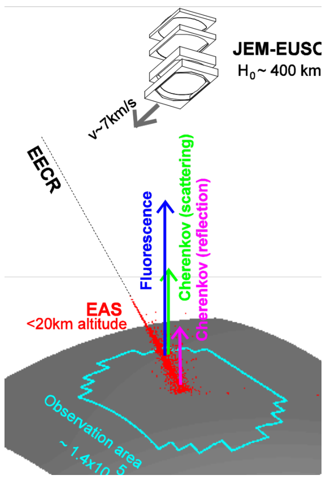
Joint Experiment Missions-
Extreme Universe Space Observatory

The Mini-EUSO telescope on board the International Space Station: mission results in view of UHECR measurements from space

M. Bertaina – Univ. & INFN Torino
for the JEM-EUSO Collaboration
UHECR 2024, Malargue

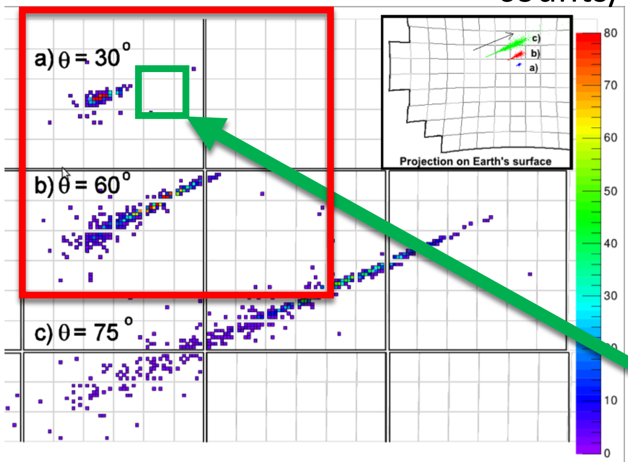
JEM-EUSO & Mini-EUSO

JEM-EUSO

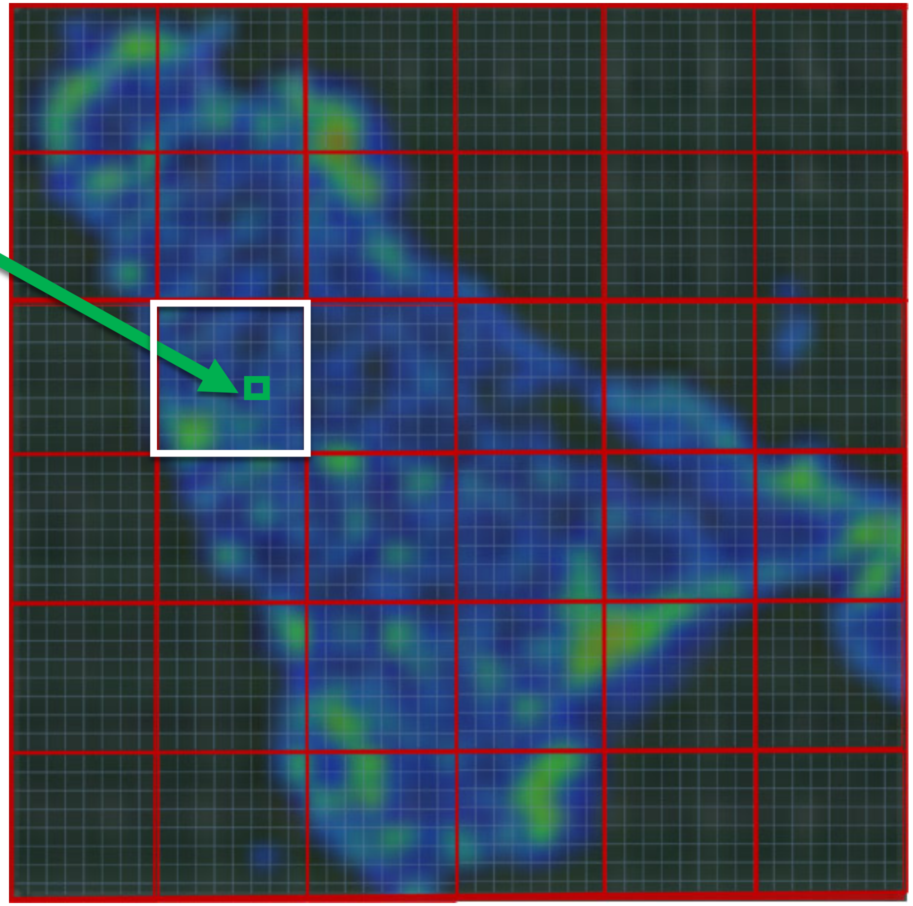


FoV

counts/GTU



Mini-EUSO



Simulation
pre-flight

K. Shinozaki

Comparison @ order of magnitude level

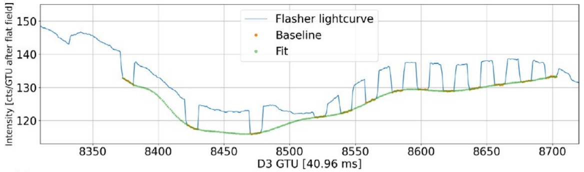
	Mini-EUSO	JEM-EUSO
	~1 pixel	~ 1.5 MAPMT
	~1 PMT	~ 3 PDM
Spatial resolution	**~6.3 km**	**~0.55 km**
Optics aperture	**~0.05 m²**	**~4.5 m²**

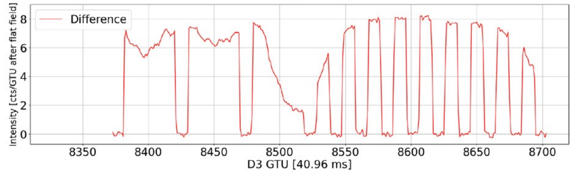
Similar counts/pixel from diffuse light
in JEM-EUSO & Mini-EUSO
x100 light in JEM-EUSO from point-like sources

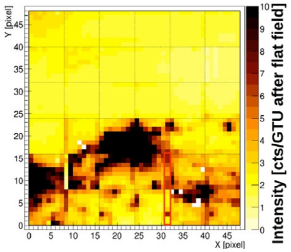
J. Adams et al. Astrop. Phys. 44 (2013) 76, S. Abe et al., Eur. Phys. J. C (2023) 83:1028

Mini-EUSO end-to-end calibration @ λ = 400 nm

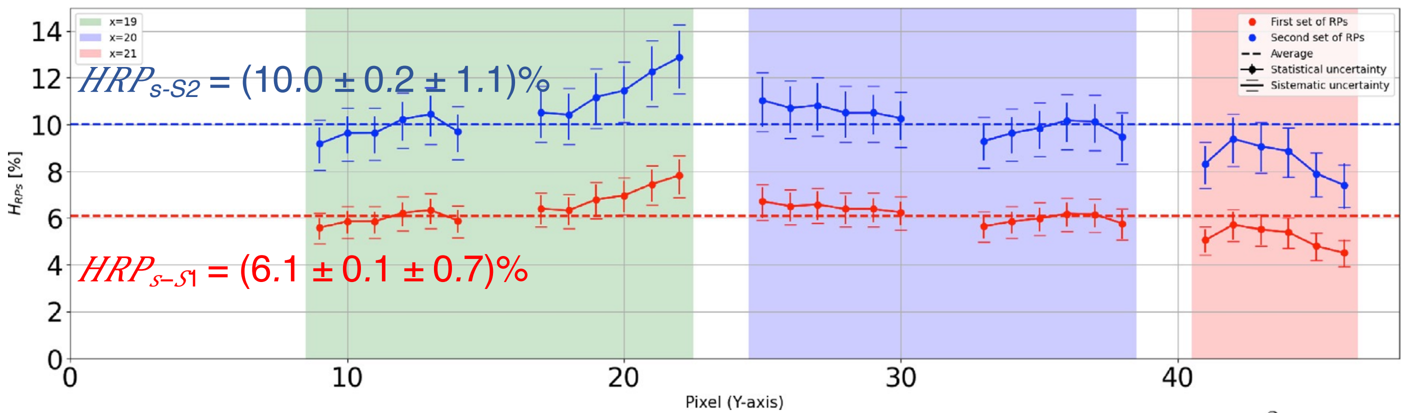
M. Battisti et al. Astroparticle Physics 165 (2025) 103057



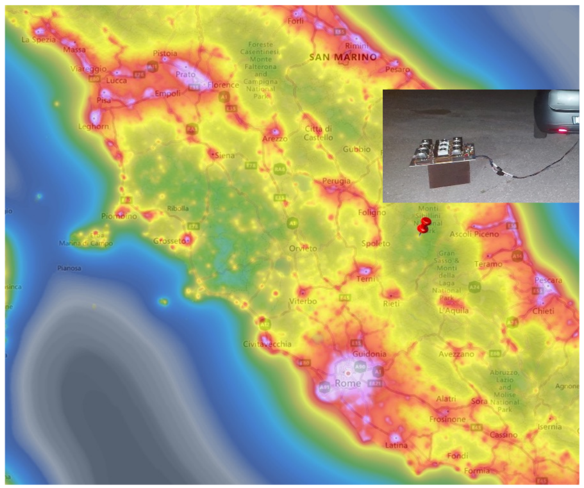


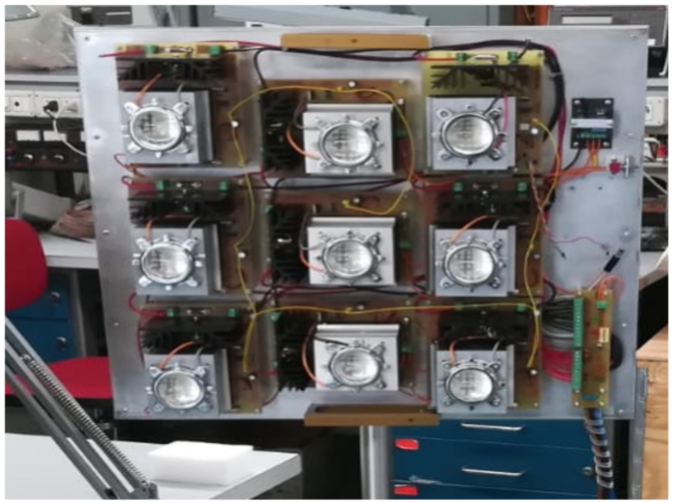


counts/GTU

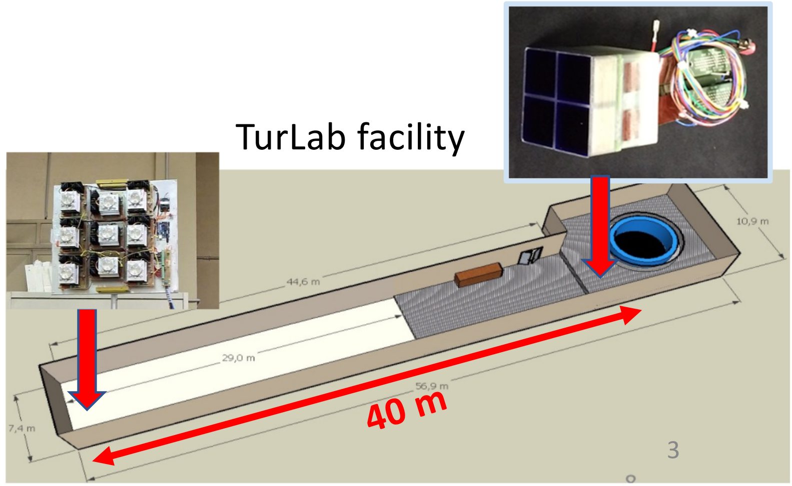


$$n_{photons}^{window} = n_{photons}^{TurLab} \times Angular_{lens} \times Abs_{atm} \times \frac{Area(ME)}{Area(To\text{-}EC)} \times \left(\frac{Distance(To\text{-}EC)}{Distance(ME)}\right)^2 \times cos(\theta)$$

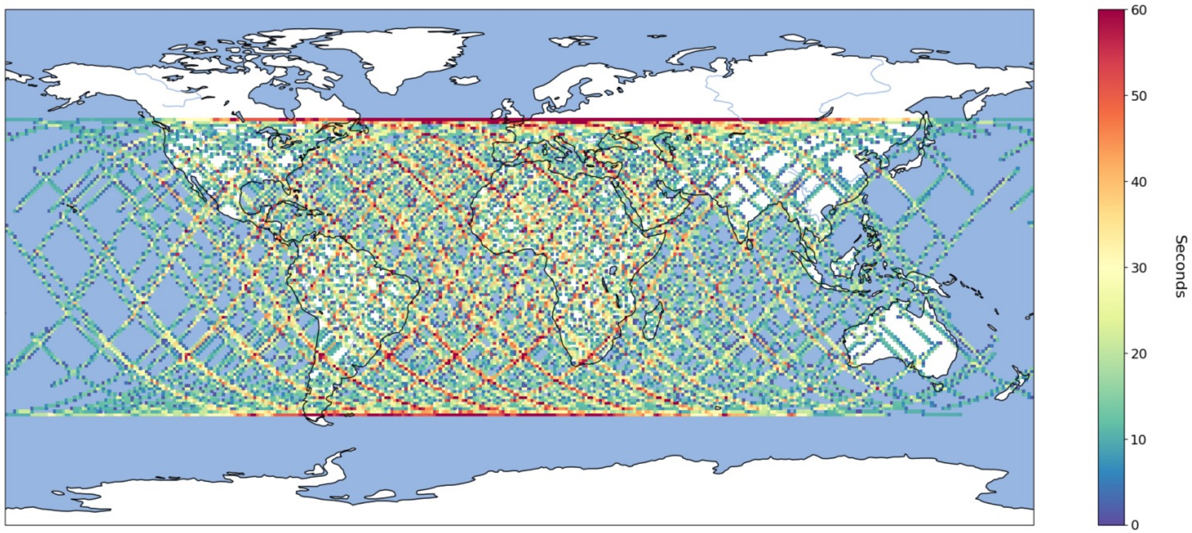




TurLab facility



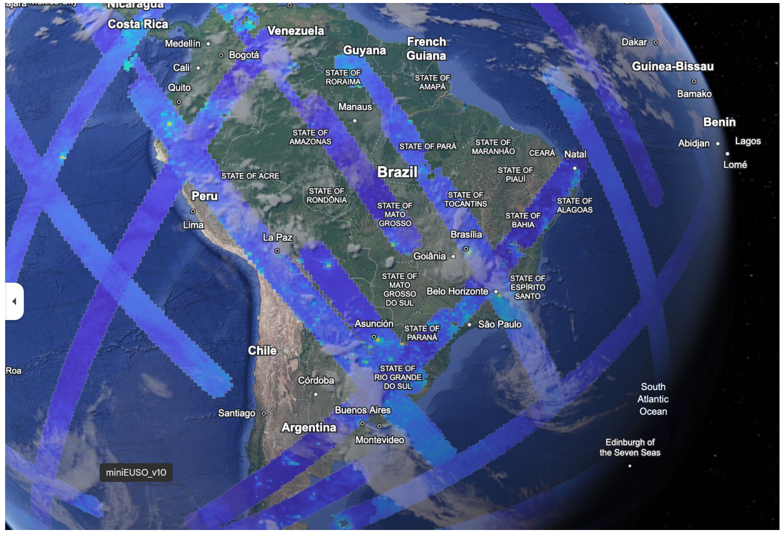
Mini-EUSO measurements over the globe

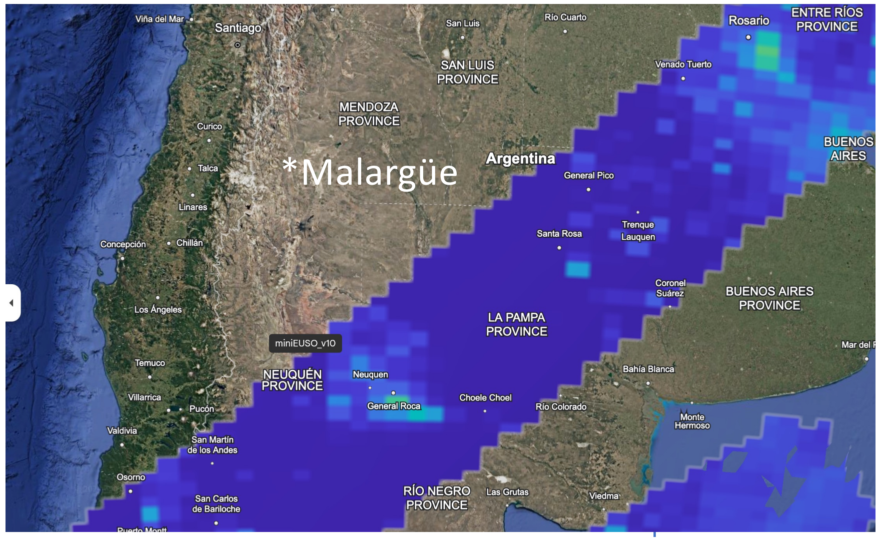


Sessions 4 - 44

From Matteo B.

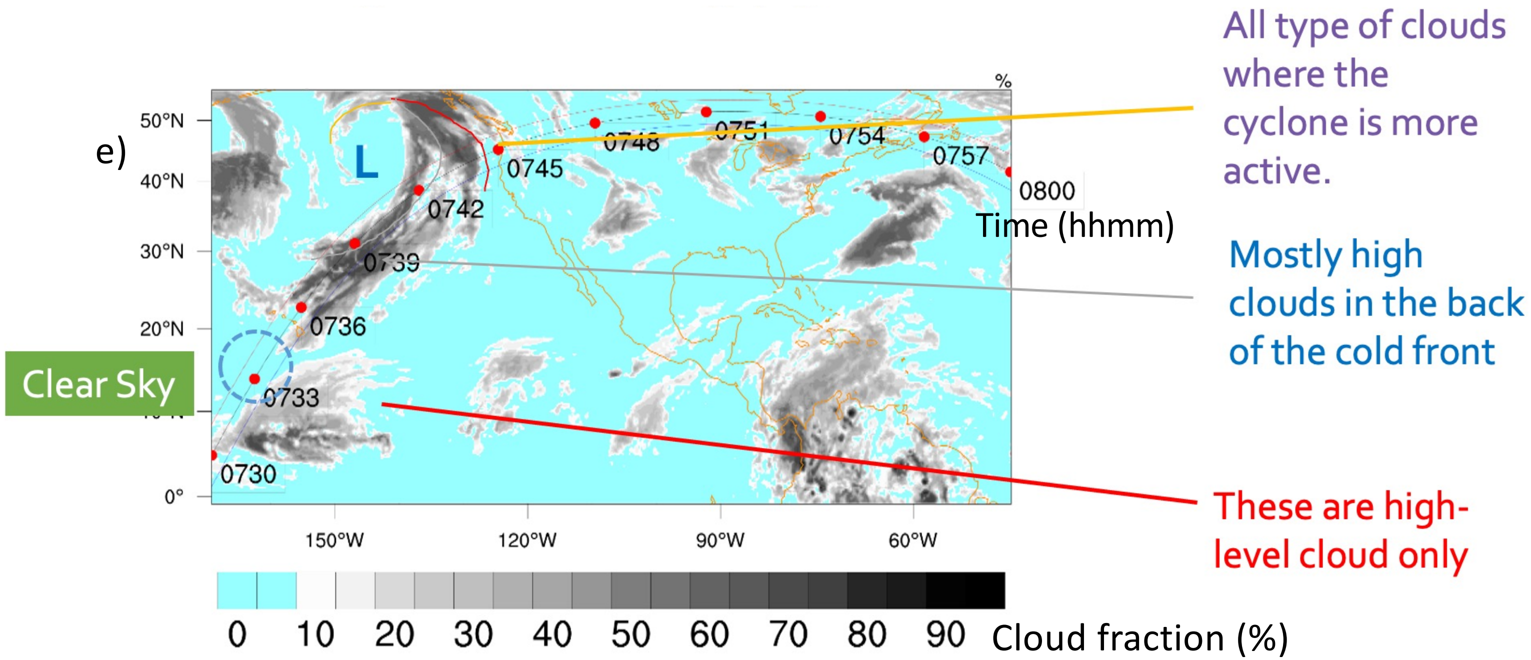
UV maps – South America

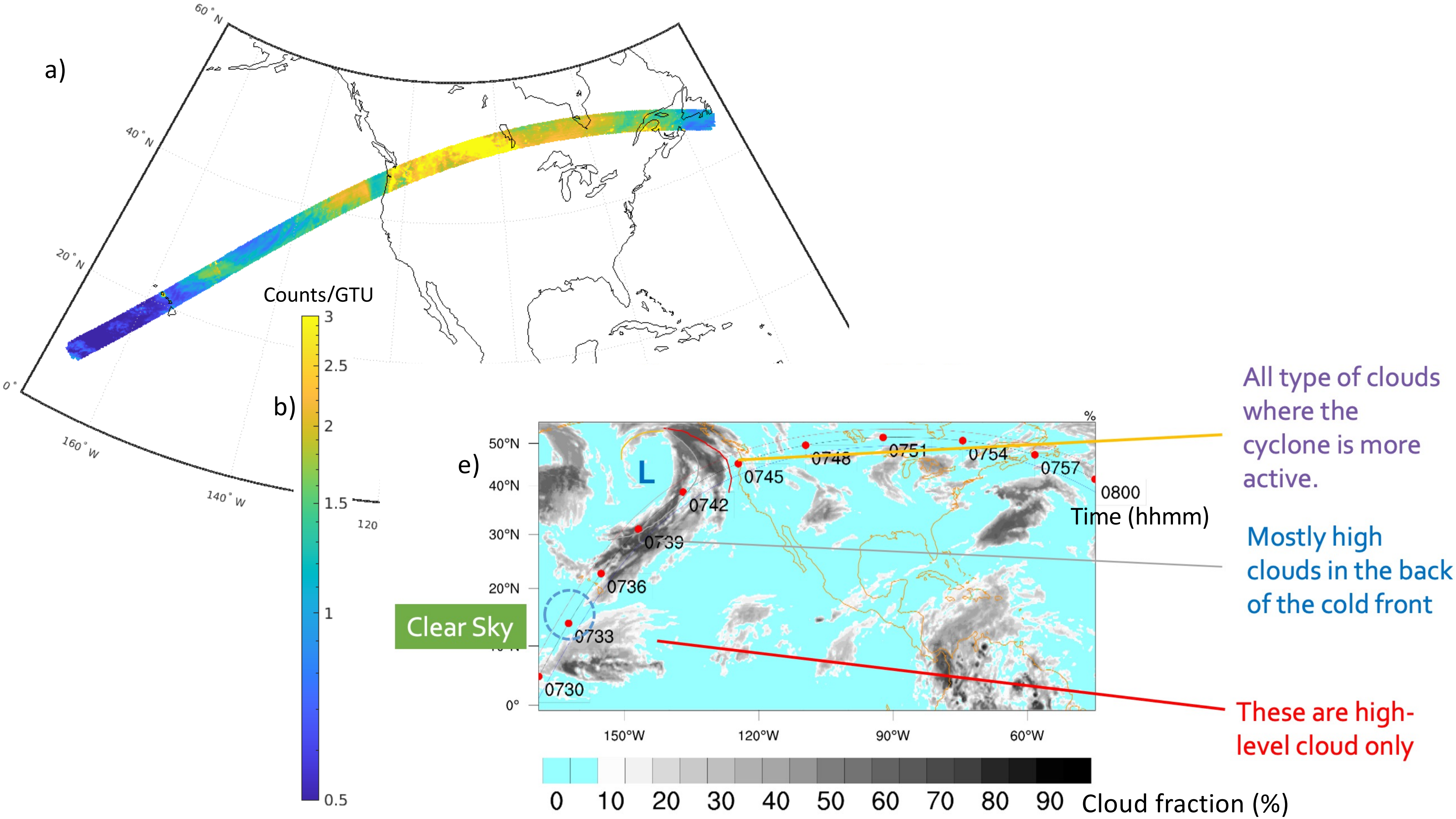


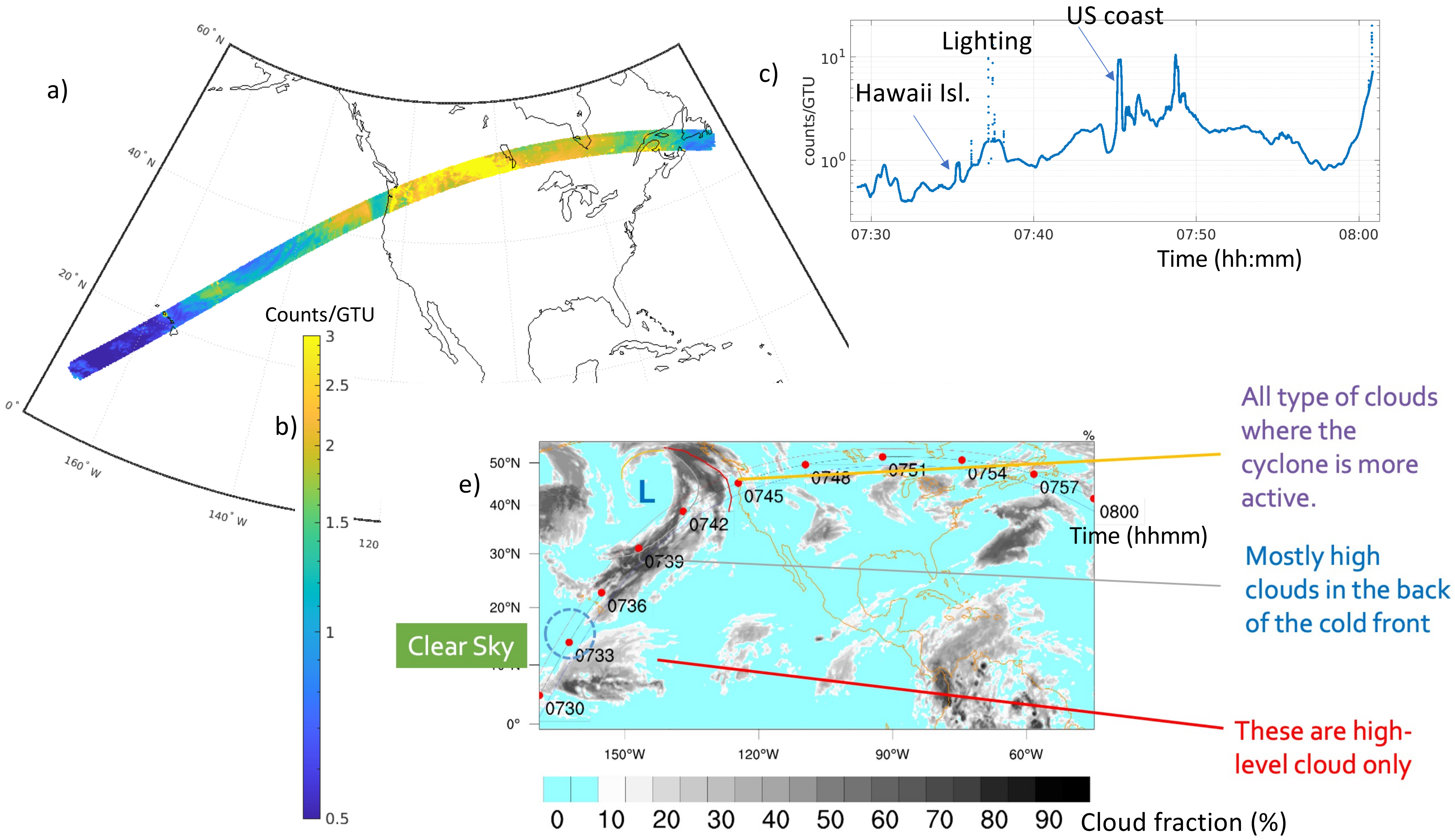


137 sessions performed,
only available data till session 44

L. Marcelli et al.
Data in Brief 48 (2023) 109105


e)
L
0730
0733
0736
0739
0742
0745
0748
0751
0754
0757
0800
Time (hhmm)
50°N
40°N
30°N
20°N
0°
150°W
120°W
90°W
60°W
%
Clear Sky
All type of clouds where the cyclone is more active.
Mostly high clouds in the back of the cold front
These are high-level cloud only
0
10
20
30
40
50
60
70
80
90
Cloud fraction (%)


a)
b)
e)
Counts/GTU
3
2.5
2
1.5
1
0.5
60° N
40° N
20° N
0°
160° W
140° W
120
L
50°N
40°N
30°N
20°N
0°
150°W
120°W
90°W
60°W
%
0730
0733
0736
0739
0742
0745
0748
0751
0754
0757
0800
Time (hhmm)
Clear Sky
0 10 20 30 40 50 60 70 80 90
Cloud fraction (%)
All type of clouds where the cyclone is more active.
Mostly high clouds in the back of the cold front
These are high-level cloud only


a)
b)
Counts/GTU
3
2.5
2
1.5
1
0.5
60° N
40° N
20° N
0°
160° W
140° W
120
c)
counts/GTU
US coast
Lighting
Hawaii Isl.
07:30
07:40
07:50
08:00
Time (hh:mm)
e)
L
0730
0733
0736
0739
0742
0745
0748
0751
0754
0757
0800
Time (hhmm)
50°N
40°N
30°N
20°N
0°
150°W
120°W
90°W
60°W
Clear Sky
0
10
20
30
40
50
60
70
80
90
Cloud fraction (%)
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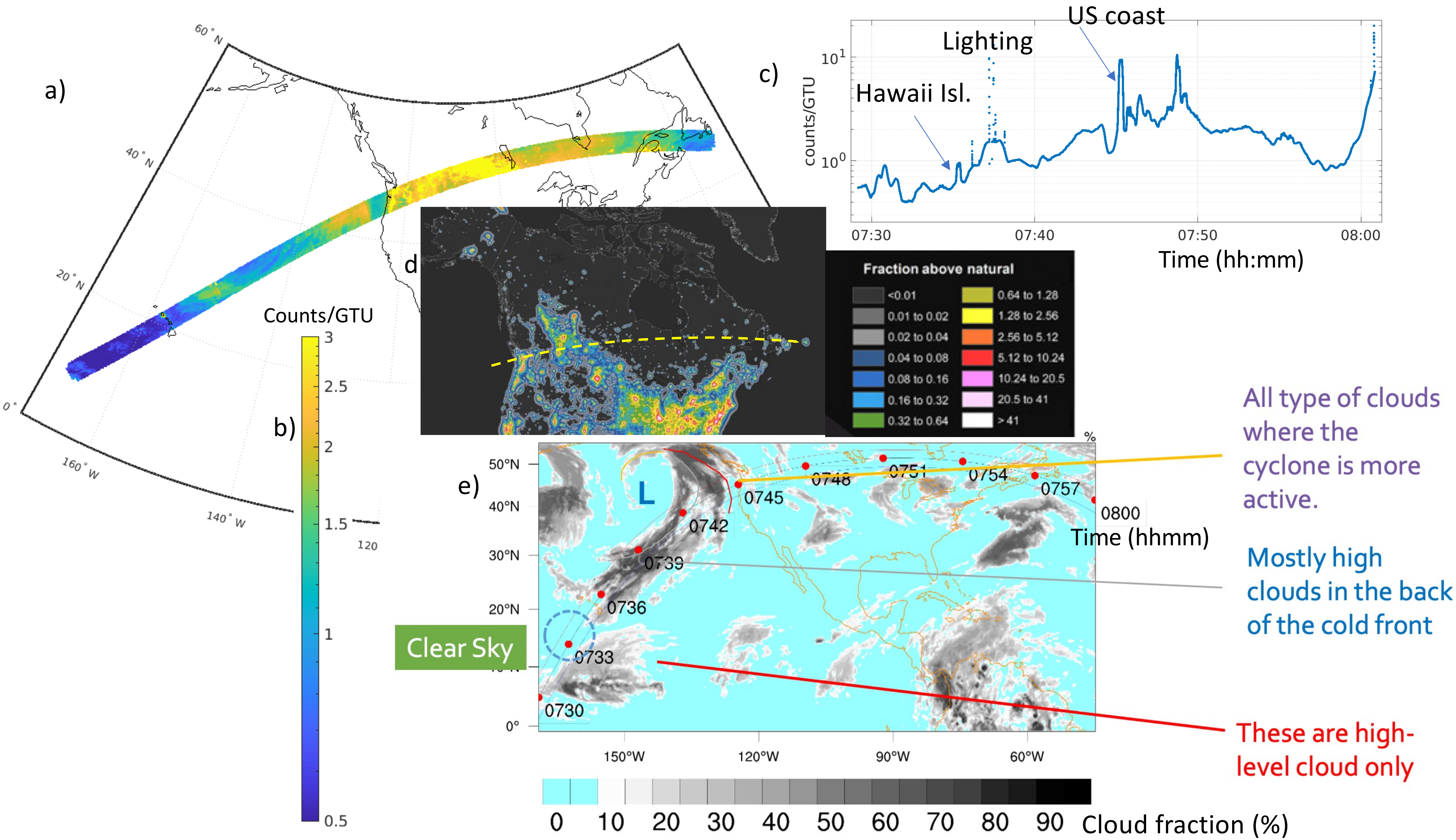
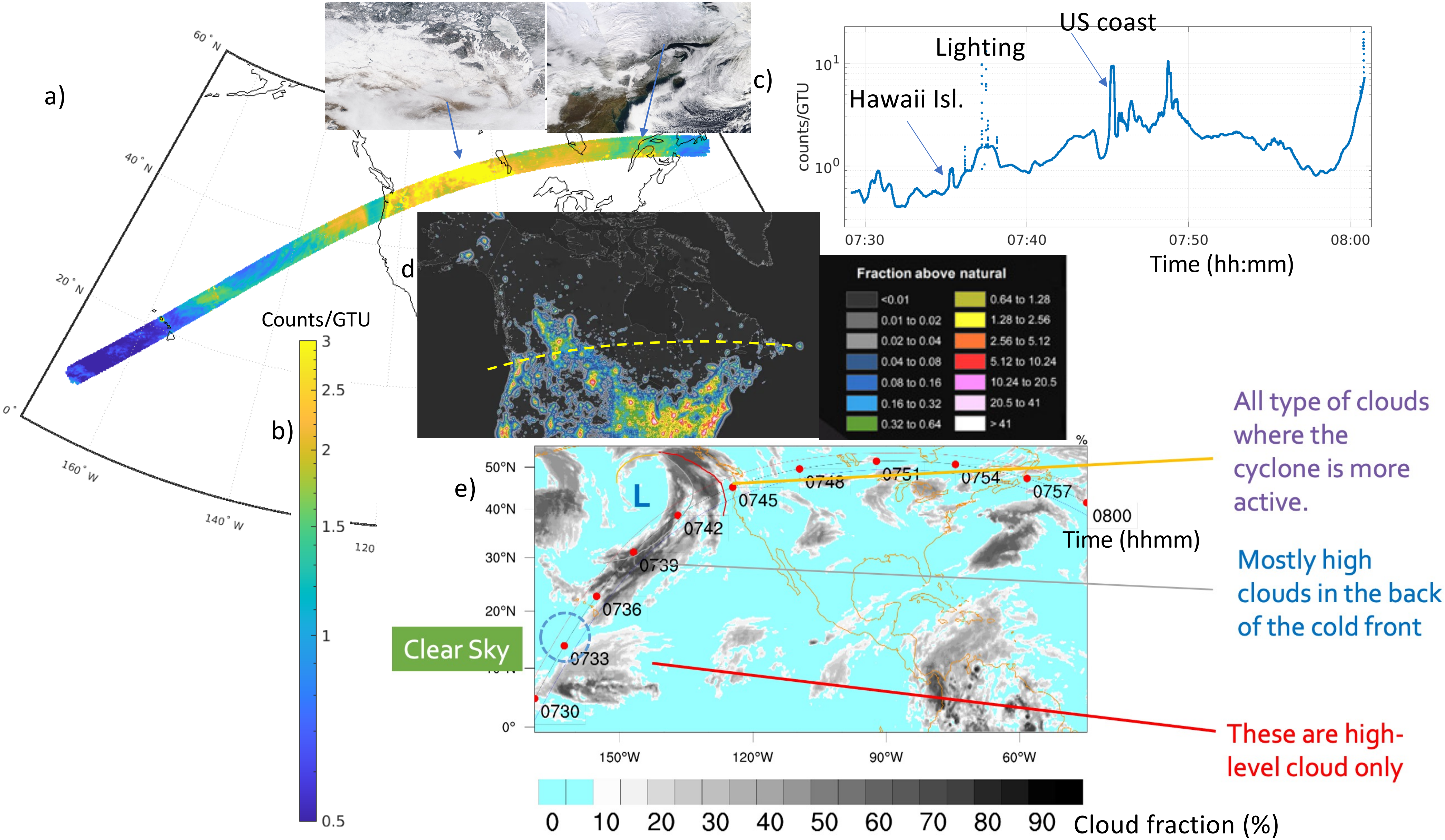


a)
60° N
40° N
20° N
0°
160° W
140° W
120
Counts/GTU
3
2.5
2
1.5
1
0.5
b)
c)
Lighting
US coast
Hawaii Isl.
counts/GTU
10^1
10^0
07:30
07:40
07:50
08:00
Time (hh:mm)
d
Fraction above natural
<0.01
0.01 to 0.02
0.02 to 0.04
0.04 to 0.08
0.08 to 0.16
0.16 to 0.32
0.32 to 0.64
0.64 to 1.28
1.28 to 2.56
2.56 to 5.12
5.12 to 10.24
10.24 to 20.5
20.5 to 41
> 41
e)
%
50°N
40°N
30°N
20°N
0°
L
0730
0733
0736
0739
0742
0745
0748
0751
0754
0757
0800
Time (hhmm)
150°W
120°W
90°W
60°W
Clear Sky
0
10
20
30
40
50
60
70
80
90
Cloud fraction (%)
All type of clouds where the cyclone is more active.
Mostly high clouds in the back of the cold front
These are high-level cloud only



a)
b)
c)
d
e)
60° N
40° N
20° N
0°
160° W
140° W
120
Counts/GTU
3
2.5
2
1.5
1
0.5
US coast
Lighting
Hawaii Isl.
counts/GTU
07:30
07:40
07:50
08:00
Time (hh:mm)
Fraction above natural
<0.01
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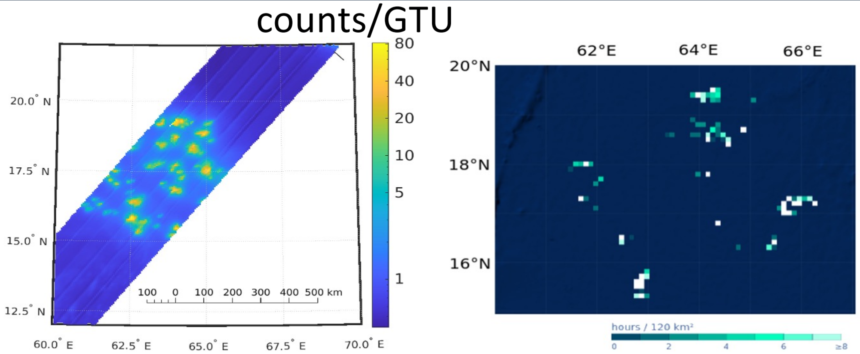
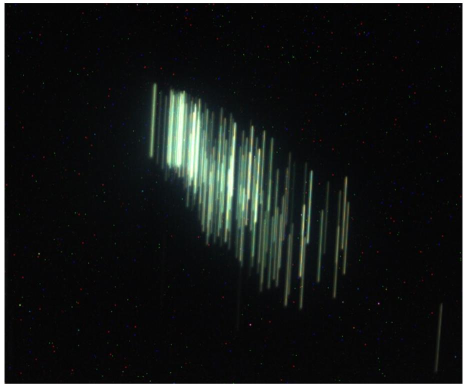
0.04 to 0.08
0.08 to 0.16
0.16 to 0.32
0.32 to 0.64
0.64 to 1.28
1.28 to 2.56
2.56 to 5.12
5.12 to 10.24
10.24 to 20.5
20.5 to 41
>41
All type of clouds where the cyclone is more active.
Mostly high clouds in the back of the cold front
These are high-level cloud only
Clear Sky
50°N
40°N
30°N
20°N
0°
150°W
120°W
90°W
60°W
L
0730
0733
0736
0739
0742
0745
0748
0751
0754
0757
0800
Time (hhmm)
0
10
20
30
40
50
60
70
80
90
Cloud fraction (%)

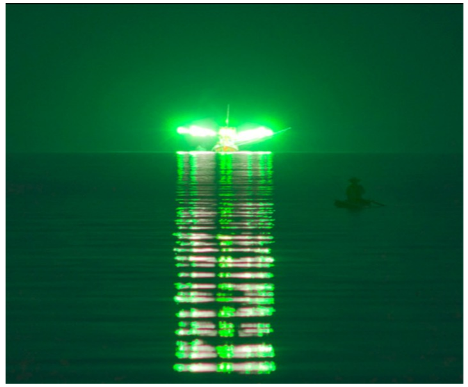
Fishing boats and AC modulation



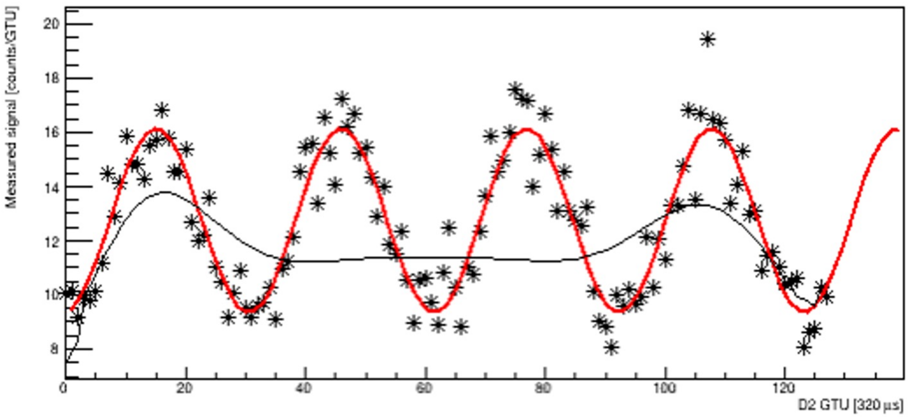
Fishing boats in the Arabian sea. Left: Mini-EUSO data. Right: Data from the Global Fishing Watch [https://globalfishingwatch.org]



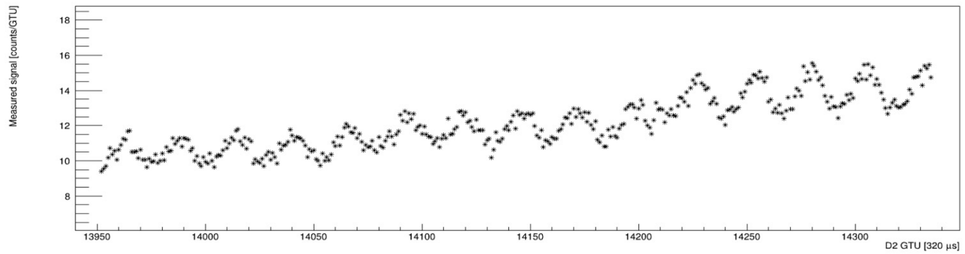
Mini-EUSO visible camera off the coast of Argentina



Squid fishermen use bright lights to draw fish and squid toward the sea surface at night. (©2012 Jay Lawler)

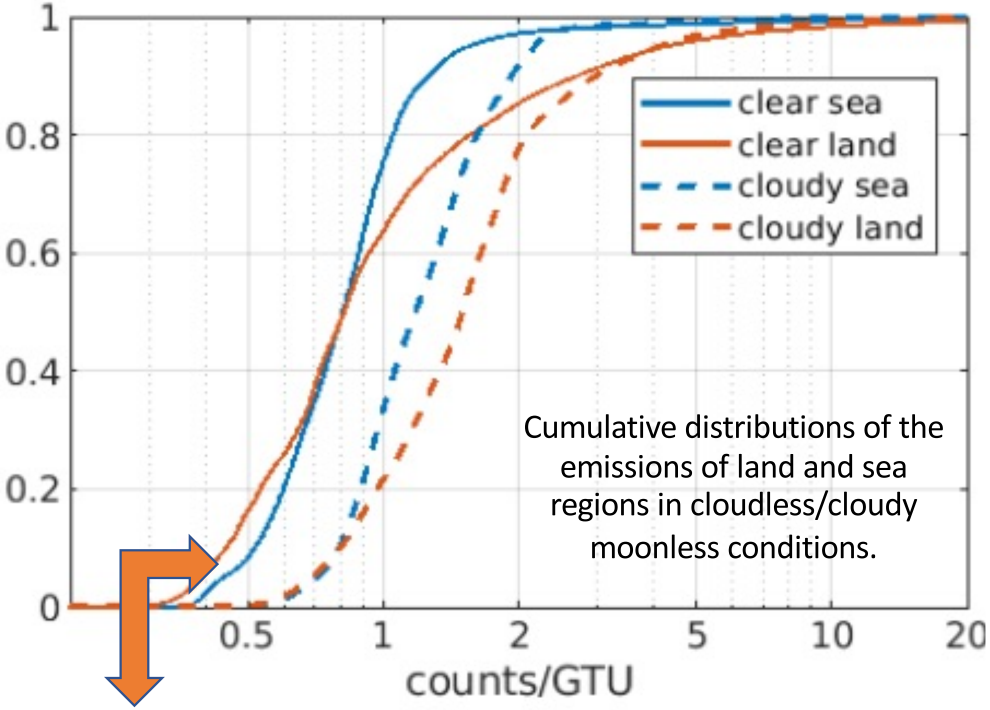


50 Hz modulation over an Indonesian city

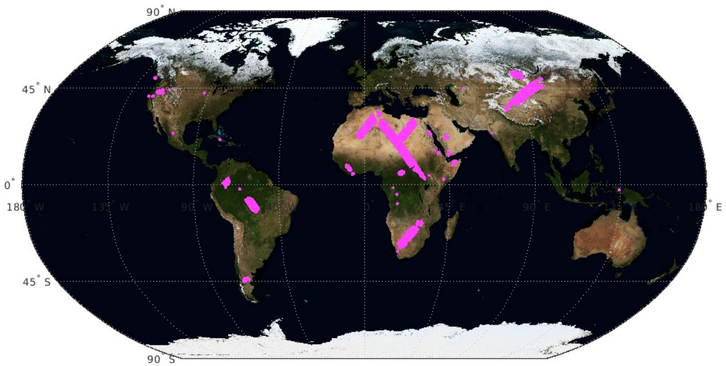


60 Hz modulation produced by the fishing boats off the coast of Argentina

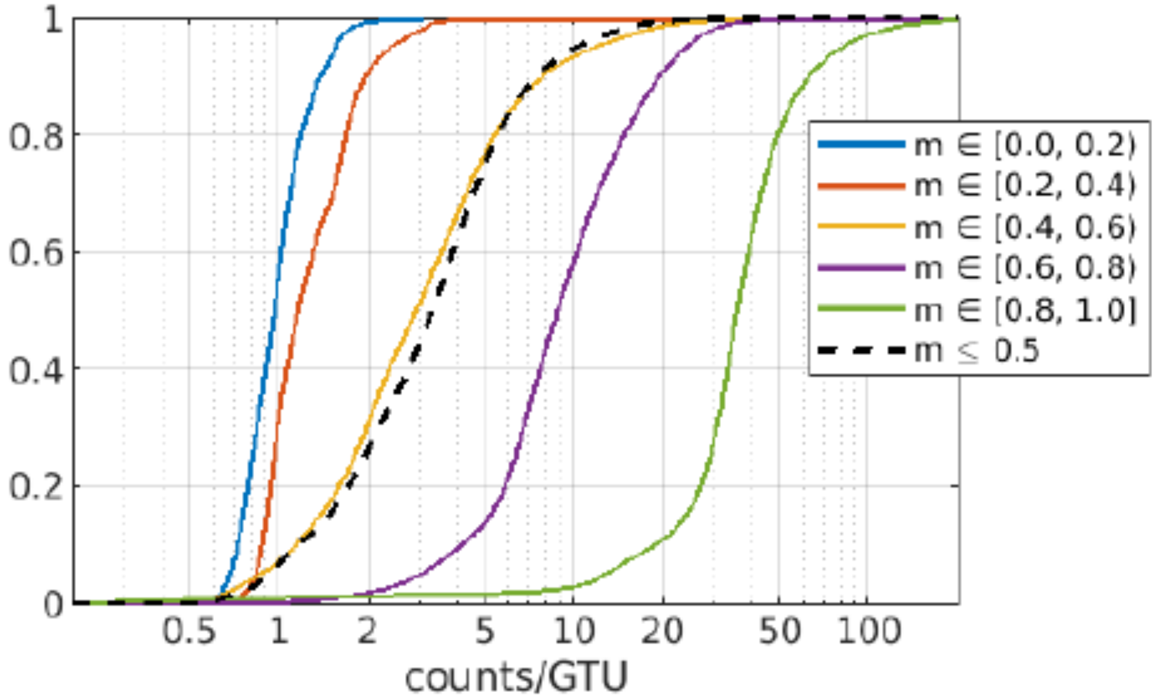
Moonless conditions



Cumulative distributions of the emissions of land and sea regions in cloudless/cloudy moonless conditions.



Moon Phases

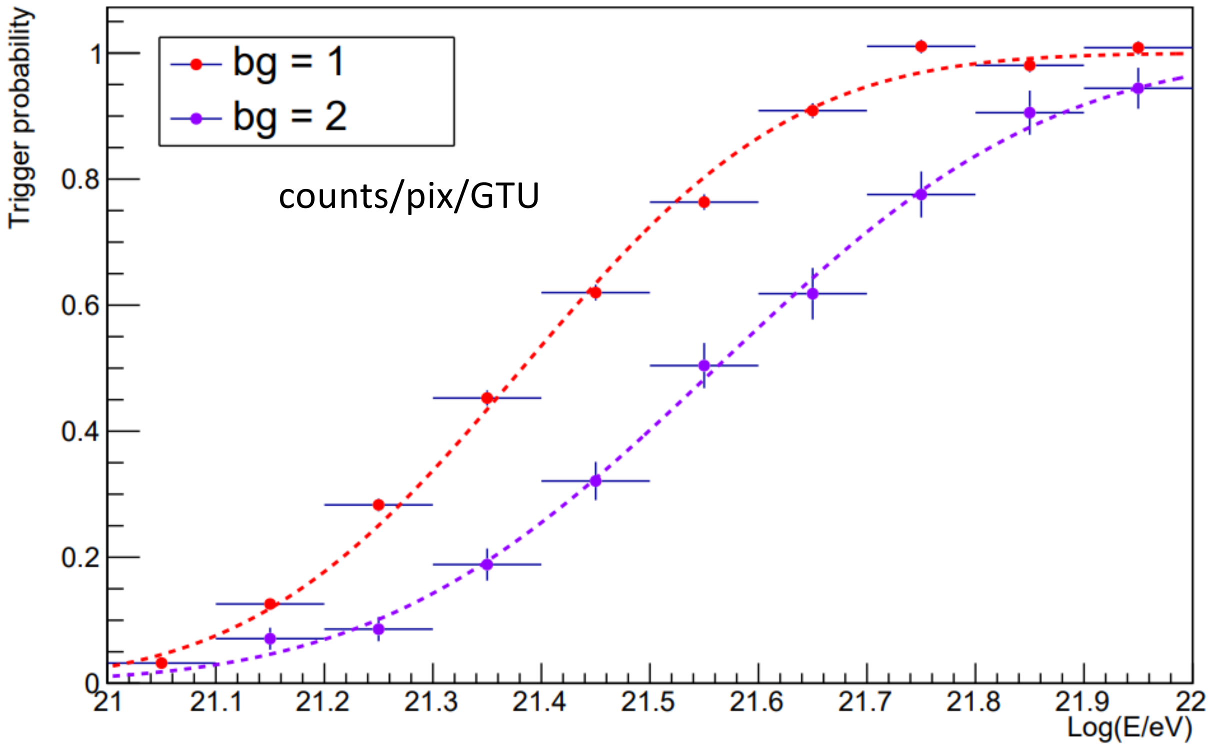


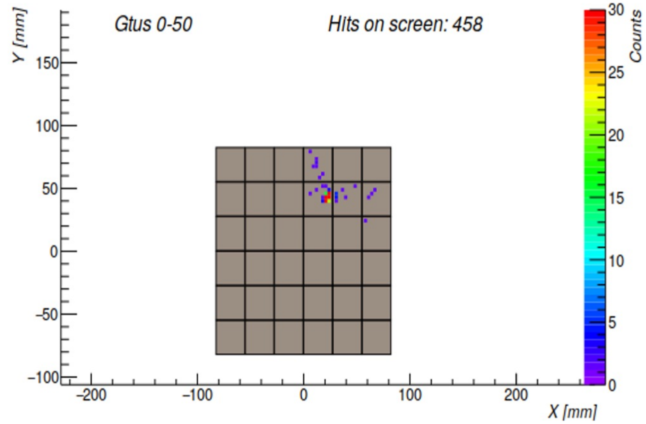
M. Casolino et al.: Remote Sensing of Environment 284 (2023) 113336
ArXiv: 2212.02353

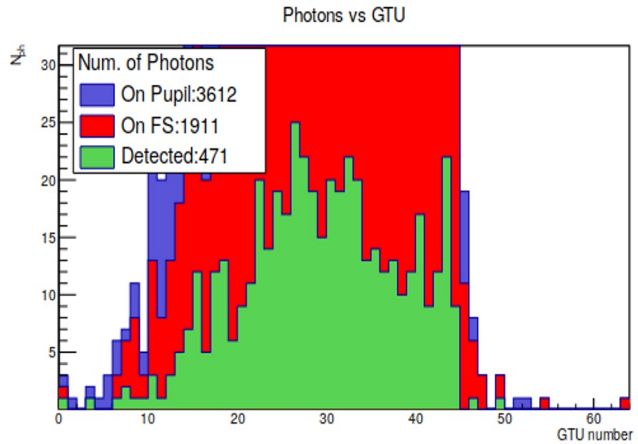
Analyzed sessions: 5 - 19

Mini-EUSO EAS trigger probability

Proton E = 5×10^{21} eV, 50°





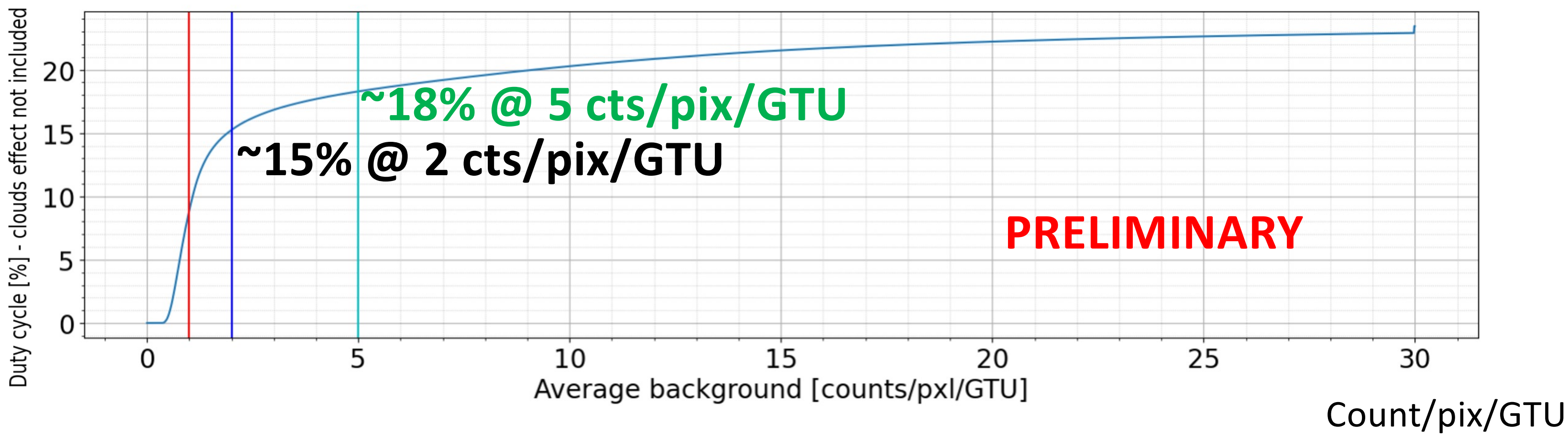


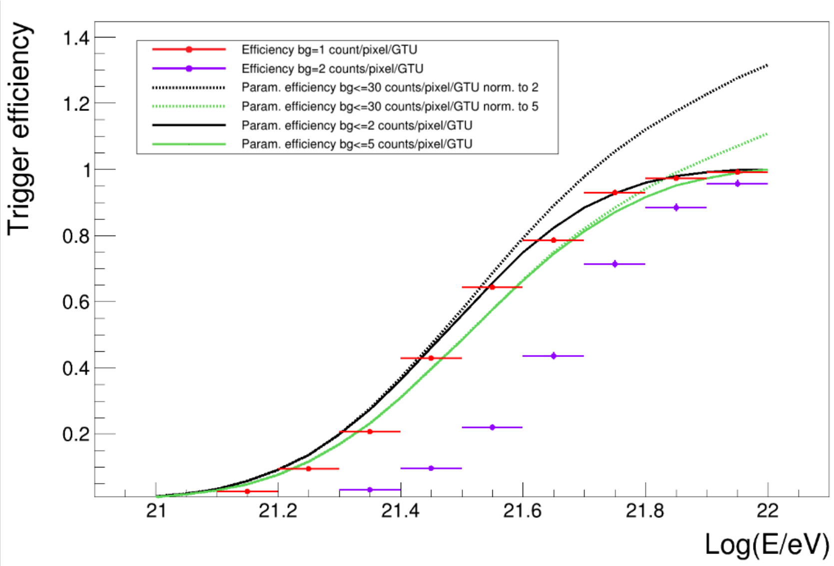
Obtained using ESAF simulations
Proton EASs

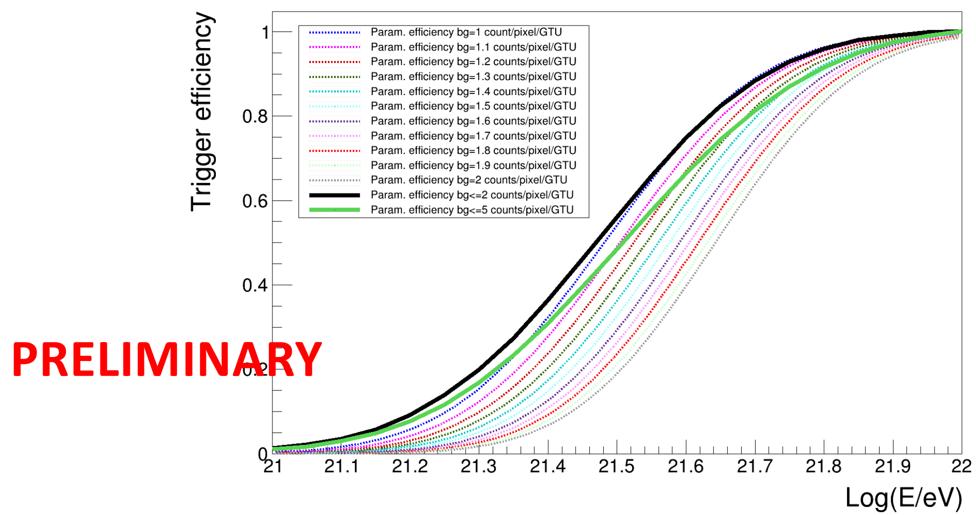
S. Abe et al., Eur. Phys. J. C (2023) 83:1028

Combining bckg distrib. and efficiency curves: the integrated exposure curve

$$\eta_0 = \frac{\sum_{\mathrm{MB}} \frac{T^{\mathrm{MB}}_{<\mathrm{Thrs}}}{F^{\mathrm{MB}}_{Conv}}}{\Delta T_{\mathrm{orbit}} \cdot N_{\mathrm{orbit}}}$$

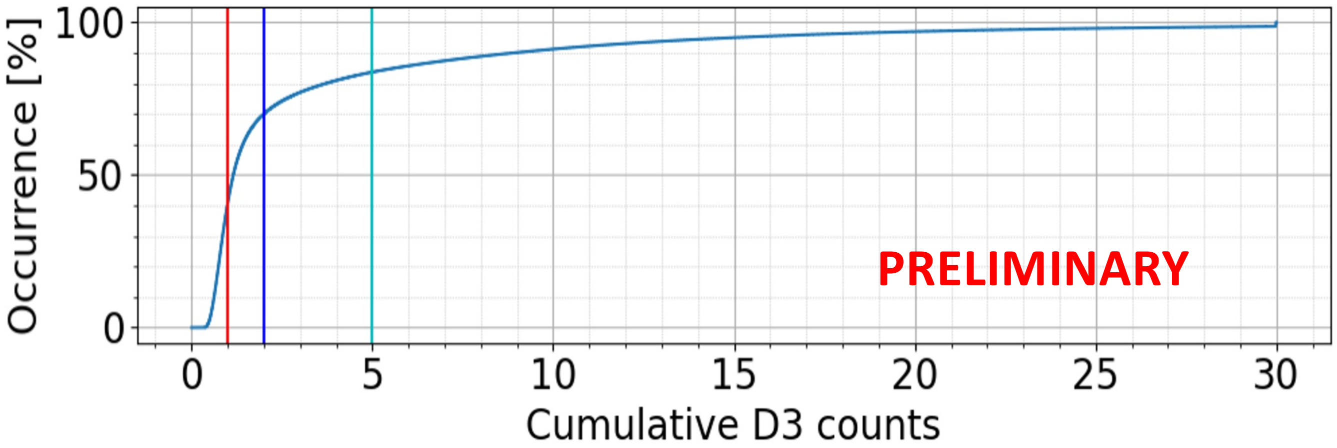






Overall experimental confirmation of JEM-EUSO duty cycle

Accumulated exposure by Mini-EUSO



T = 68. 1 h * 0.837 = 6.51E-3 yr
A = 2304 * (5.9 km)^2 = 7.97E+4 km^2
Ω = π * 0.72 (cloud factor) = 2.26
Exposure = T x A x Ω = **~1200 L**

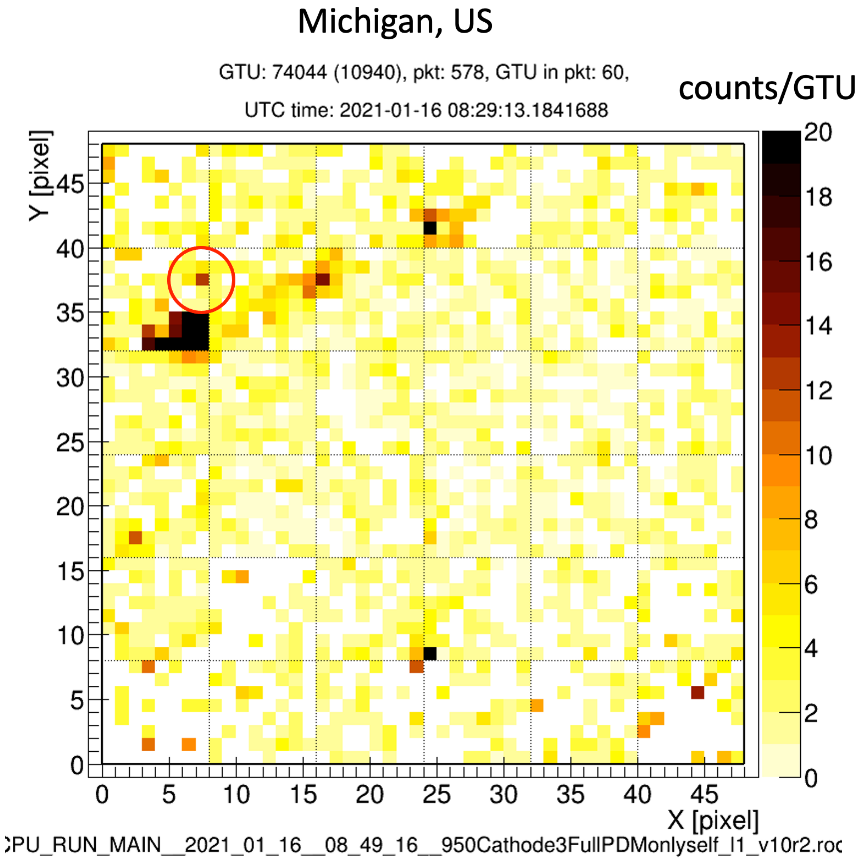
If taking into account till session **135** (November 2024) = **~6000 L**

If Mini-EUSO would have operated continuously since August 2019: ***~150000 L***
(exposure/day = ~76 L/day)

Extrapolating to all good recorded data the expected cumulated exposure for UHECRs is **~6000 L** at the highest energies. **This exposure is comparable to the one collected so far by UHECR experiments using the fluorescence technique.**

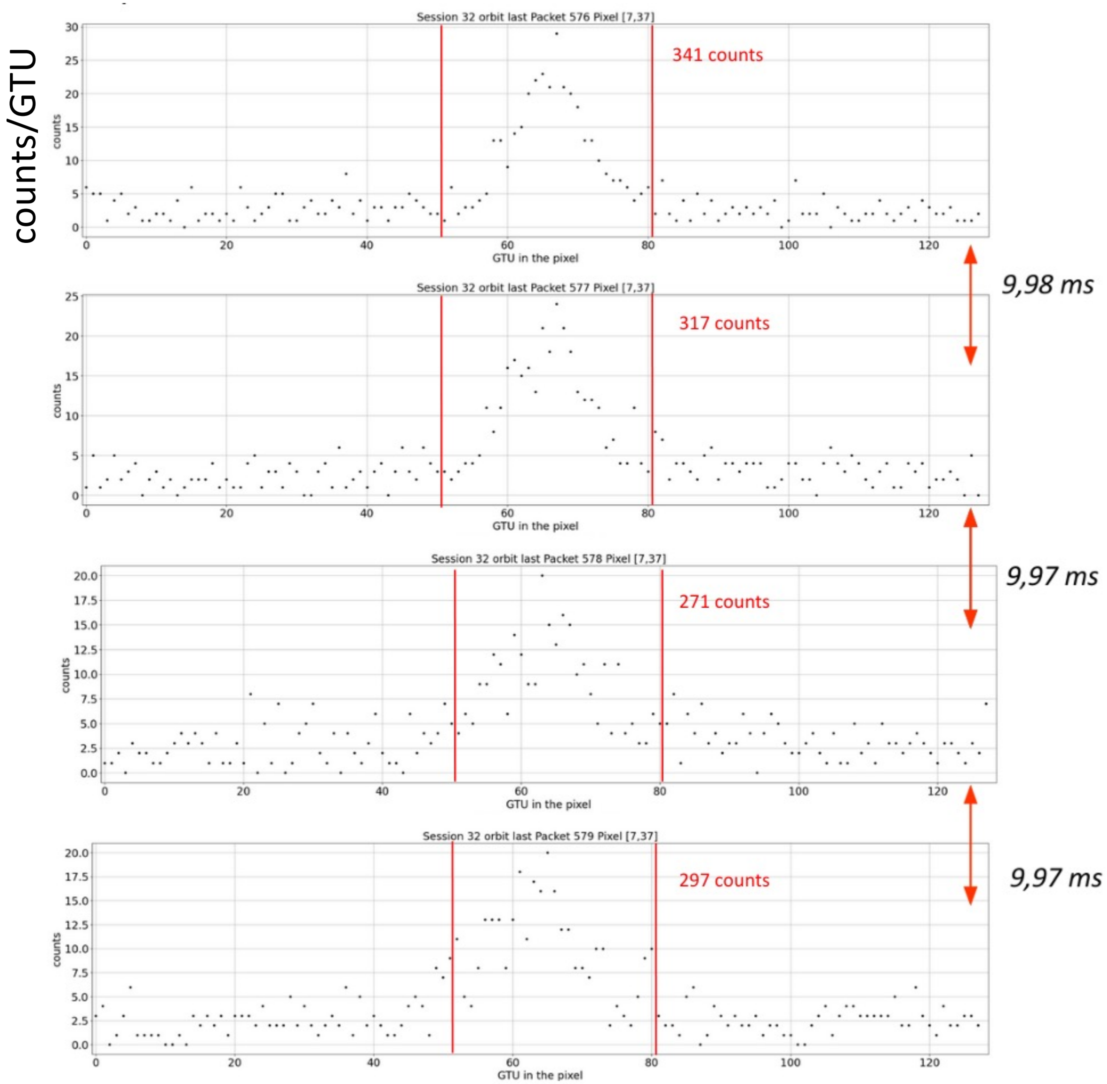
If Mini-EUSO would have operated continously in the past ~5 years it would have accumulated the exposure collected so far by ground-based experiments.

Ground Flashers



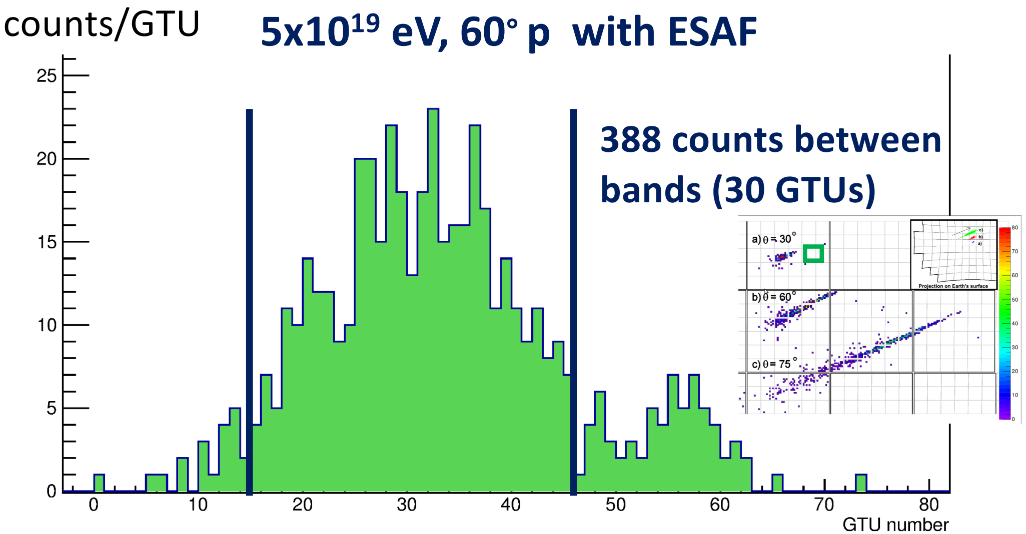
M. Battisti

Repeated ground flashers



UHECRs in JEM-EUSO & ground flashers in Mini-EUSO

JEM-EUSO
5x10^{19} eV, 60° p with ESAF

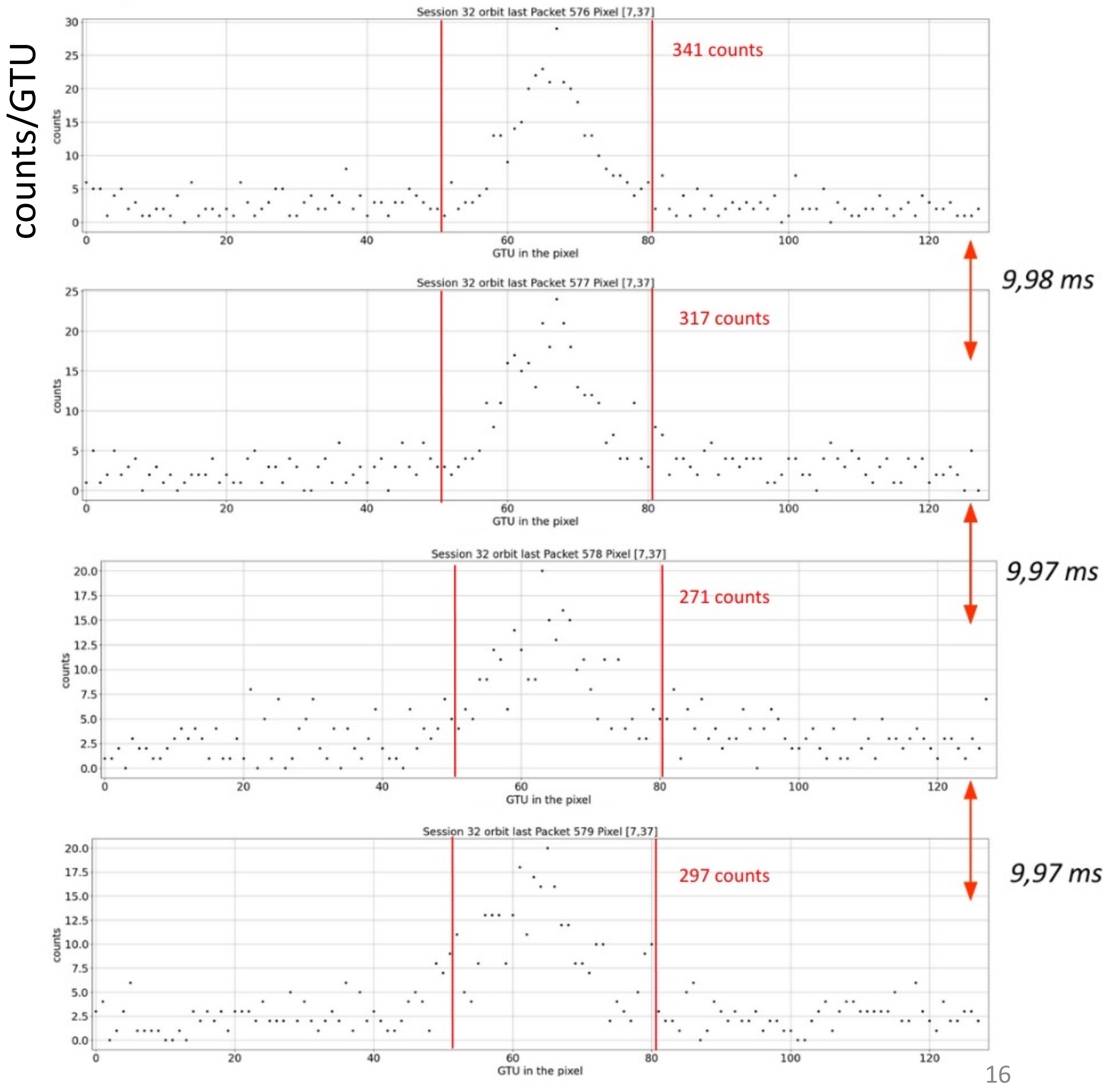


F. Fenu

Average counts: 307 counts
Spread: 35 counts
Relative error: 35/307 = 0.11
Expected Poissonan fluct.: 17 counts (5.5%)

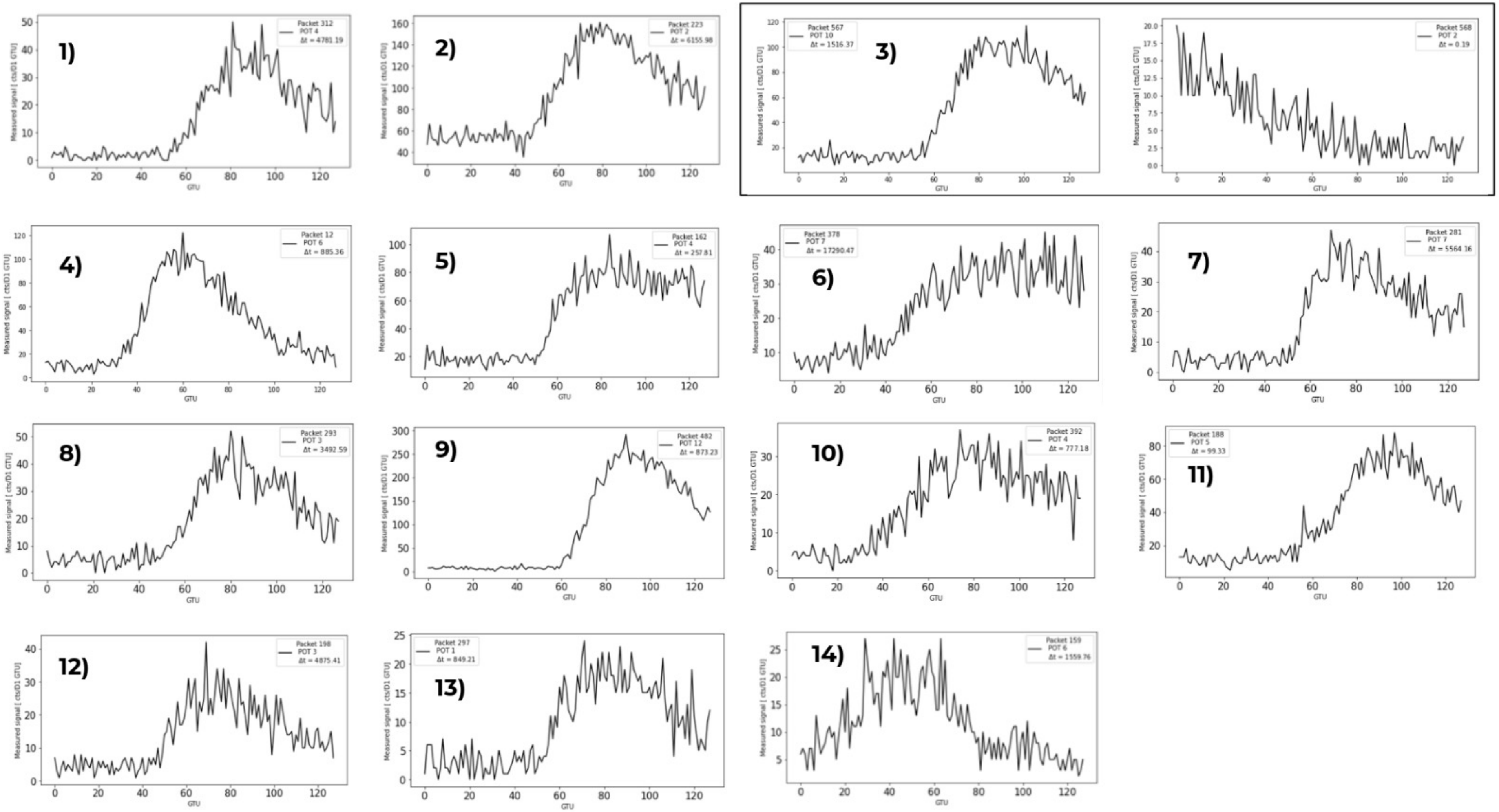
Proof of the detection principle of UHECRs from space with signals in Mini-EUSO comparable to those expected in JEM-EUSO

Repeated ground flashers

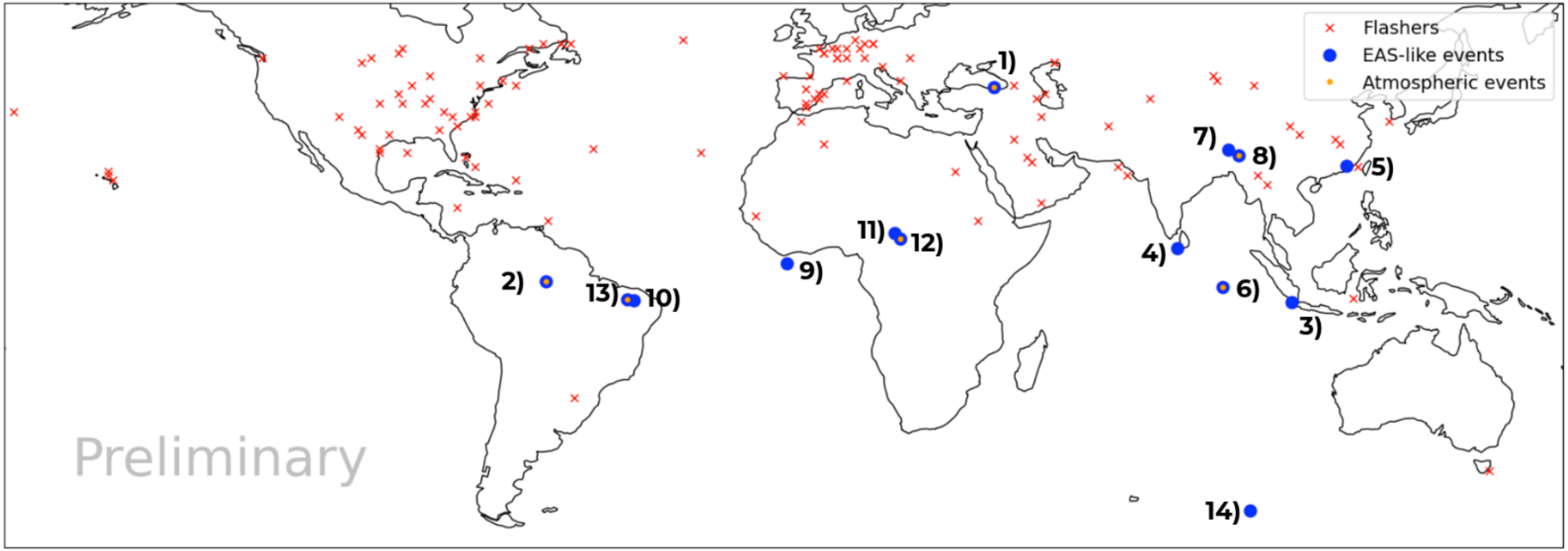


M. Battisti

Short Light Transients (SLT) lightcurves

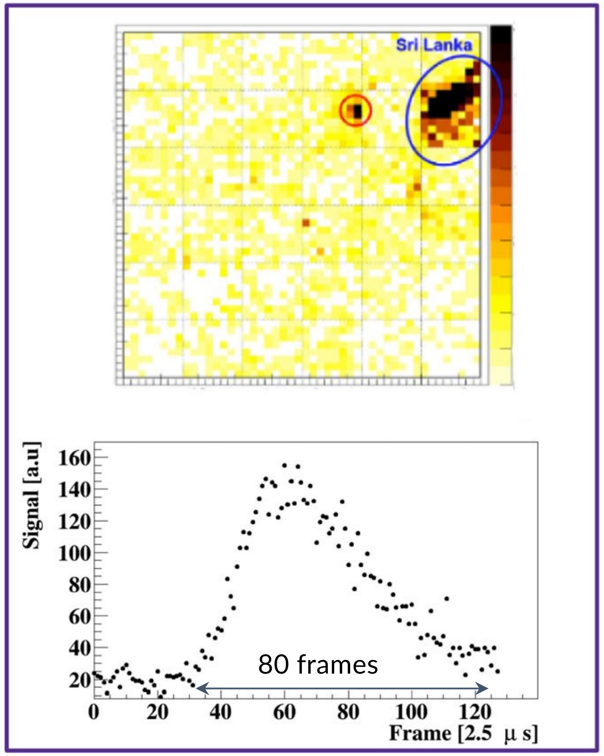


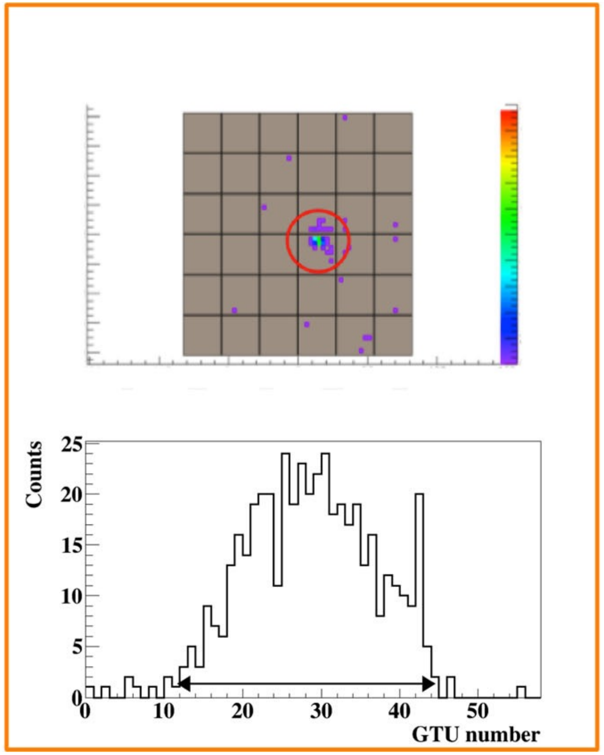
Map of the flasher (108/561) & SLT events

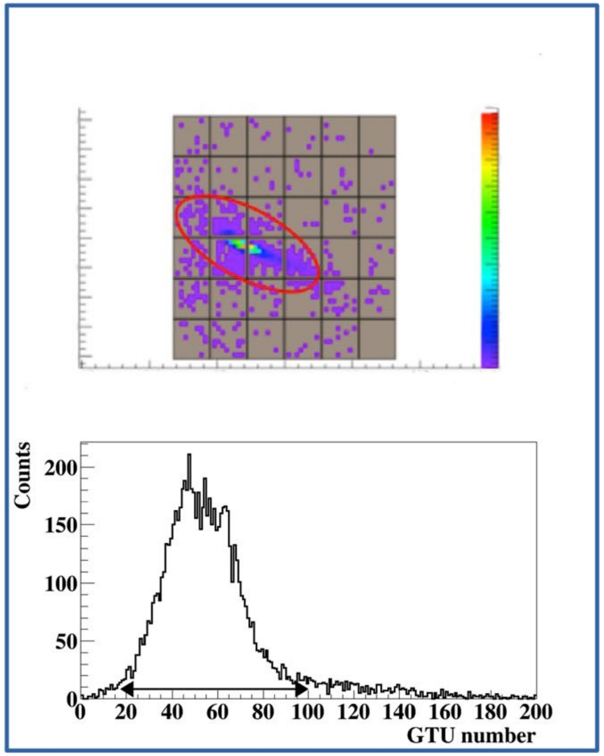


Mini-EUSO – non repetitive 'EAS-like' signal

Mini-EUSO data | **ESAF p, E = 5x10^{21} eV Zenith = 50°** | **ESAF p, E = 2x10^{22} eV Zenith = 80°**





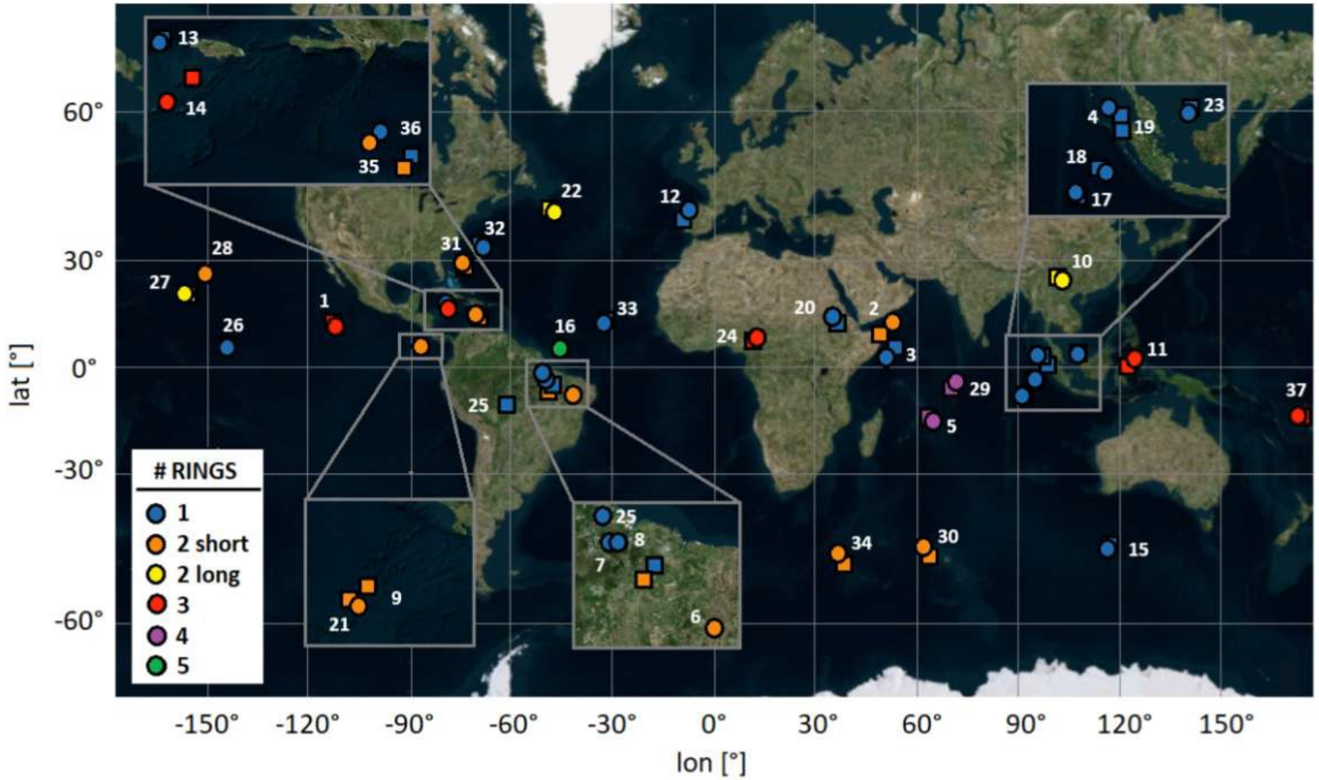


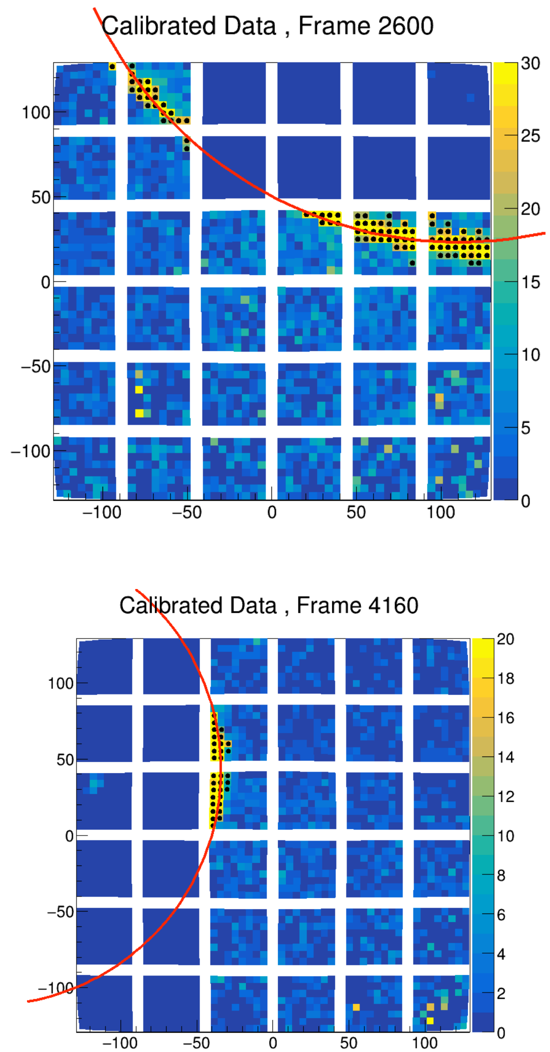
Focal plane view and lightcurve of the detected signal

- Cosmic ray simulations. Top: focal plane view. Bottom: lightcurves. Left: Zenith angle = 50°. Right: Zenith angle = 80°

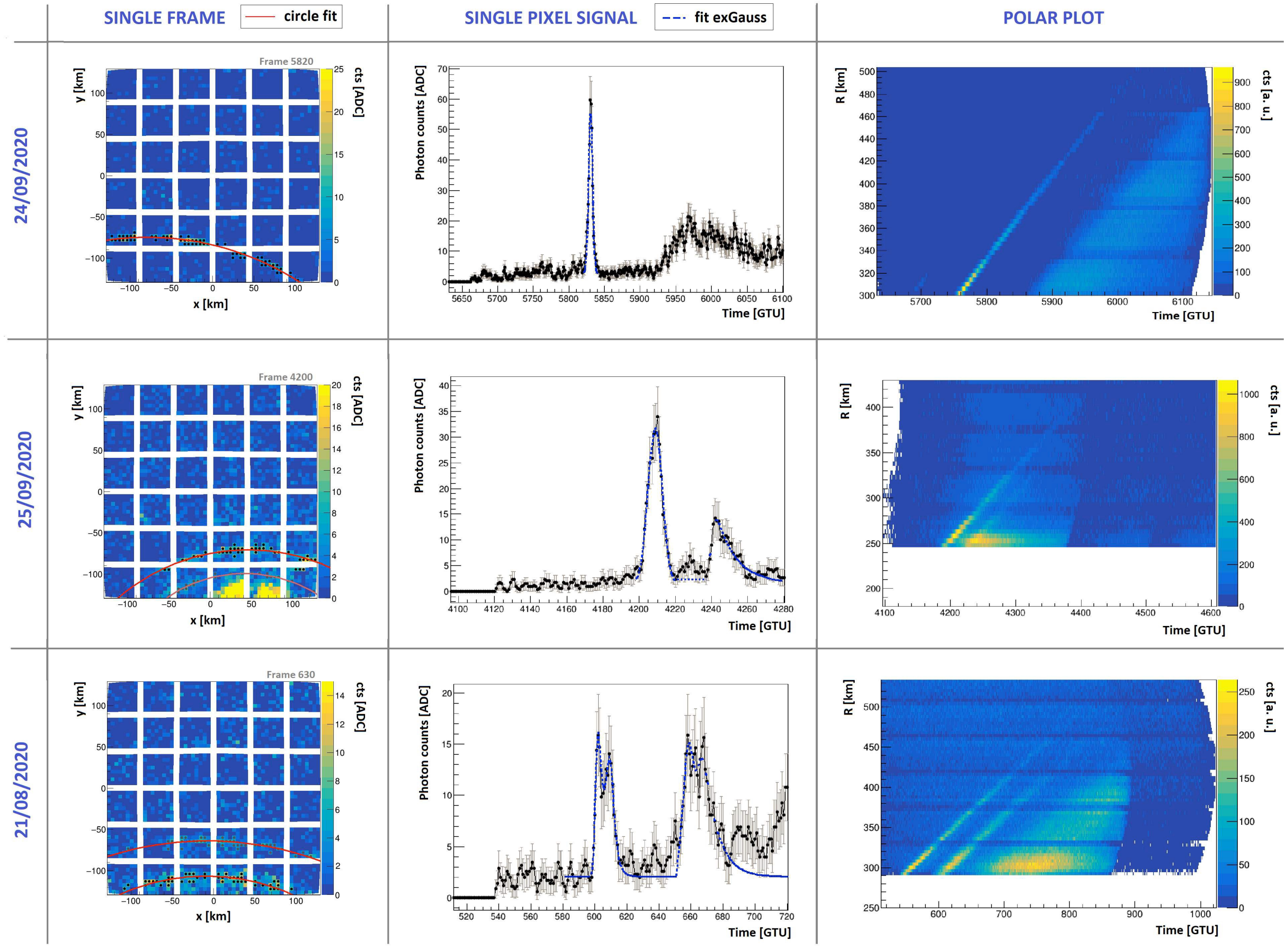
ELVES:

37 ELVES detected so far
(<1/2 dataset received)
mostly in the equatorial region





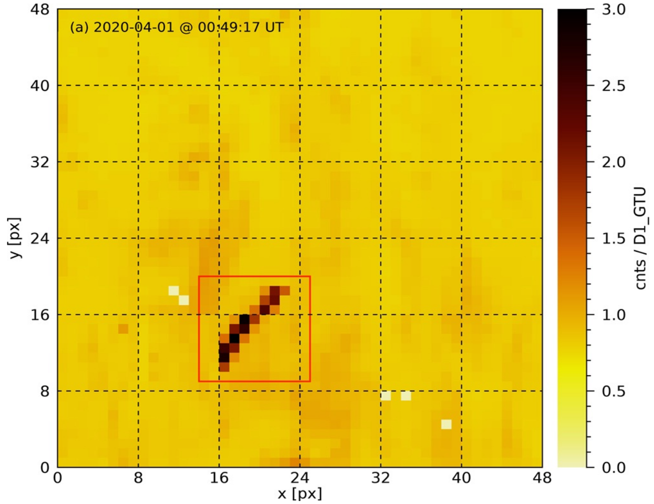
ELVES:

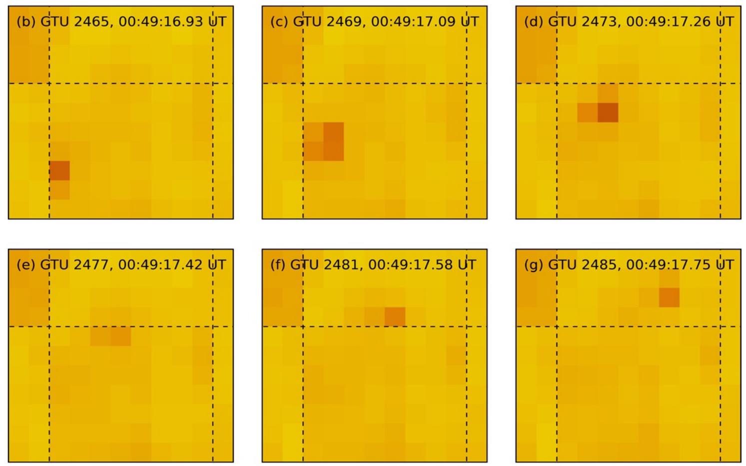

SINGLE FRAME
circle fit
SINGLE PIXEL SIGNAL
fit exGauss
POLAR PLOT
24/09/2020
25/09/2020
21/08/2020
Frame 5820
Frame 4200
Frame 630
y [km]
x [km]
cts [ADC]
Photon counts [ADC]
Time [GTU]
R [km]
cts [a. u.]

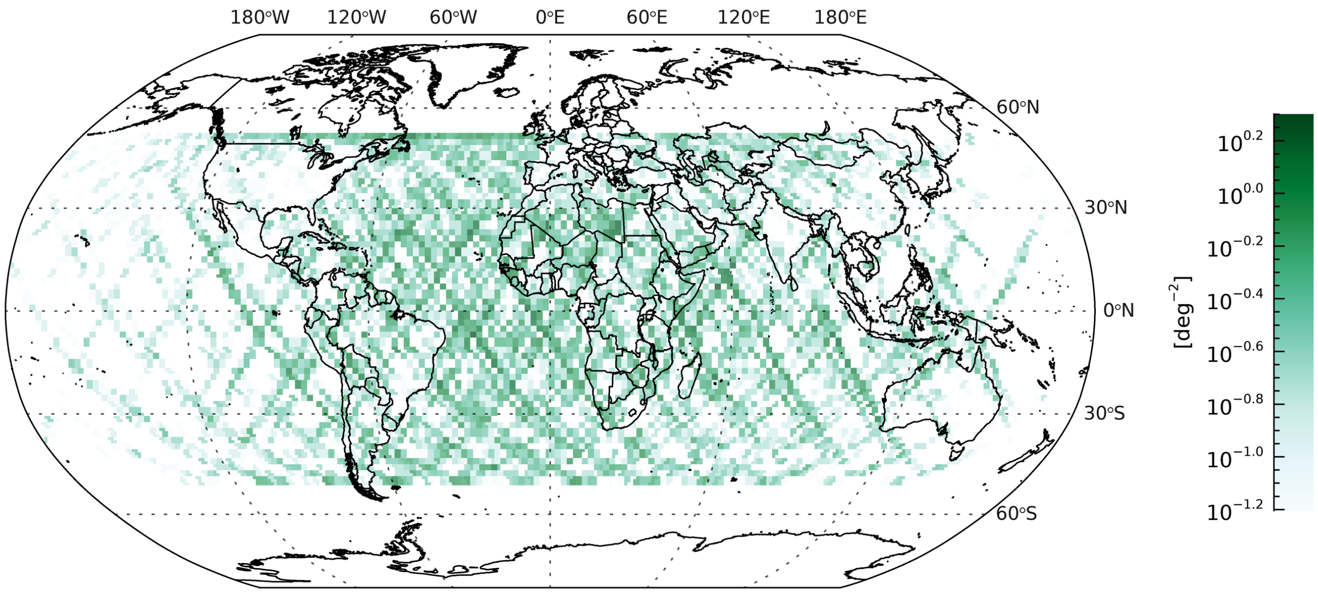
Meteors:

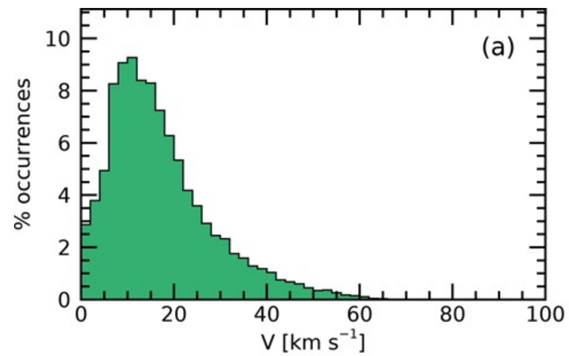
Mini-EUSO is making the first systematic detection & study from space

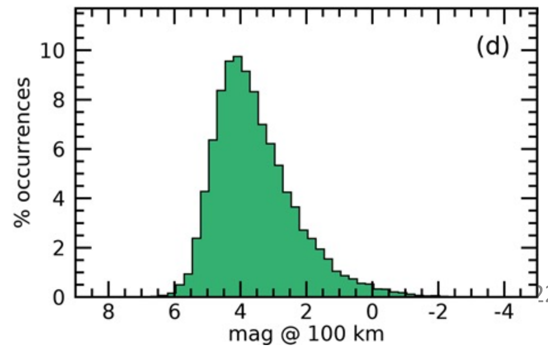
~24 k candidates





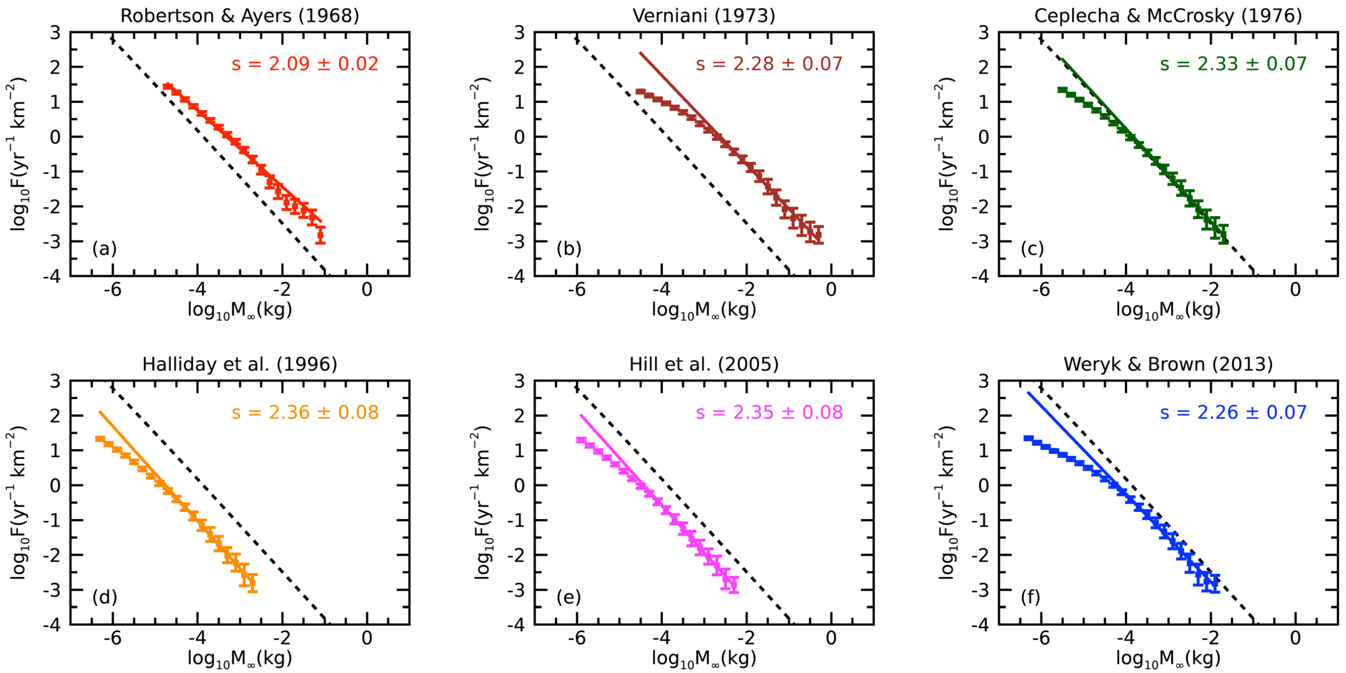






D. Barghini et al. A&A, 687, A304 (2024)
https://doi.org/10.1051/0004-6361/202449236

Cumulative flux density distribution

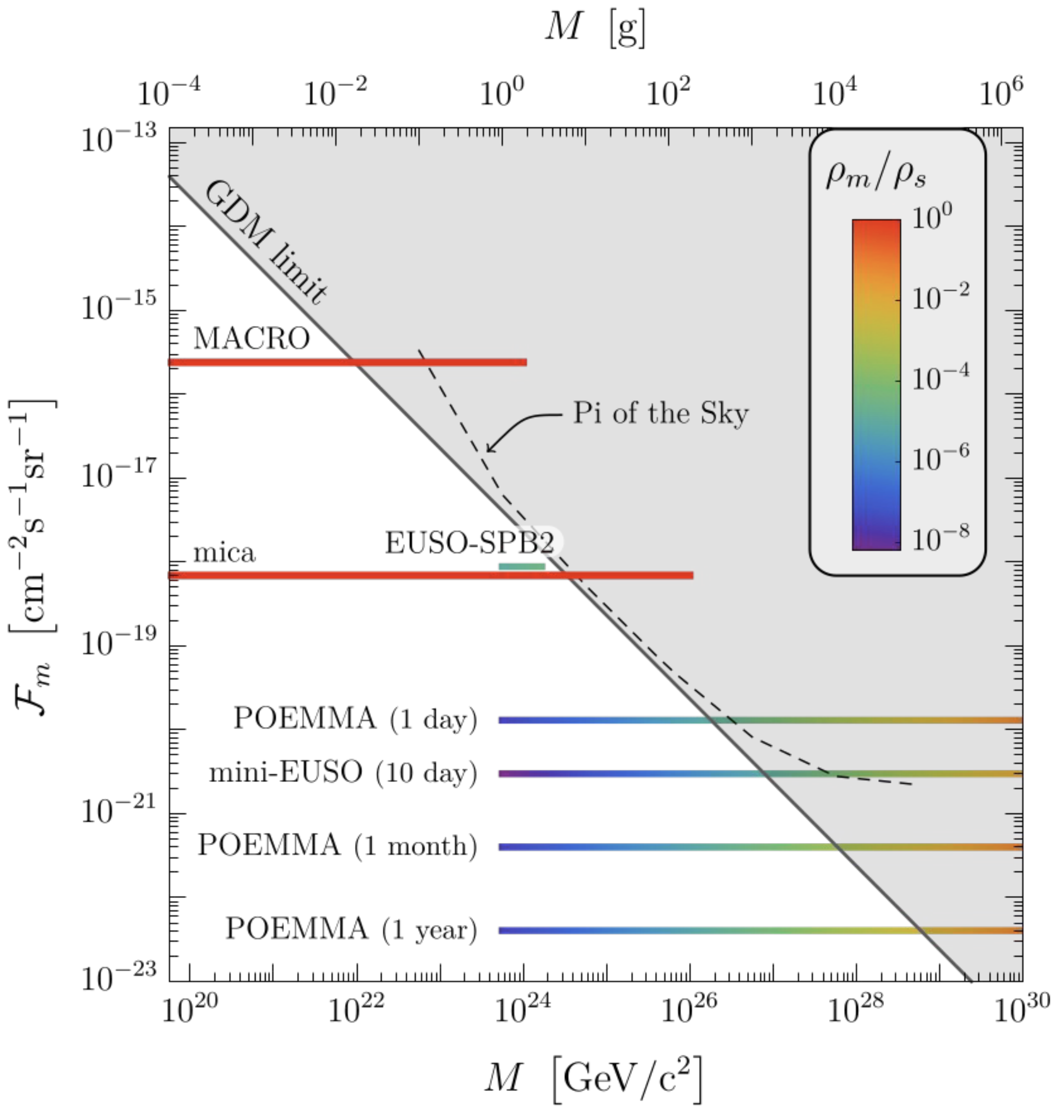


Comparison of the cumulative flux density distribution of meteoroids computed thanks to the observations of meteors by the Mini-EUSO telescope, resulting from the application of different methods to compute the pre-atmospheric mass of the meteoroid from the intensity of the observed meteor and consisting of different formulations of the luminous efficiency as a function of the pre-atmospheric speed V∞, according to the literature. These are: (a) Robertson & Ayers (1968); (b) Verniani (1973); (c) Ceplecha & McCrosky (1976); (d) Halliday et al. (1996), (e) Hill et al. (2005); and (f) Weryk & Brown (2013). In each panel, coloured squares plot the results of Mini-EUSO for mass bins associated with an overall trigger efficiency $\epsilon > 20\%$ and the thick coloured line reports the result of a linear fit in the log-log space. For panel a, the linear fit is made against the whole range of masses, while for panels b-f it is made against the half interval of larger masses and extended to the whole range in order to enhance its visibility. The fitted value of the mass index s for each case

MACROscopic dark matter

"As a complementary effort, experiments with sufficient exposure (> 5 x 10⁵ km² sr yr) are needed to search for Lorentz-invariance violation (LIV), SHDM, and other BSM physics at the Cosmic and Energy Frontiers, and to identify UHECR sources at the highest energies." from SNOWMASS 2021

MACRO candidates in Mini-EUSO searched as fast moving `meteors'



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CONCLUSIONS

- Mini-EUSO on ISS for already 5 years.
- Mini-EUSO observes events of different nature showing the broader impact of an UHECR detector in space.
- It proves that it is possible – with larger detectors – to perform UHECR observation from space.
- Preliminary results indicate that measurements are in agreement with predictions from simulations.

THANK YOU