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

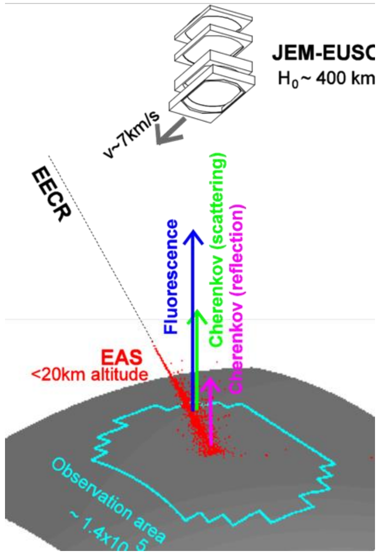
M. Bertaina – Univ. & INFN Torino
for the JEM-EUSO Collaboration
for ICRC2025, Geneva

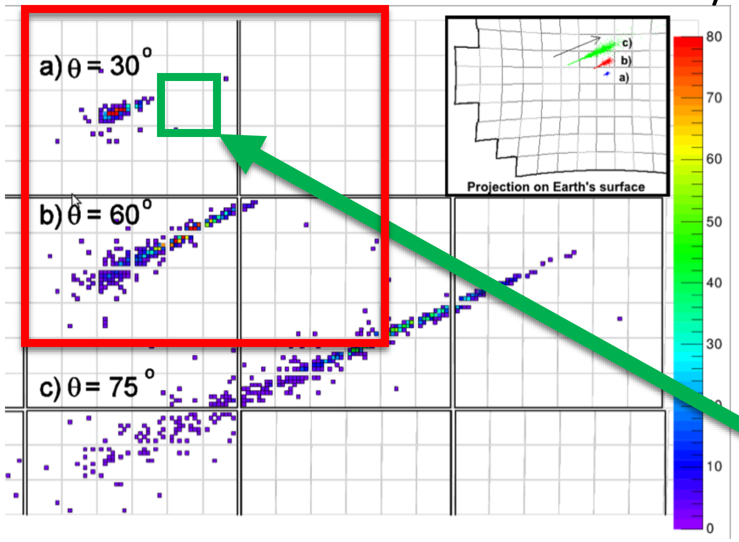
JEM-EUSO & Mini-EUSO

JEM-EUSO

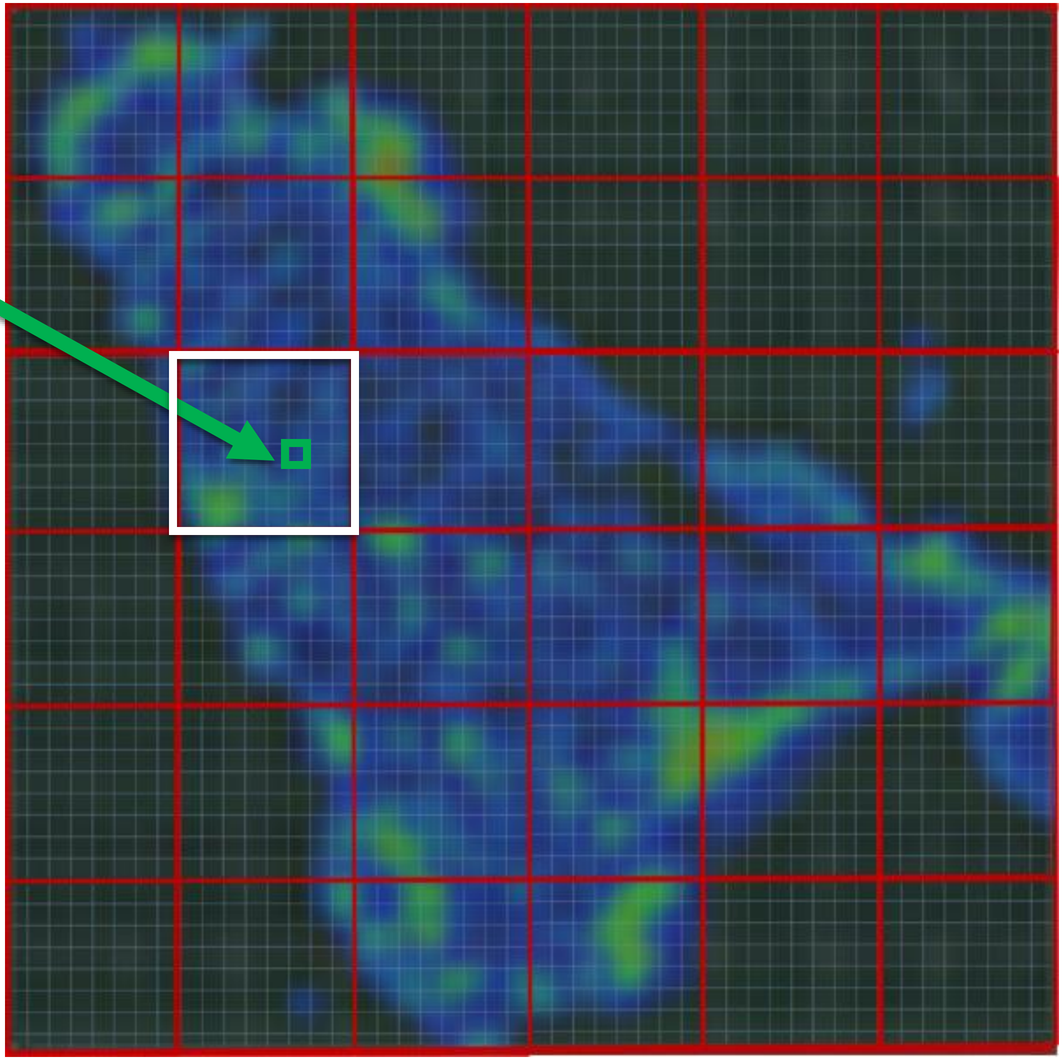
FoV

counts/GTU





Mini-EUSO



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**

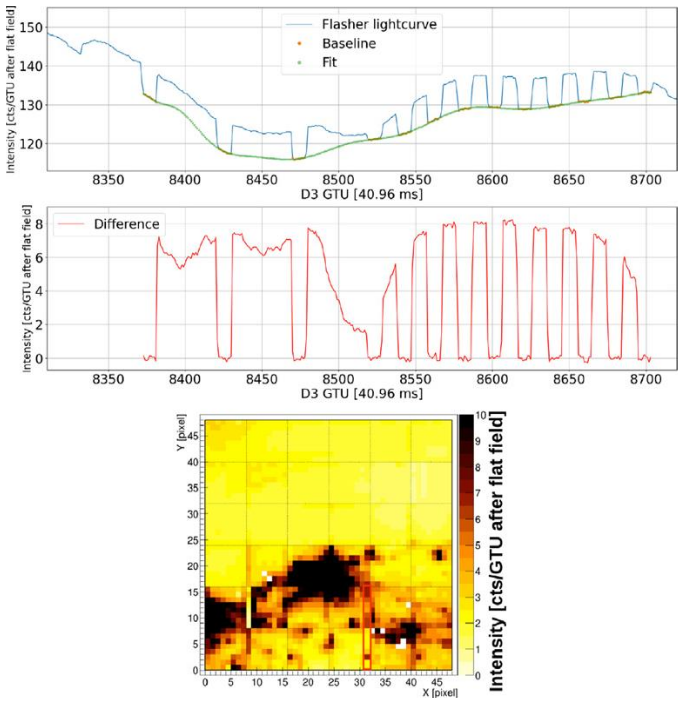
Simulation pre-flight

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

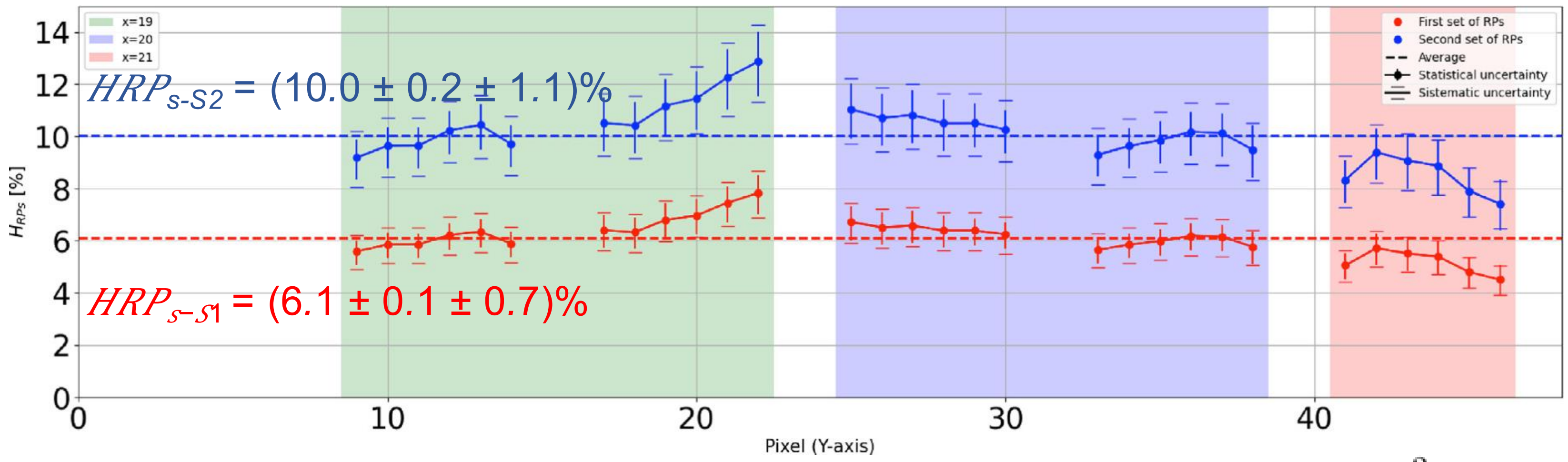
K. Shinozaki

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

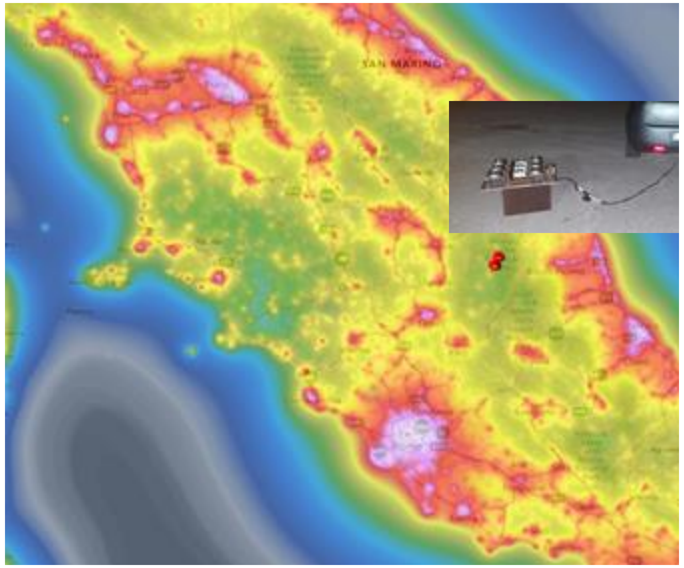


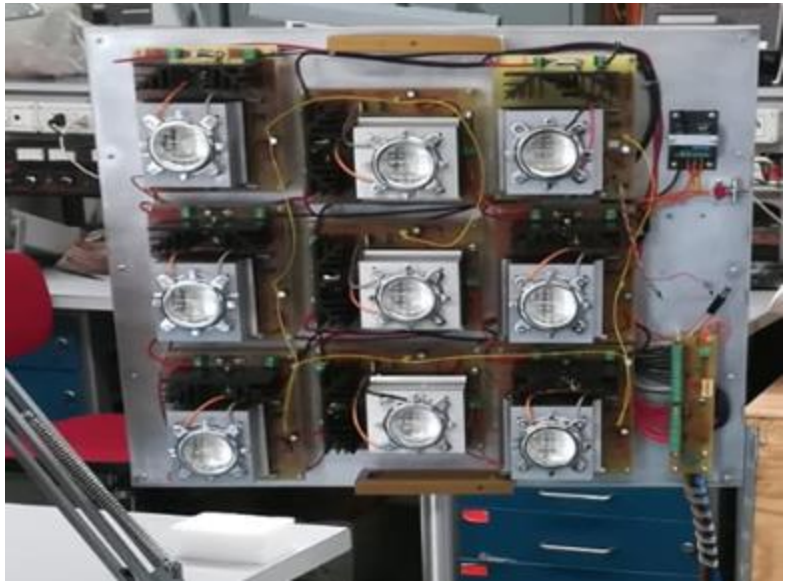
counts/GTU

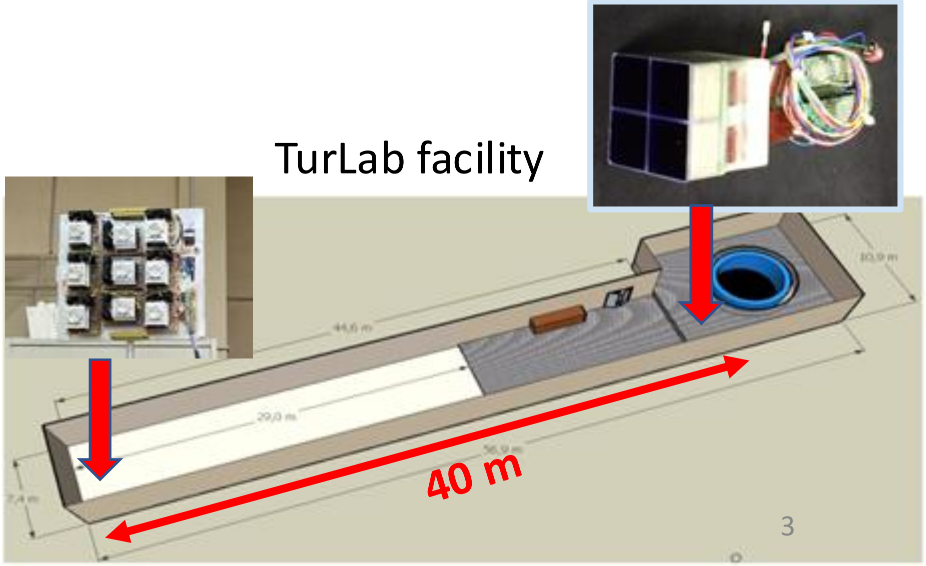
M. Battisti et al. Astroparticle Physics 165 (2025) 103057



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

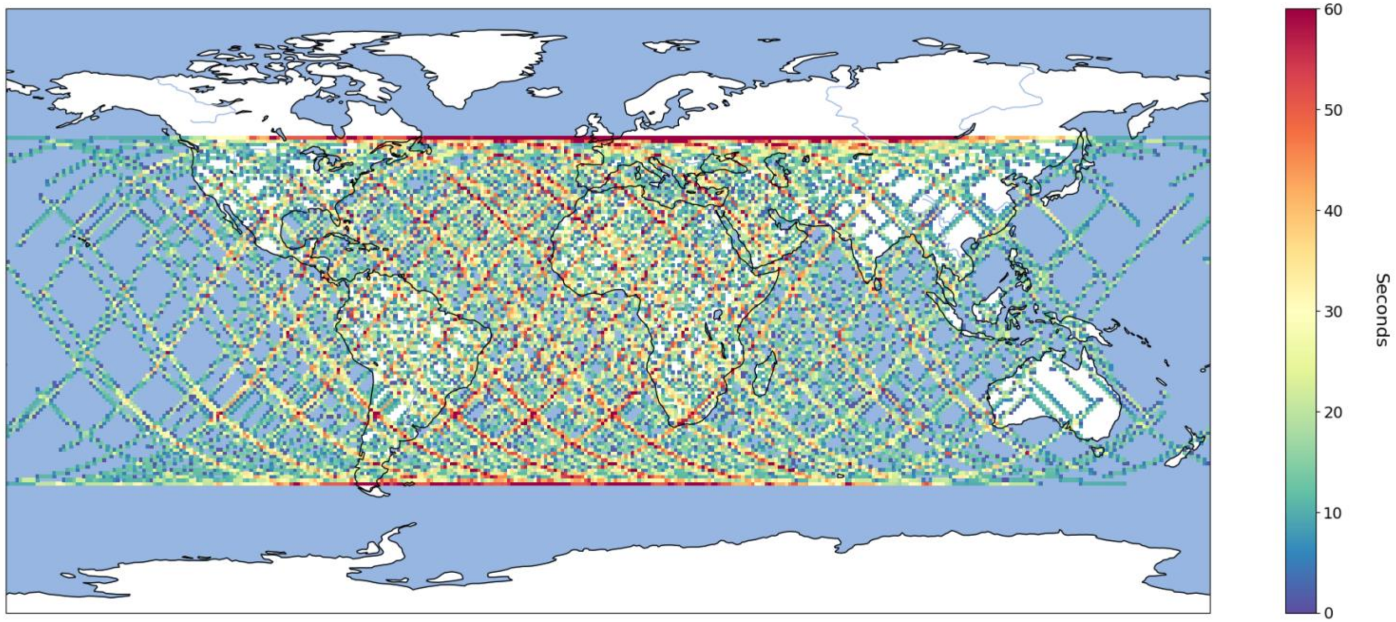






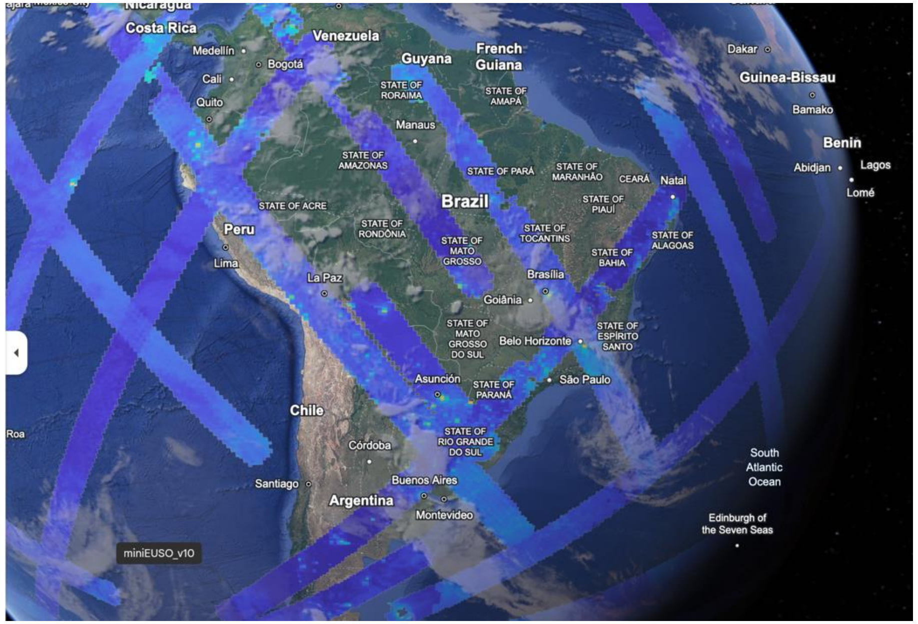
UV maps – South America

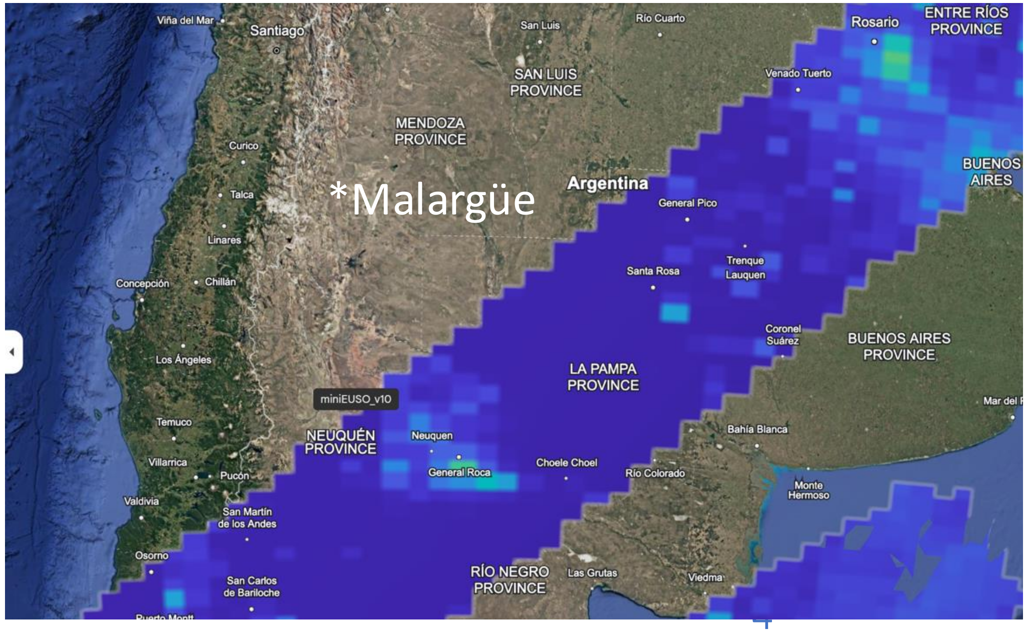
Mini-EUSO measurements over the globe



Sessions 4 - 44

From Matteo B.

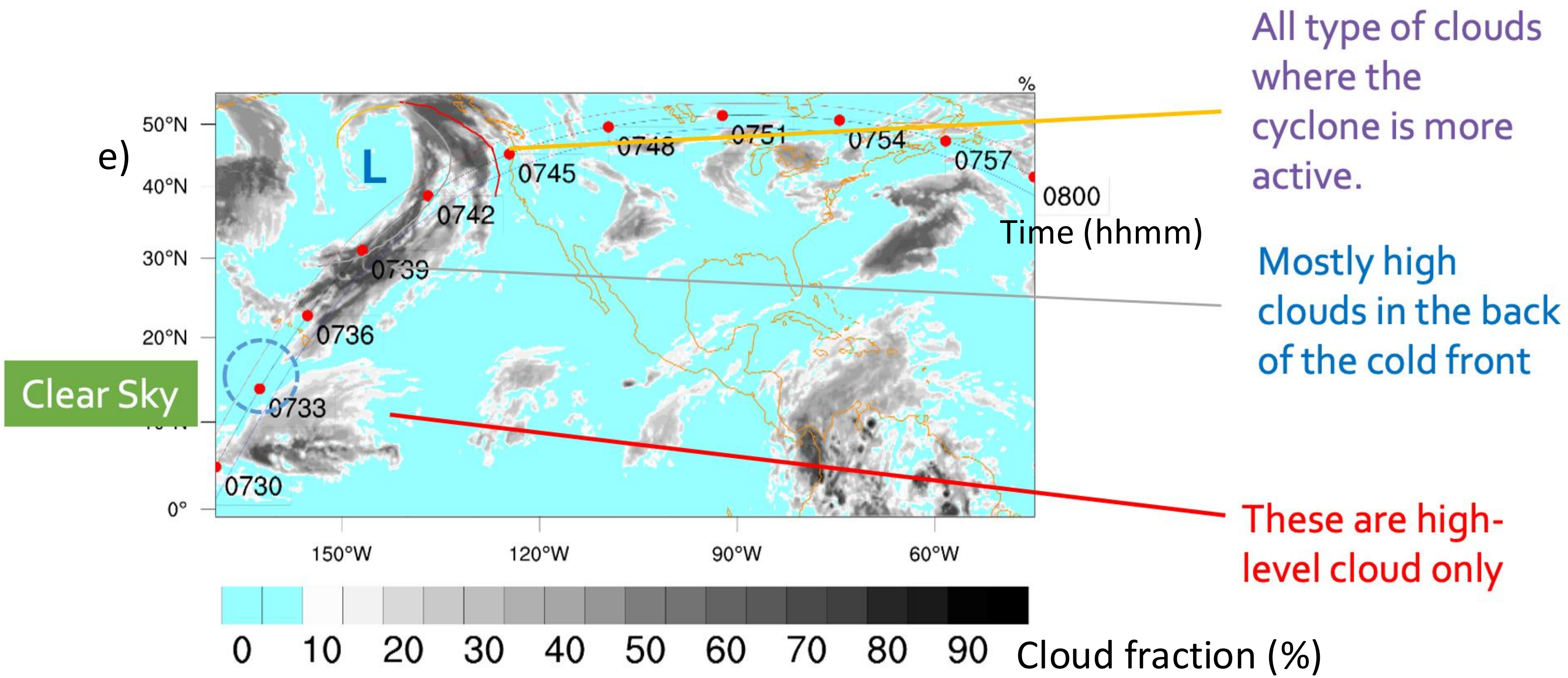


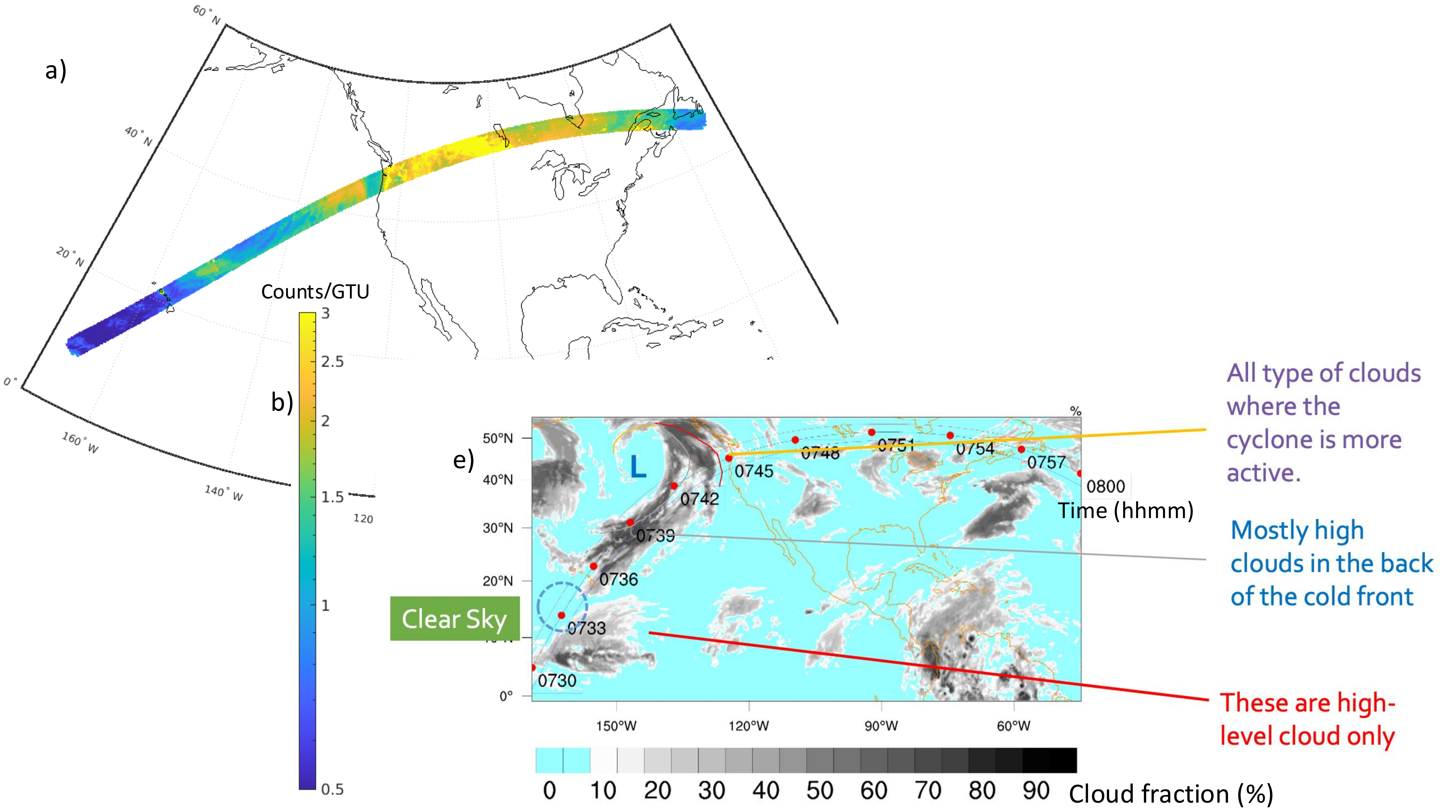


137 sessions performed,
only available data till session 44

Change with Europe maps

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


e)
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)
60° N
40° N
20° N
0°
160° W
140° W
120
Counts/GTU
3
2.5
2
1.5
1
0.5
b)
e)
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)
Clear Sky
0
10
20
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90
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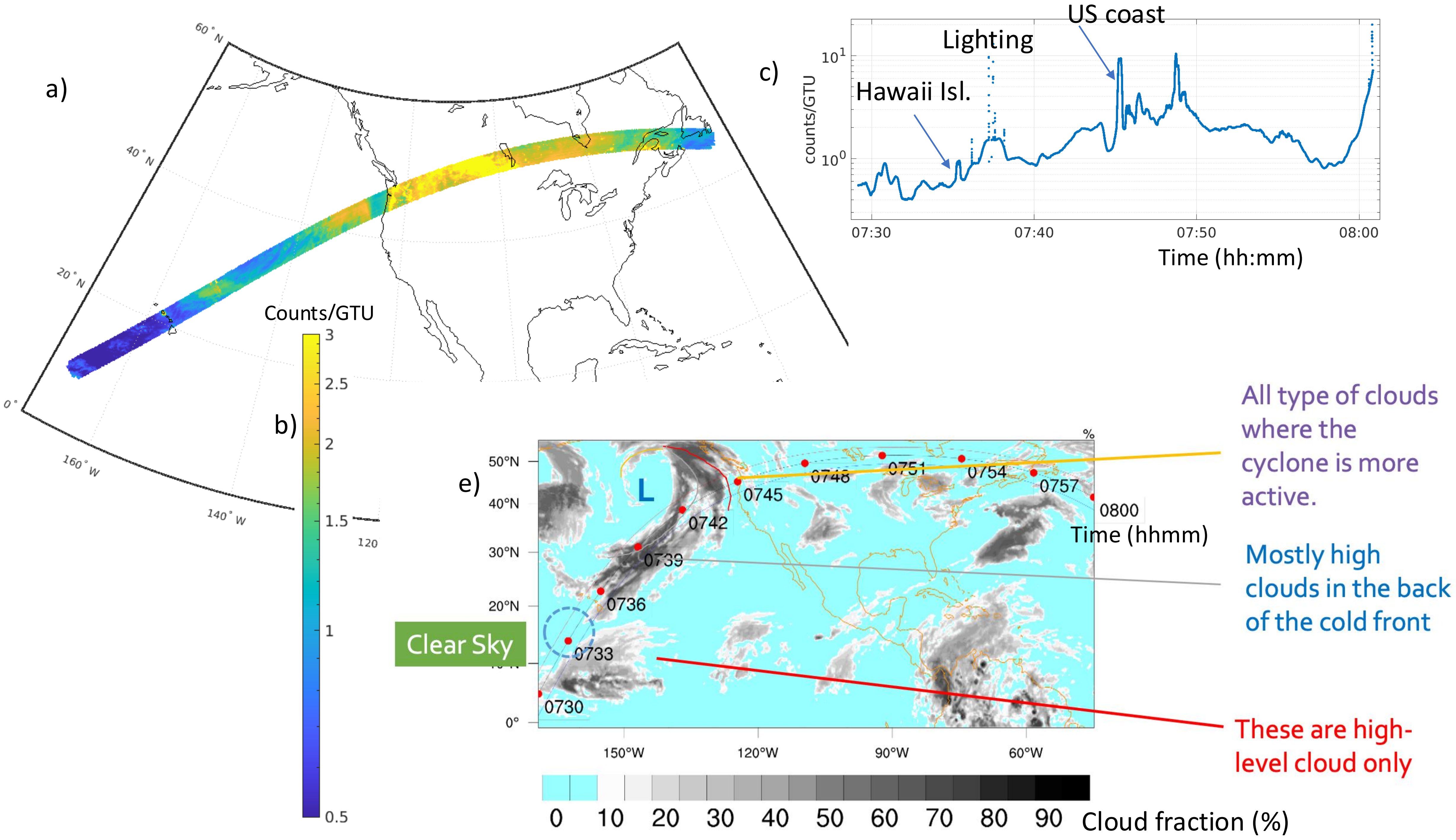

a)
60° N
40° N
20° N
0°
160° W
140° W
120
Counts/GTU
3
2.5
2
1.5
1
0.5
b)
c)
Lighting
US coast
Hawaii Isl.
counts/GTU
10^1
10^0
07:30
07:40
07:50
08:00
Time (hh:mm)
e)
%
50°N
40°N
30°N
20°N
0°
L
0730
0733
0736
0739
0742
0745
0748
0751
0754
0757
0800
Time (hhmm)
150°W
120°W
90°W
60°W
Clear Sky
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Mostly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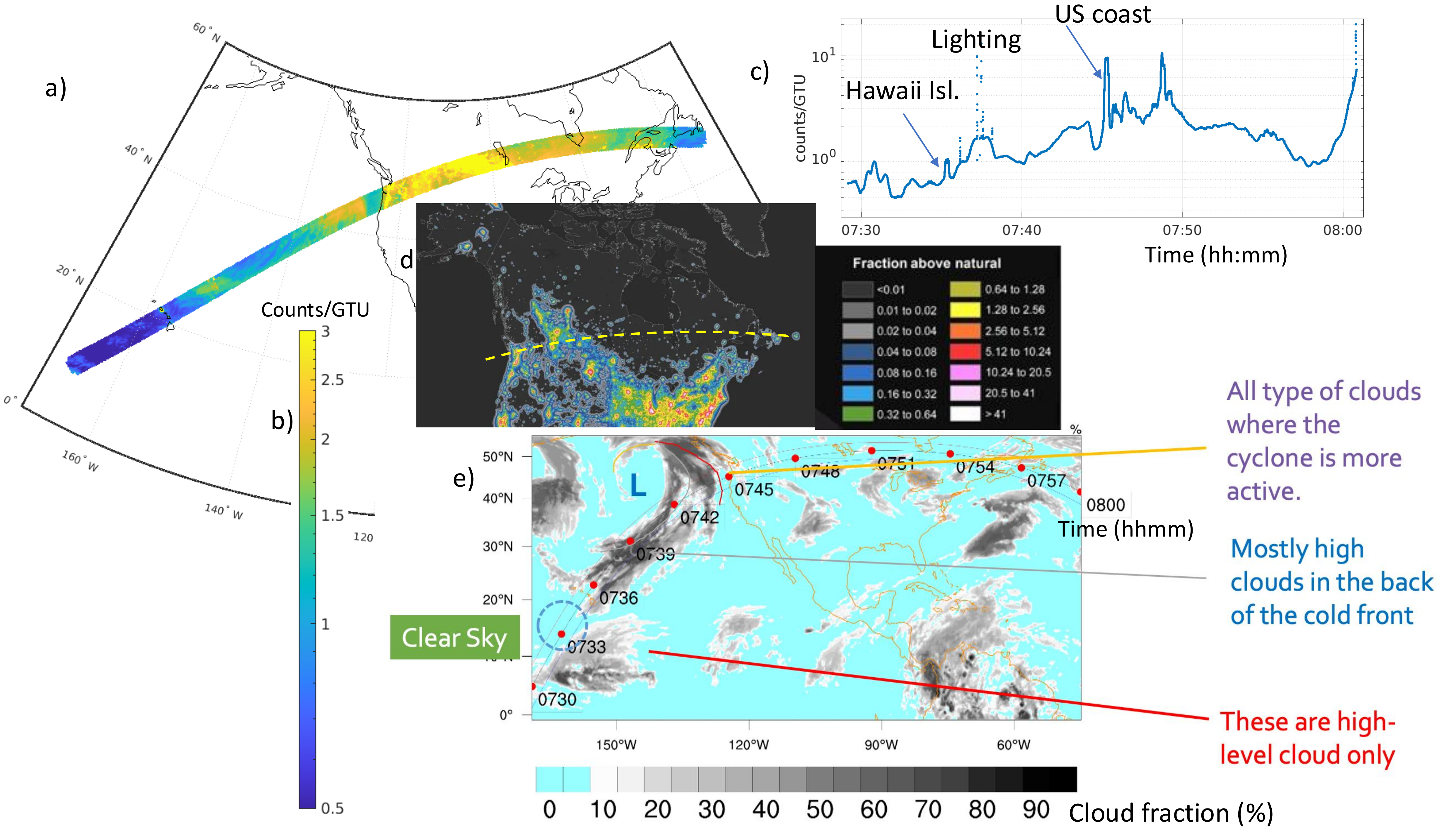
0
10
20
30
40
50
60
70
80
90
Cloud fraction (%)



a)
60° N
40° N
20° N
0°
160° W
140° W
120
Counts/GTU
b)
3
2.5
2
1.5
1
0.5
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)
%
L
50°N
40°N
30°N
20°N
0°
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
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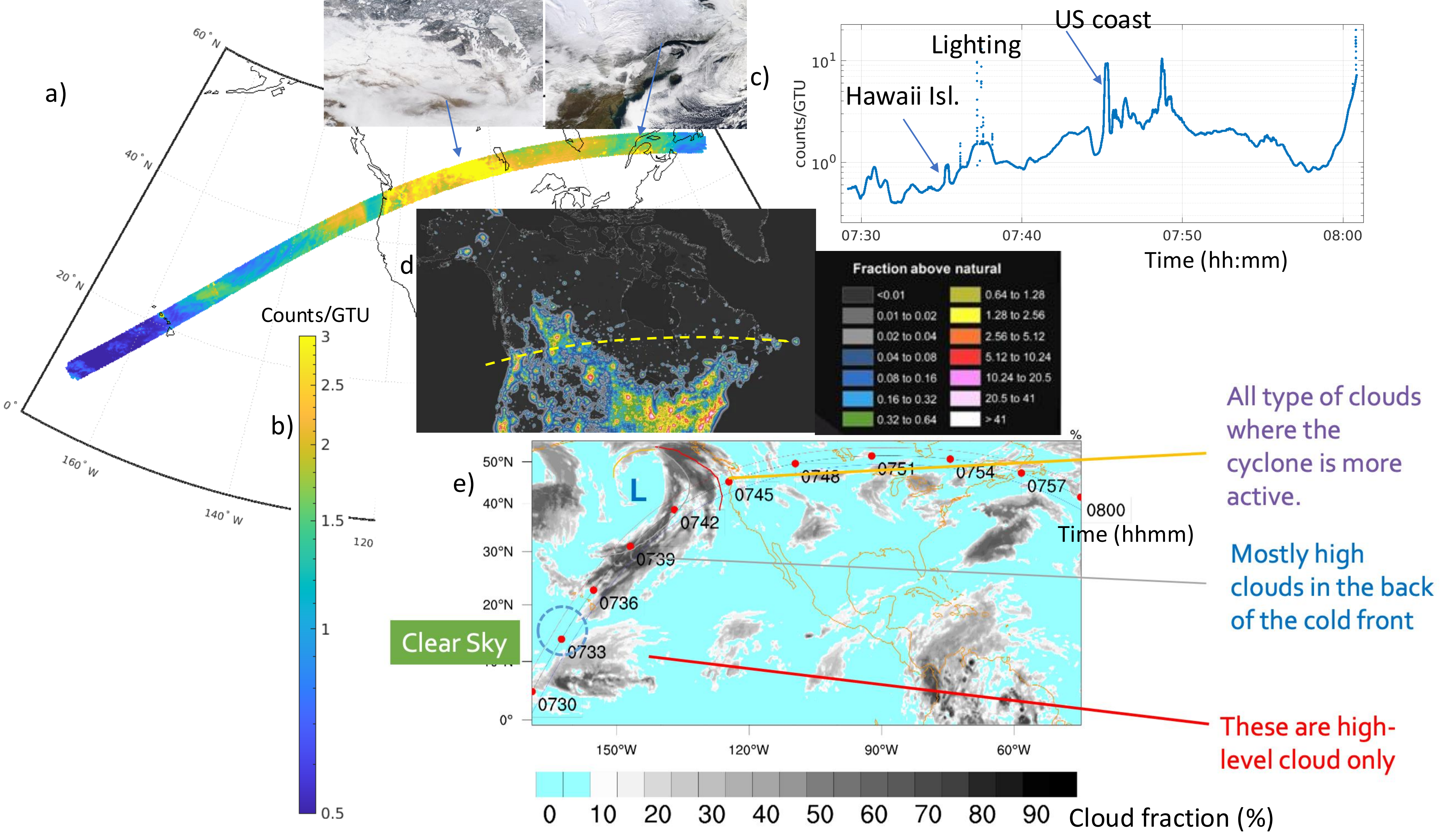

a)
60° N
40° N
20° N
0°
160° W
140° W
120
b)
Counts/GTU
3
2.5
2
1.5
1
0.5
c)
Hawaii Isl.
Lighting
US coast
counts/GTU
10^1
10^0
07:30
07:40
07:50
08:00
Time (hh:mm)
d
Fraction above natural
<0.01
0.01 to 0.02
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0.04 to 0.08
0.08 to 0.16
0.16 to 0.32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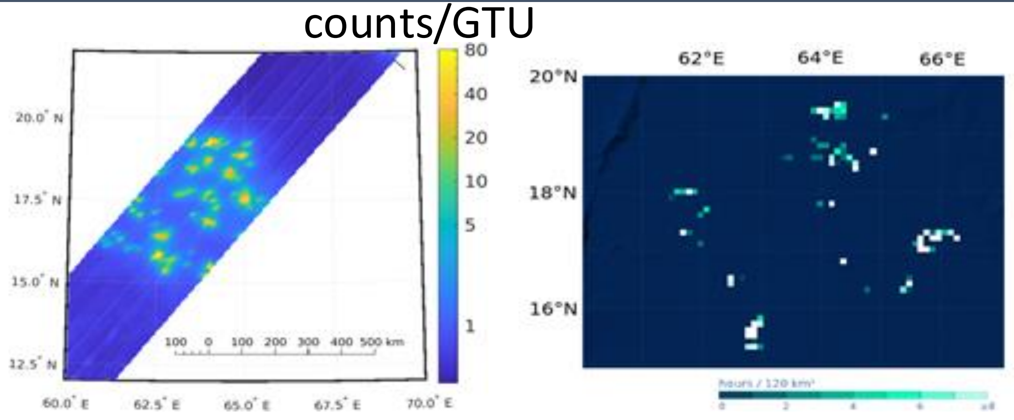
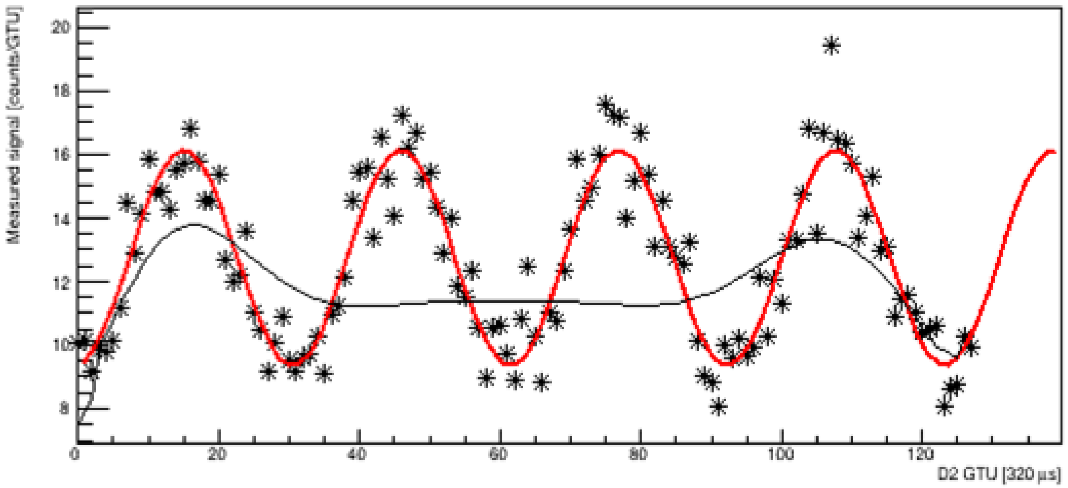
Mostly high clouds in the back of the cold front
These are high-level cloud only
0
10
20
30
40
50
60
70
80
90
Cloud fraction (%)

Fishing boats and AC modulation



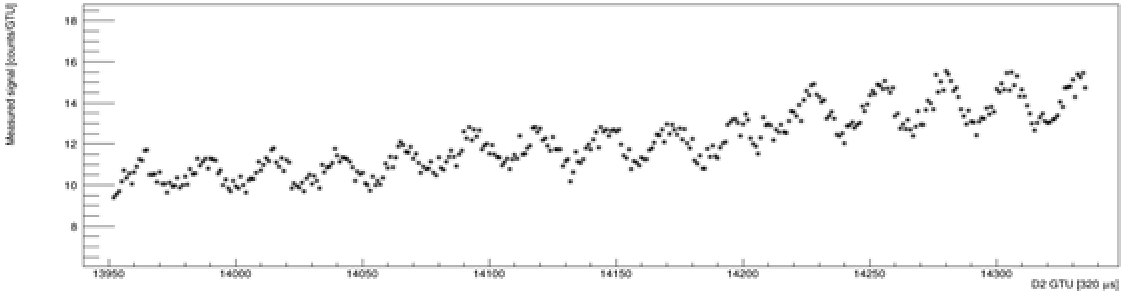
Fishing boats in the Arabian sea. Left: Mini-EUSO data. Right: Data from the Global Fishing Watch [https://globalfishingwatch.org]



50 Hz modulation over an Indonesian city

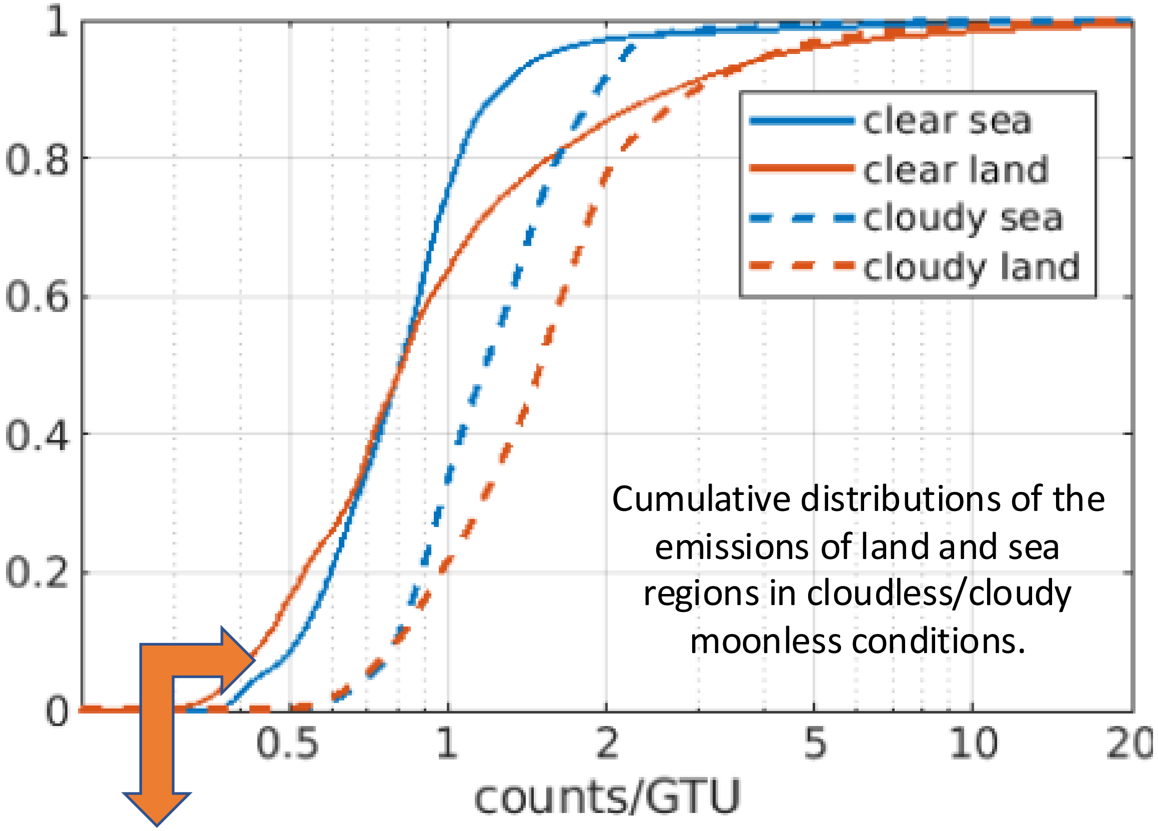
Mini-EUSO visible camera off the coast of Argentina

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

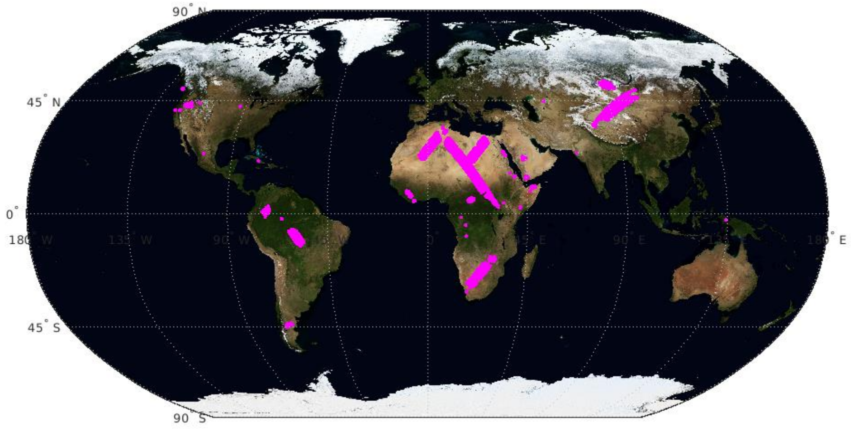


60 Hz modulation produced by the fishing boats off the coast of Argentina

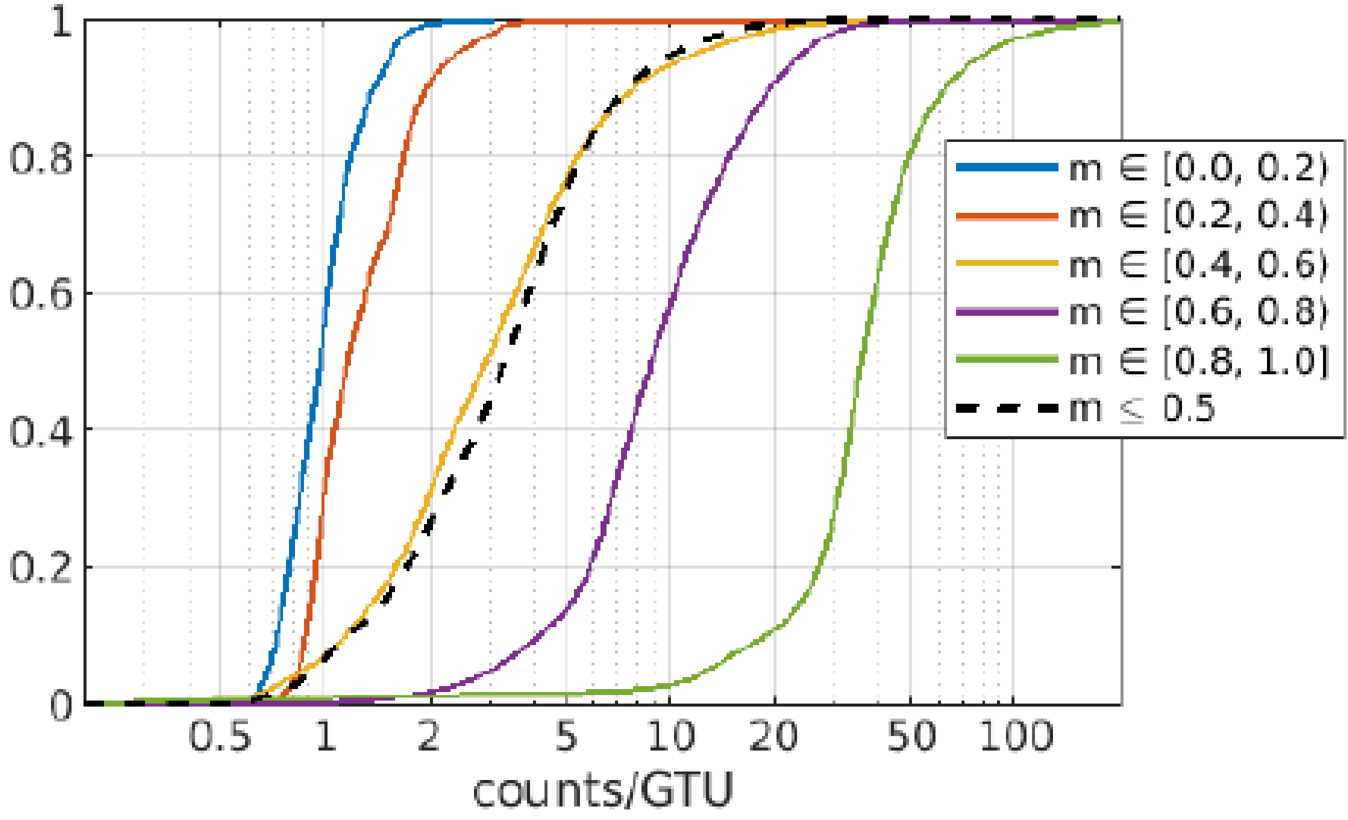
Moonless conditions



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



Moon Phases



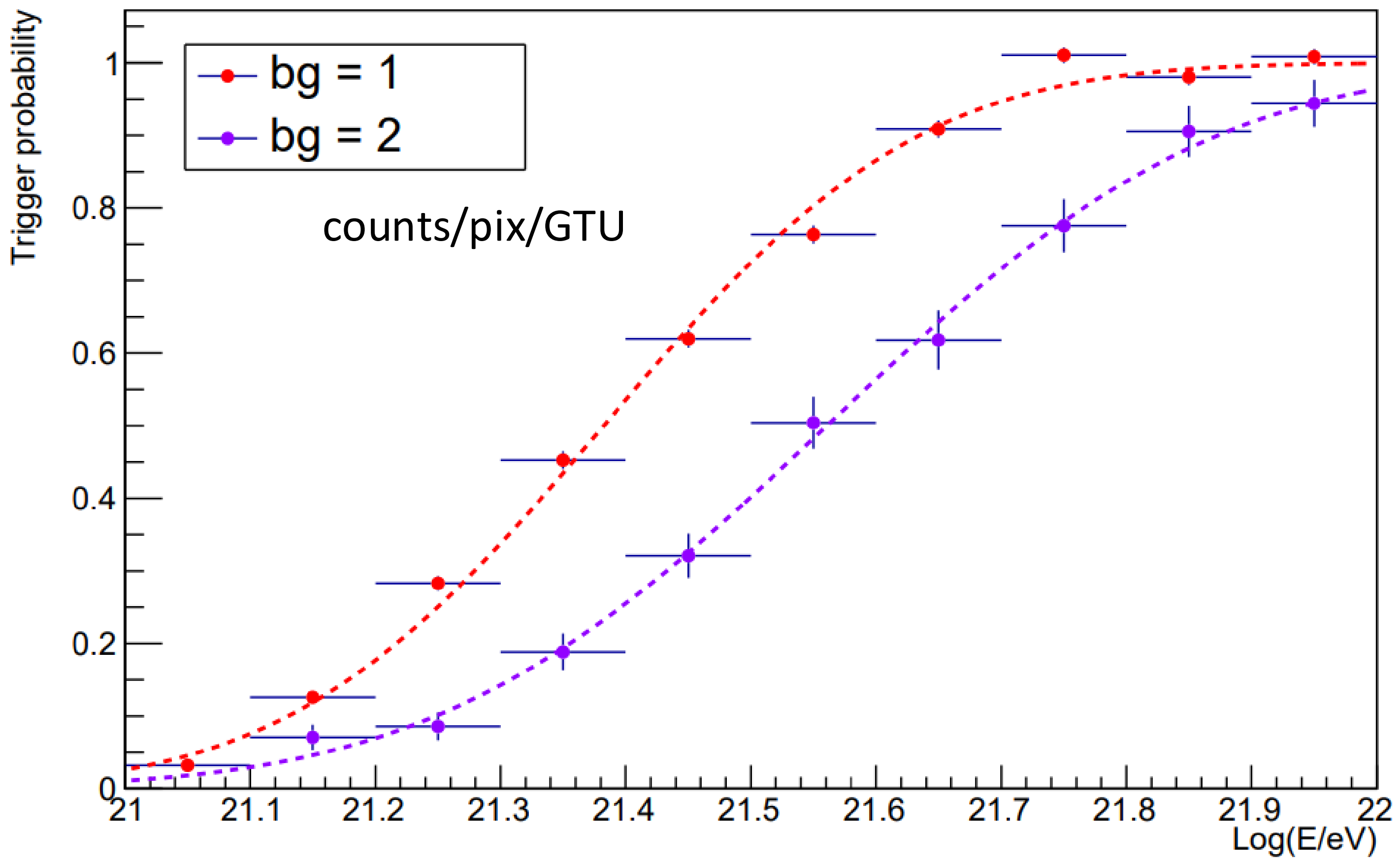
M. Casolino et al.: Remote Sensing of Environment 284 (2023) 113336
ArXiv: 2212.02353

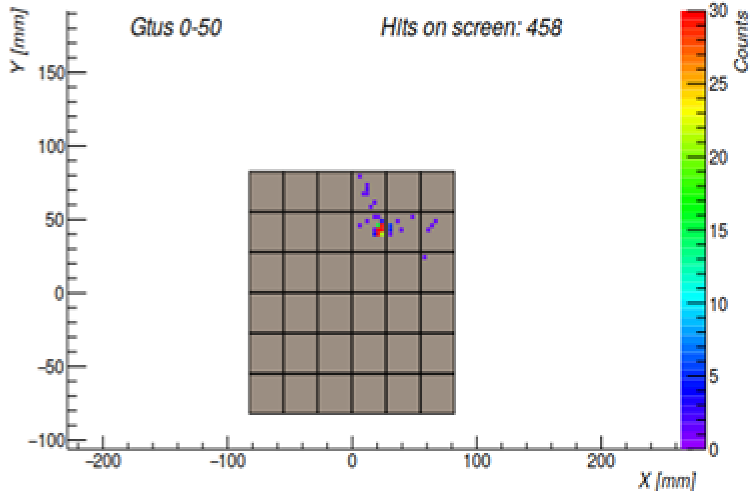
Analyzed sessions: 5 - 19

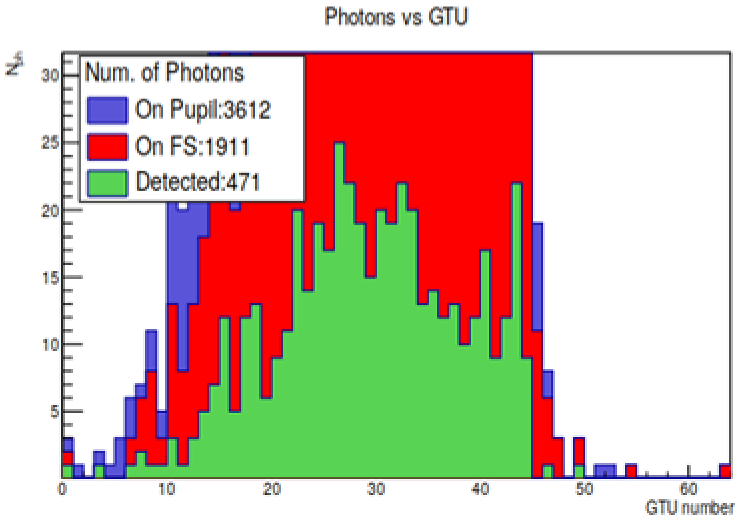
11

Mini-EUSO EAS trigger probability

Proton E = 5x10^{21} eV, 50°







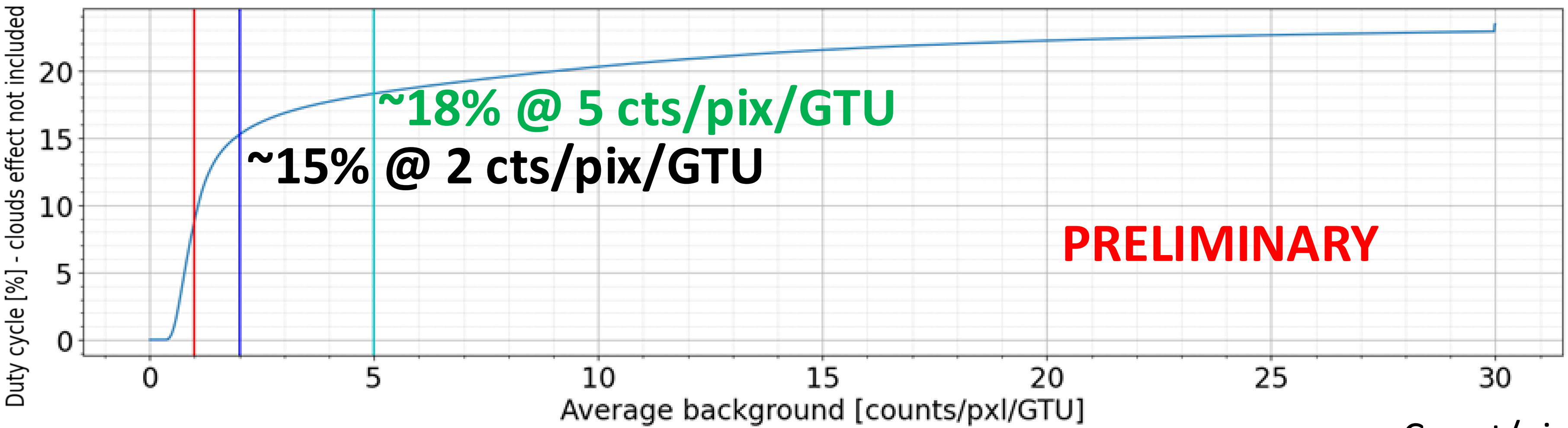
Obtained using ESAF simulations

Proton EASs

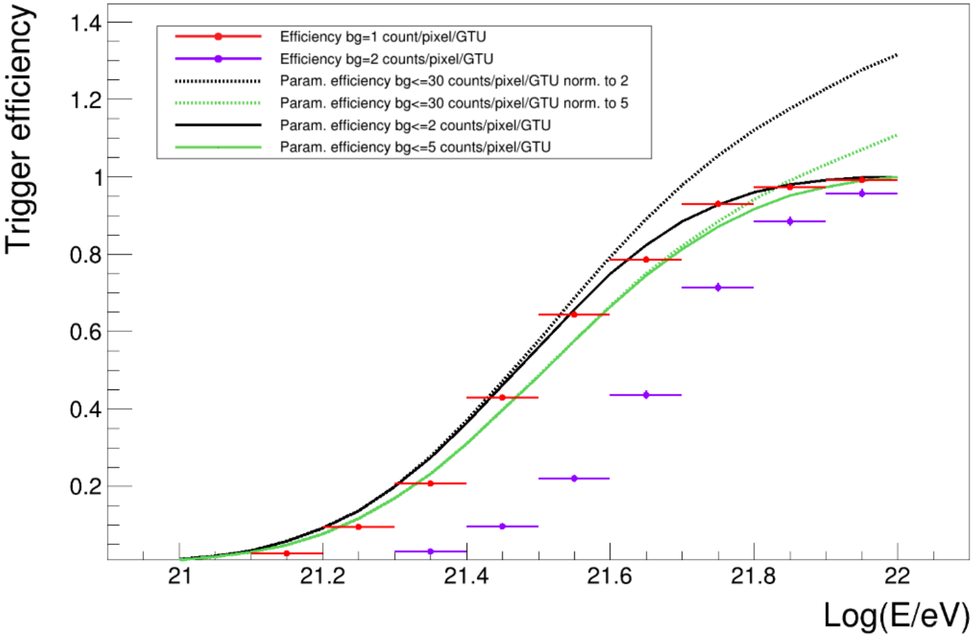
S. Abe et al., Eur. Phys. J. C (2023) 83:1028

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

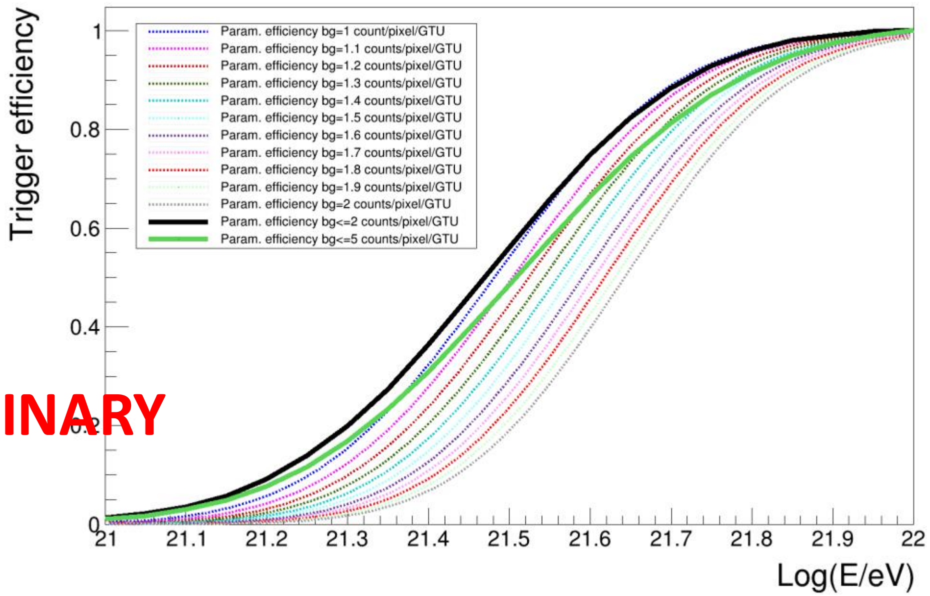
$$\eta_0 = \frac{\sum_{\mathrm{MB}} \frac{T^{\mathrm{MB}}_{<\mathrm{Thrs}}}{F^{\mathrm{MB}}_{Conv}}}{\Delta T_{\mathrm{orbit}} \cdot N_{\mathrm{orbit}}}$$



Count/pix/GTU



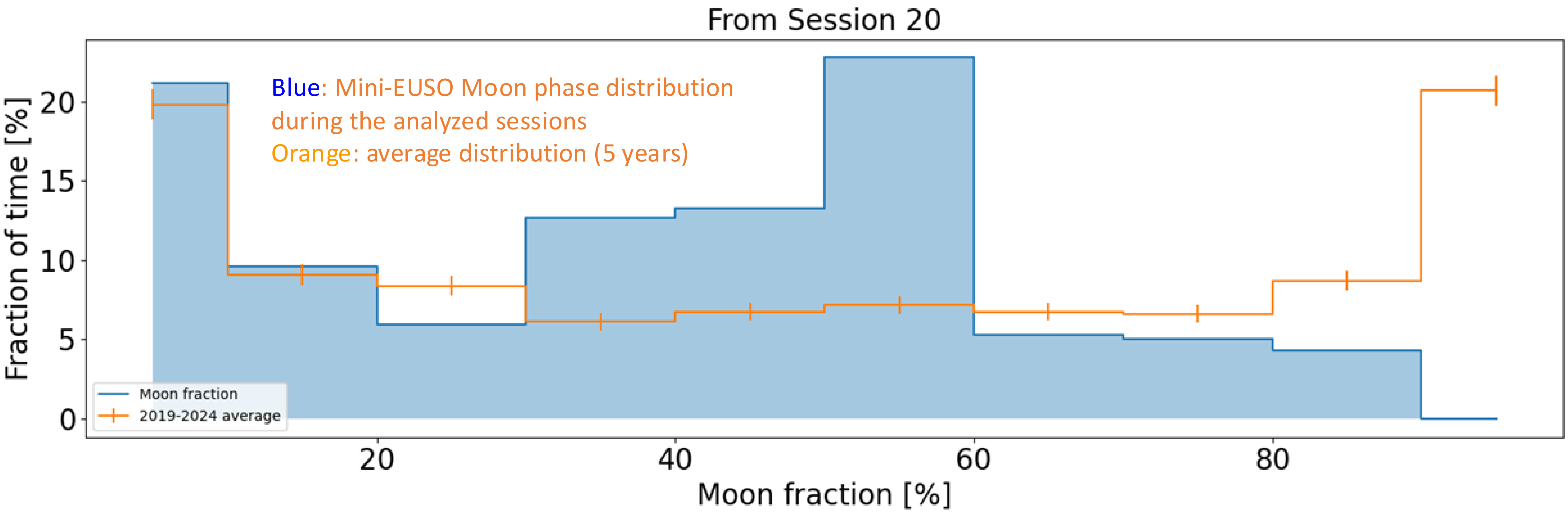
PRELIMINARY



Overall experimental confirmation of JEM-EUSO duty cycle

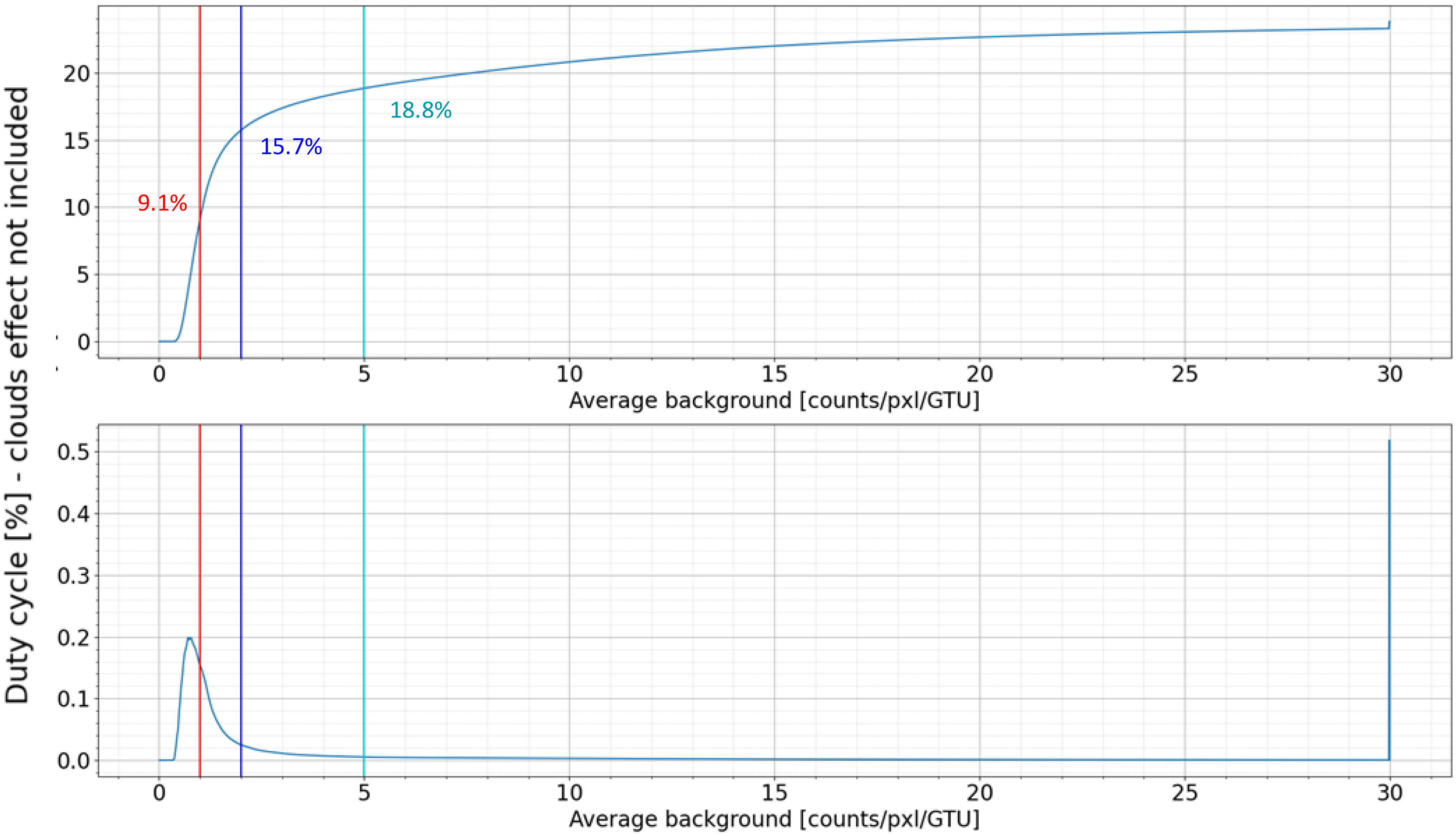
Generalization of the results

- The Moon plays an important role on the background (higher Moon phase means brighter background and longer time with the Moon above the horizon). What would be the impact on a detector working 24/7?

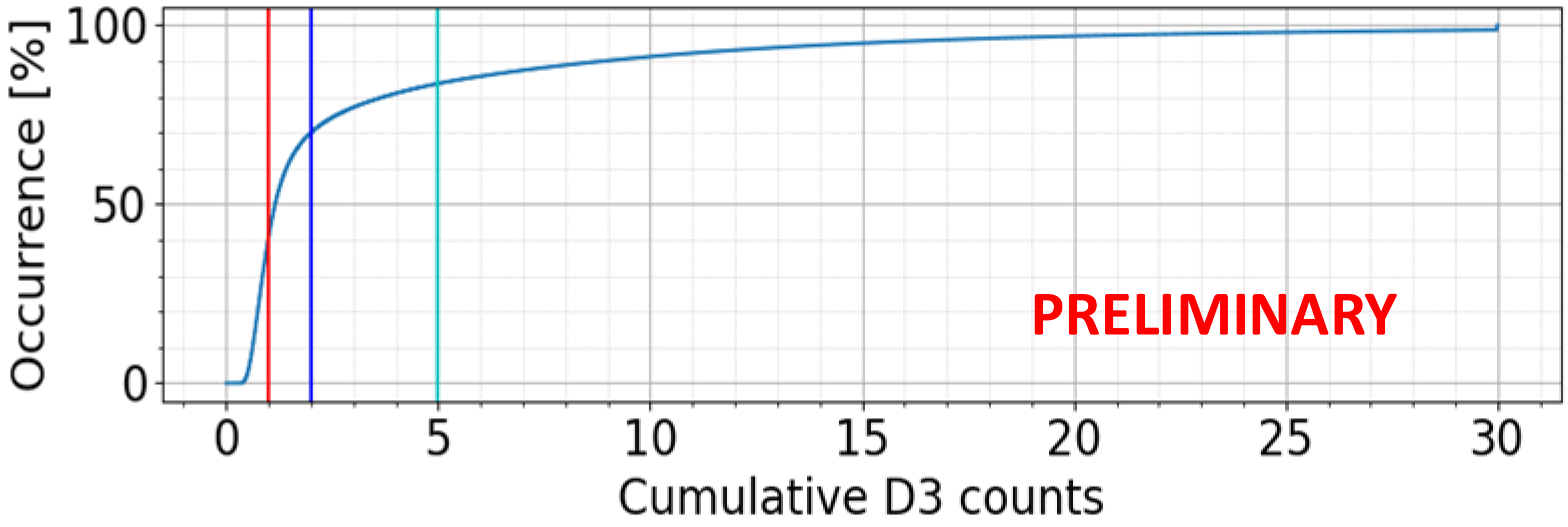


The ratio of the two distributions gives us a conversion factor

Duty cycle expected for a space-based detector



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**

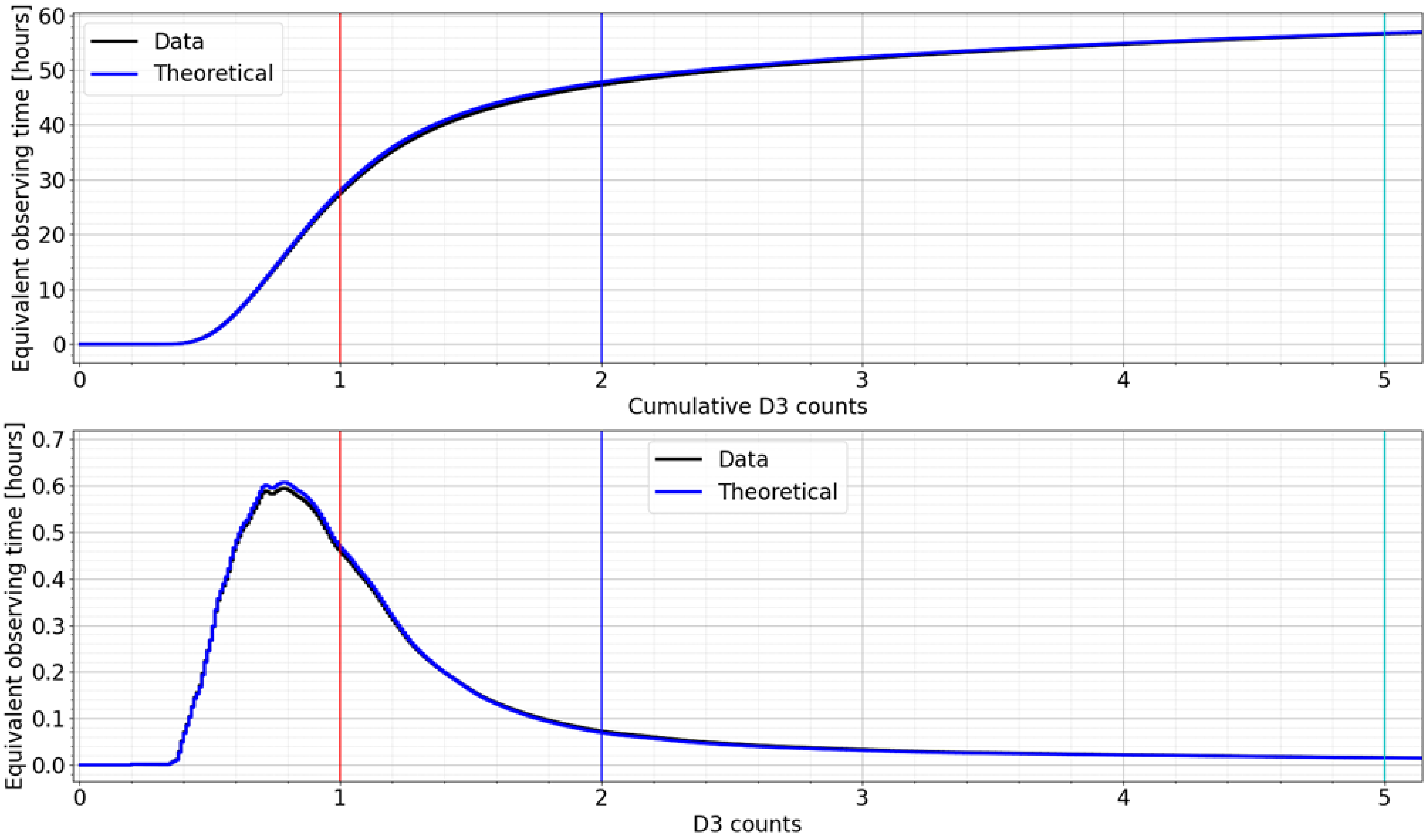
If taking into account till session **135** (November 2024) = **~6000 L**

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 <u>using the fluorescence technique</u>.**

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.

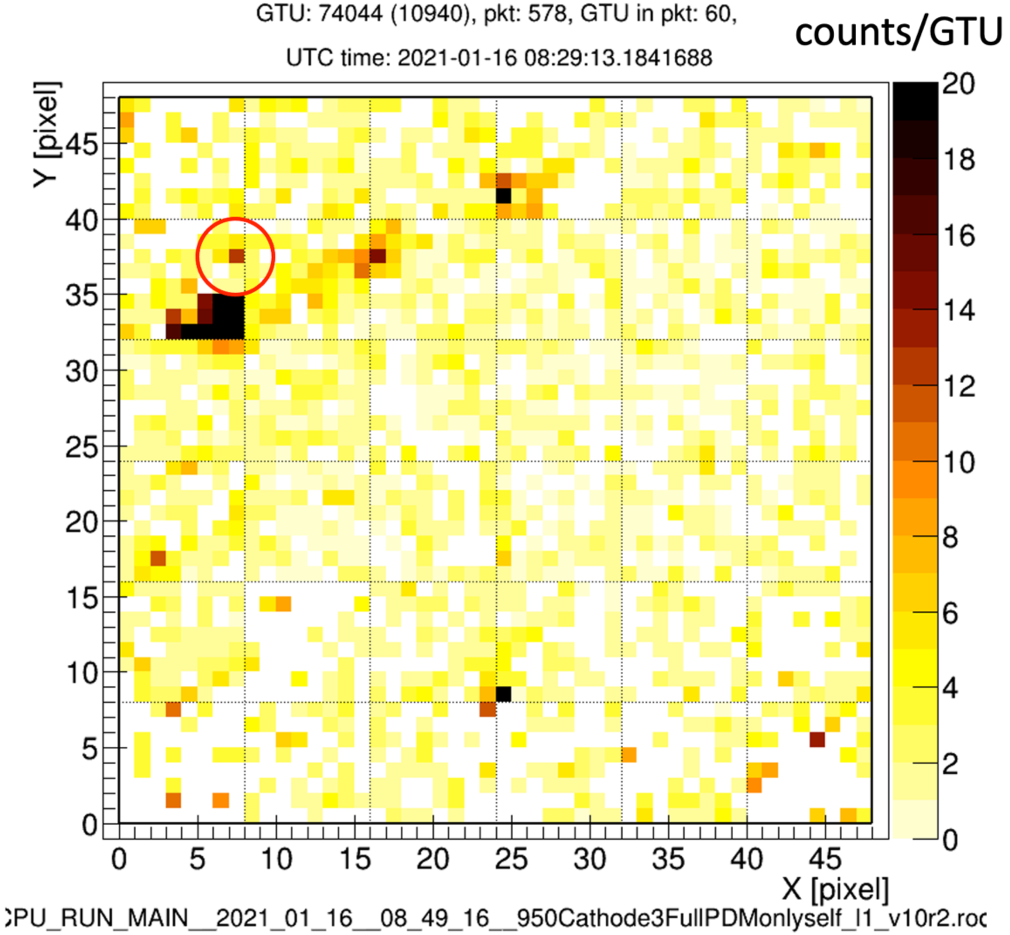
Land vs ocean - differences



The ISS spend ~70.7% of the time over the sea, 29.3% over land. So we can weight the two distribution by a factor (70.7/66.1) for the ocean and (29.3/33.9) for the continents. The results is shown in **blue**, while in **black** the sum without the corrections factors

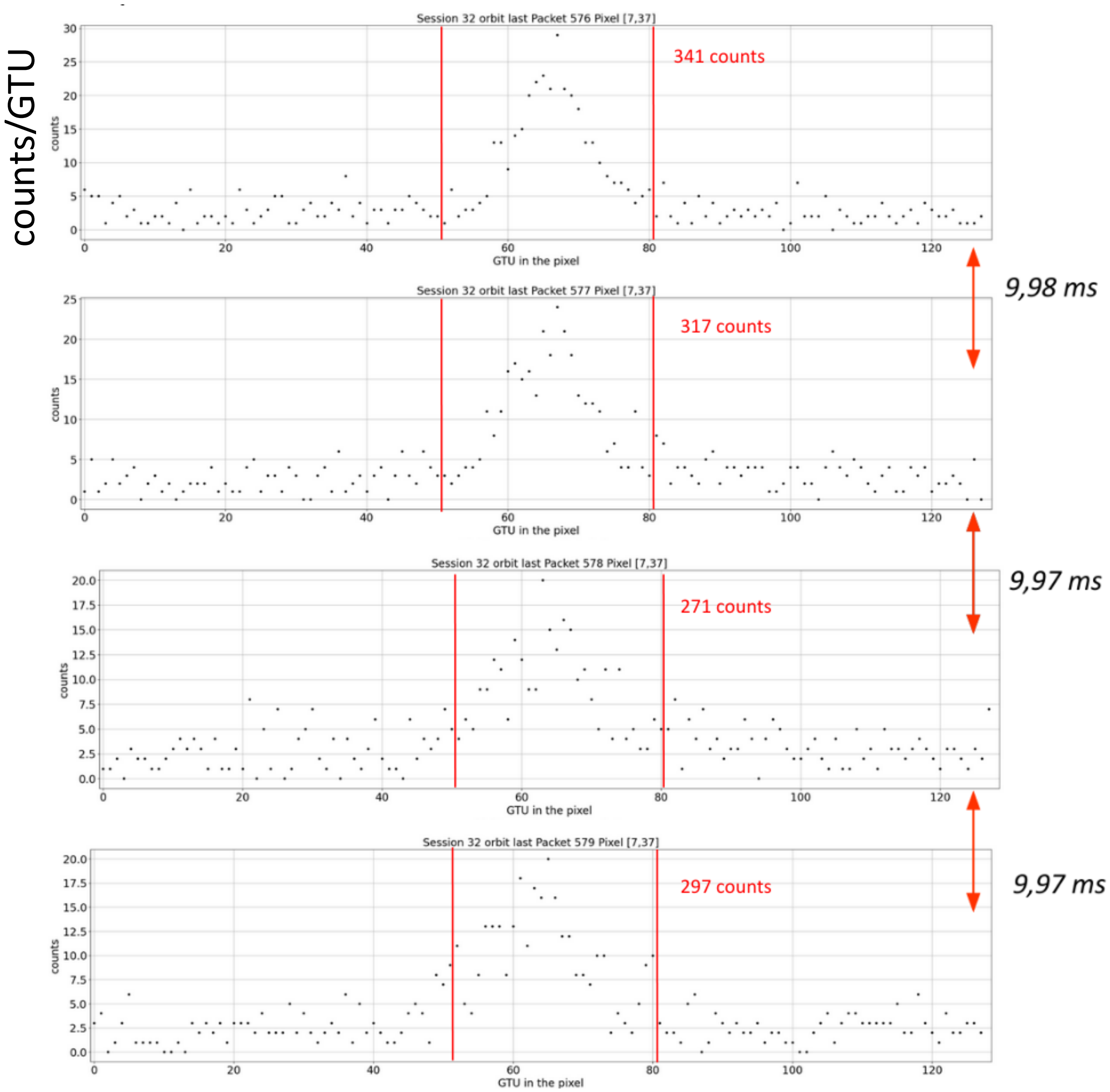
Ground Flashers

Michigan, US



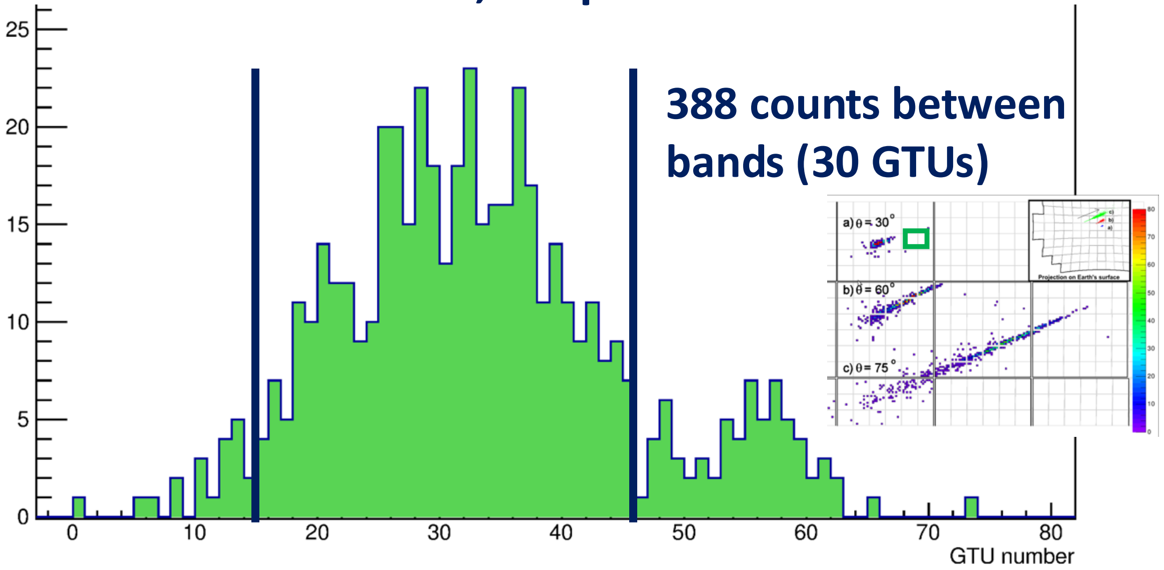
M. Battisti

Repeated ground flashers



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

JEM-EUSO
5×10^{19} eV, 60° p with ESAF

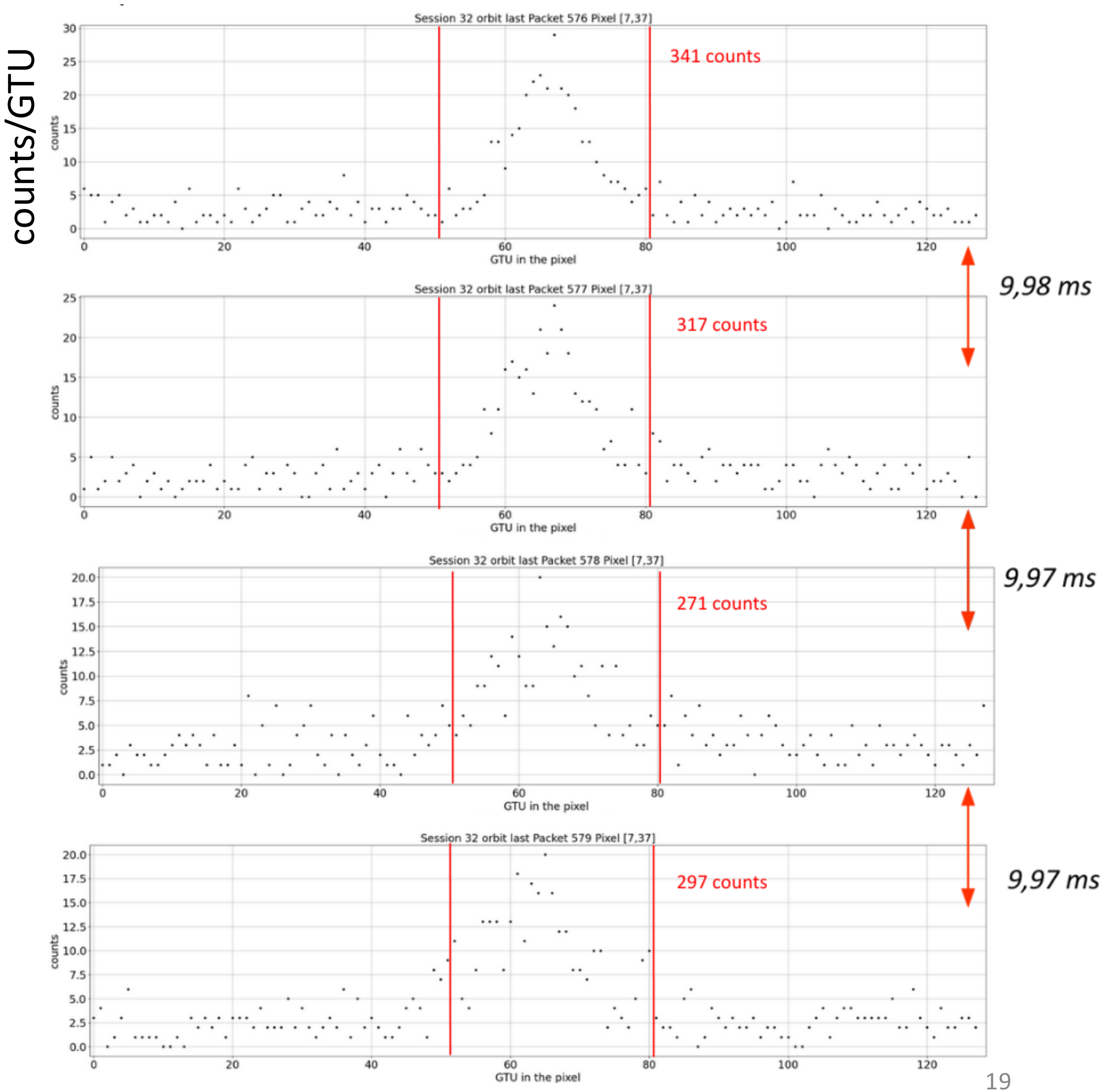


F. Fenu

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

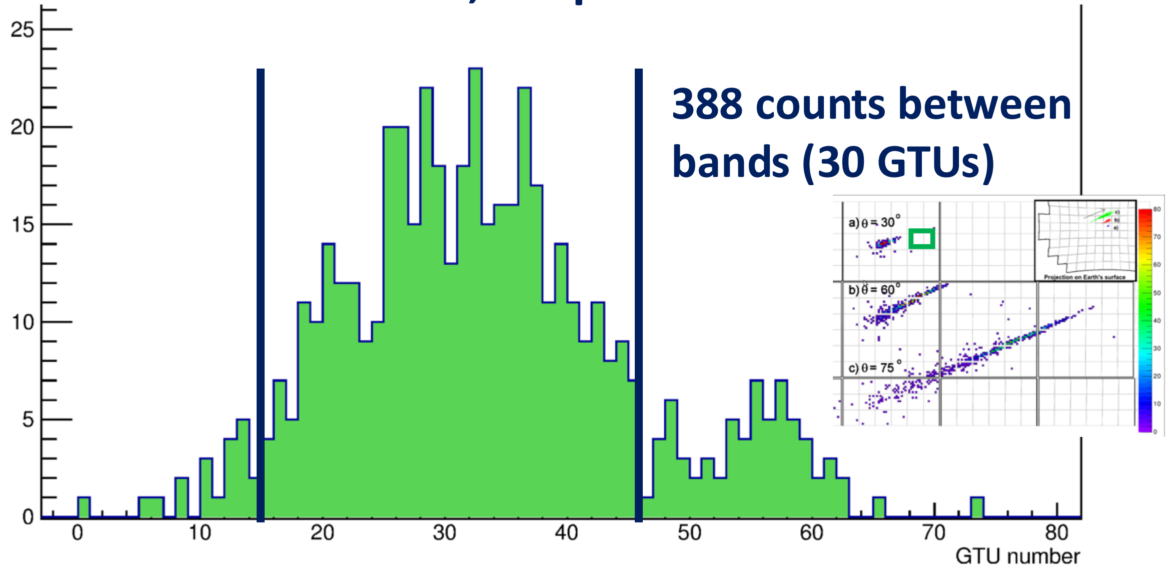
Repeated ground flashers



M. Battisti

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

M-EUSO
~10^{20} eV, 60° p with ESAF

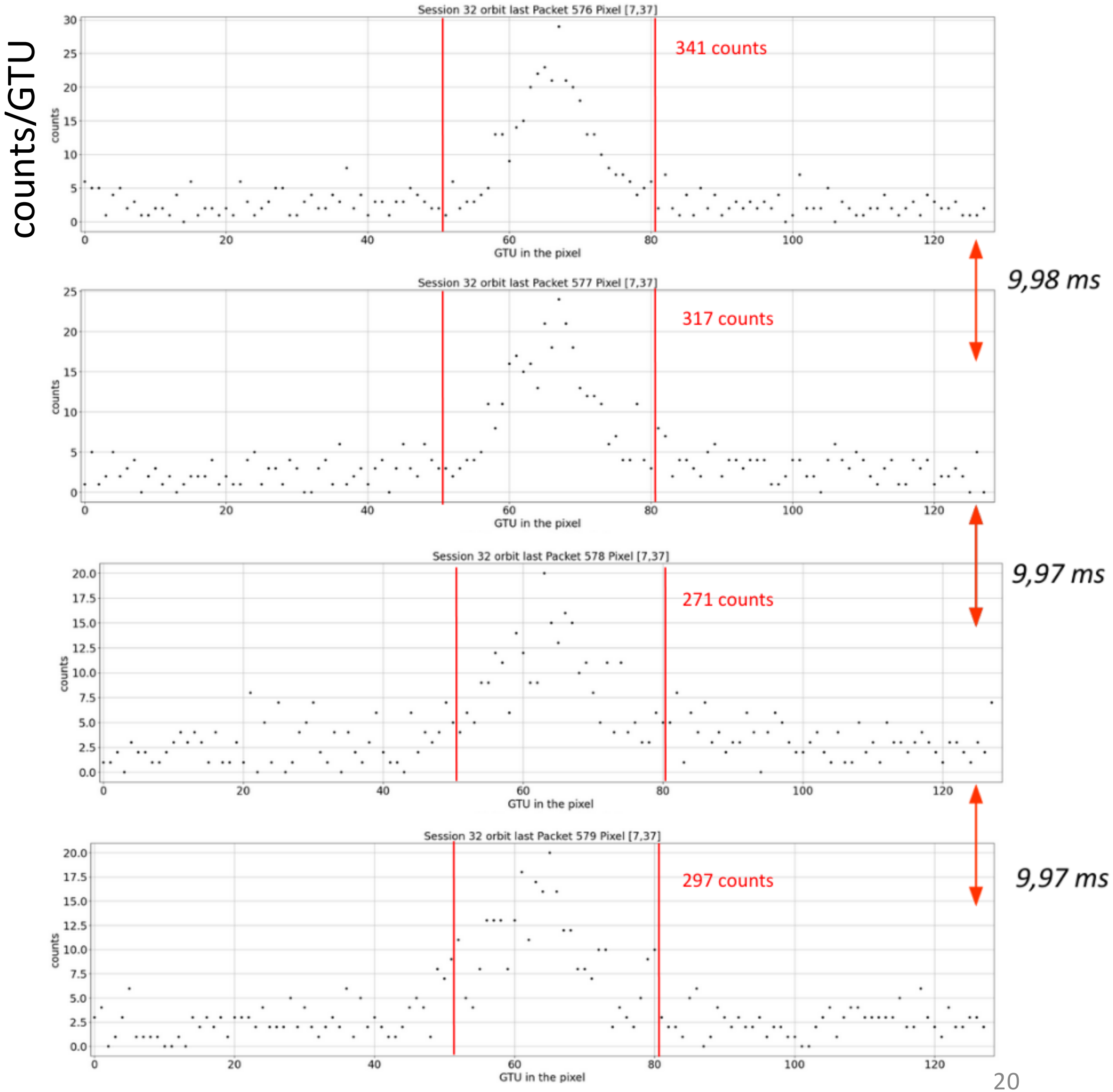


F. Fenu

Scaling factor M/JEM-EUSO:
$(0.12°/0.074°) \times (4.5/4)^{2.5} = 2.2$

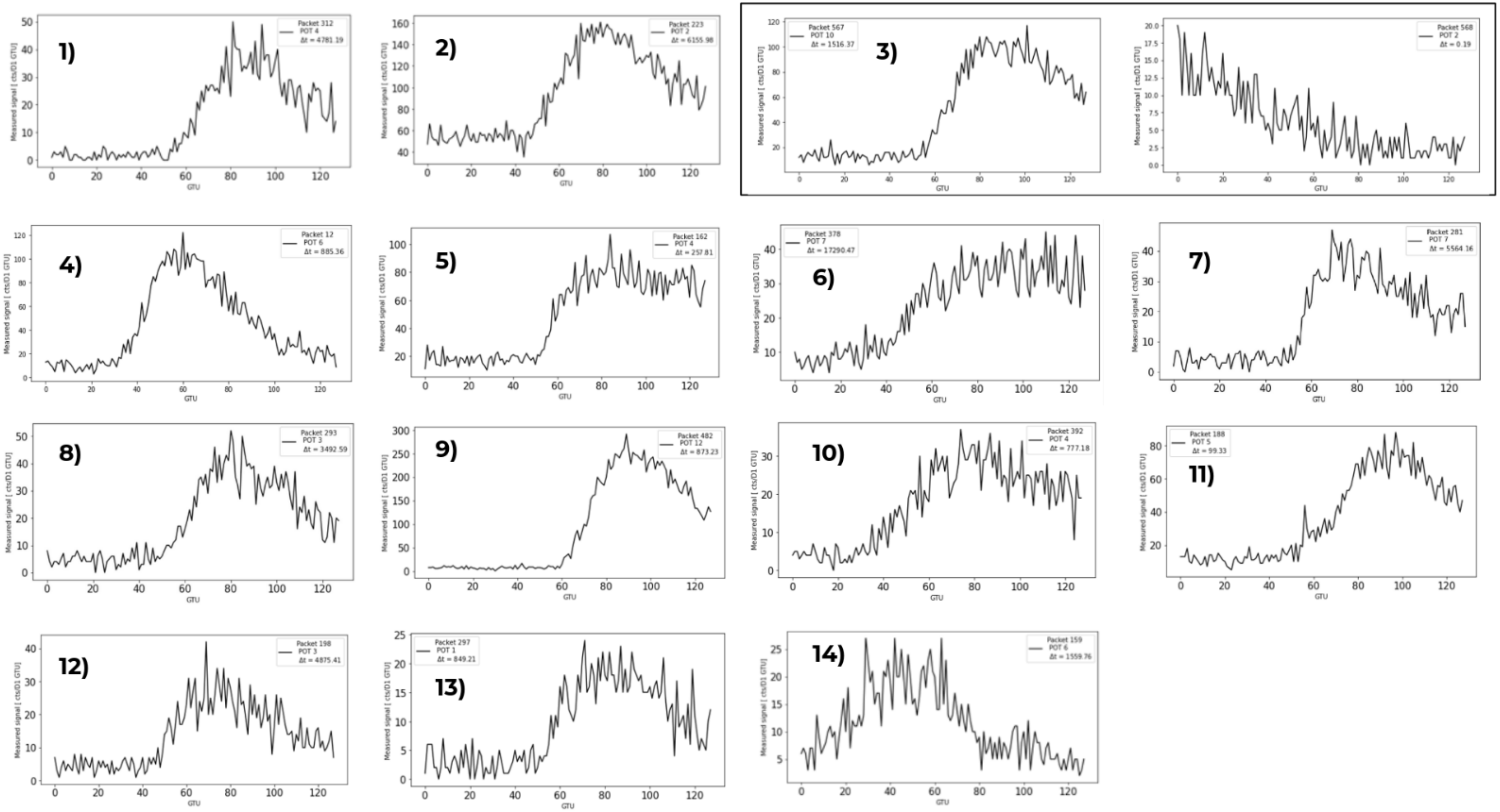
Proof of the detection principle of UHECRs from space with signals in Mini-EUSO comparable to those expected in M-EUSO

Repeated ground flashers

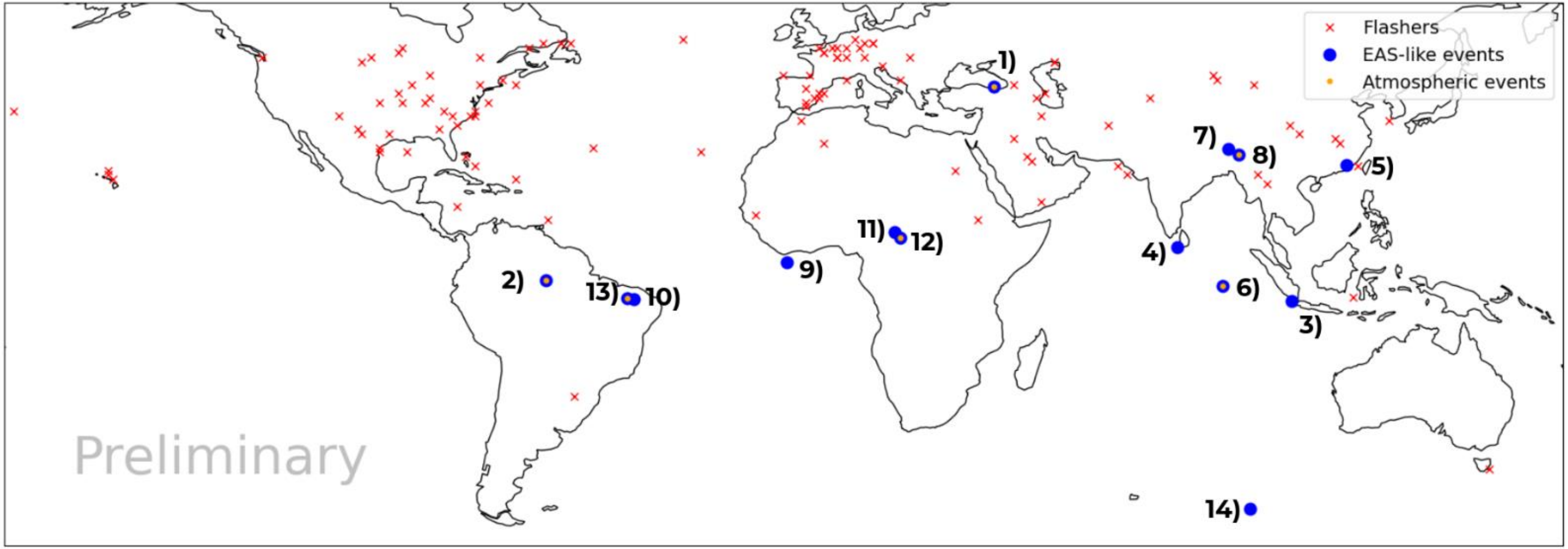


M. Battisti

Short Light Transients (SLT) lightcurves

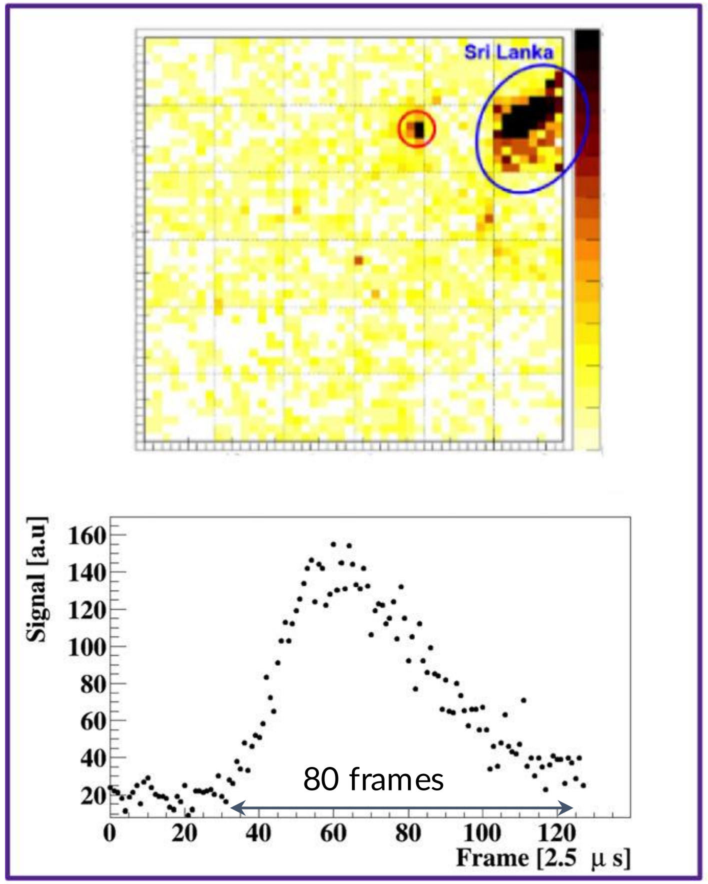


Map of the flasher (108/561) & SLT events



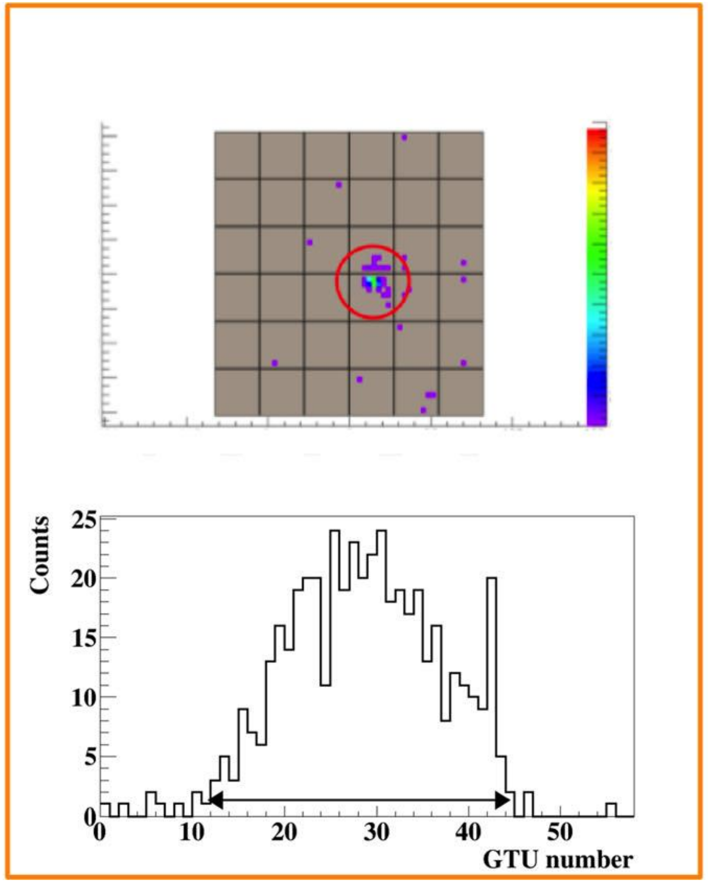
Mini-EUSO – non repetitive ‘EAS-like’ signal

Mini-EUSO data

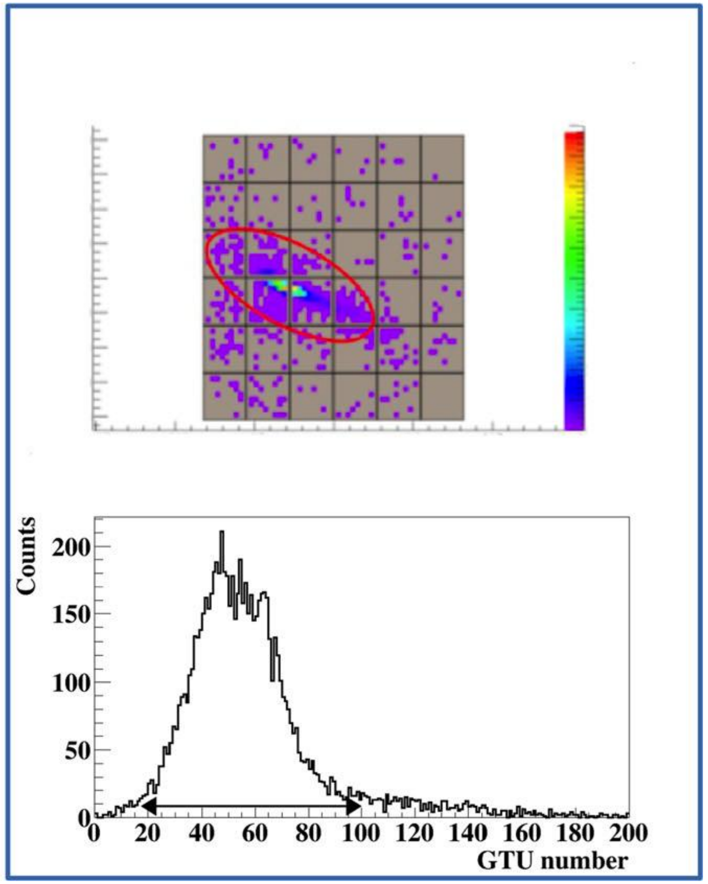


Focal plane view and lightcurve of the detected signal

ESAF p, E = 5x10²¹ eV Zenith = 50°



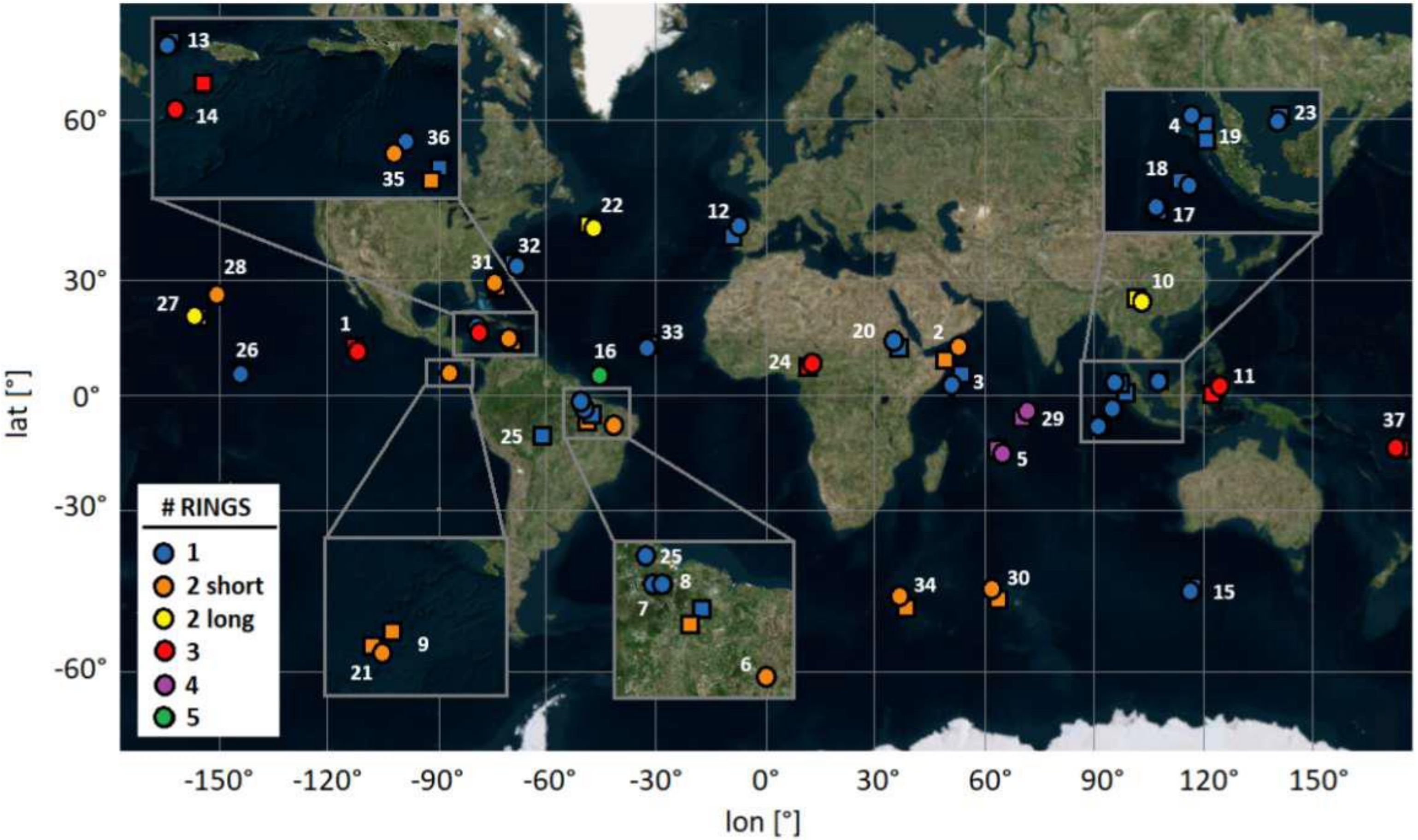
ESAF p, E = 2x10²² eV Zenith = 80°

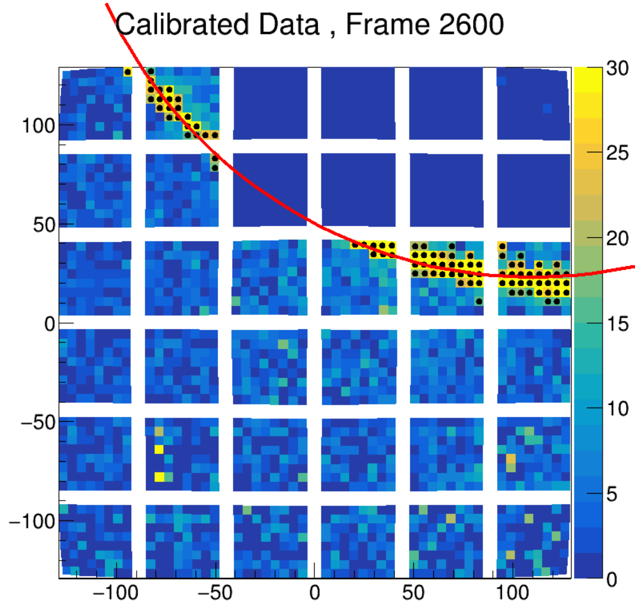


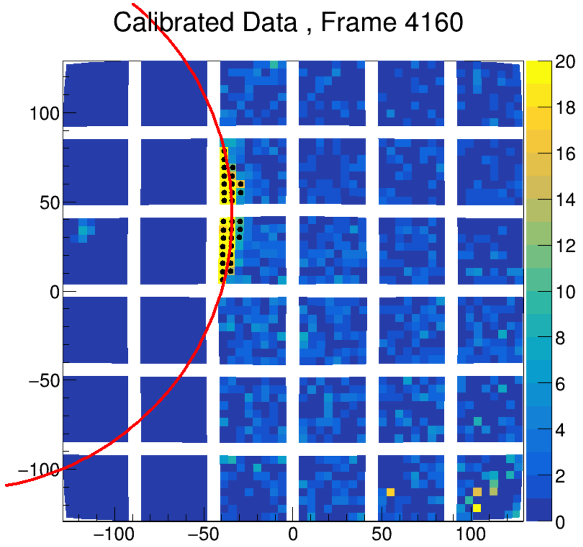
- **Cosmic ray simulations. Top: focal plane view. Bottom: lightcurves. Left: Zenith angle = 50°. Right: Zenith angle = 80°**

ELVES:

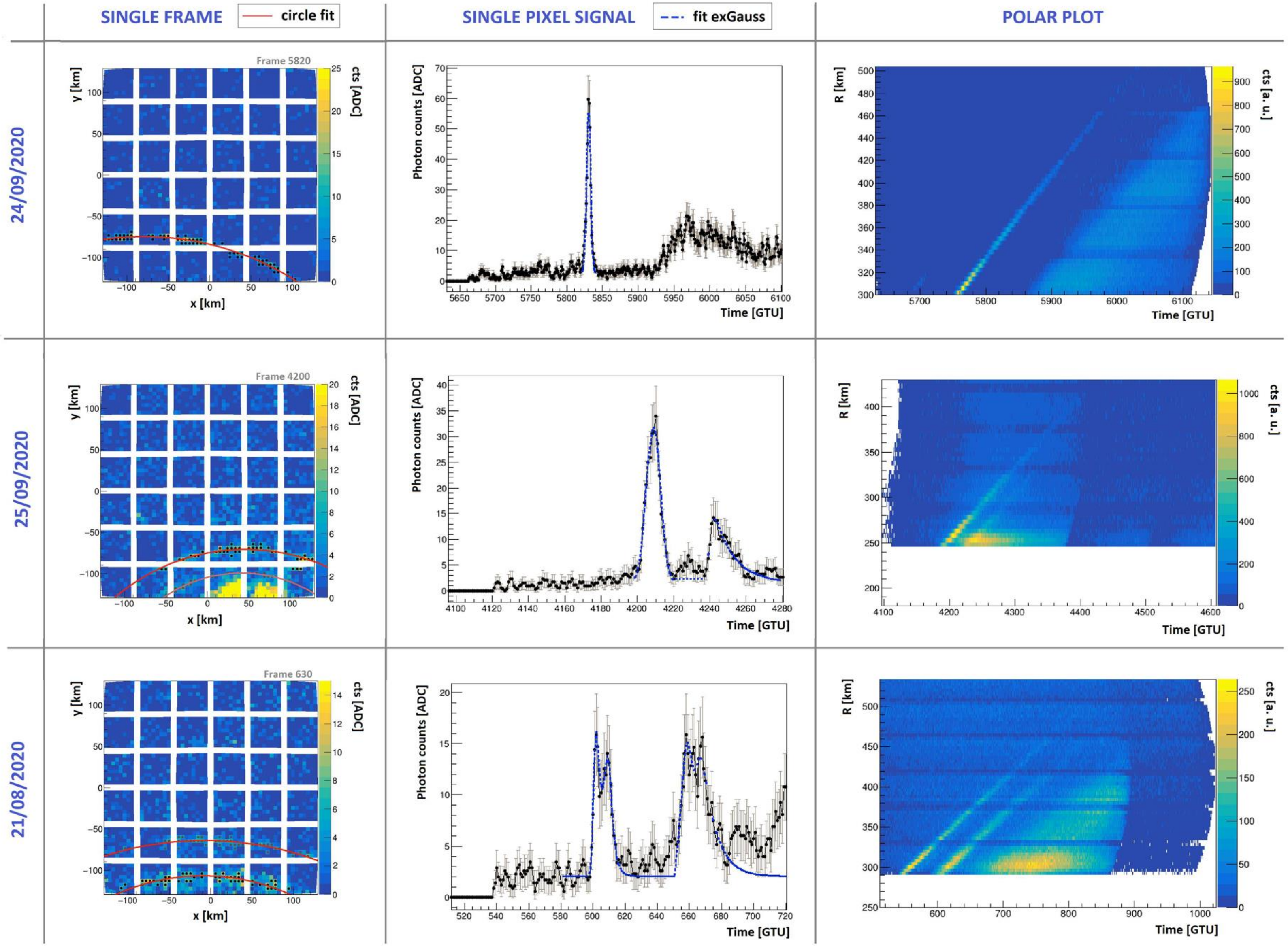
37 ELVES detected so far
(<1/2 dataset received)
mostly in the equatorial region







ELVES:

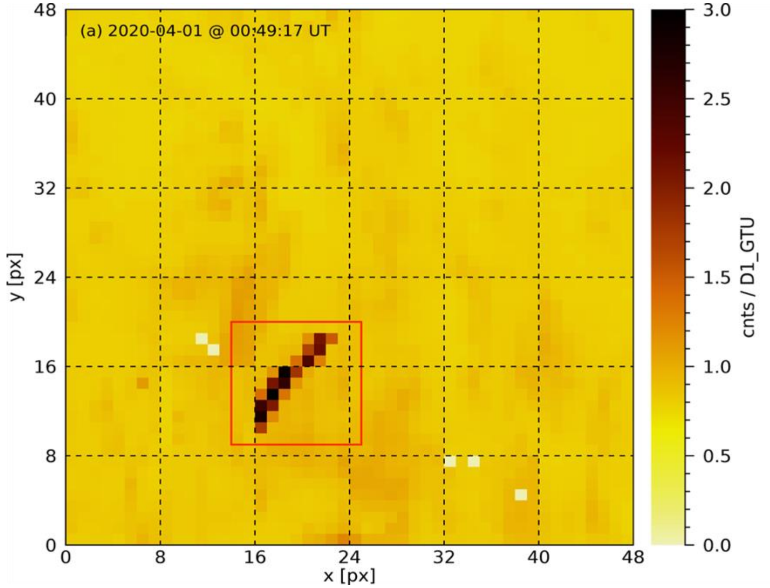


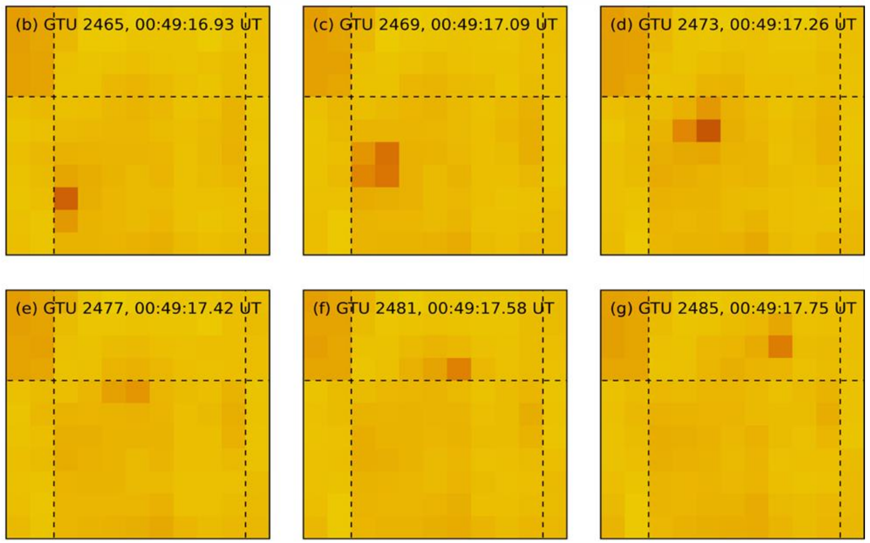
SINGLE FRAME
circle fit
SINGLE PIXEL SIGNAL
fit exGauss
POLAR PLOT
24/09/2020
25/09/2020
21/08/2020
Frame 5820
Frame 4200
Frame 630
x [km]
y [km]
cts [ADC]
Photon counts [ADC]
Time [GTU]
R [km]
cts [a. u.]

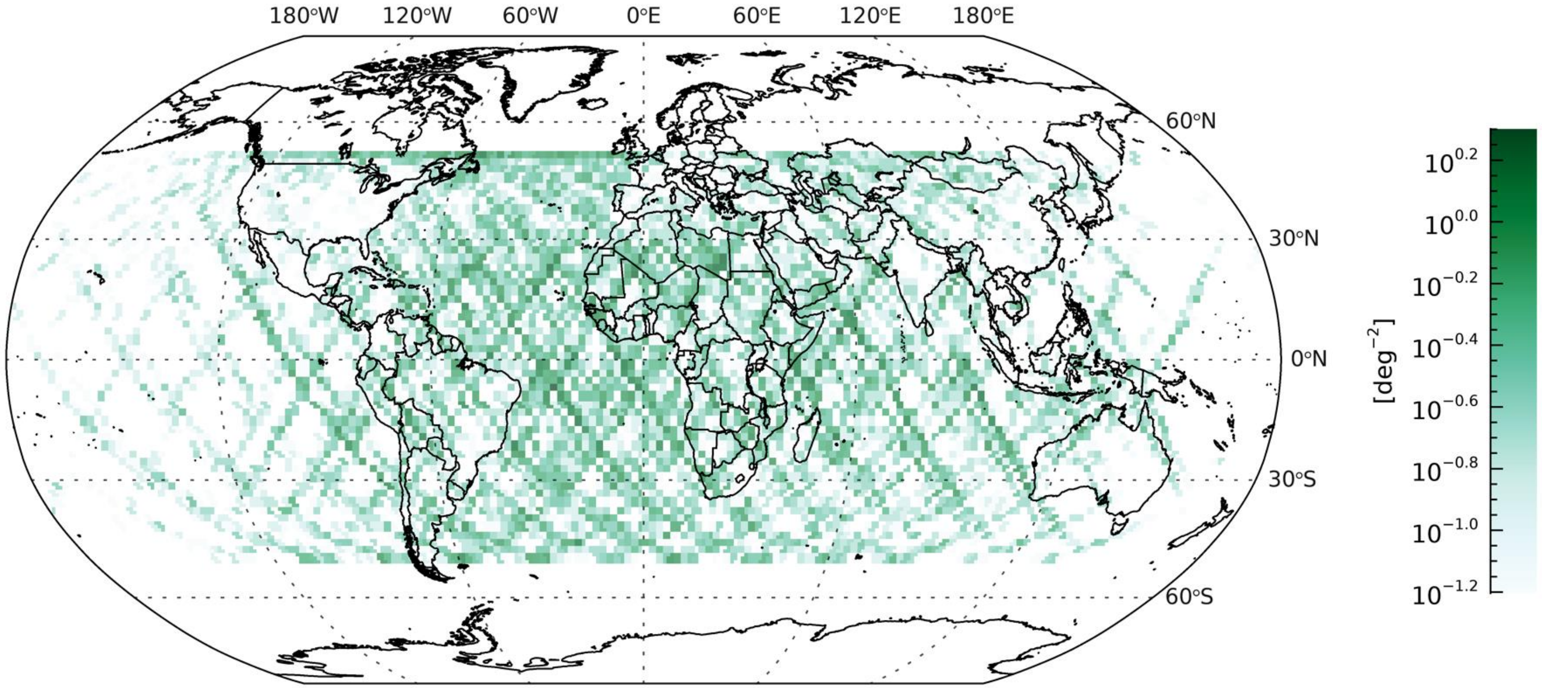
Meteors:

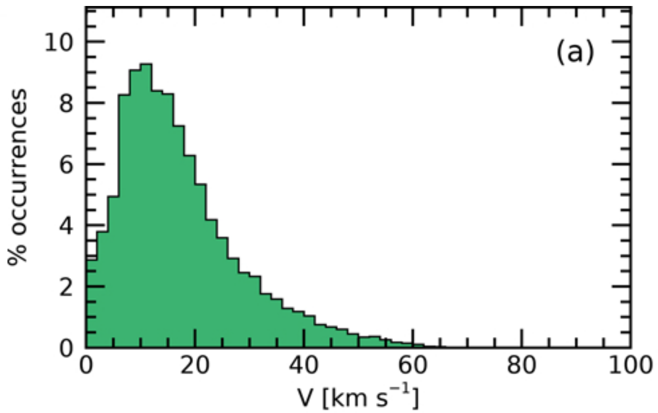
Mini-EUSO is making the first systematic detection & study from space

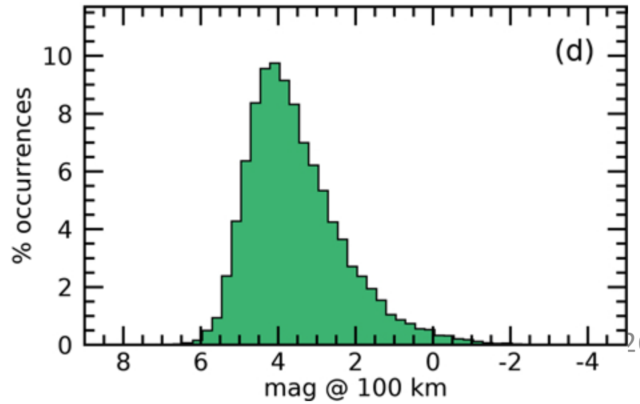
~24 k candidates





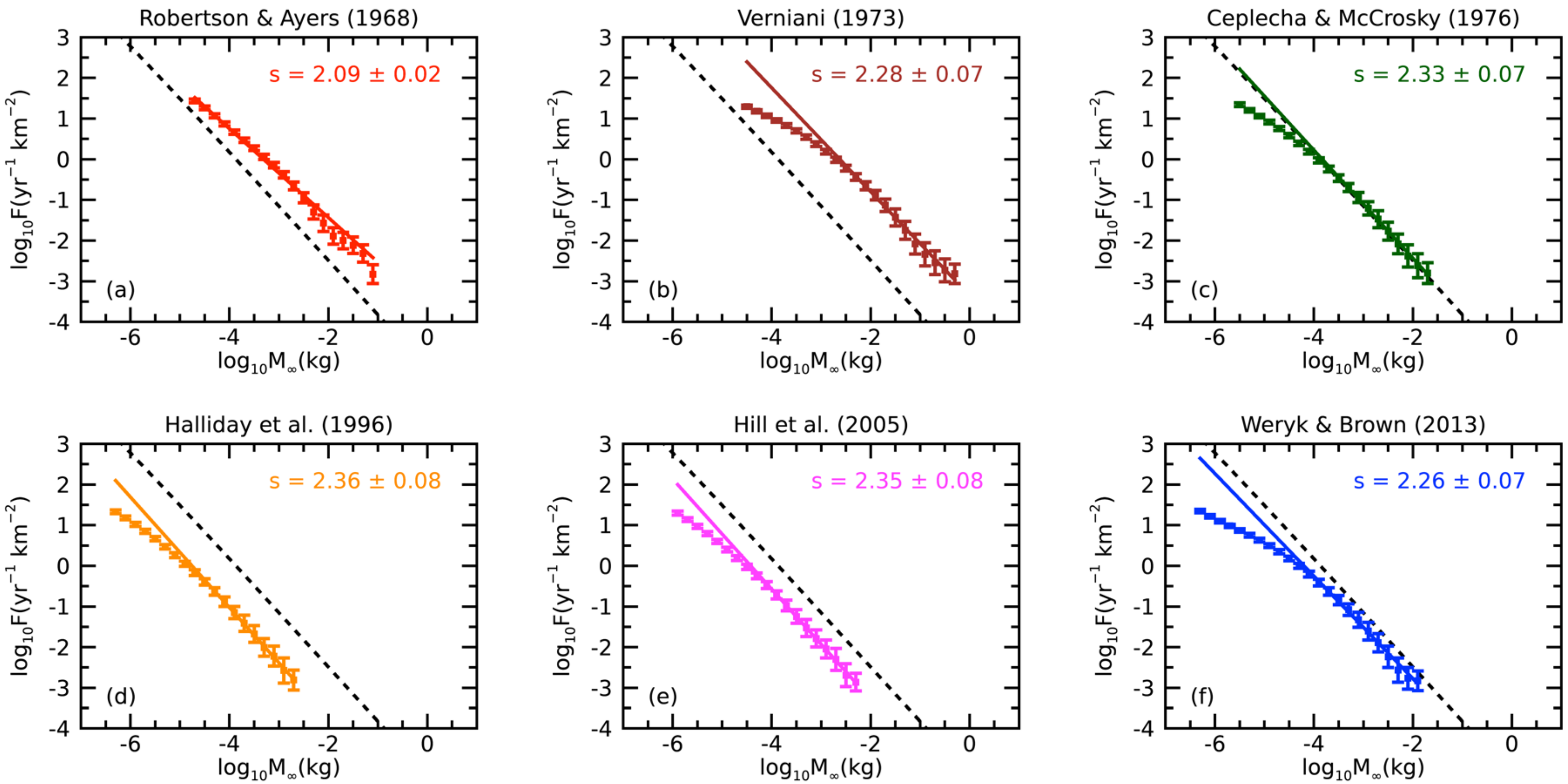






D. Barghini et al. A&A, 687, A304 (2024)
https://doi.org/10.1051/0004-6361/202449236

Cumulative flux density distribution

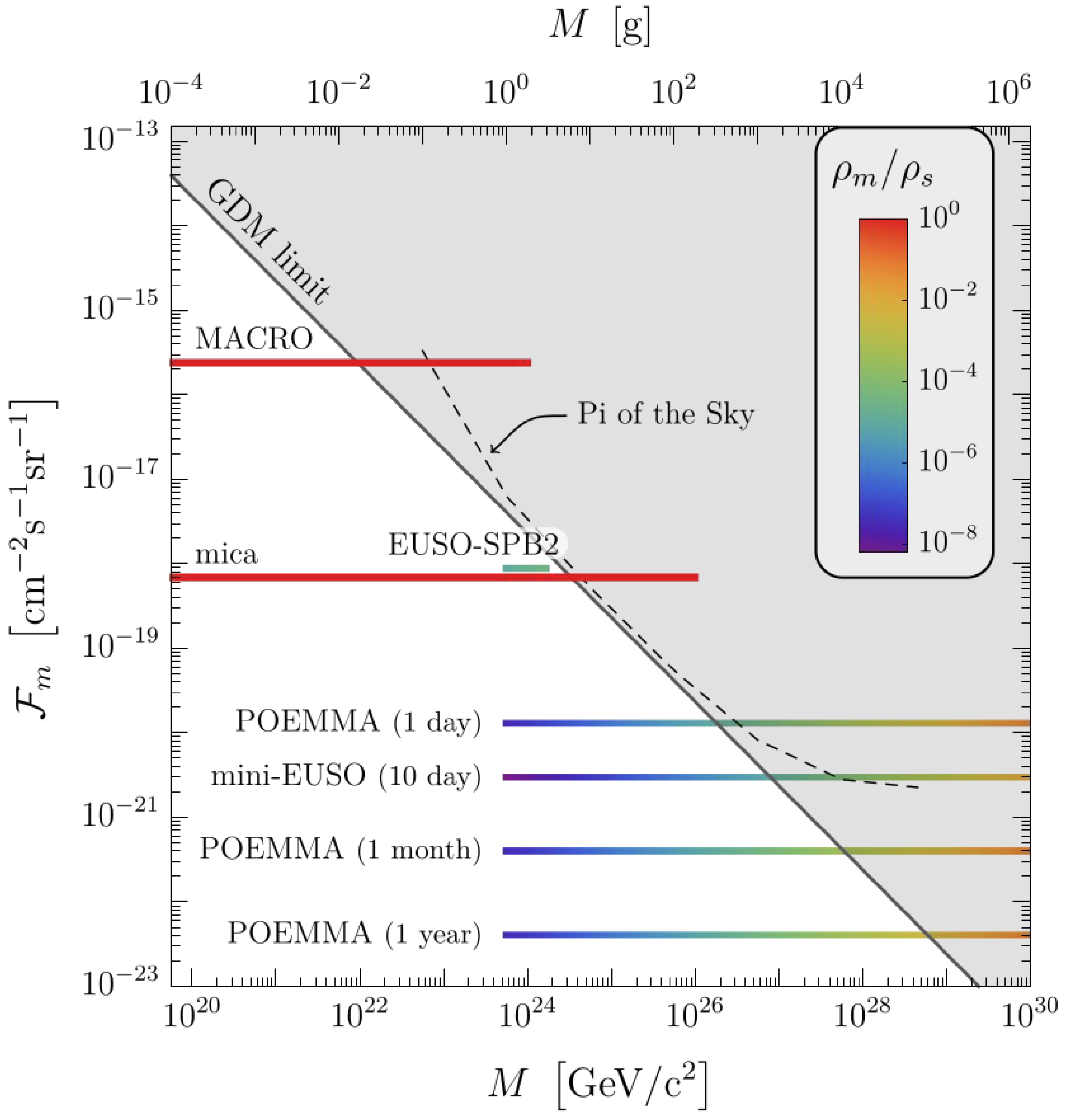


Comparison of the cumulative flux density distribution of meteoroids computed thanks to the observations of meteors by the Mini-EUSO telescope, resulting from the application of different methods to compute the pre-atmospheric mass of the meteoroid from the intensity of the observed meteor and consisting 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 10^5 km^2 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'



L. Anchordoqui et al. EPL 135 (2021) 5

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