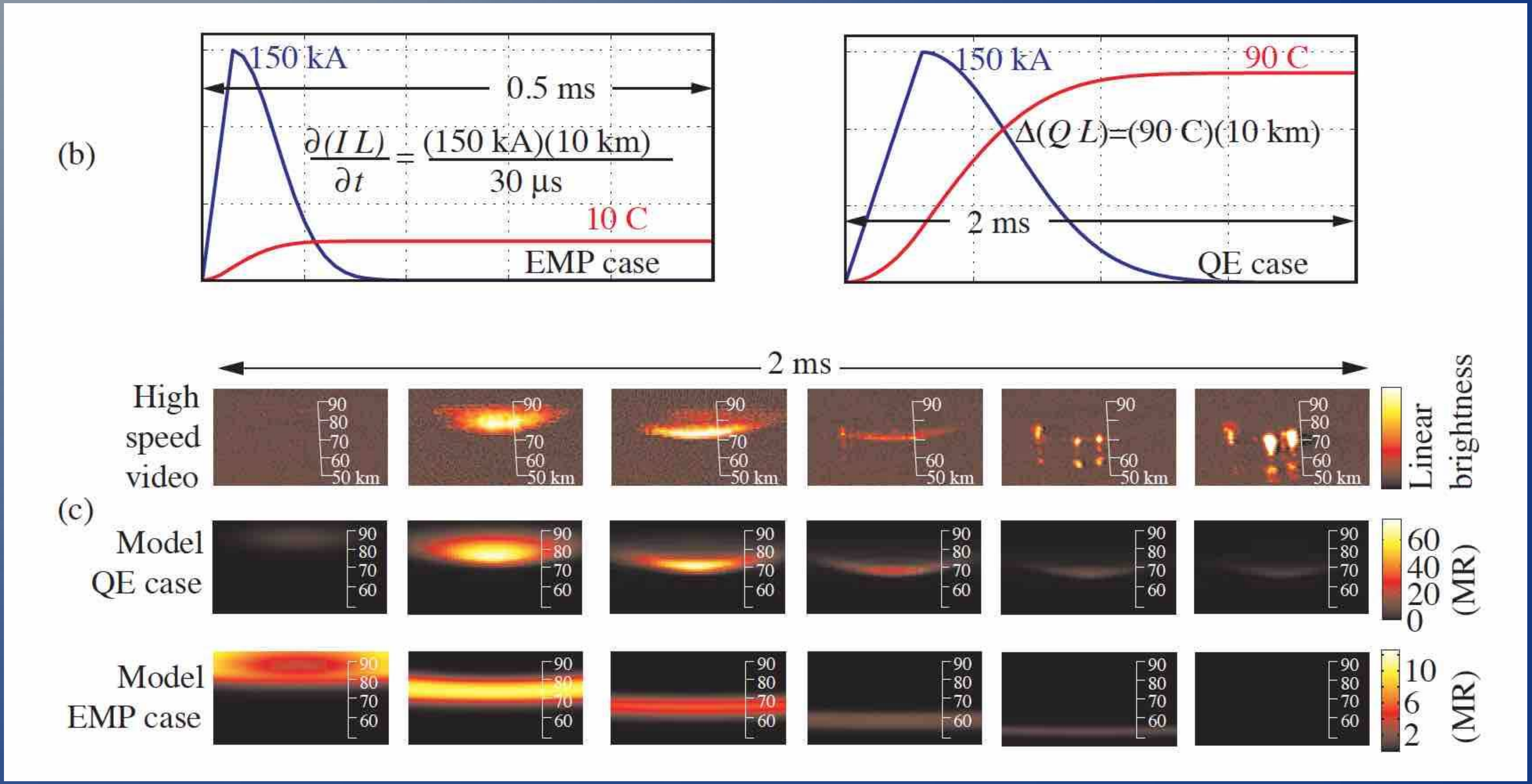


Comparing ELVES reconstructions with the GOES-16 satellite data on cloud tops, we see that anyway ELVES sources are located high in the thunderstorms. This supports the hypothesis of a causal connection between ELVES and TGFs.

The lack of evidence of double elves from the bounce mechanism may be related to the specific surface properties of the Argentinian pampas.

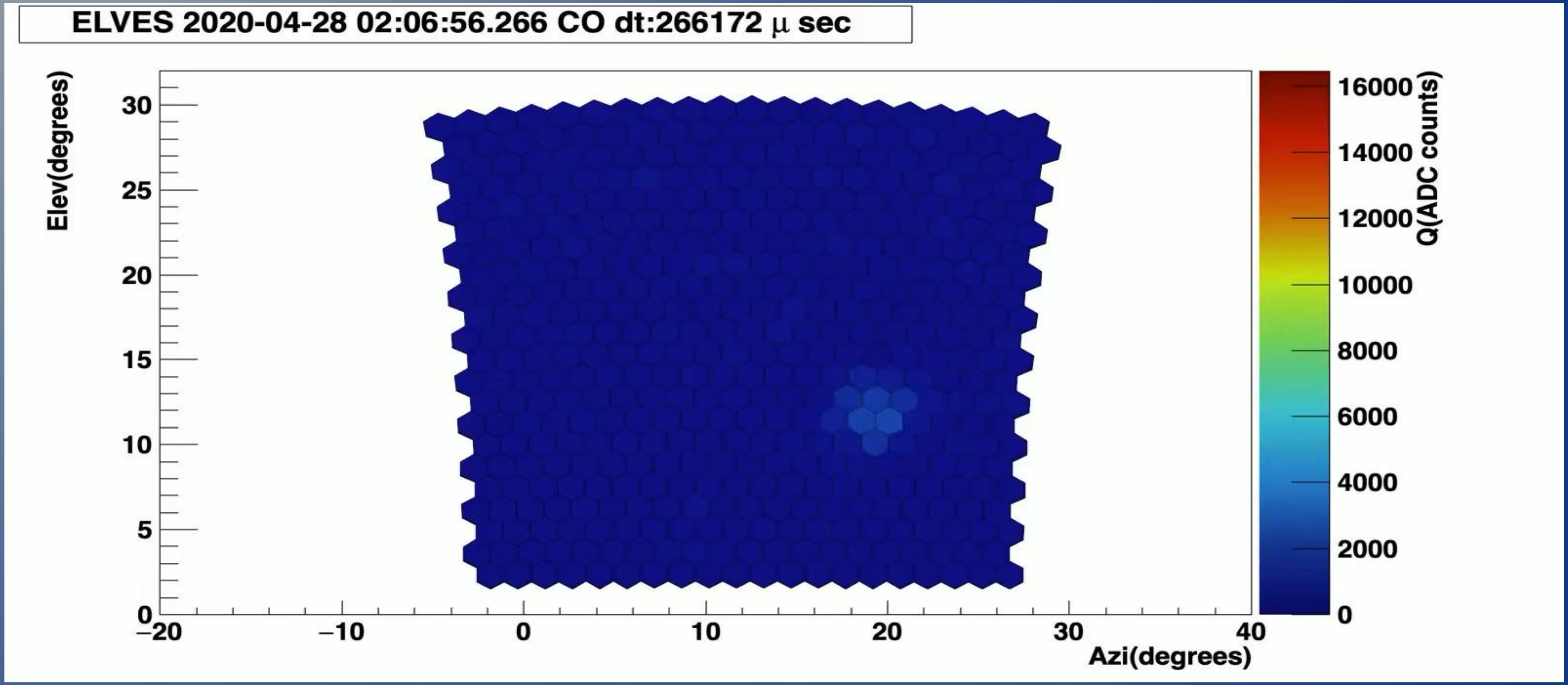
What is a HALO?

Halos are created by the quasi static component [1] of the EM pulse which produce the ELVES, at heights around 80 km. Halos are typically brighter than ELVES and have diameters around 80km. Halos are 10 times less frequent than ELVES, according to the ISUAL three years dataset from space [2]. Halos are often followed by sprites, when the originating lightning leader has positive charge.



[1] C.P.Barrington-Leigh, PhD Thesis, Stanford 2001.
[2] A.B.Chen et al., JGR113 (2008) A08306

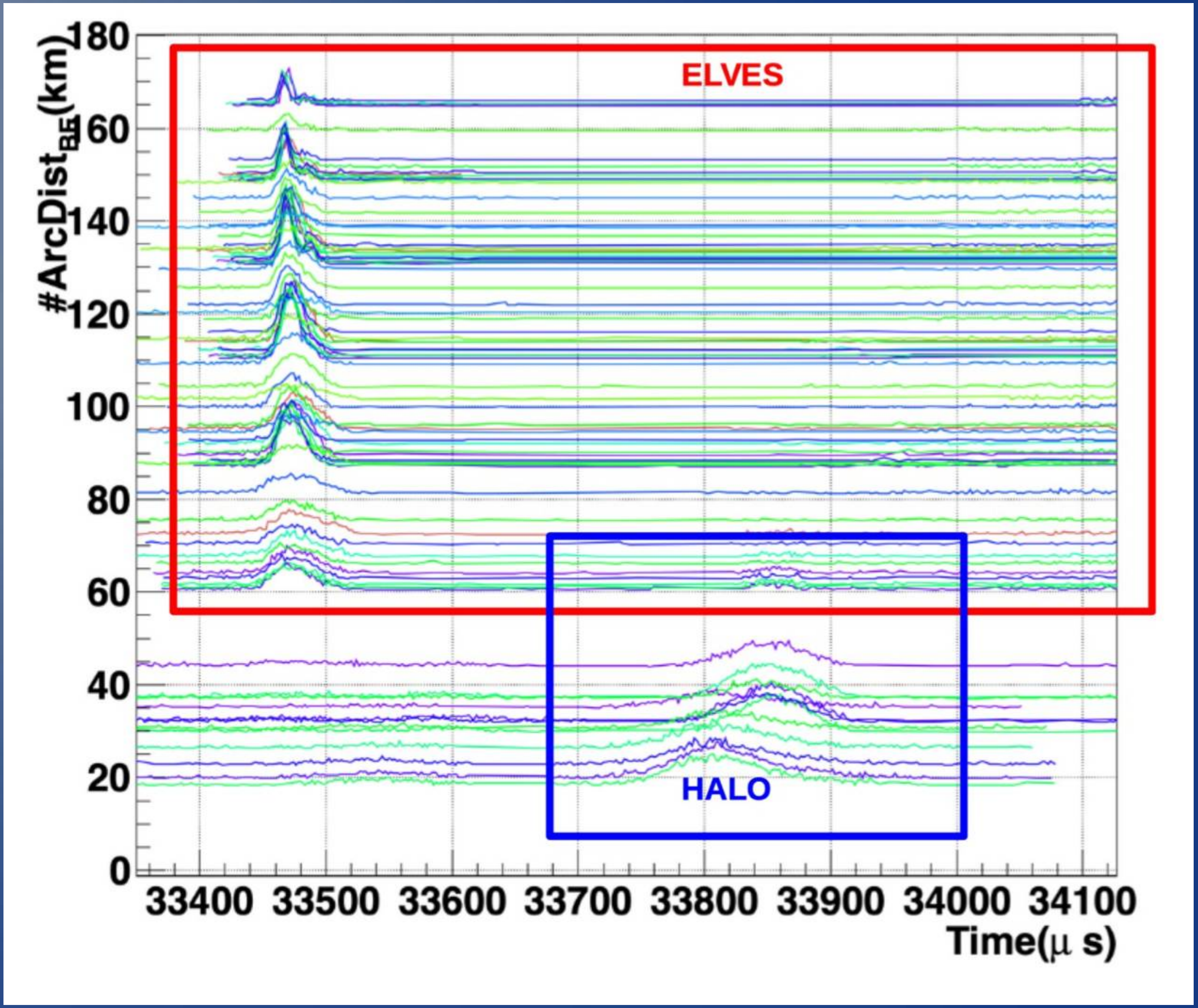
ELVES+HALO



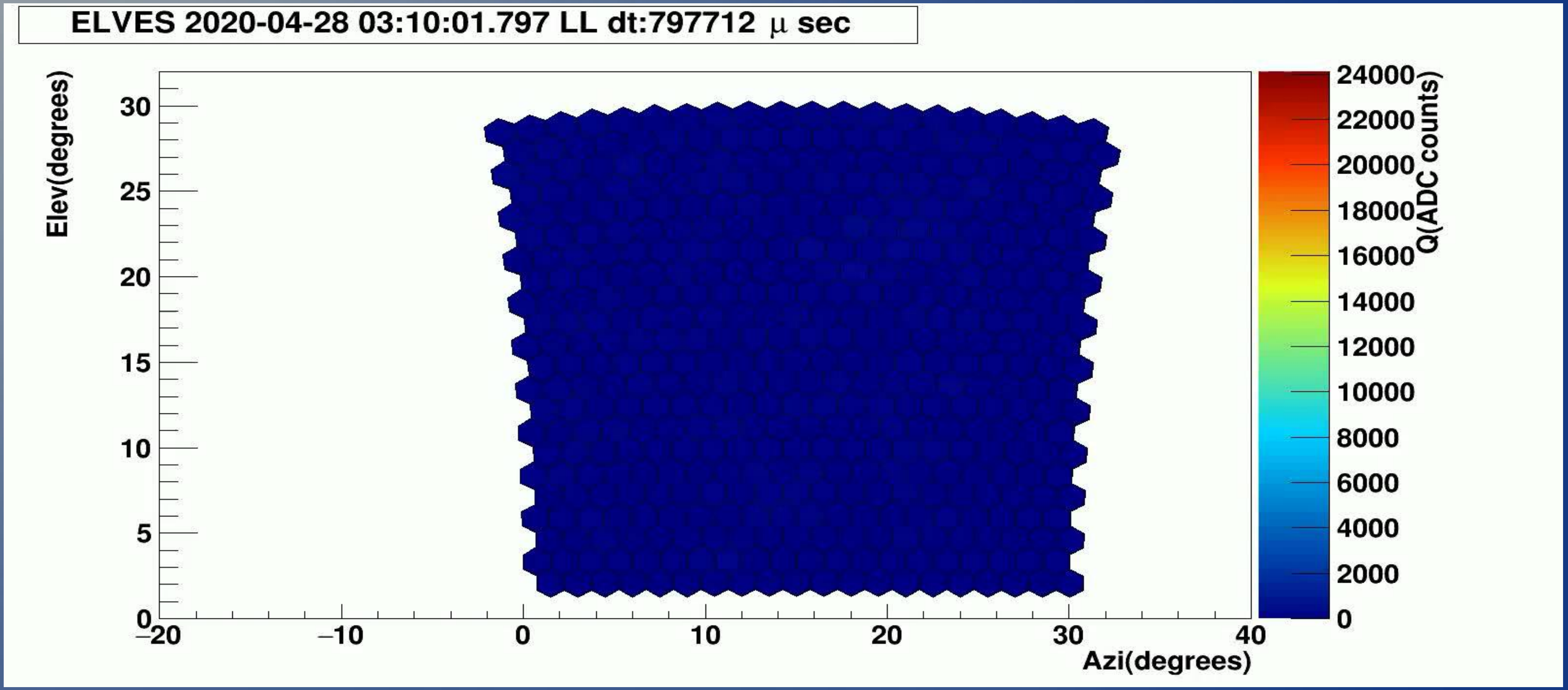
Animation from FD point of view, without transit time correction

ELVES+HALO

Traces from the ELVES and the subsequent halo are aligned by correcting for the transit time between source and FD, and sorted with arc distance respect the vertical of the lightning source.



HALO between two elves



Animation from FD point of view, without transit time correction
This complex event is made of a (double) ELVES, a halo, and another ELVES

TLE Camera

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:

- Sony a7-III camera with 7artisans 50mm f/0.95 (dec.2023)
- CMOS sensor ZWO ASI294MC with Sigma 20mm f/1.4 (apr.2024)

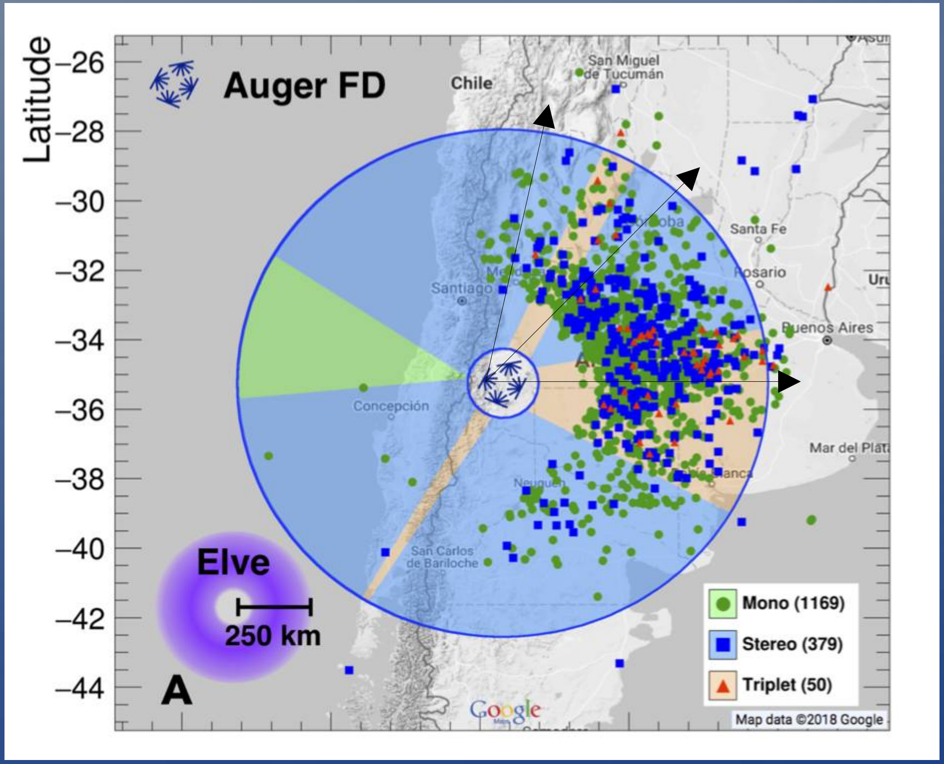
Azimuth motion is controlled by an Arduino microprocessor.

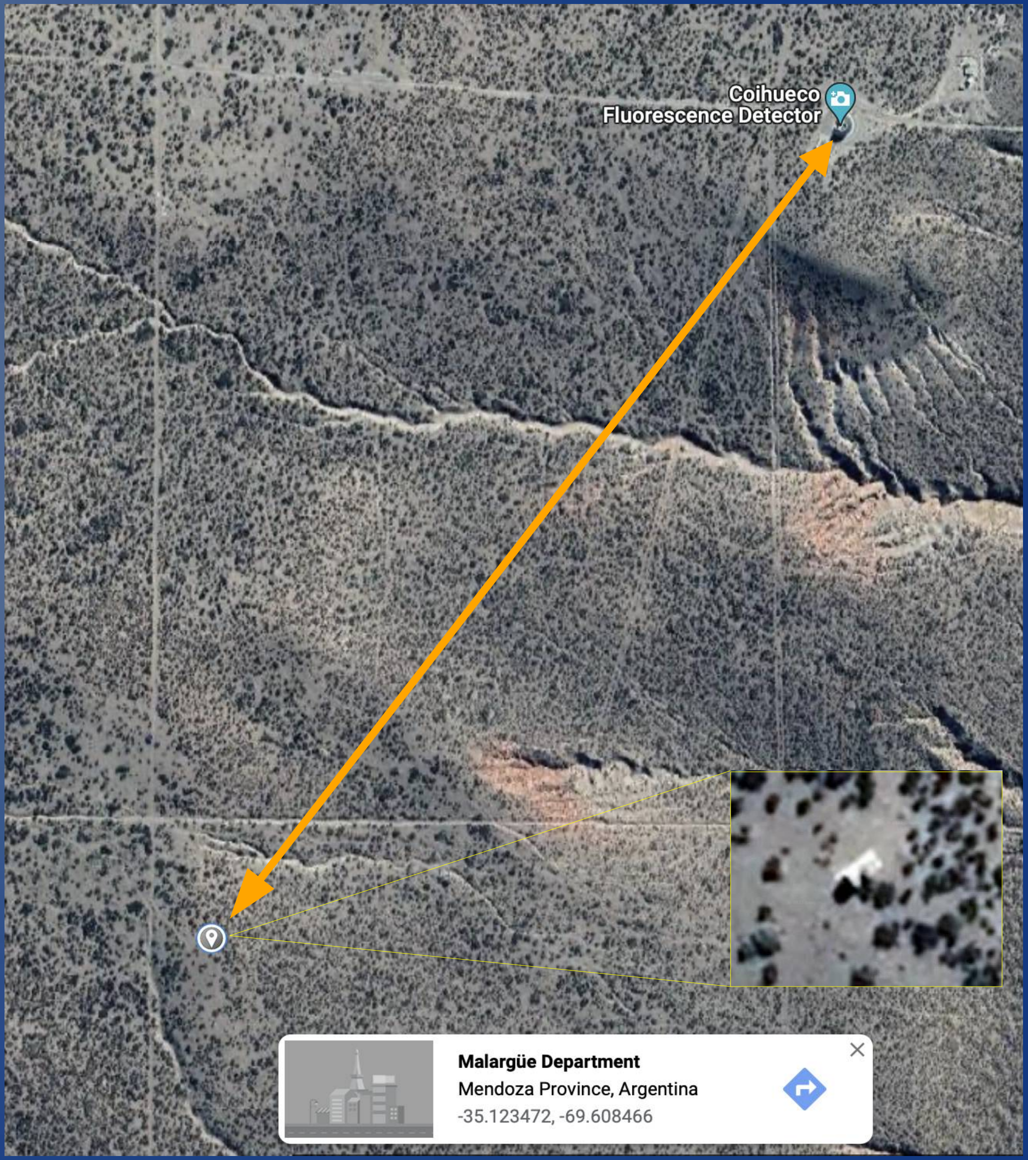
TLE Camera location

At a distance of 1.4 km SW of the Coihueco FD site

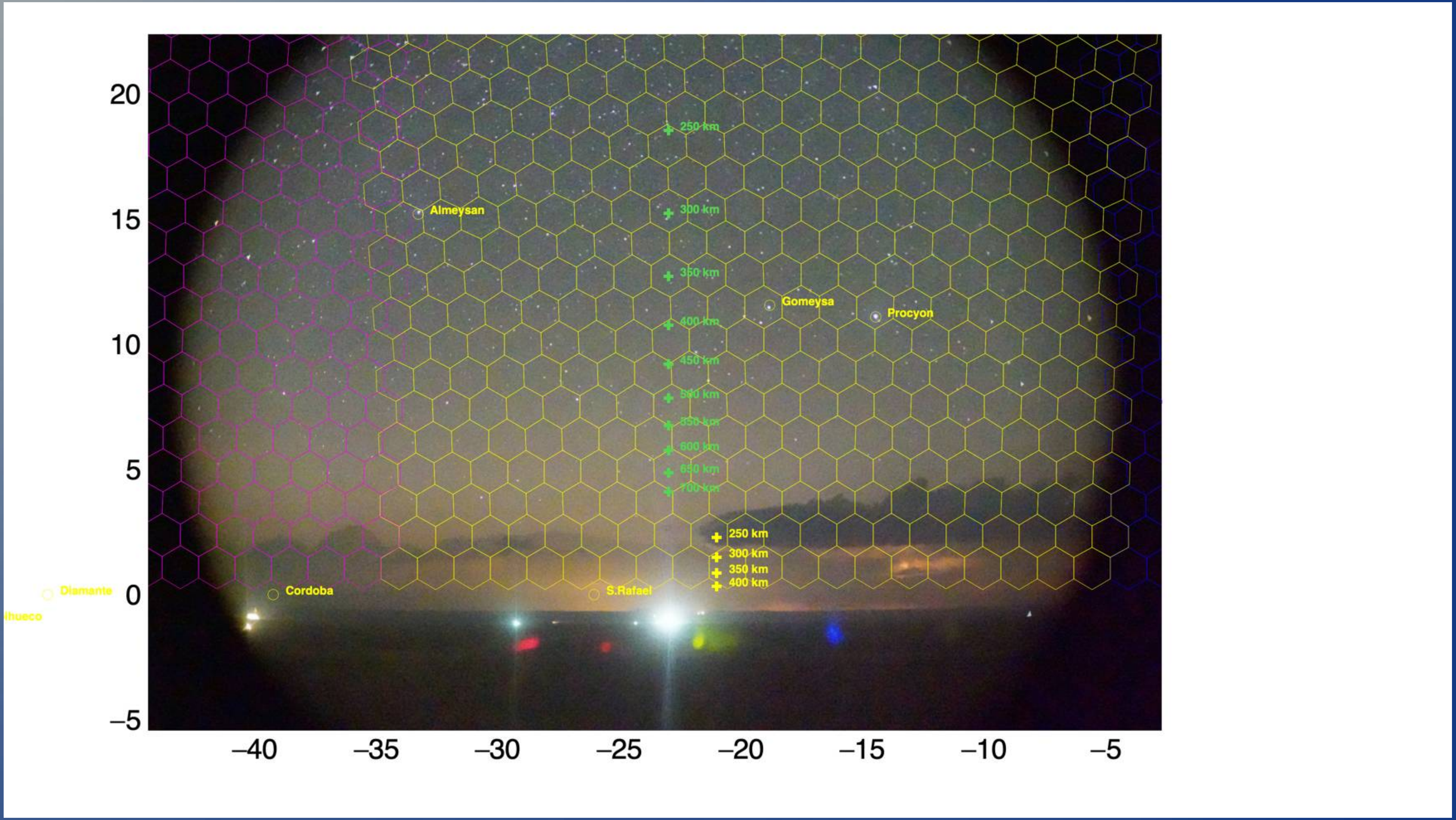
Pointing towards NE, in the region where the majority of ELVES storms are observed

Data transfered via radio link





Alignment

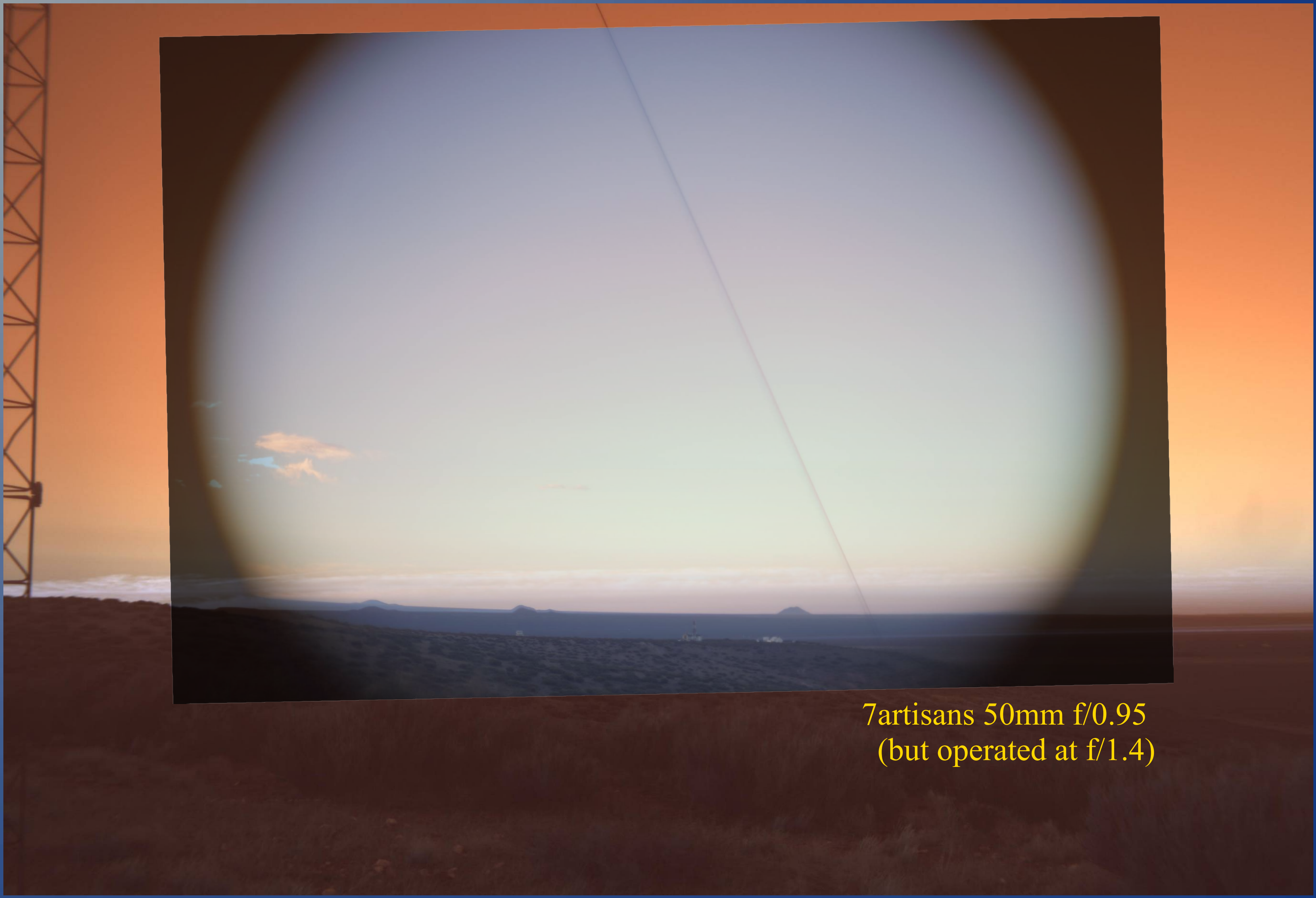


The camera absolute alignment is done with brightest stars.
Green crosses indicate the elevation of ELVES center vs distance
Yellow crosses indicate the elevation of a 15km cloud top vs distance

Alignment: ZWO vs Sony

Sigma 20mm f/1.4

Alignment: ZWO vs Sony



Sigma 20mm f/1.4

Dec.13, 3:11:16 UTC: 1st SPRITE !

Dec.13: four sprites in total

Images recorded at a speed of 12.5 fps.

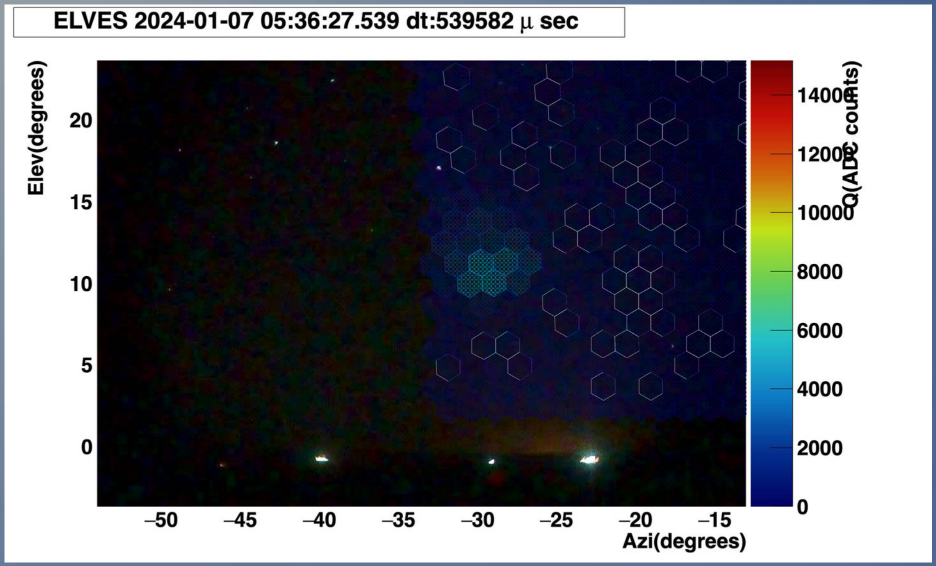
Each frame is 40 ms.

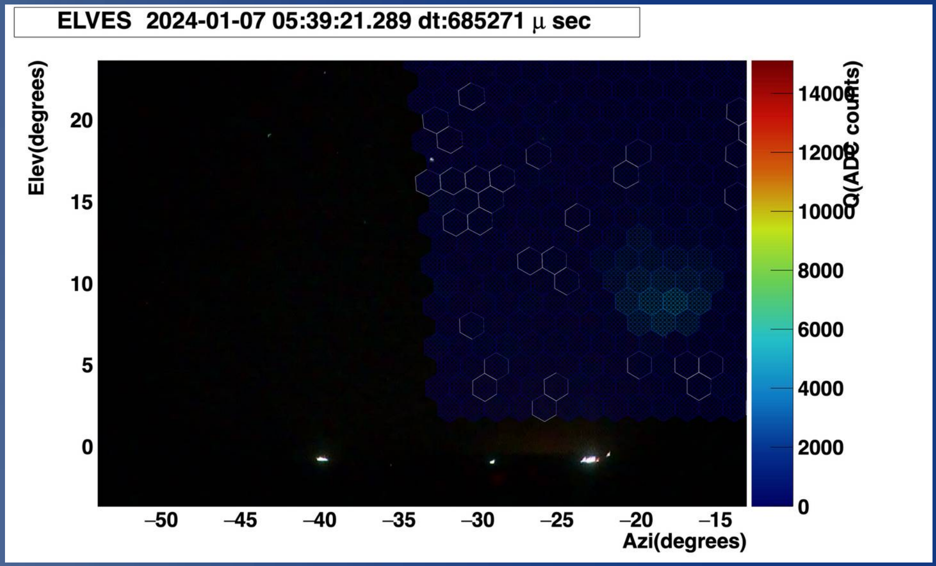
The 1st sprite occurs in three consecutive frames

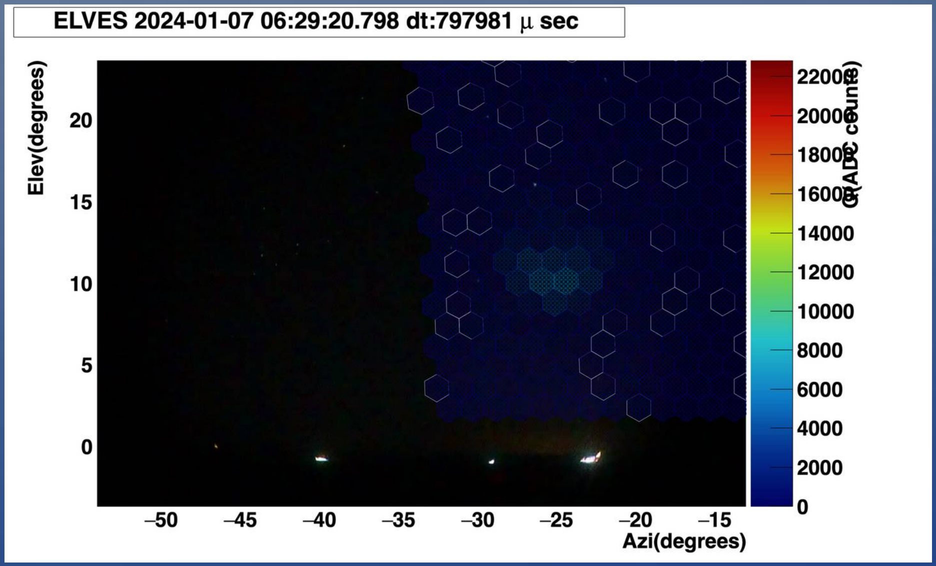
03:36:42: 1st with correlated elves trigger on the right side

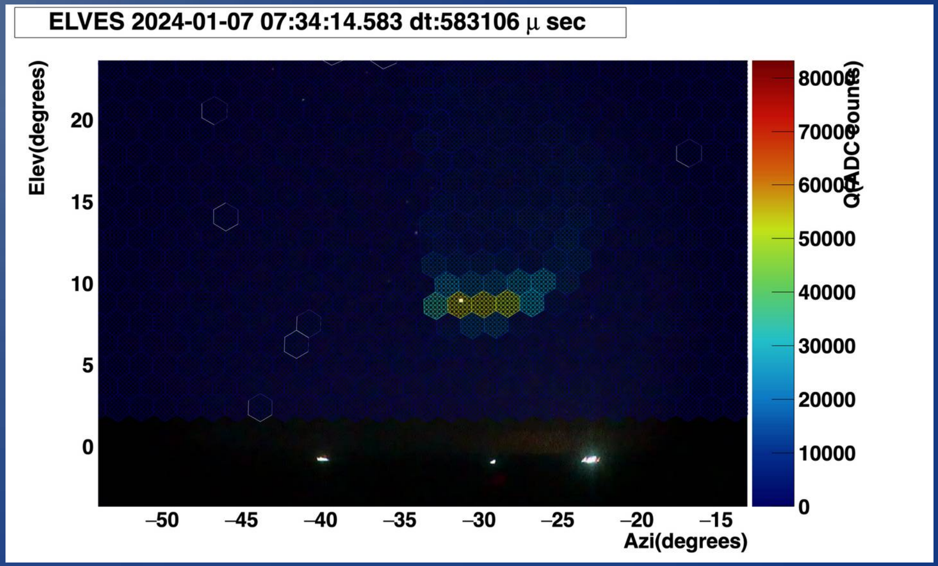
The 4th sprite occurs in two consecutive frames

Sprites and ELVES on Jan.7 2024

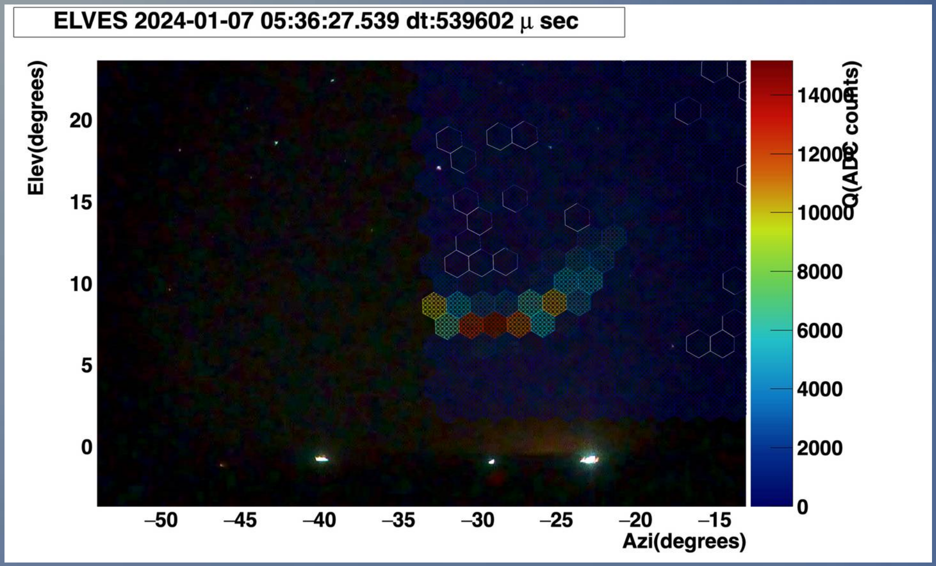


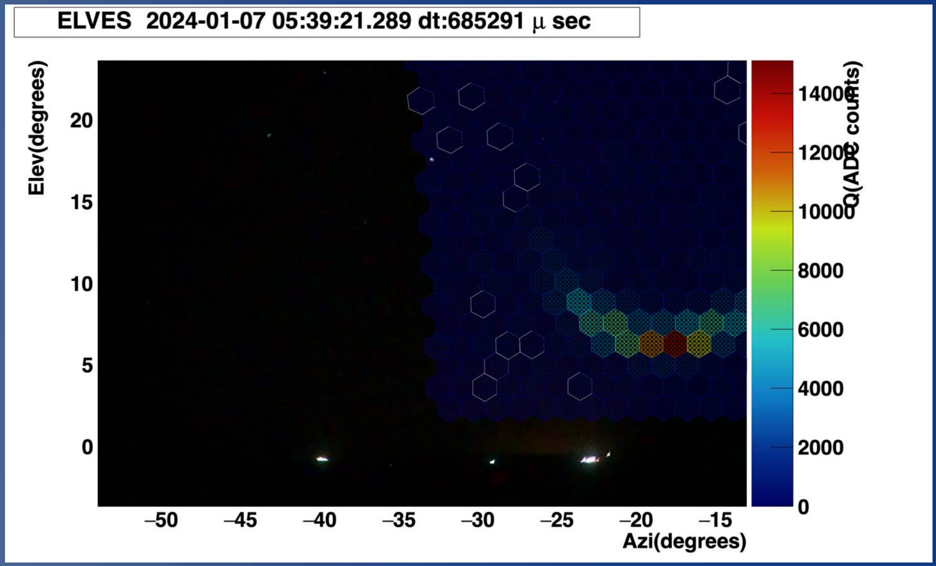


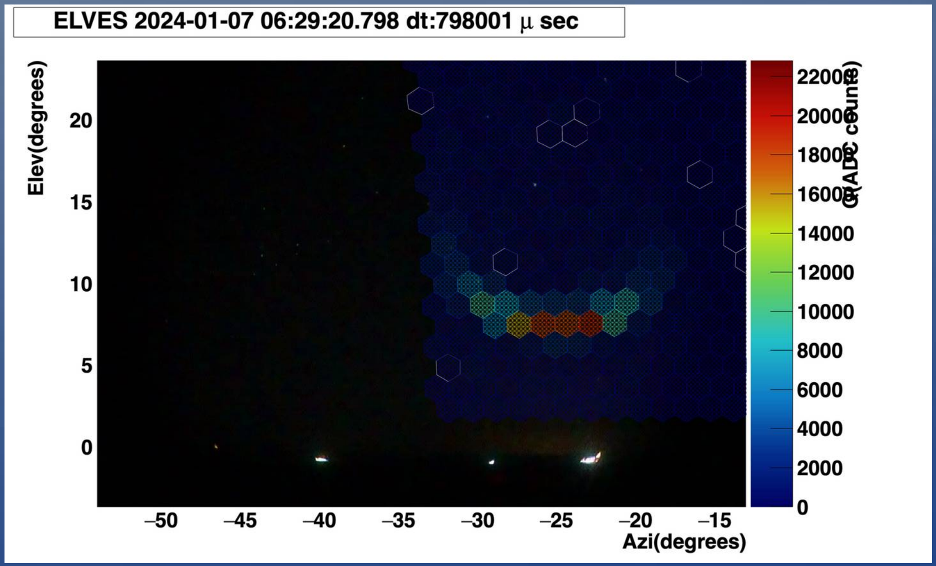


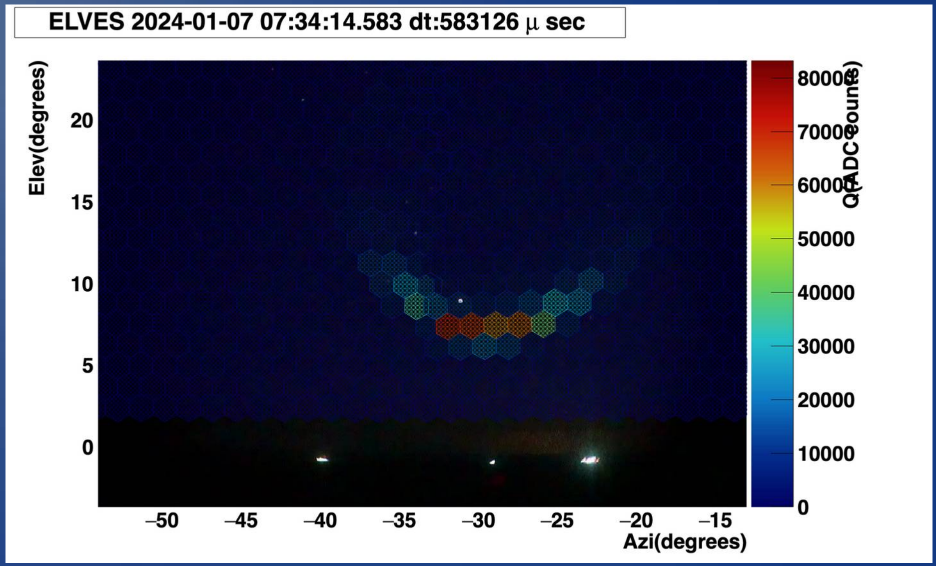


Sprites and ELVES on Jan.7 2024

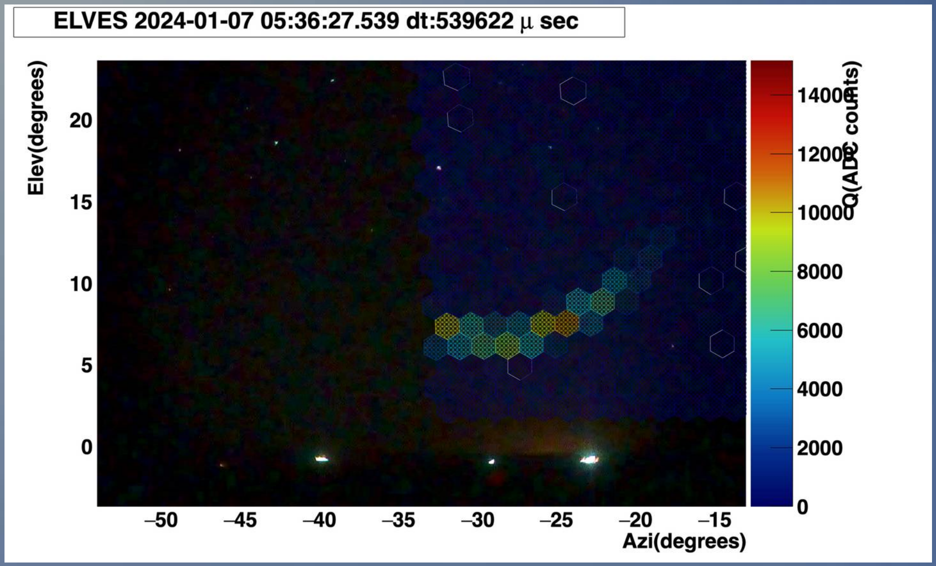


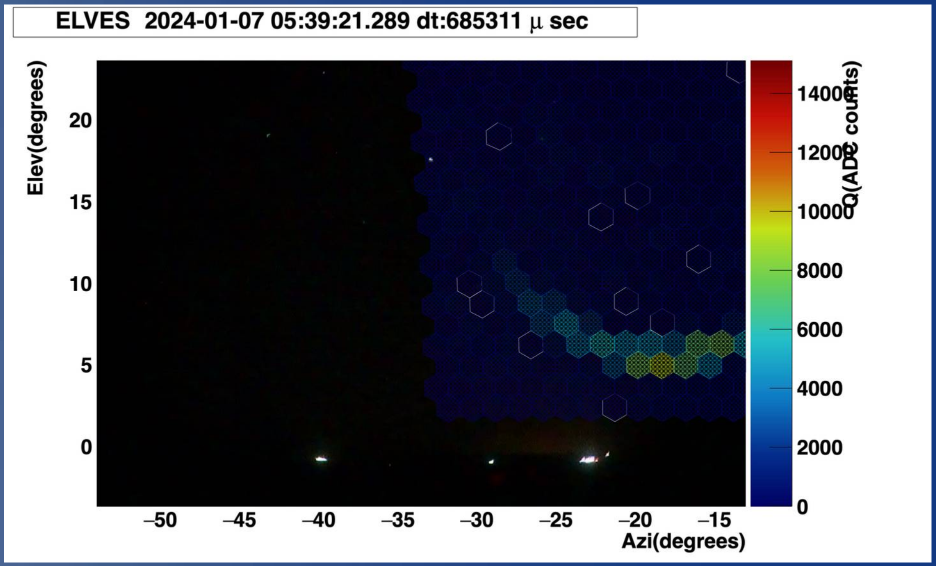


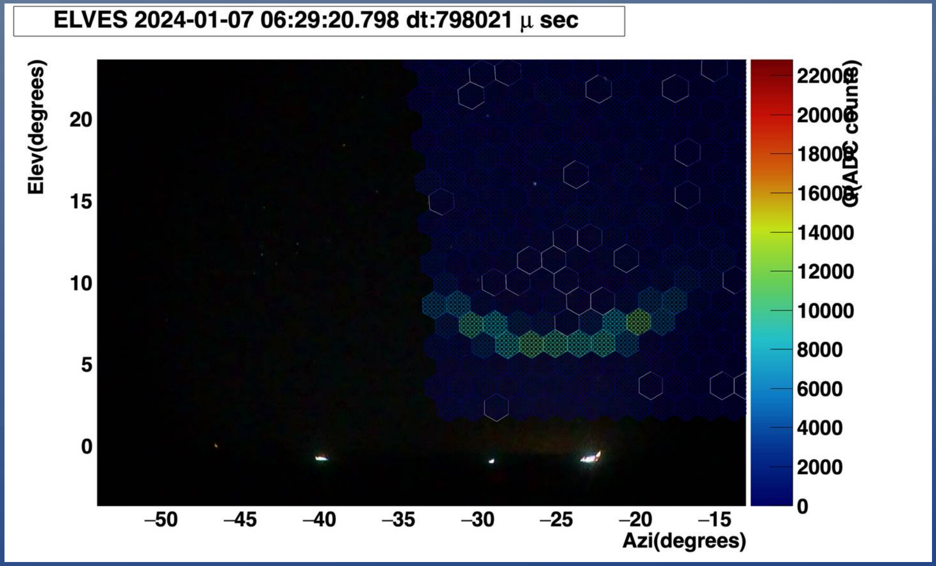


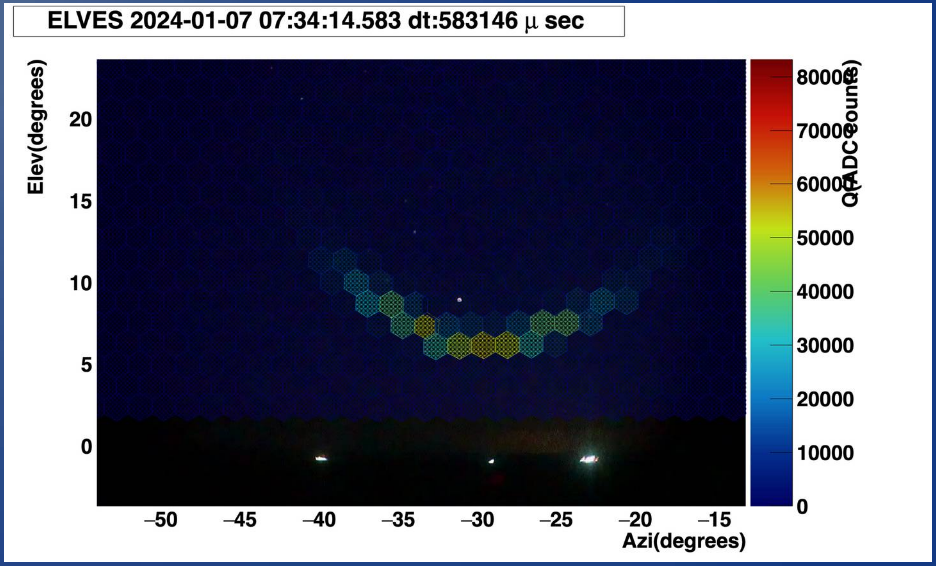


Sprites and ELVES on Jan.7 2024

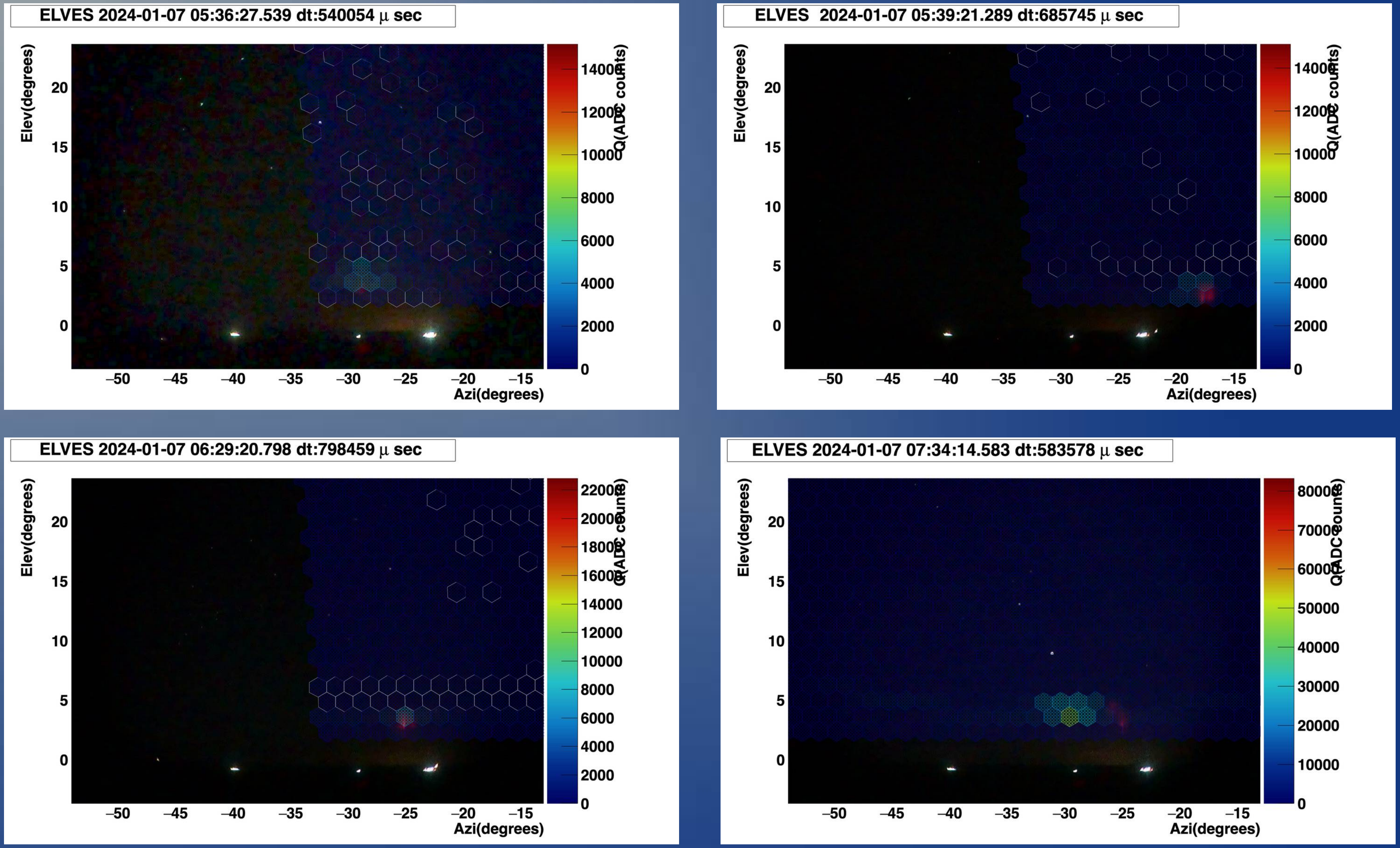




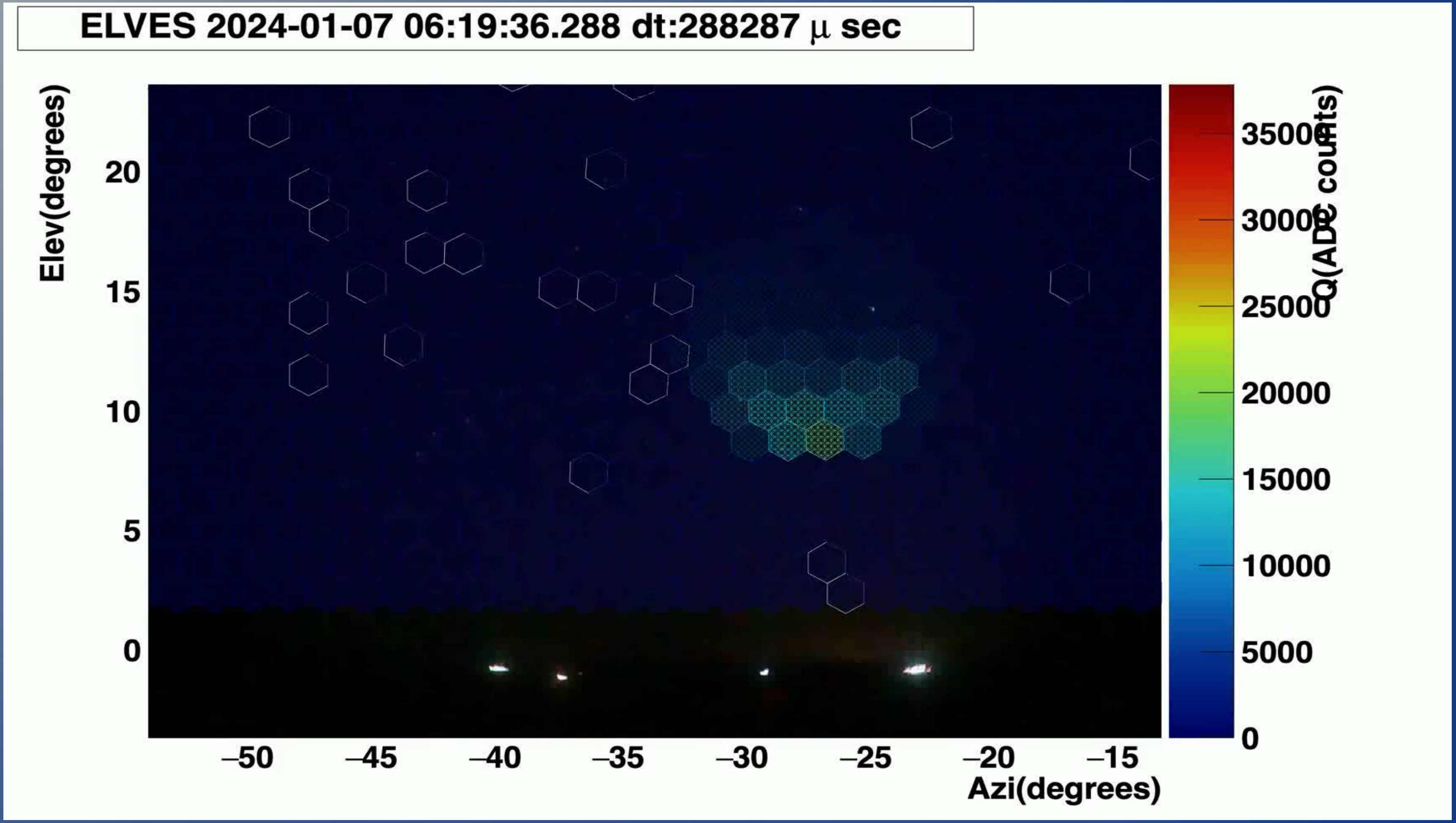


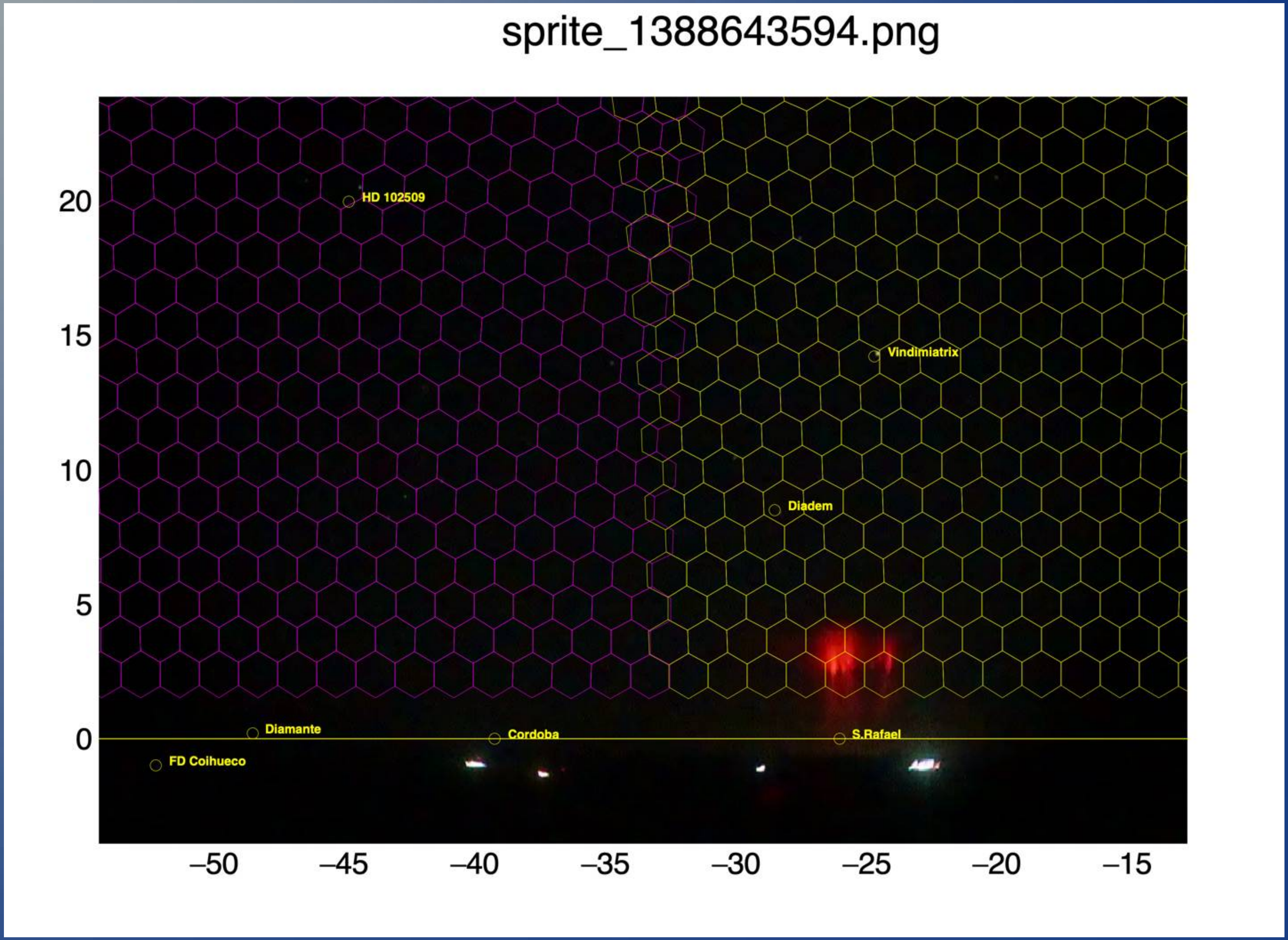


Sprites and ELVES on Jan.7 2024



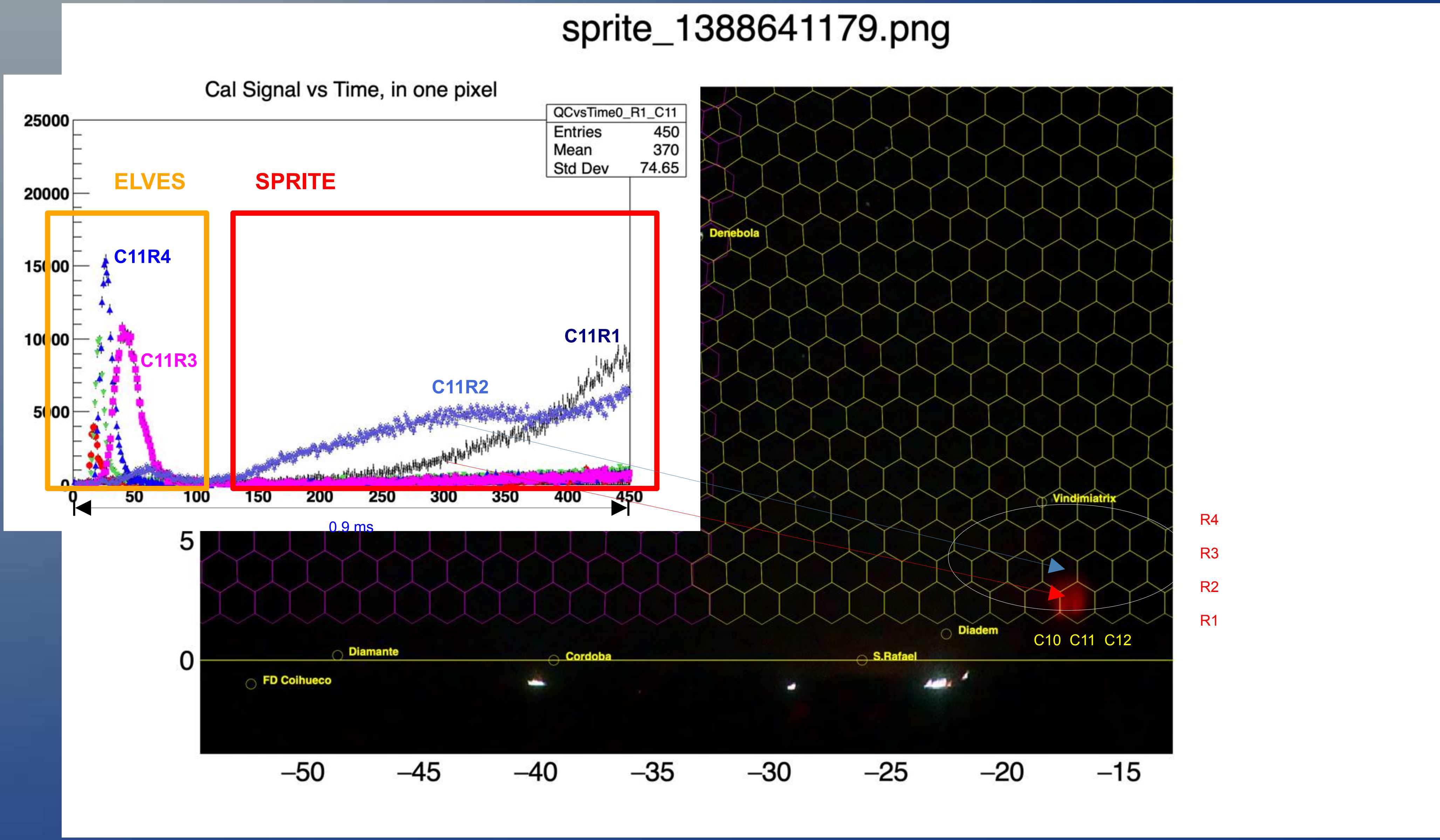
GPS 1388643594





sprite_1388643594.png
HD 102509
Vindimiatrix
Diadem
Diamante
Cordoba
S.Rafael
FD Coihueco
20
15
10
5
0
–50
–45
–40
–35
–30
–25
–20
–15

Sprites vs ELVES intensity



Sprite events on March.9 2024

In less than one hour we observed seven SPRITES from a close thunderstorm.

Coihueco site was not operational

Los Leones saw ELVES triggers but not in the same GPS seconds.

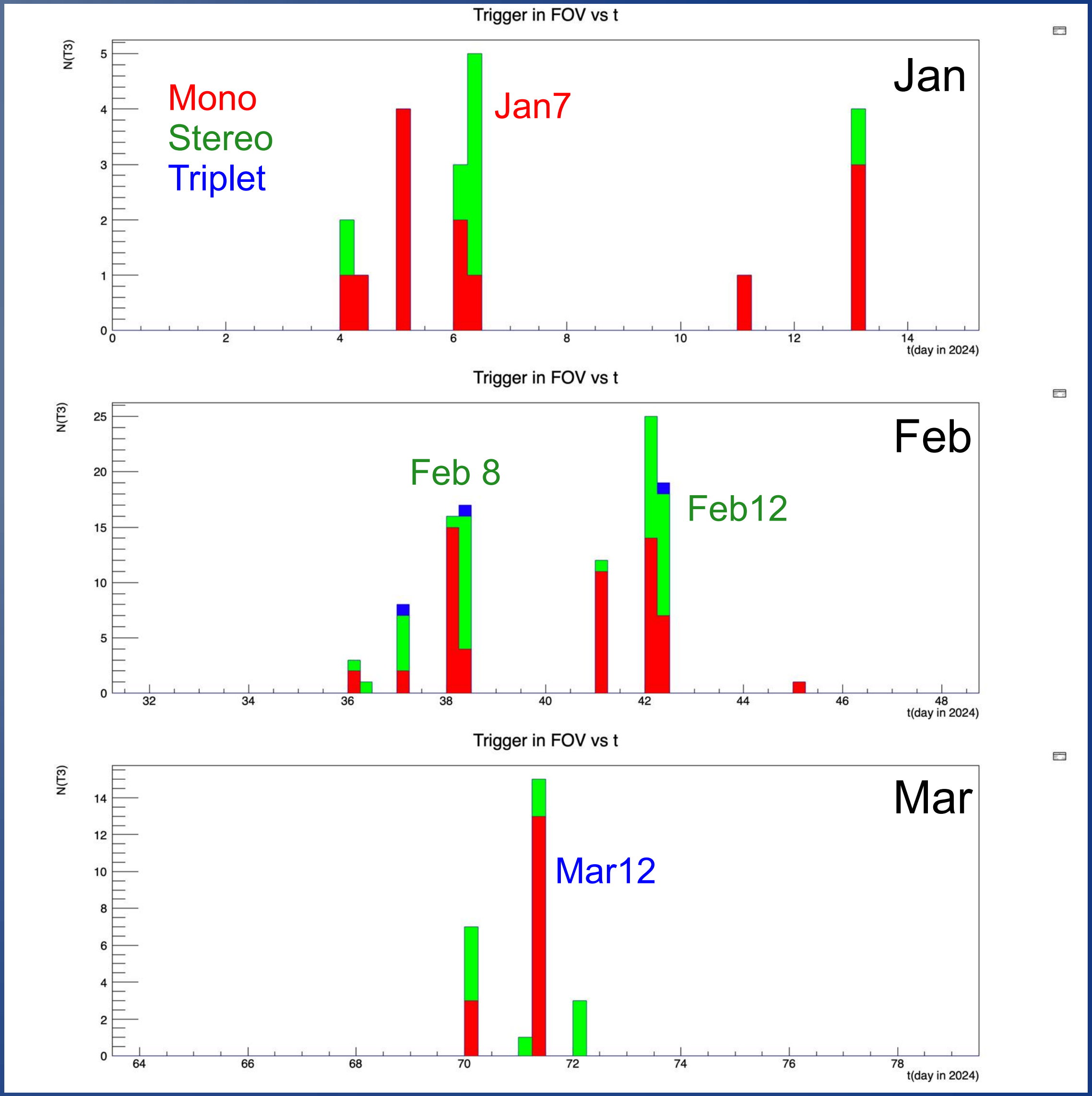
TLE vs ELVES events in 2024

- SPRITES were observed on:
  *Jan.7 (ELVES triggers in CO)
  * Mar.9 (CO not working, ELVES triggers in LL, but not in time)

- Feb.8,12 and Mar.12 storms had many ELVES but no TLE were observed in coincidence

The causal connection between ELVES and SPRITES depends on the type of thunderstorm?

ELVES Triggers in Coihueco (CO4,5,6)



Summary

In the last ten years, the Pierre Auger Observatory has exploited a dedicated trigger and extended readout, and its very high time resolution, to record the world's largest sample of multiple ELVES.

By comparing the time gaps between flashes with waveforms recorded by the antennas of the ENTLN network, we observe the correlation expected by models for what concerns double ELVES.

Using a large sample of triple ELVES, from four different thunderstorms, despite the GOES-16 images prove that most sources are locate on the top of high clouds (>10 km), we have very few multiple ELVES events which can be explained by the ground reflection mechanism.

In the same data sample, we could observe another type of TLE, the halo, a few hundred microseconds after some ELVES. This has motivated the installation, in December 2023, of new TLE cameras, to complement the observations done with our Fluorescence Detector.

Preliminary results, including the first observation of SPRITES in Auger, show the potential of the new TLE cameras for further studies on the correlation between TLEs in Auger.

Thank you for you attention!

Camera
Sony a7-III

7artisans 50mm f/0.95

Sensor

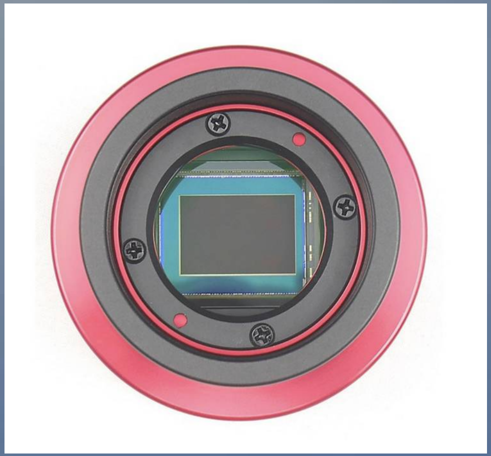
Sensor Type	BSI-CMOS
Sensor Size	Full frame
Sensor Dimensions	35.8 x 23.8 mm
Sensor Area	$852.04mm^2$
Sensor Resolution	24 megapixels
Max Image Resolution	6000 x 4000
Max Native ISO	51,200
Max Boosted ISO	204800
Min Native ISO	100
Min Boosted ISO	50
RAW Support	✔

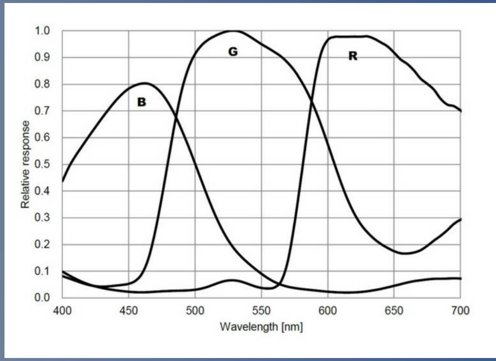
Main Features

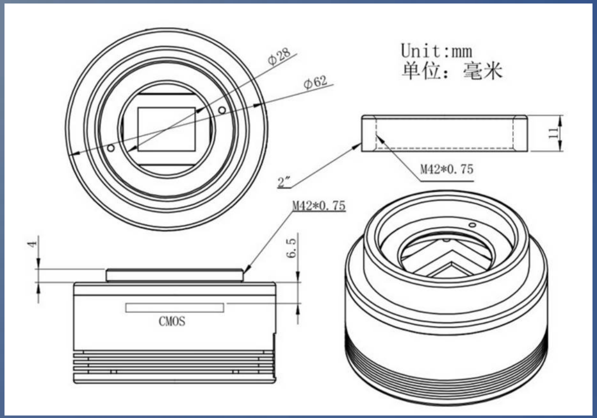
- 24MP - Full frame BSI-CMOS Sensor
- ISO 100 - 51200(expands to 50 - 204800)
- 5-axis Sensor-shift Image Stabilization
- 3.00" Tilting Screen
- 2360k dot Electronic viewfinder
- 10.0fps continuous shooting
- 4k at 30fps and FHD at 120fps Video Recording
- Built-in Wireless
- 650g. 127 x 96 x 74 mm
- Weather-sealed Body

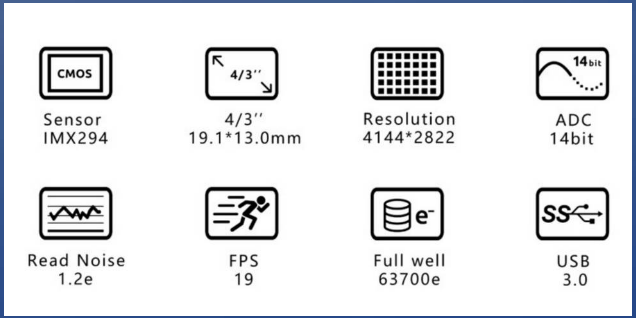
CMOS sensor

ZWO ASI294MC









SIGMA 20 mm f/1.4