Skobeltsyn Institute of Nuclear Physics
Lomonosov Moscow State University

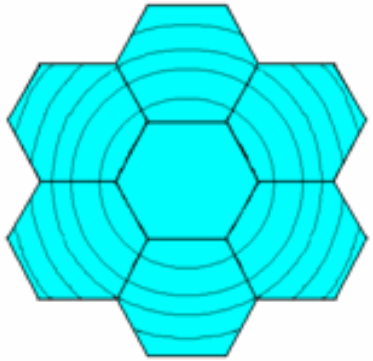
First results on transient atmospheric events from Tracking Ultraviolet Set-up (TUS) on board of Lomonosov satellite

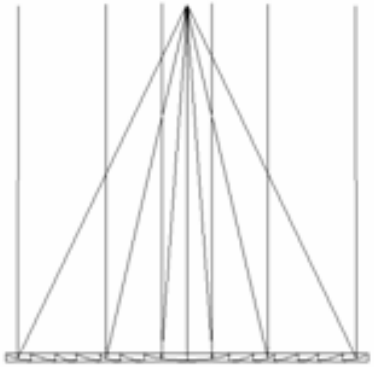
Klimov P.A., Khrenov B.A., Garipov G.K., Morozenko V.S., Kaznacheeva M., Panasyuk M.I., Petrov V.L., Sharakin S.A., Zotov M.Yu., Yashin I.V., Chirskaya N.P.

Thunderstorms and Elementary Particle Acceleration

October 3-7, 2016

TUS detector on board the Lomonosov satellite





Fresnel type mirror–concentrator

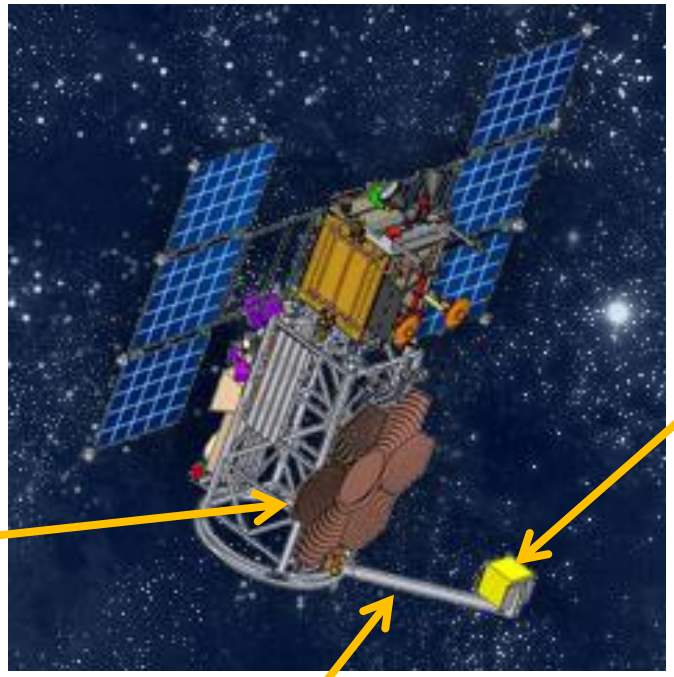
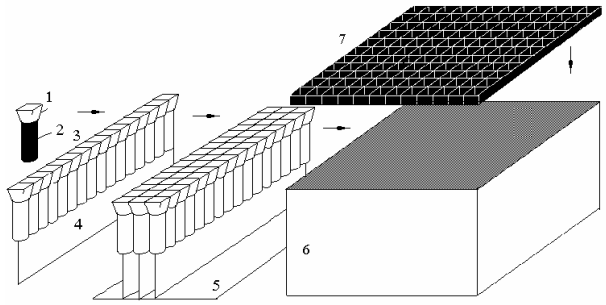
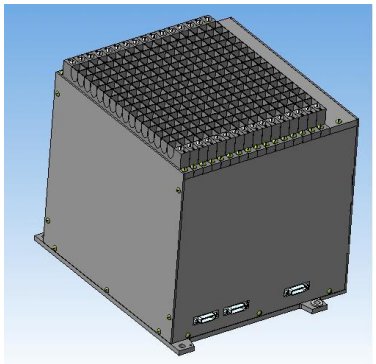


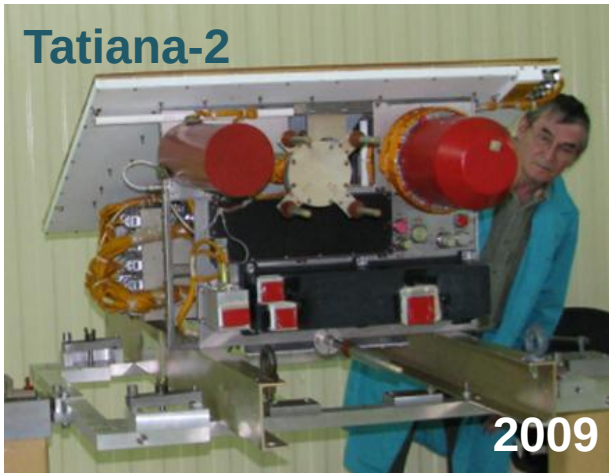
Photo receiver moving system

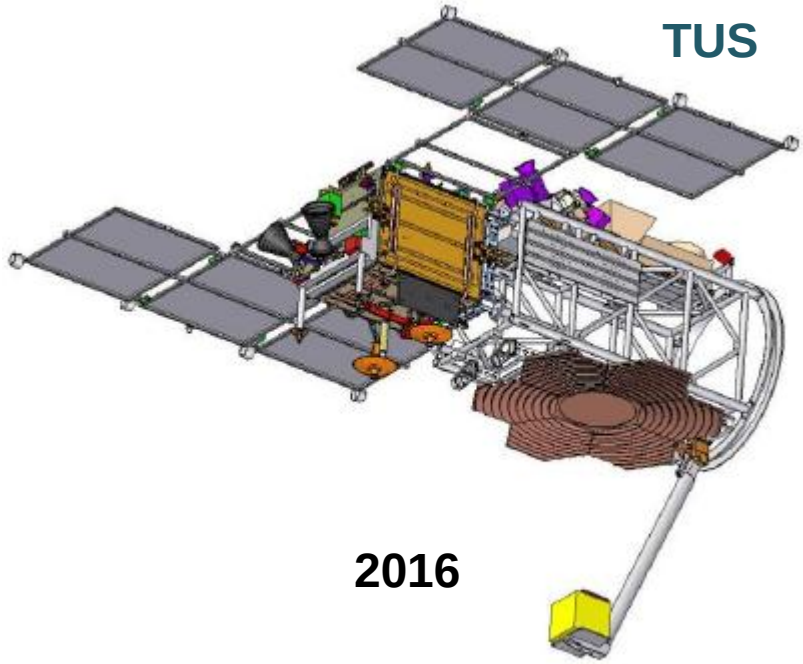
Photo receiver



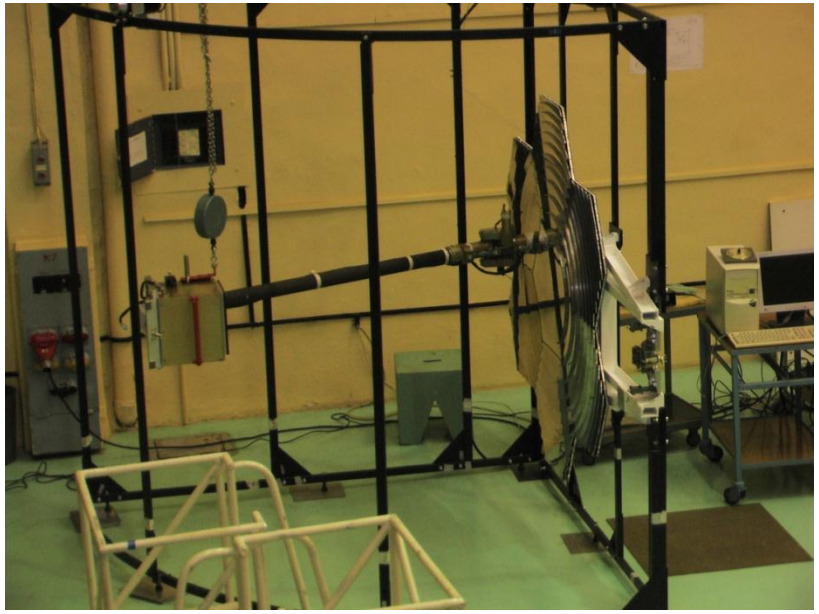


MSU satellites with UV detectors





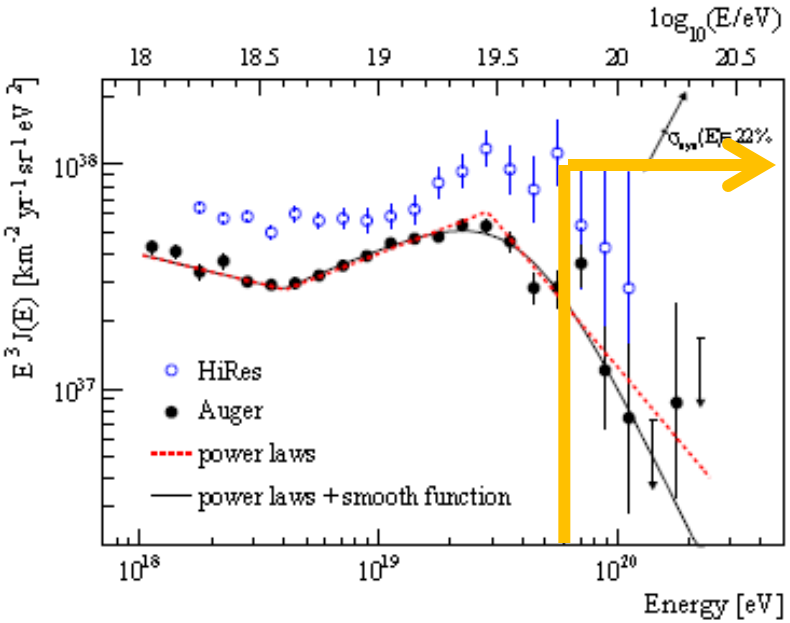
TUS detector on board the Lomonosov satellite



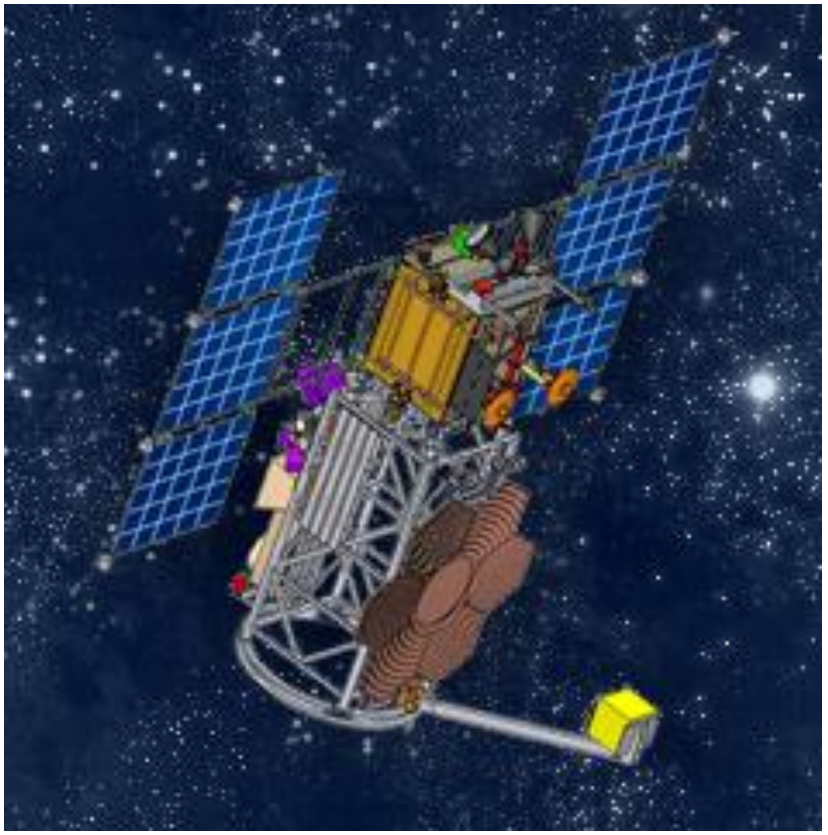
Mass	< 60 kg
Power (maximum)	65 W
Data (maximum)	200 Mbyte/day
FOV	±4,5 degree
Number of pixels	256 (16 clusters of 16 PMTs)
Pixel size	10 mrad (5×5 km)
Mirror area	~2 m^2
Focal distance	1,5 m
Duty cycle, %	30

Scientific goals of the experiment

Detector TUS is designed as a multifunctional orbital telescope for various luminous atmospheric processes research.

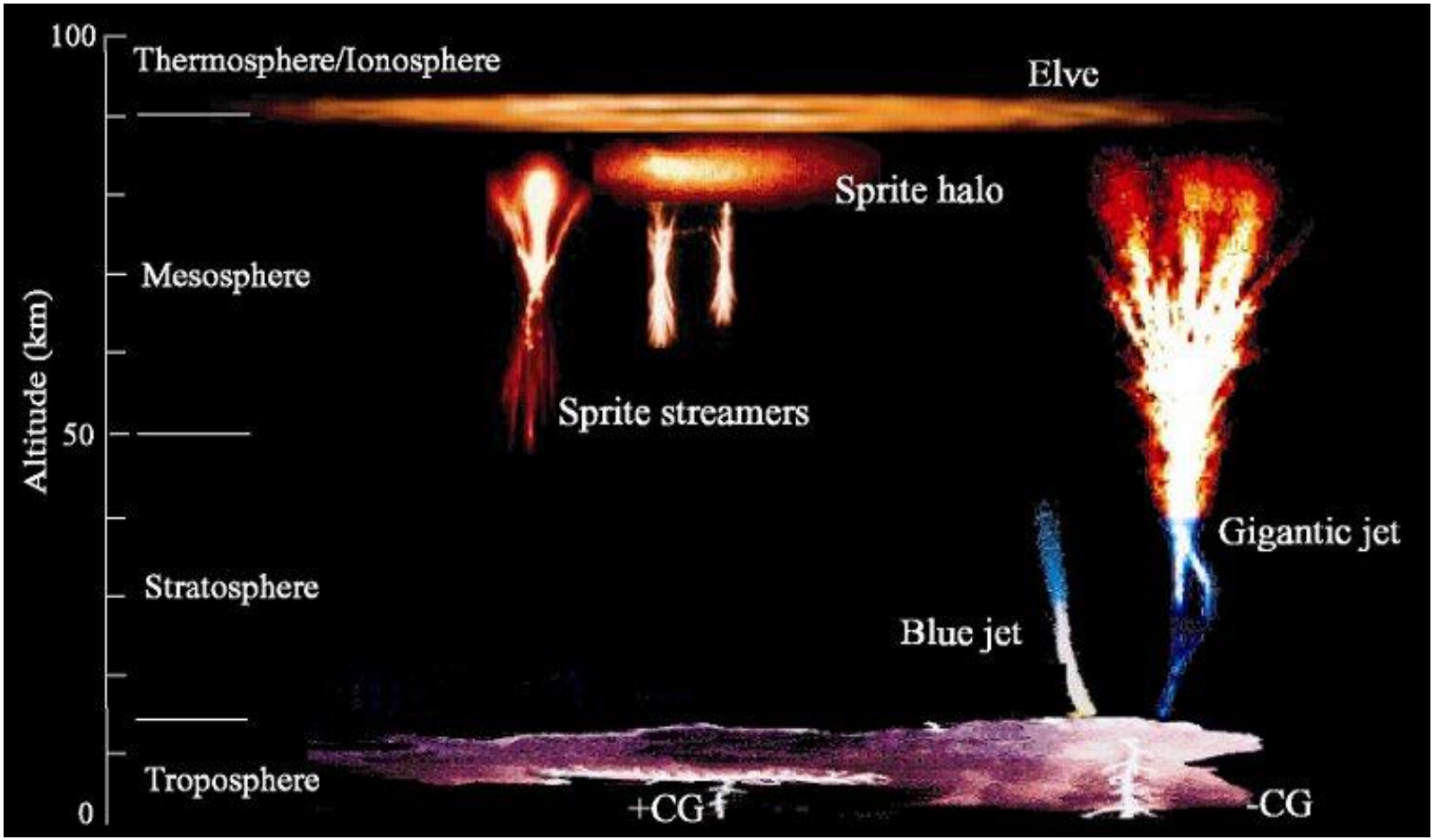


The Pierre Auger Collaboration, Physics Letters B 685, (2010) 239



Test of orbital technology of UHECR measurements!

Scientific goals of the experiment

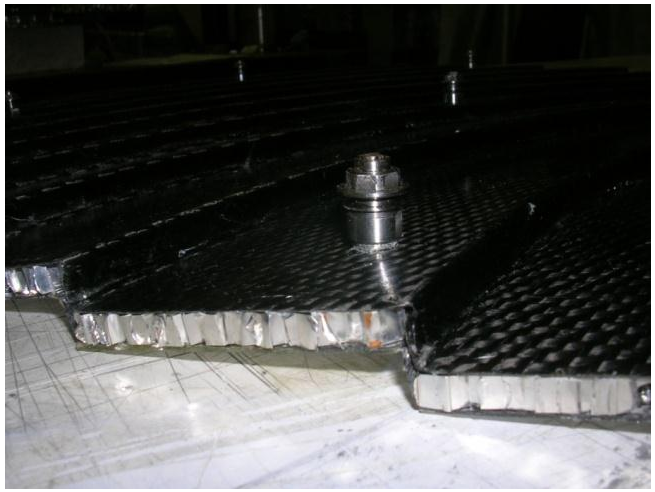


TUS detector trigger and data

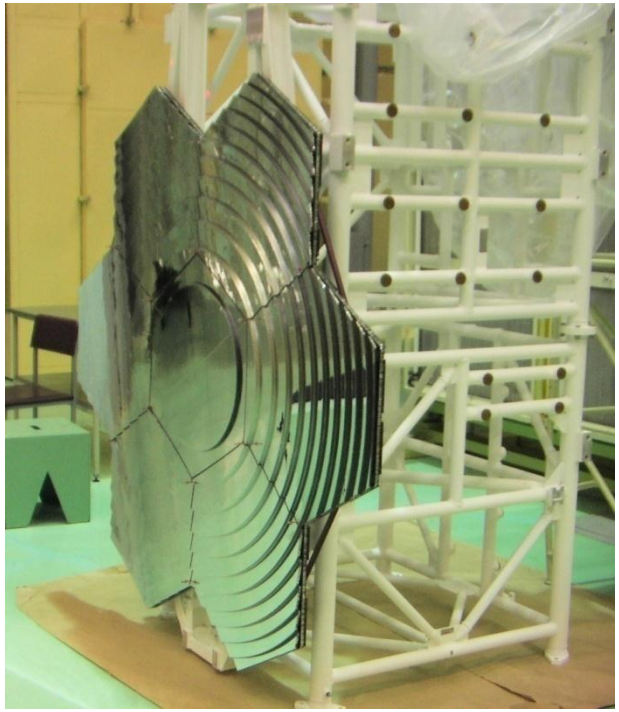
Phenomena	Time sample	Integration time	Oscillogram length
EAS	$\tau = \tau_0 = 0{,}8$ μs	$t = 2^4\tau = 12{,}8$ μs	$\Delta T = 256\tau = 205$ μs
Short TLE (elves)	$\tau = 2^5\tau_0 = 25{,}6$ μs	$t = 2^3\tau = 0{,}2$ ms	$\Delta T = 256\tau = 6{,}6$ ms
Long TLE (sprites, jets)	$\tau = 2^9\tau_0 = 0{,}4$ ms	$t = \tau = 0{,}4$ ms	$\Delta T = 256\tau = 105$ ms
Micro-meteor	$\tau = 2^{13}\tau_0 = 6{,}6$ ms	$t = 2^4\tau = 105$ ms	$\Delta T = 256\tau = 1{,}7$ s

$$\tau_{HVcontrol} = 100 \text{ ms}$$

Mirror-concentrator



- LTD «Space Regatta», SINP MSU and JINR
- Lightweight and thermostable segmented mirror based on carbon-plastic structure



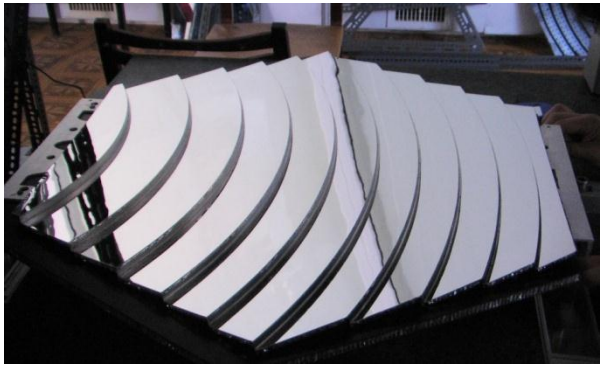
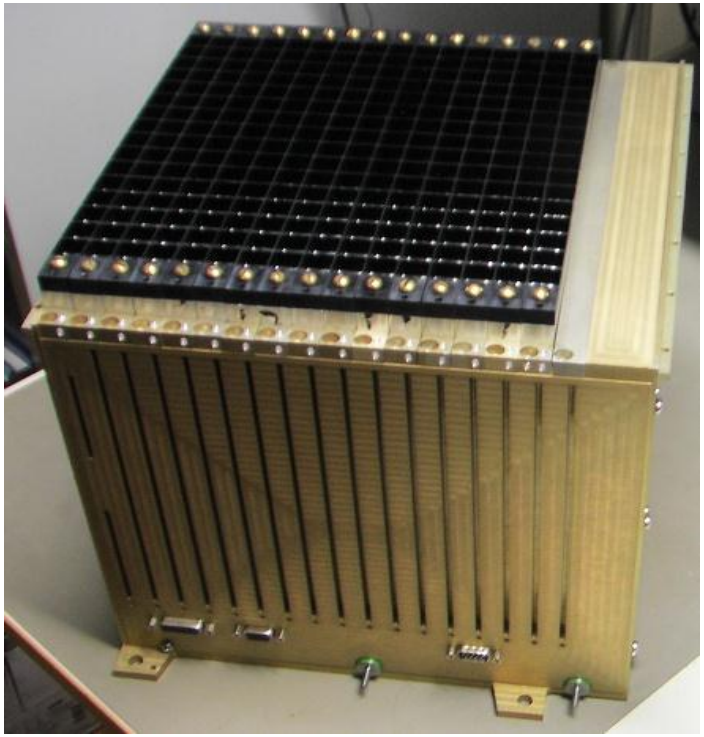
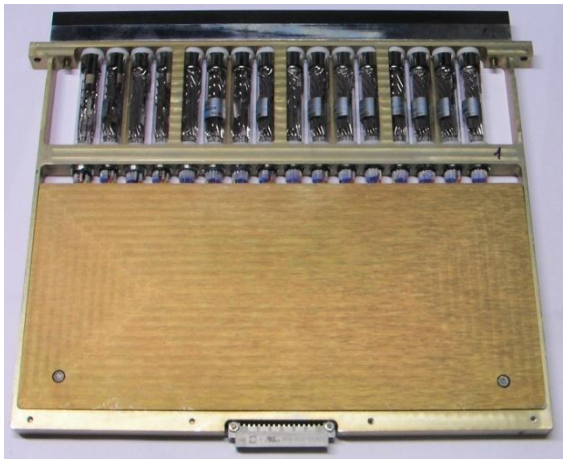


Photo receiver of TUS detector

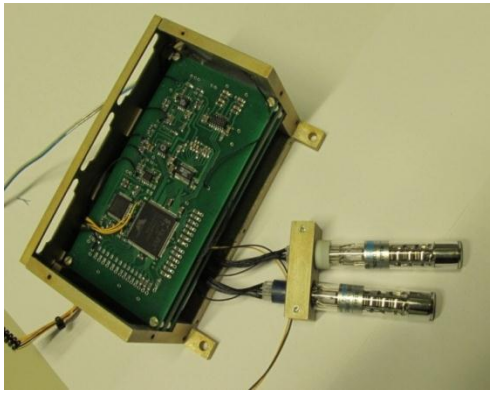


TUS photodetector

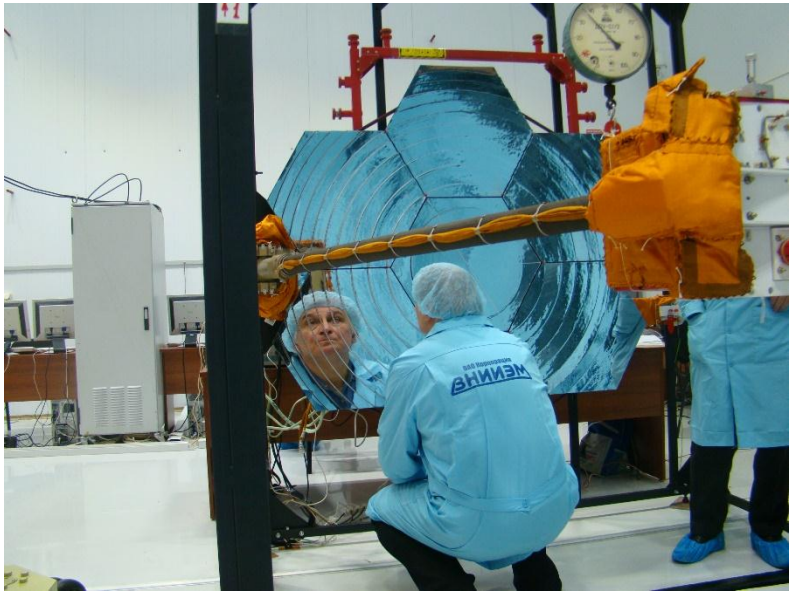


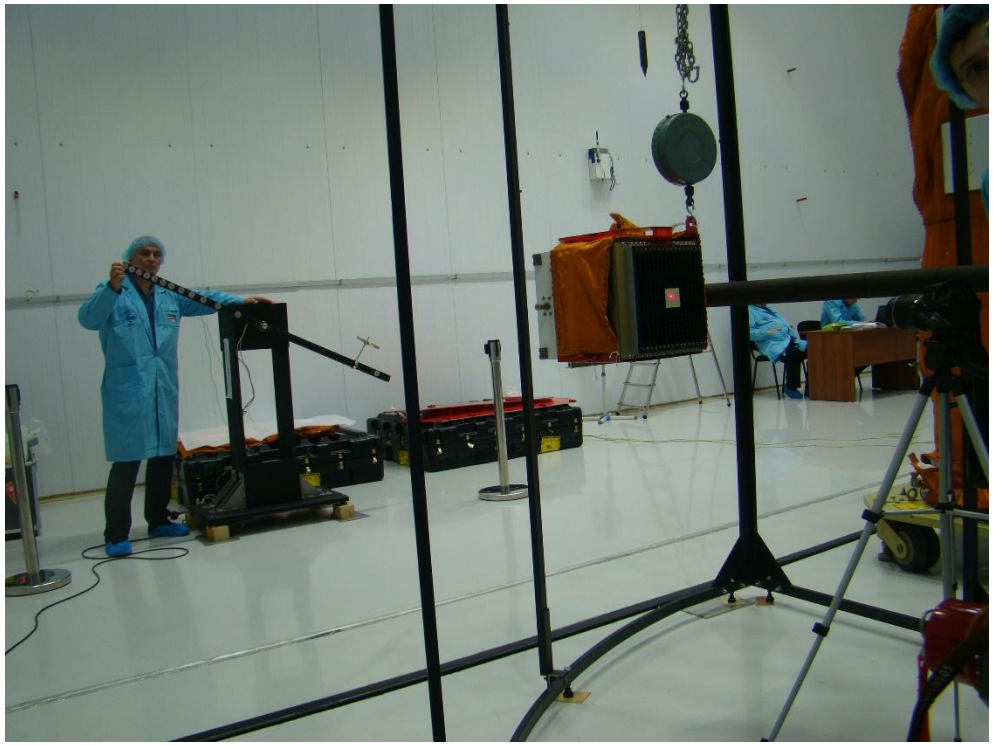
PMT module

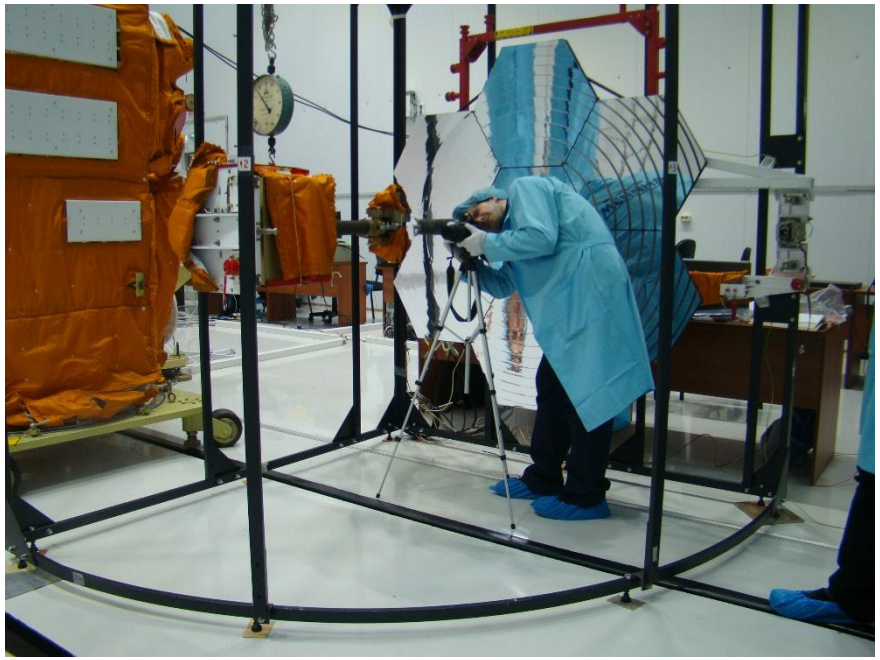
Tatiana-2
UV&IR detector

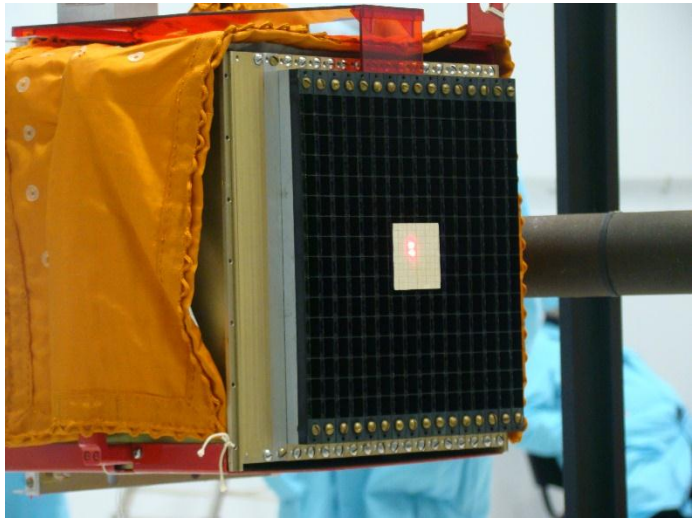


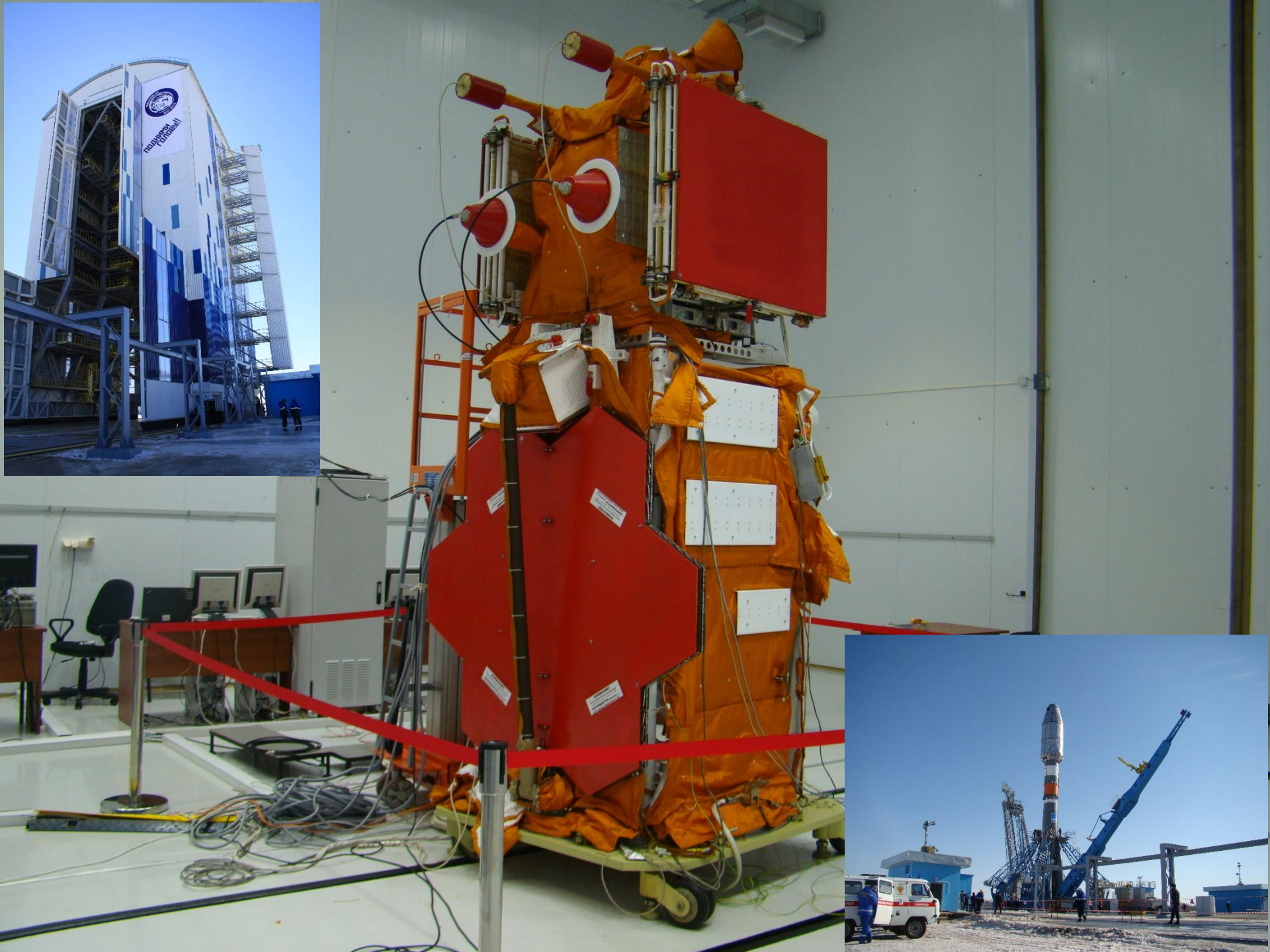
Preflight tests on the cosmodrome Vostochny





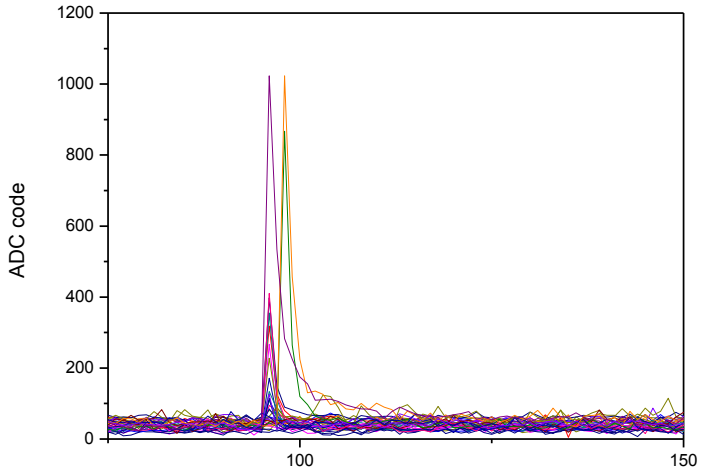


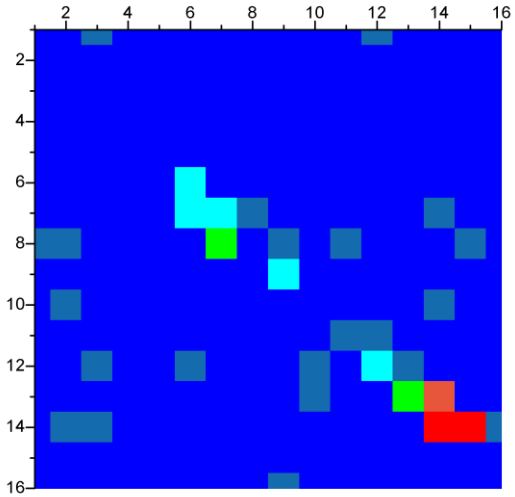


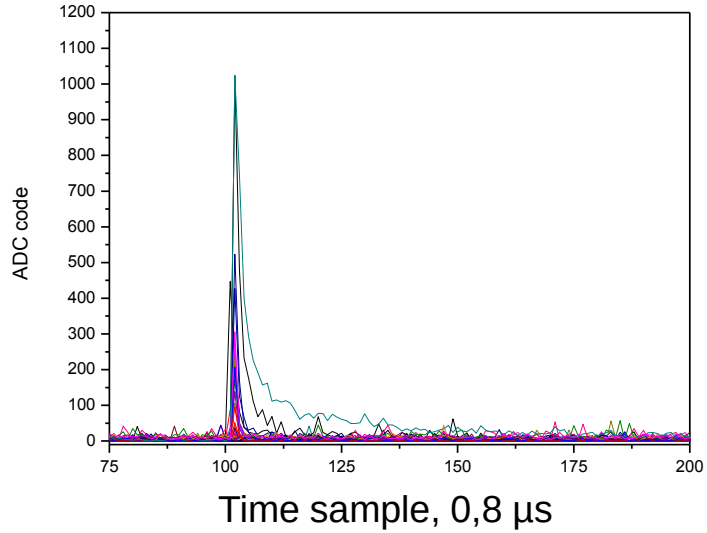


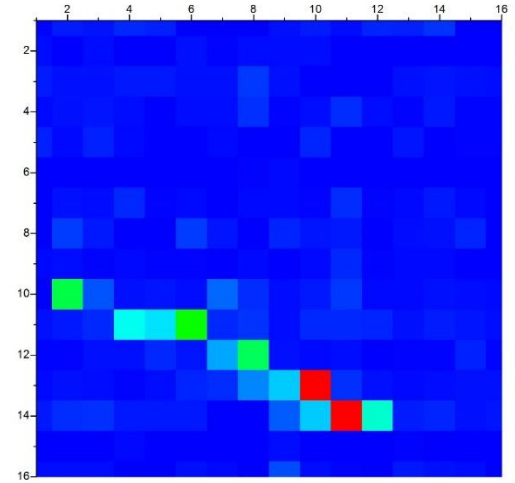
Preliminary results of data analyses during first months of the detector operation in space

Short pulses (less than 1 µs)

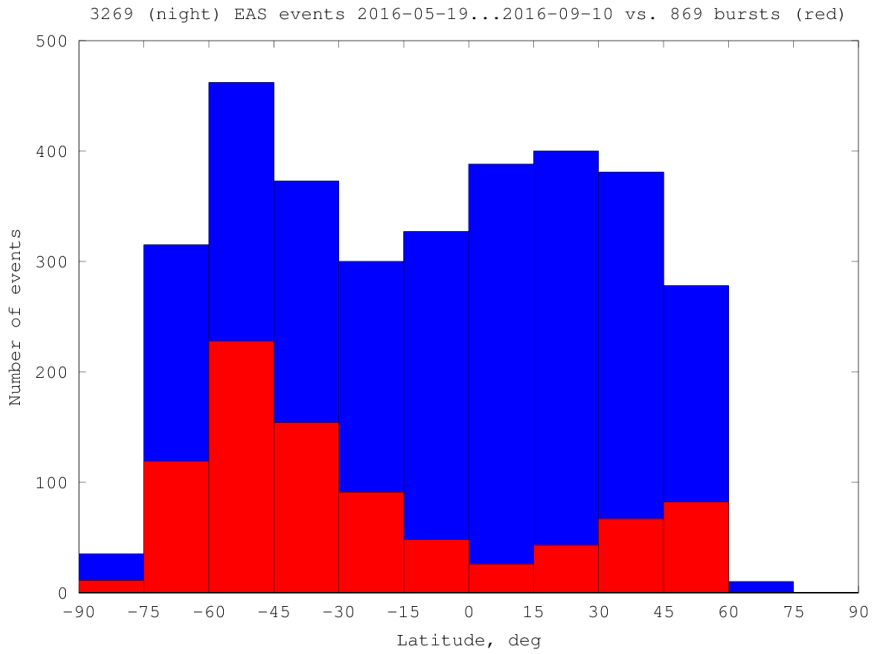




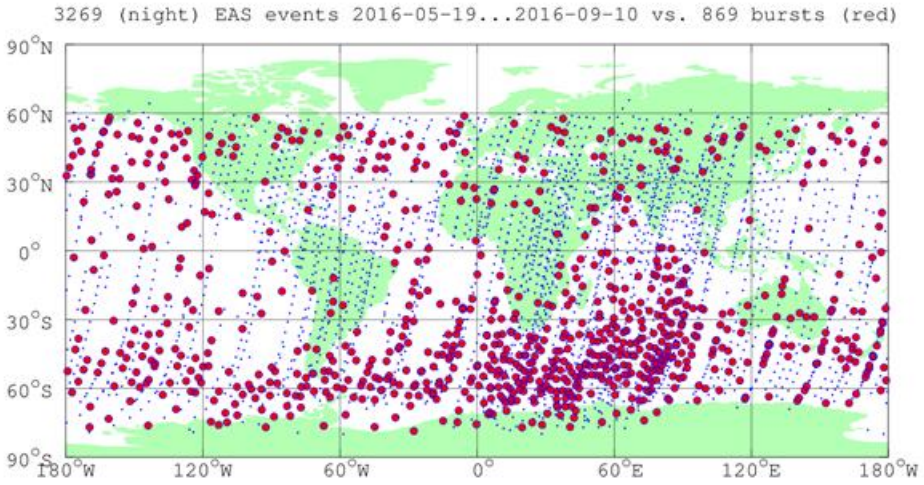




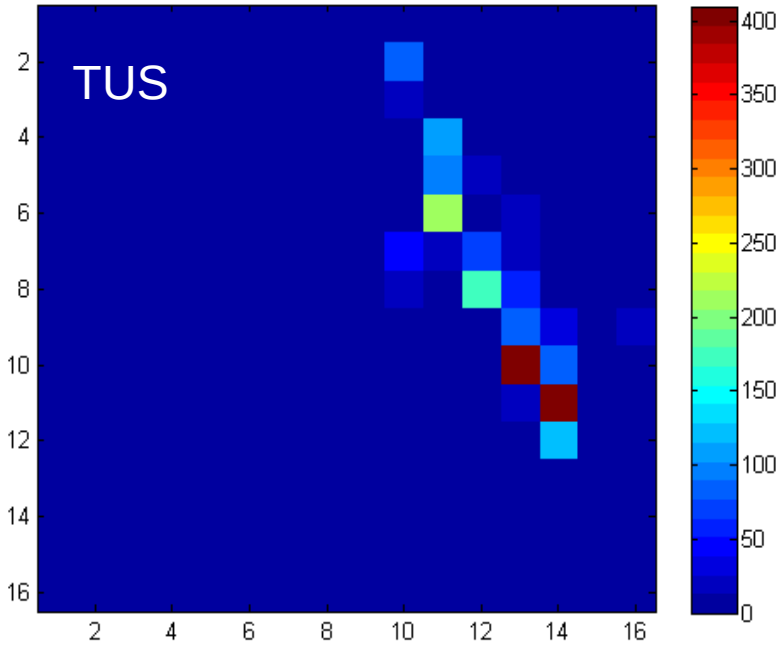
Geographical distribution

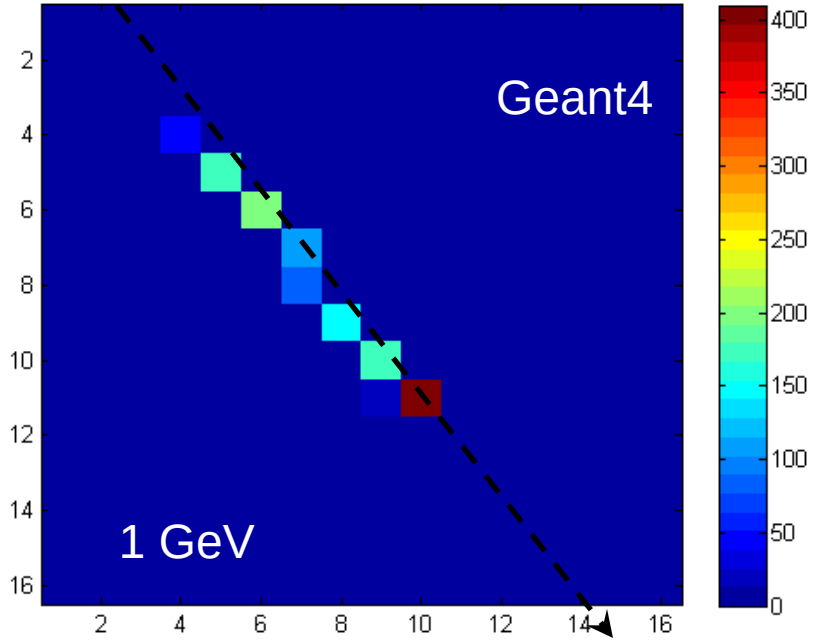


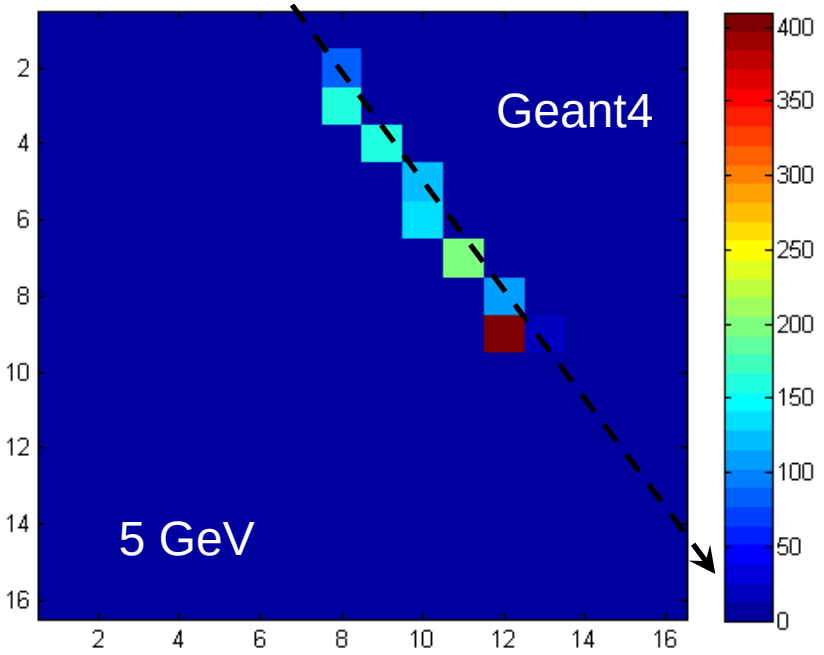
- ✓ September, 10
- ✓ 869 events
- ✓ Measurements in both hemispheres



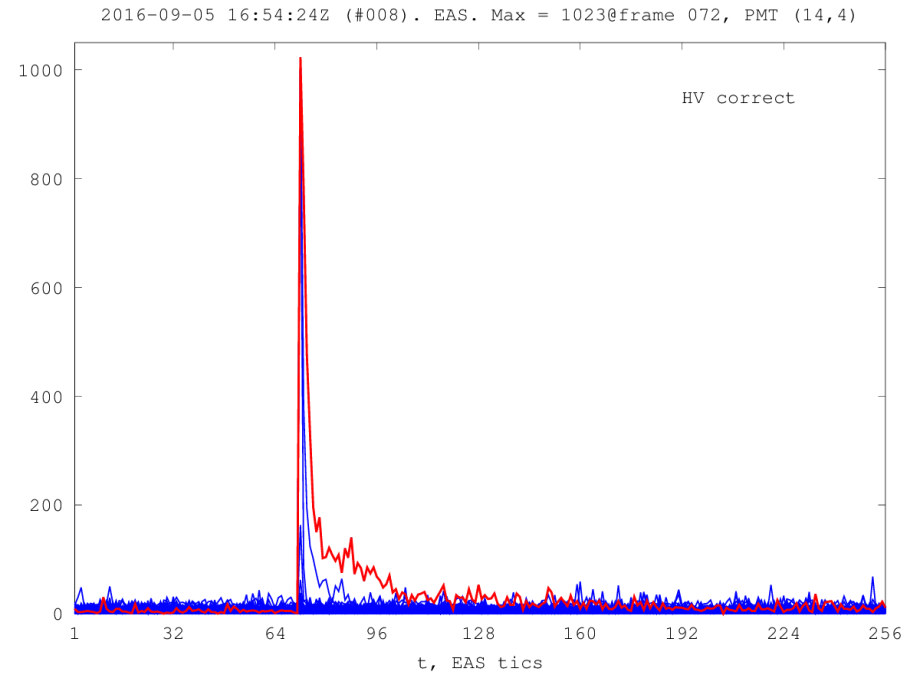
Results of simulation in Geant4





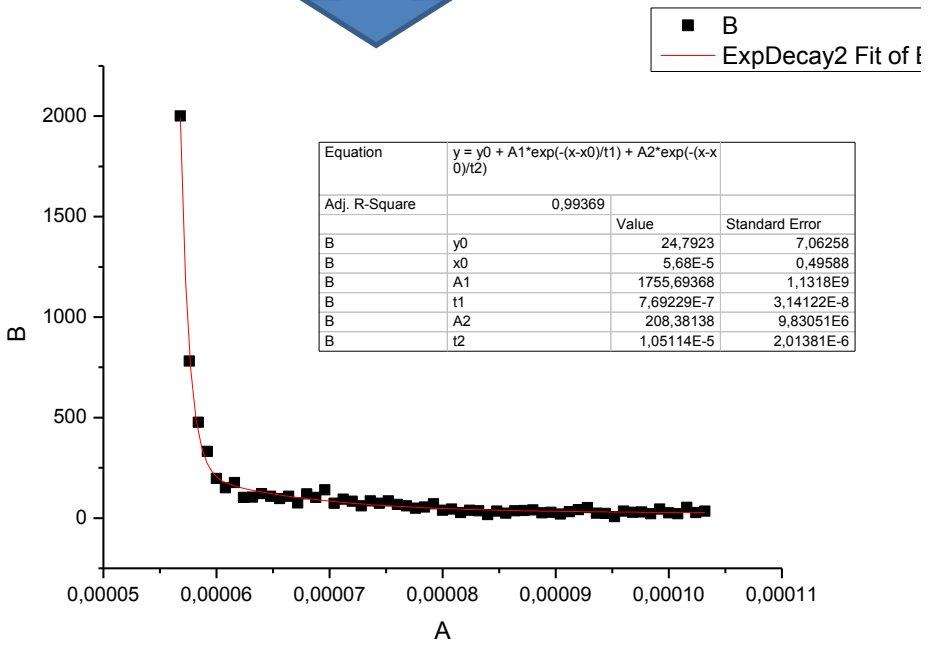


Temporal structure



Experimental data

Fit with two exponential decay



Equation	y = y0 + A1*exp(-(x-x0)/t1) + A2*exp(-(x-x0)/t2)		
Adj. R-Square	0,99369		
		Value	Standard Error
B	y0	24,7923	7,06258
B	x0	5,68E-5	0,49588
B	A1	1755,69368	1,1318E9
B	t1	7,69229E-7	3,14122E-8
B	A2	208,38138	9,83051E6
B	t2	1,05114E-5	2,01381E-6

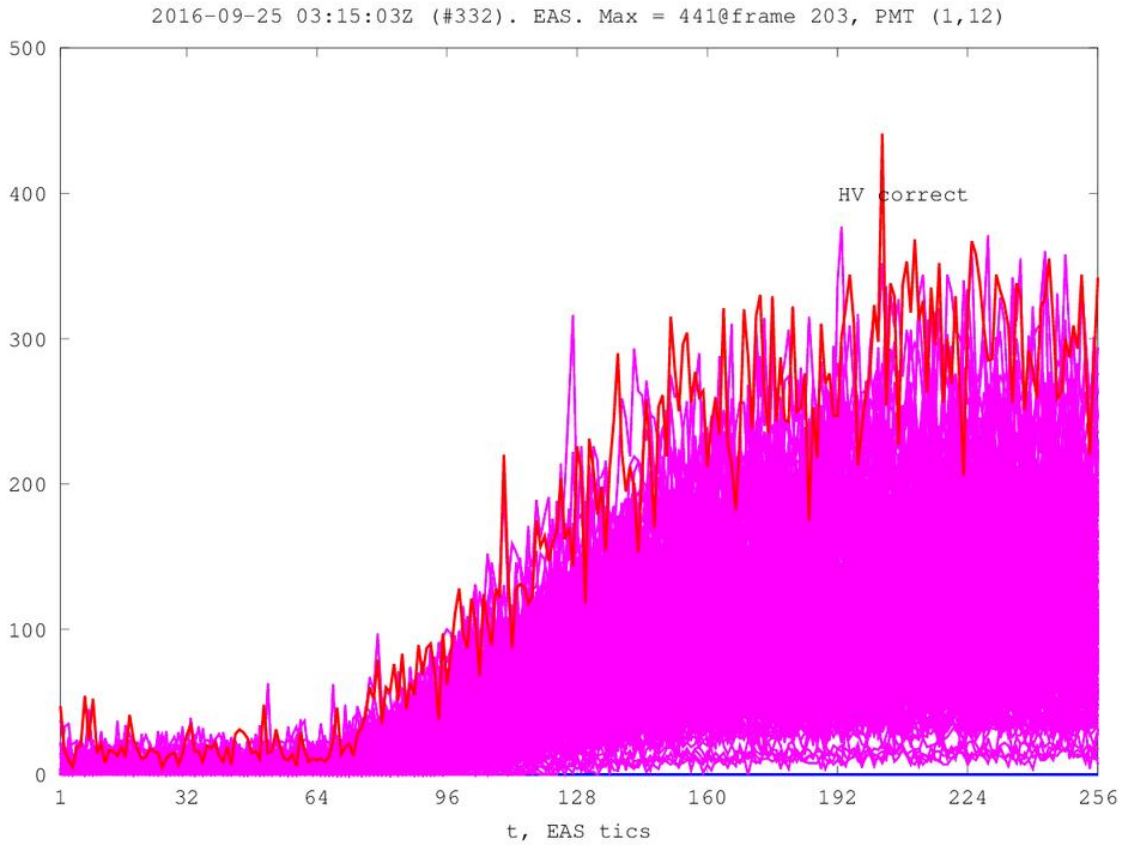
1. Immediate growth of signal in several pixels
2. Fast decrease with t~0,6 μs
3. Long signal (tens of us)

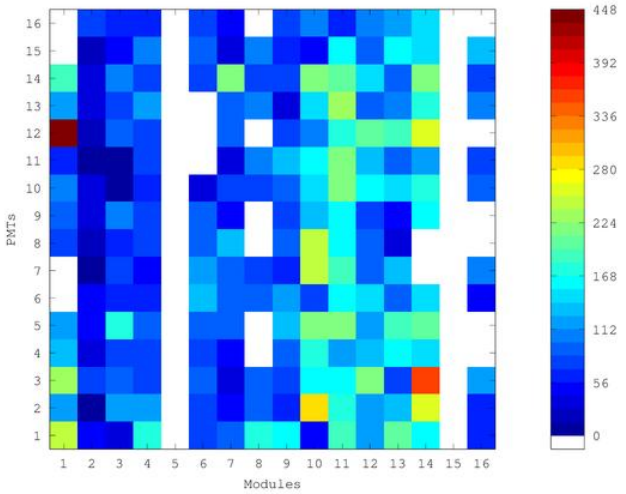
Important information for future UHECR missions to make a correct trigger

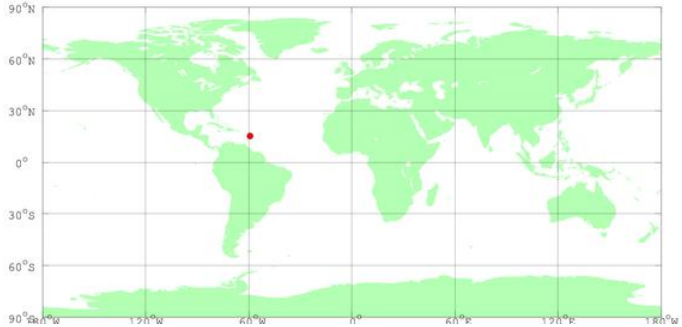
Interesting UV flashes with 0,8 µs temporal resolution

1. Simultaneous signal increasing in the whole FOV.
2. Local event with spatial dynamics .
3. Fast movement of spot across FOV.

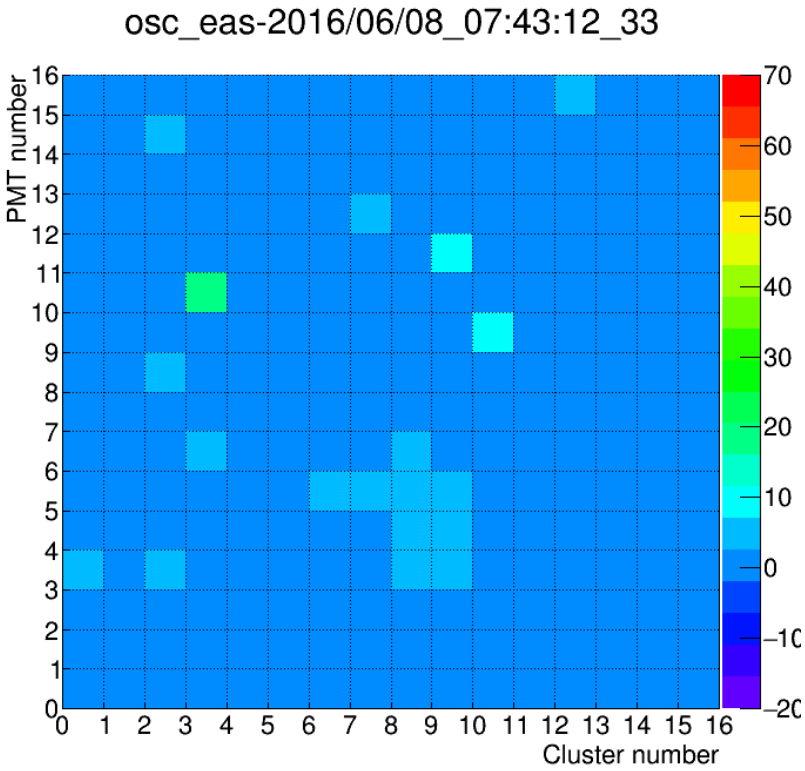
Simultaneous signal increasing in the whole FOV

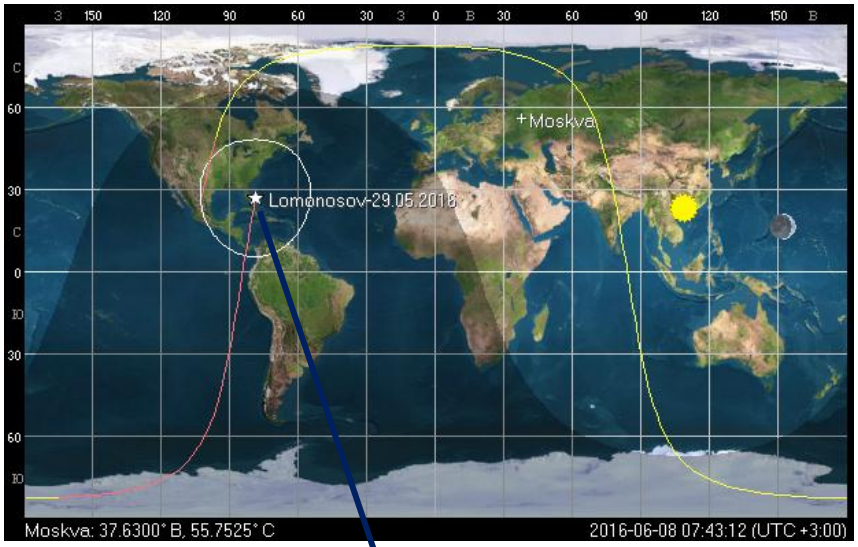


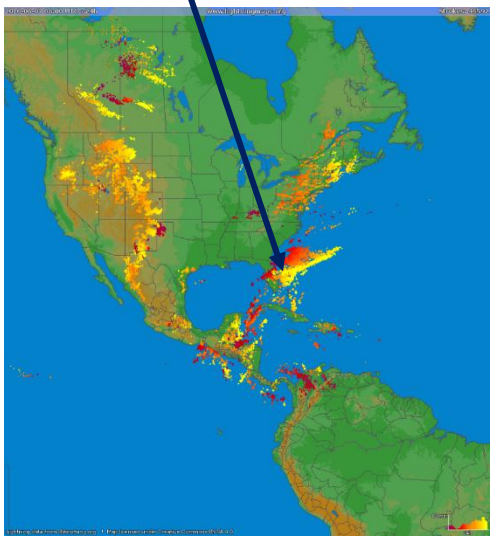




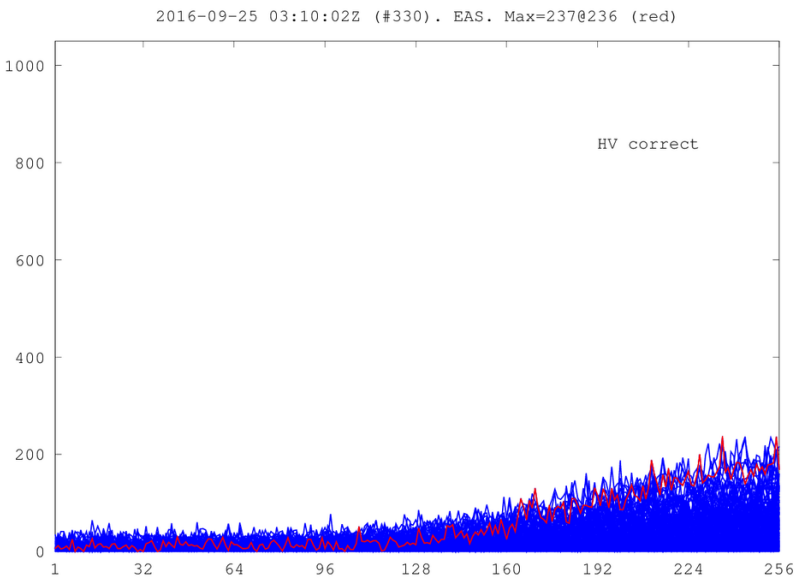
Local event with spatial dynamics

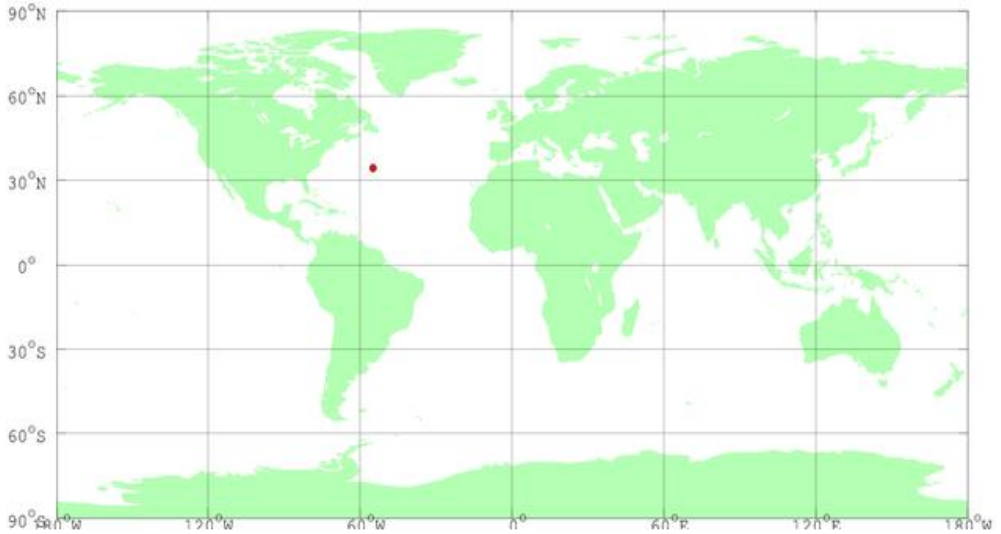


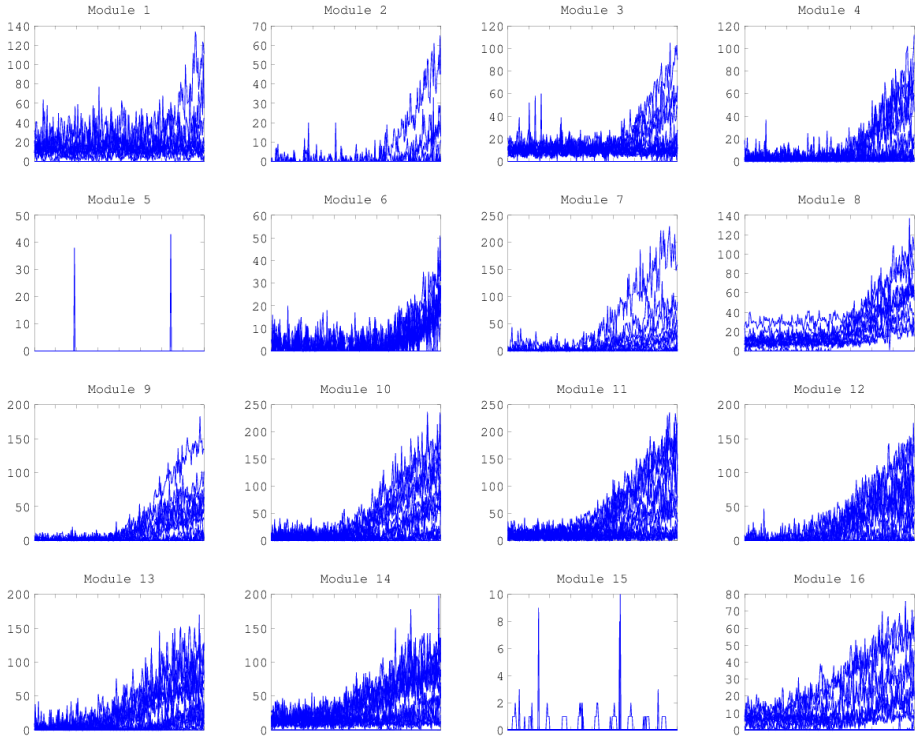


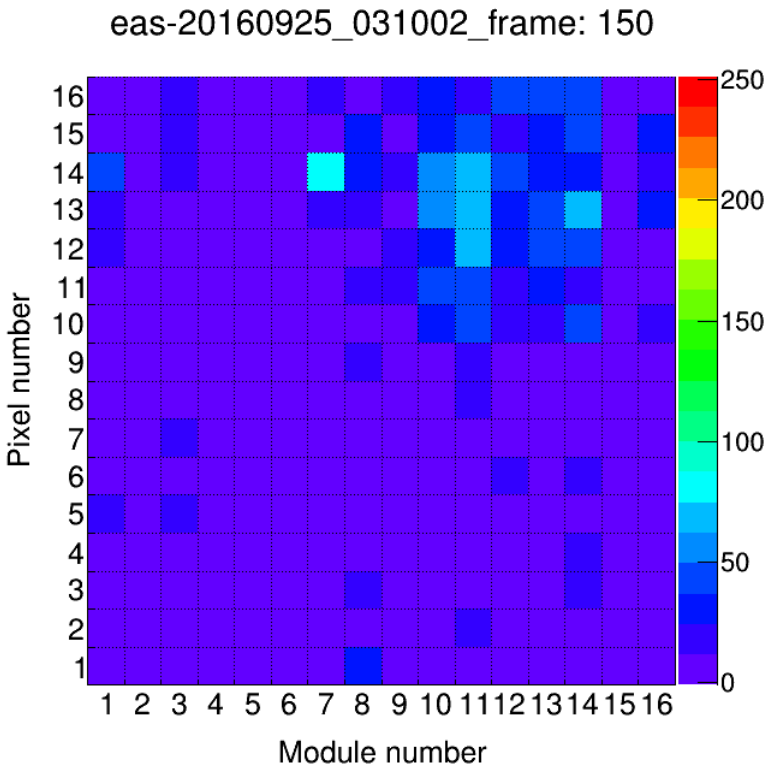


Event in the region of large thunderstorm activity
Temporal resolution 0,8 μs
Duration of waveform ~200 μs

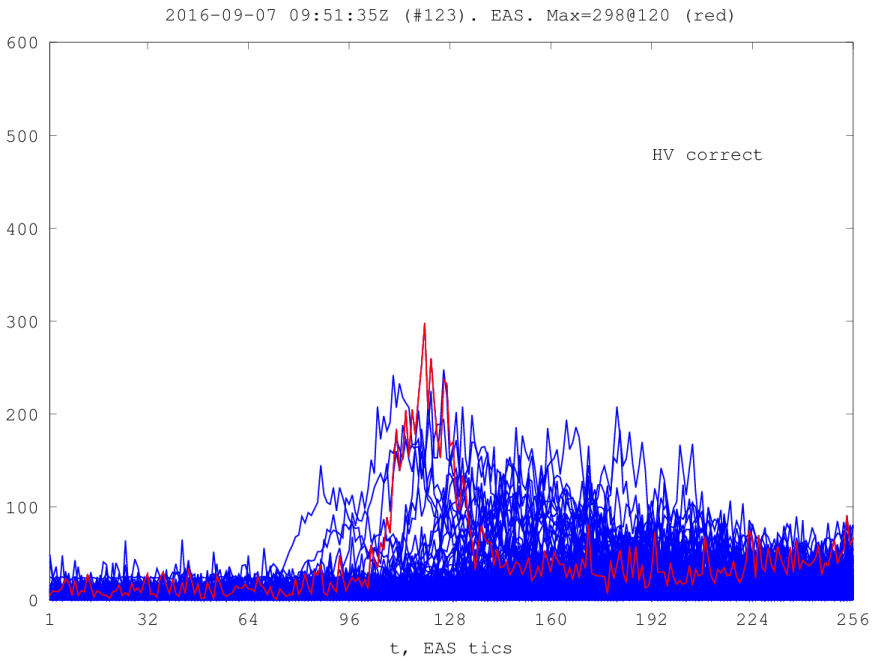

2016-09-25 03:10:02Z (#330). EAS. Max=237@236 (red)
HV correct
1000
800
600
400
200
0
1
32
64
96
128
160
192
224
256

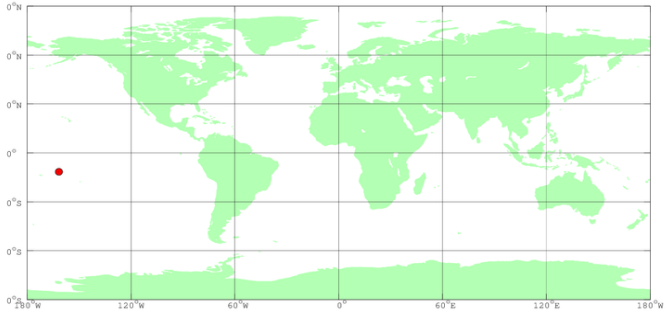

90°N
60°N
30°N
0°
30°S
60°S
90°S
120°W
60°W
0°
60°E
120°E
180°W


Module 1
Module 2
Module 3
Module 4
Module 5
Module 6
Module 7
Module 8
Module 9
Module 10
Module 11
Module 12
Module 13
Module 14
Module 15
Module 16


eas-20160925_031002_frame: 150
Pixel number
Module number
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
250
200
150
100
50
0

Fast movement of spot across FOV

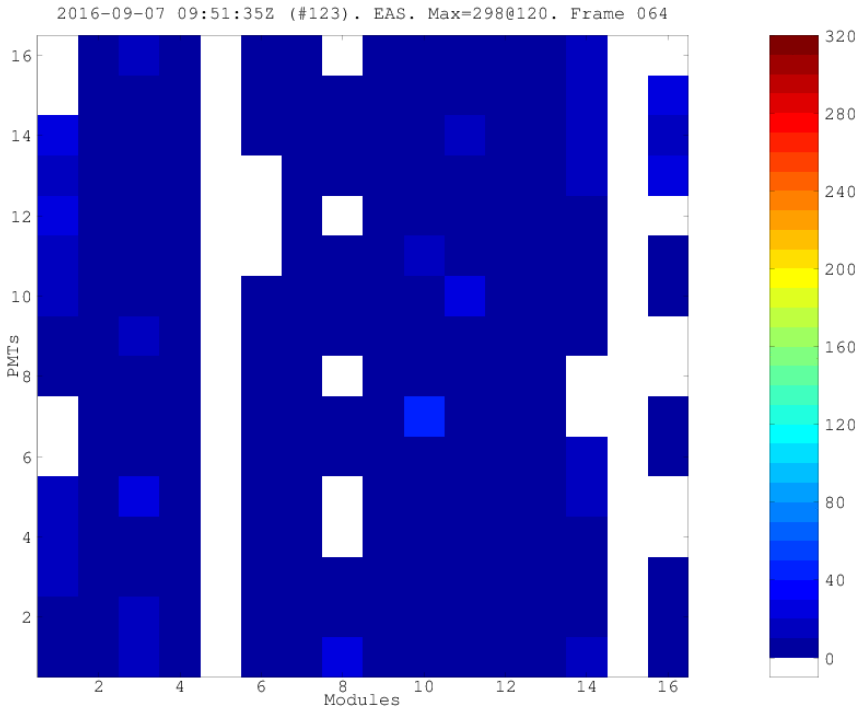


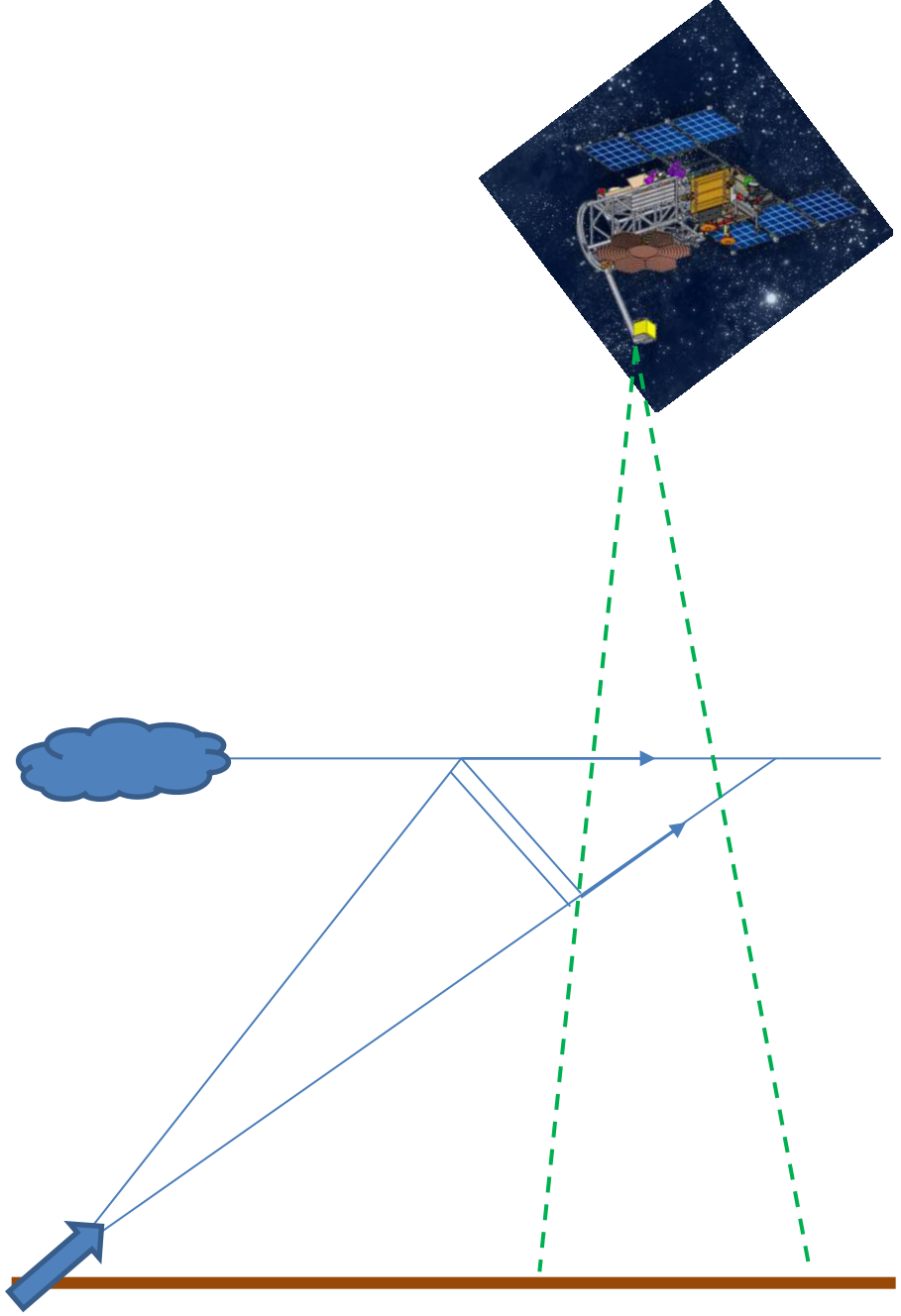


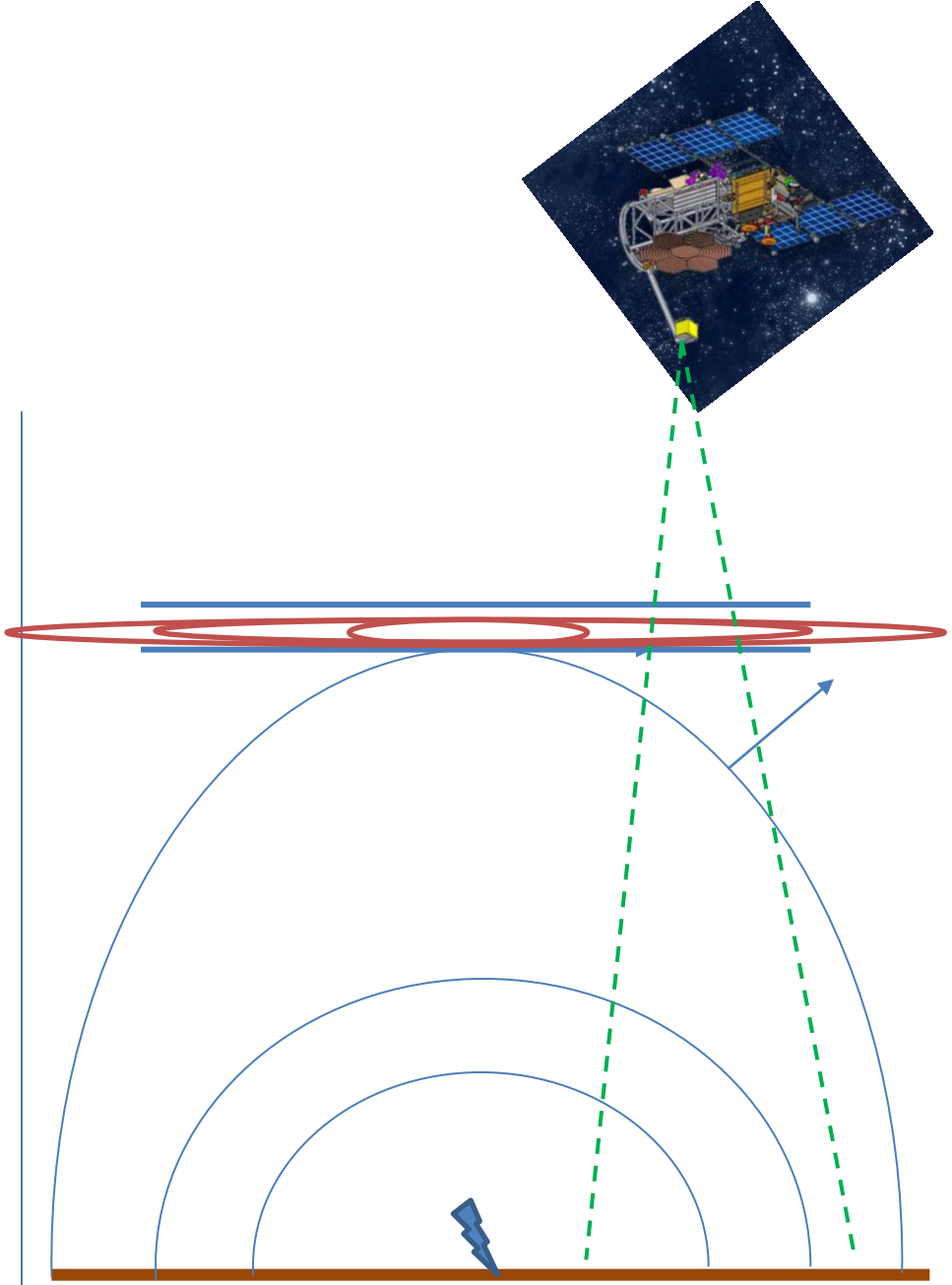
256 waveforms

Spatial structure and movement

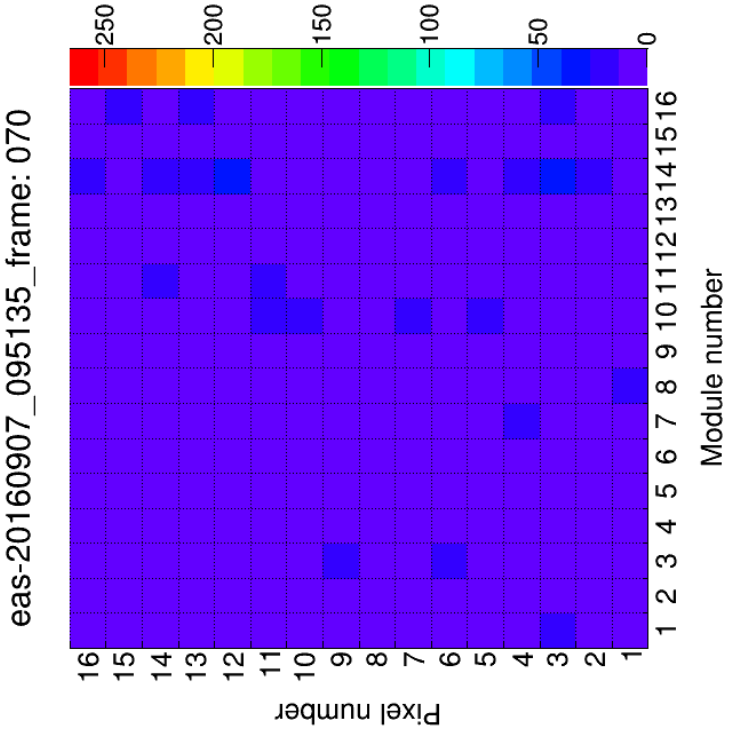
Angular speed is ~10^3 rad/s (!)

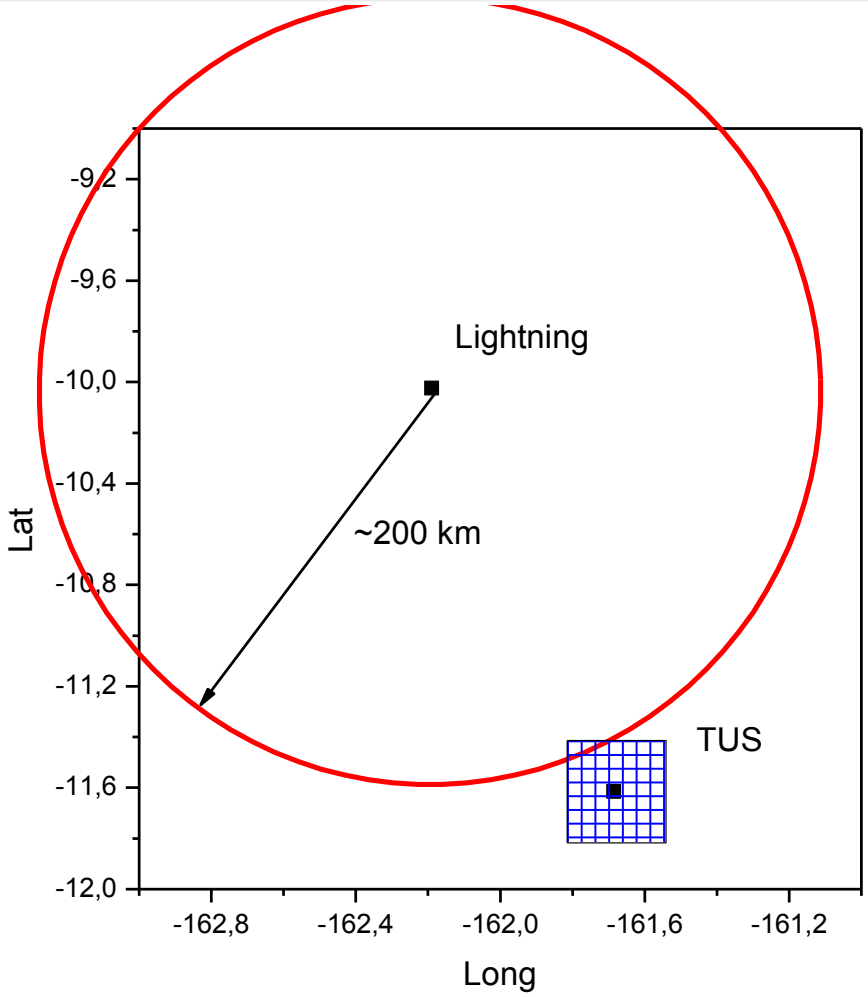






Comparison with WWLLN data





TUS event

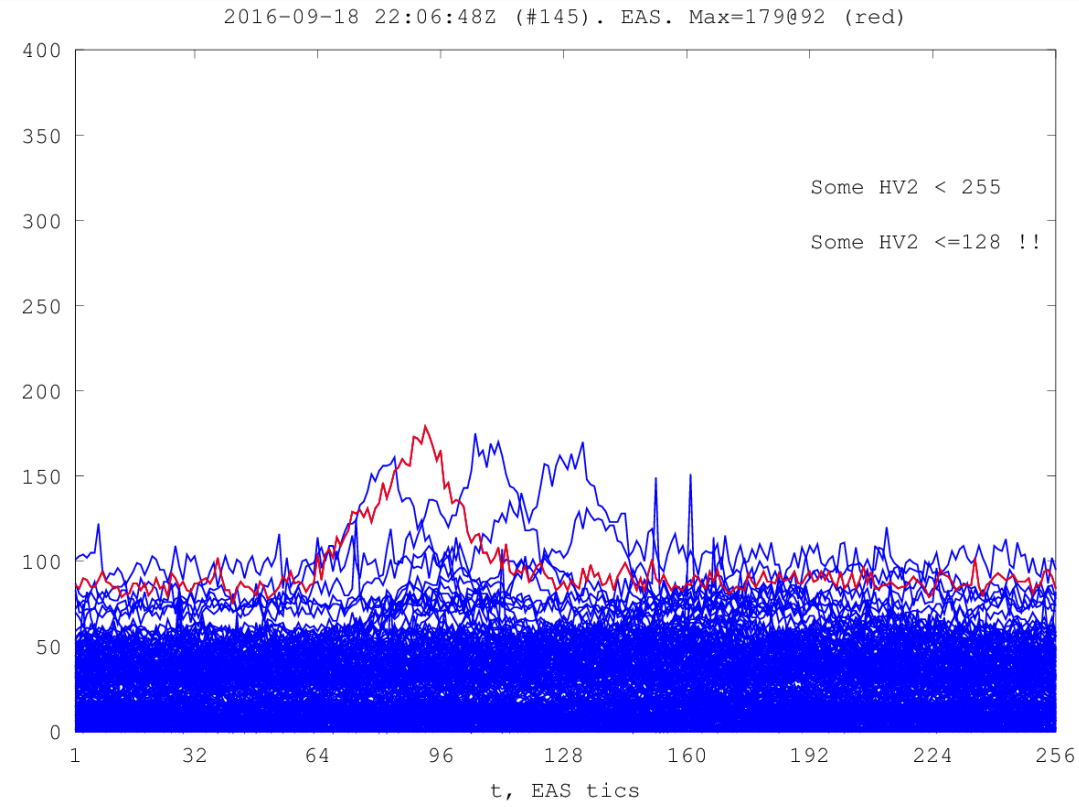
Lat	Long
-11.615	-161.685

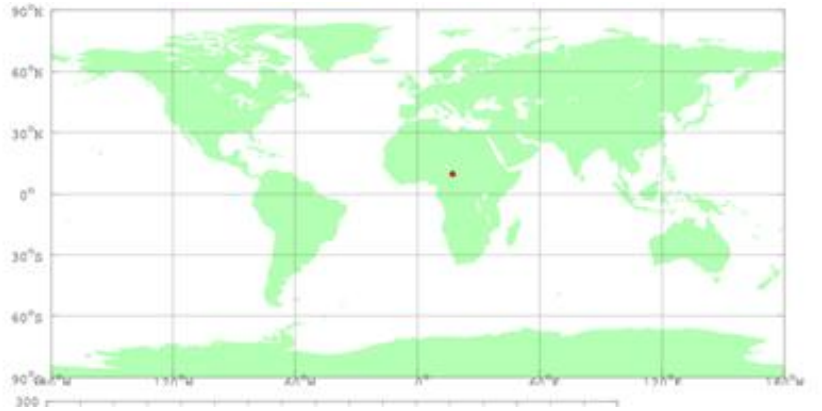
2016/9/7,09:51:35.558462, -10.0245, -162.1891, 16.9, 9, 1237.17, 585.13, 5

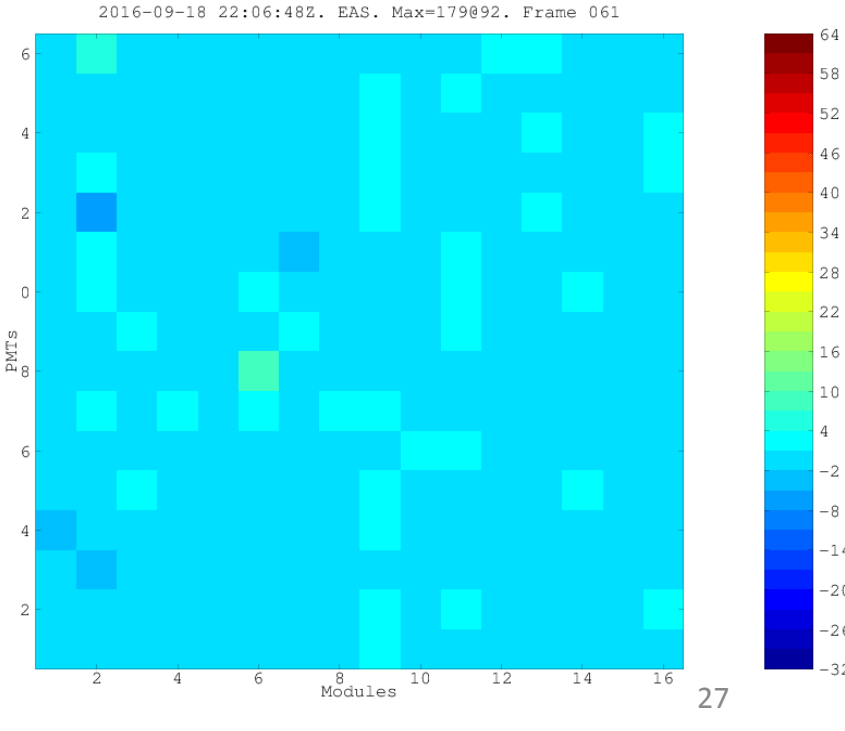
There is a lightning near the TUS location.

WWLLN data is provided by prof. R.H. Holzworth.

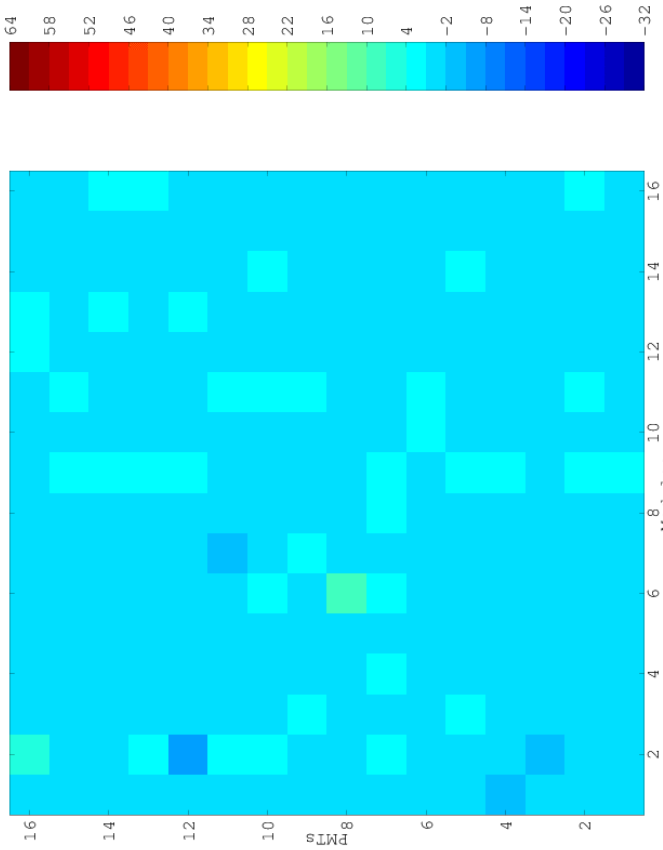
Fast movement of spot across FOV (2)

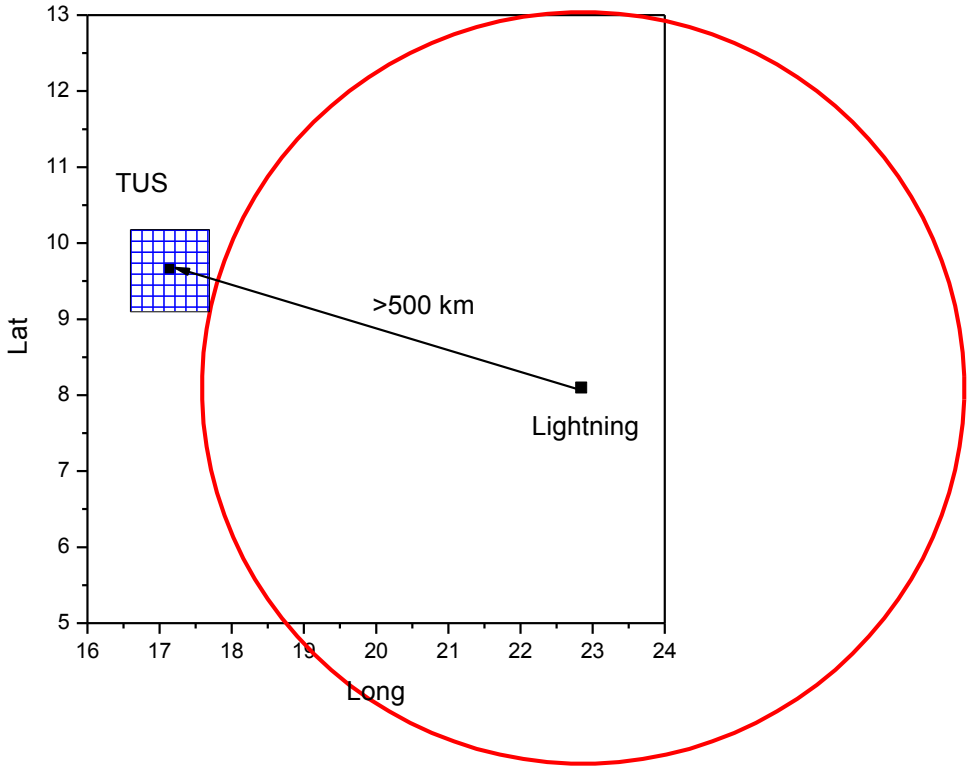






Comparison with WWLLN data





TUS event

Lat	Long
9.662	17.143

3s time difference, 500 km distance and “wrong” geometry

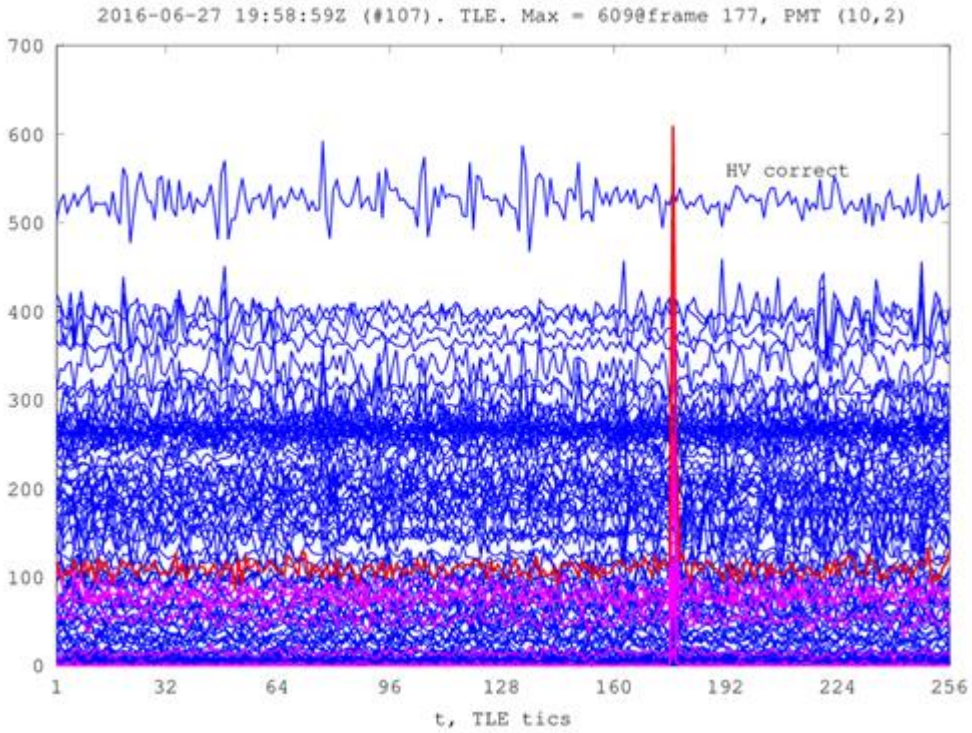
WWLLN event

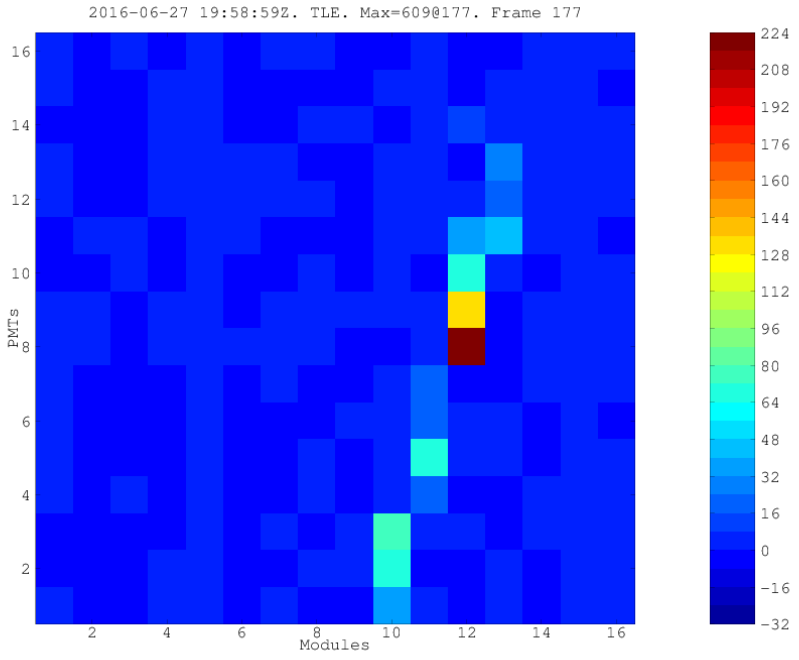
2016/9/18, 22:06:45.423296, 08.0967, 022.8457, 14.1, 7, 948.59, 544.99, 6

Interesting UV flashes with 0,4 ms temporal resolution

1. Short pulses with linear spatial structure
2. Simultaneous signal increasing in the whole FOV
3. Local event with complicated temporal and spatial dynamics.

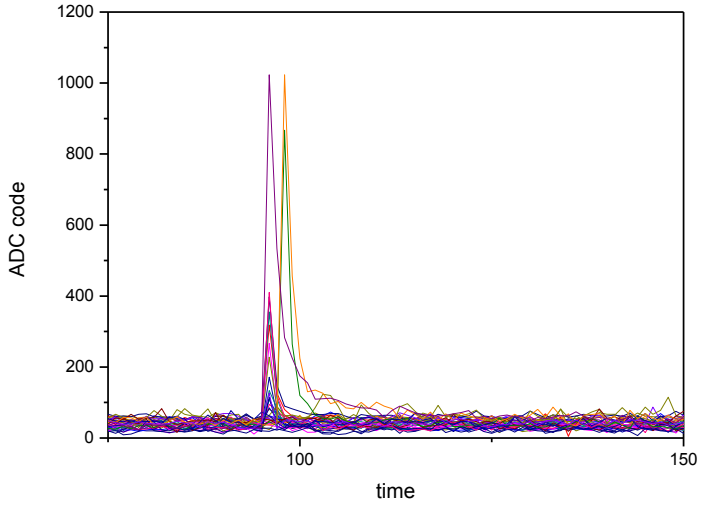
Short pulses with linear spatial structure

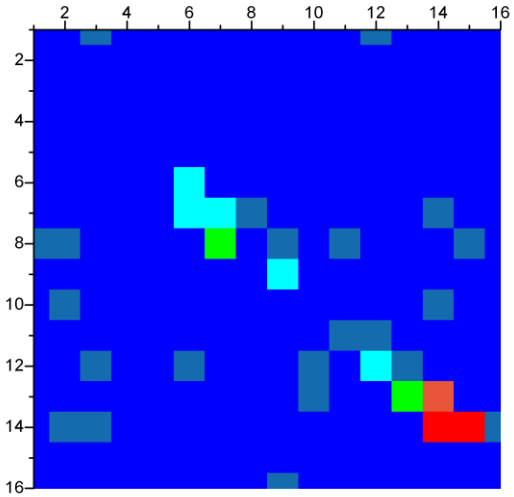


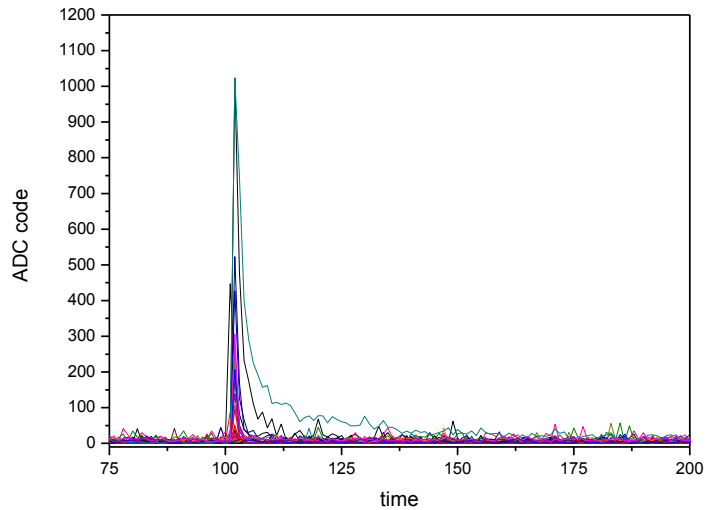


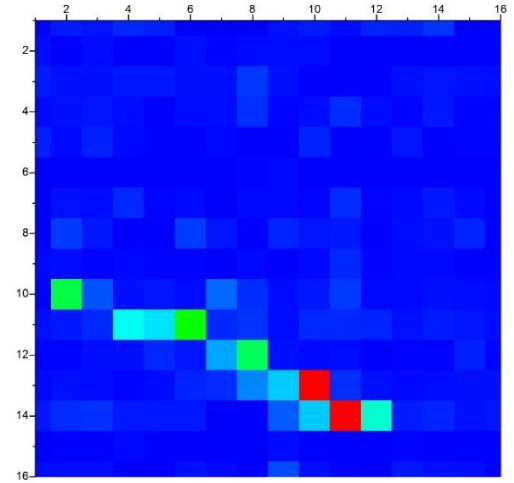
These pulses occur at high latitudes. They are triggered by charged particles which are seen in the short waveforms.

Short pulses (less than 1 µs)

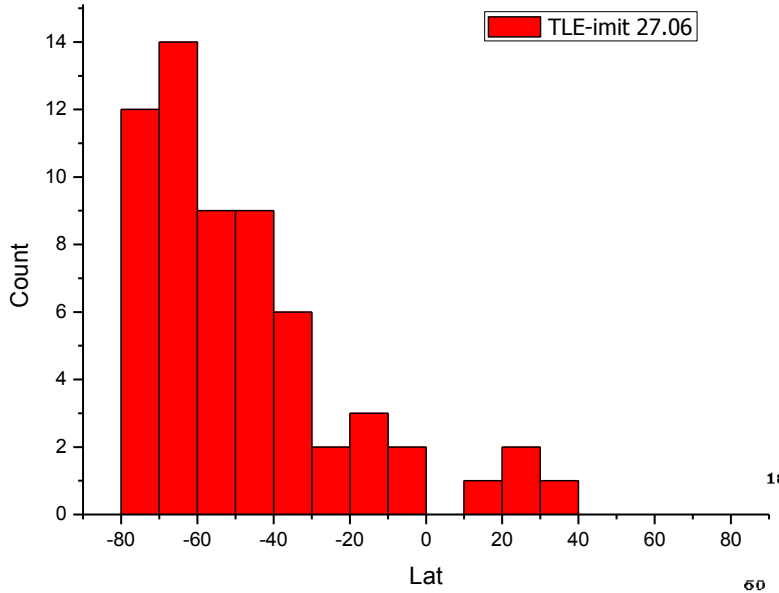


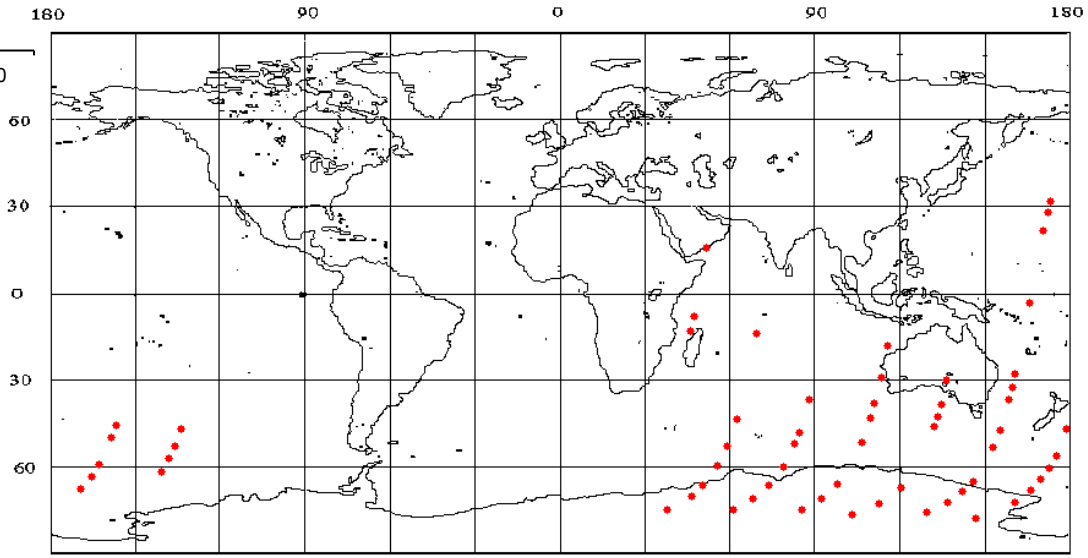


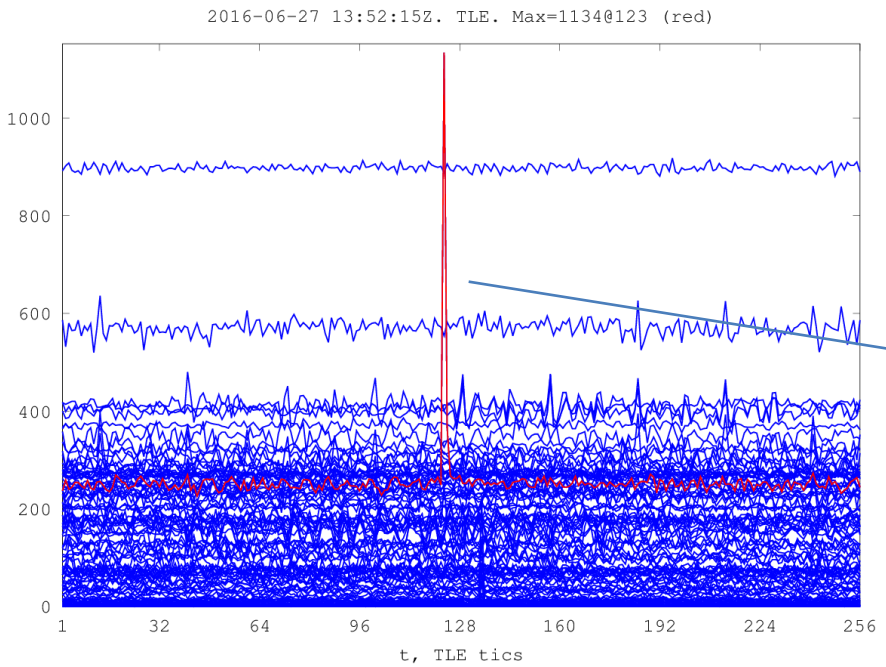




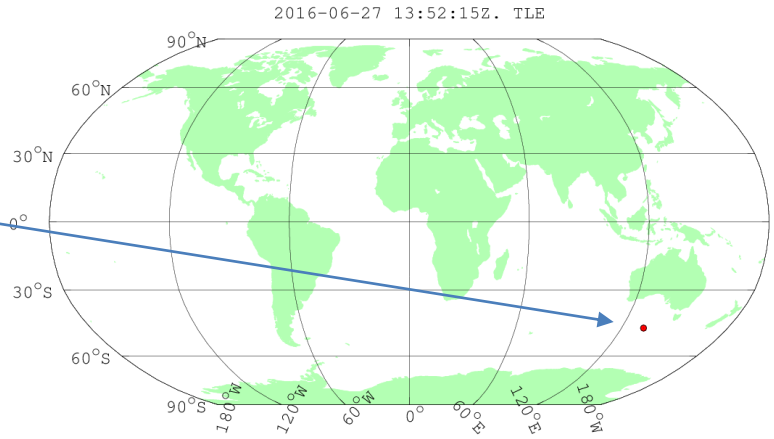
Geographical distribution of short pulses



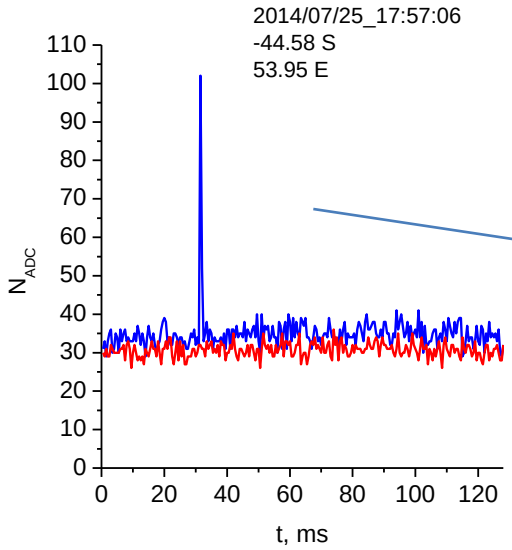


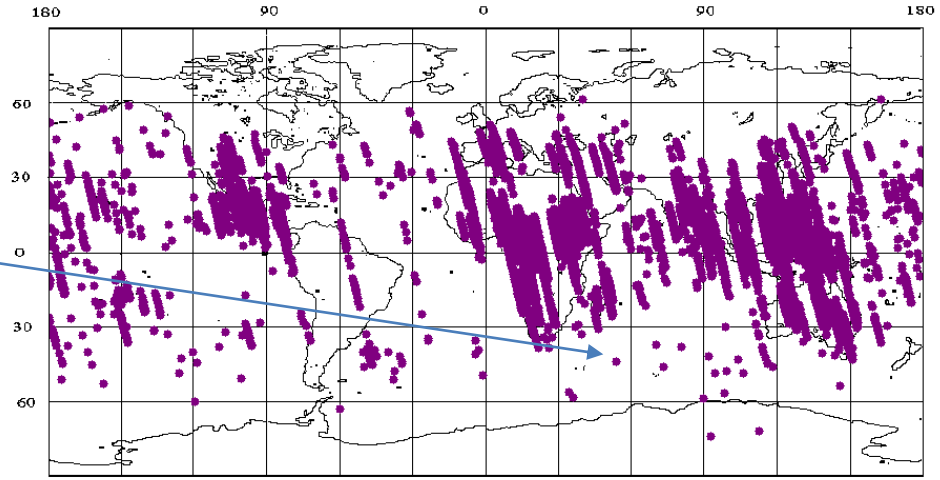


LOMONOSOV, 2016

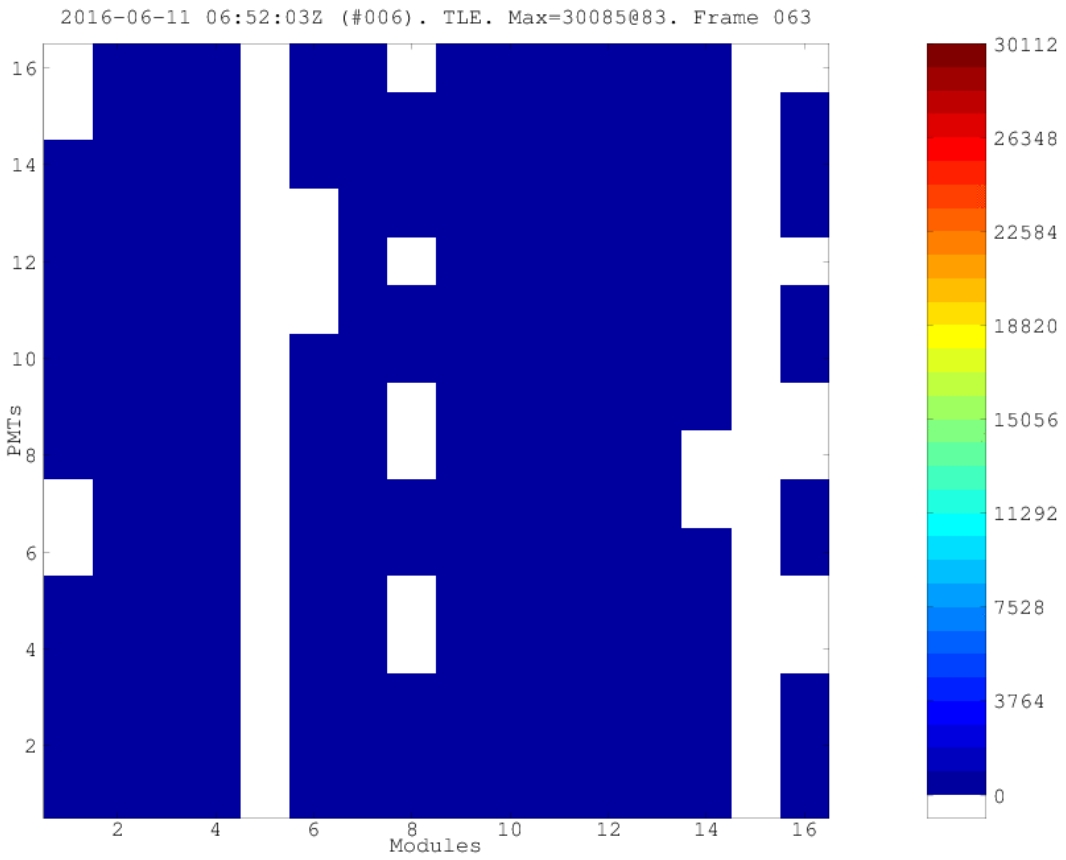


VERNOV, 2014



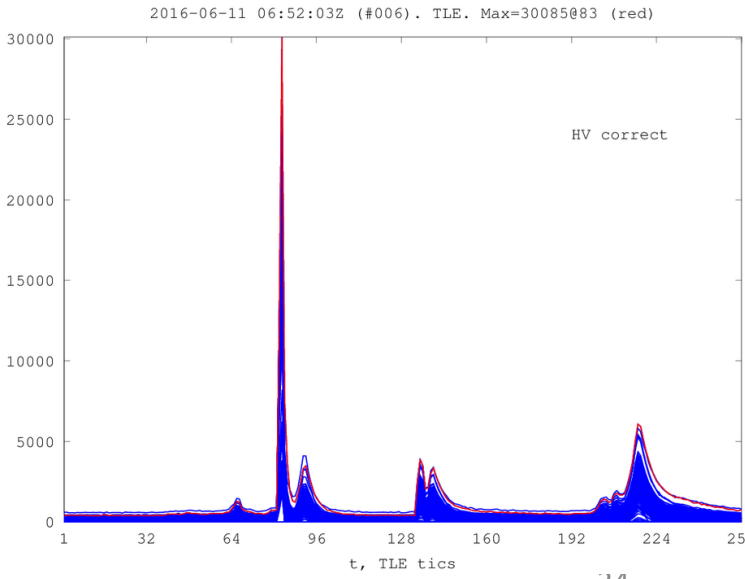


Simultaneous signal increasing in the whole FOV

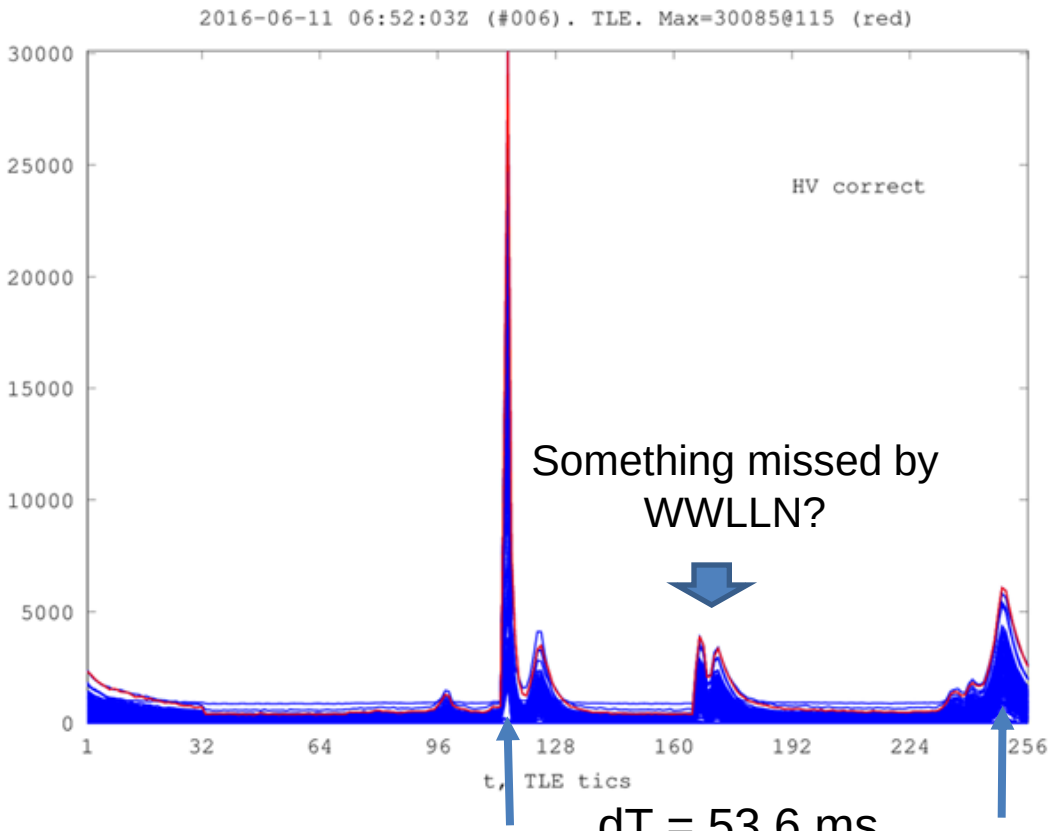


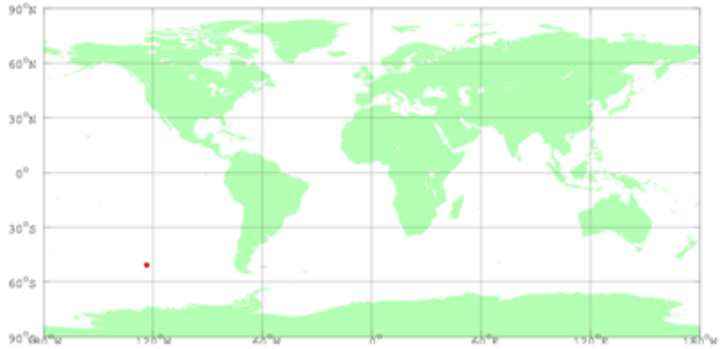
Spatial structure

Waveforms



Comparison with WWLLN





TUS event

Lat	Long	Date	time	WWLLN dist
-50,69	-123,52	160611	65203	**443,03**

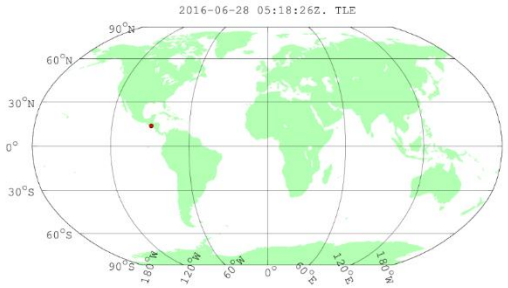
WWLLN data

11.06.2016	6	52	3,702353	-49.5523	-117.5595	26.8	5	0.00	0.00	0	
11.06.2016	6	52	3,844052	-49.8595	-117.2876	06.6	5	2400.59	300.59	5	141,699
11.06.2016	6	52	3,895276	-49.7560	-117.2198	07.4	5	752.21	213.73	5	**51,224**

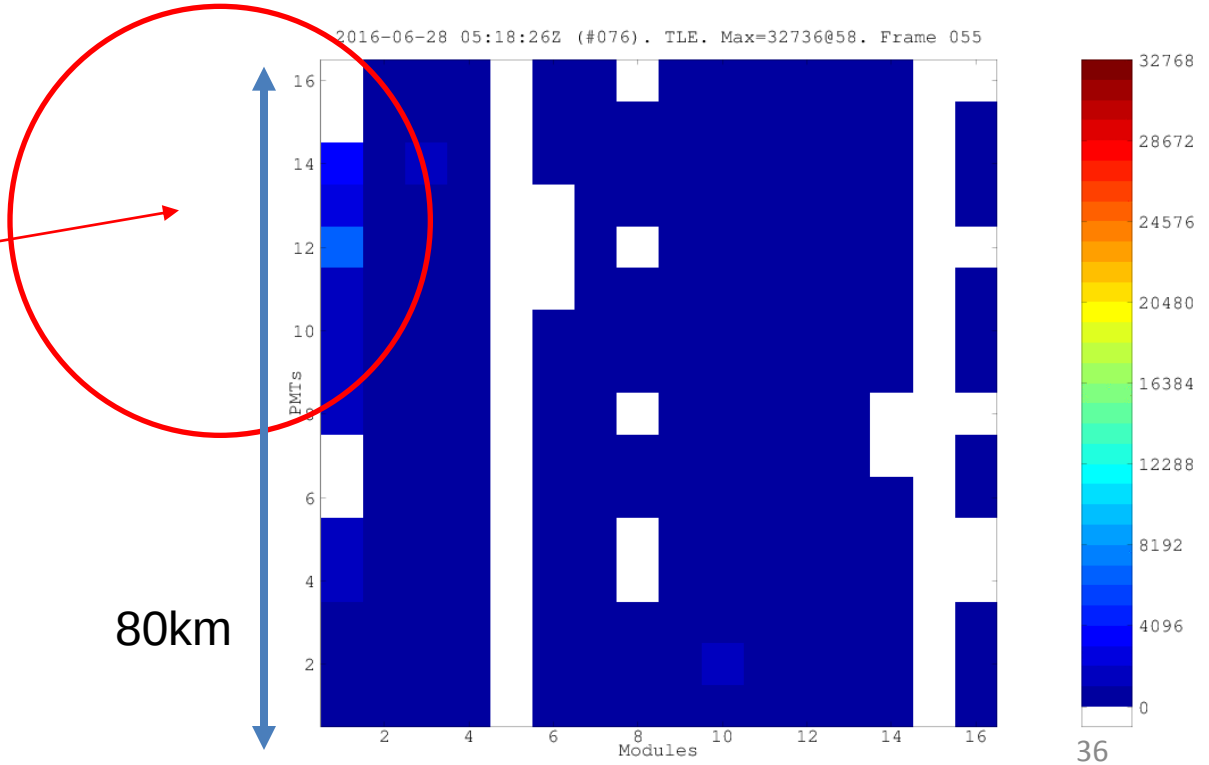
Local event in the FOV of TUS

TUS event

Lat	Long	Date	time	WWLLN dist
13.72	-89.552	160628	051826	86.1588



Events are somewhere here

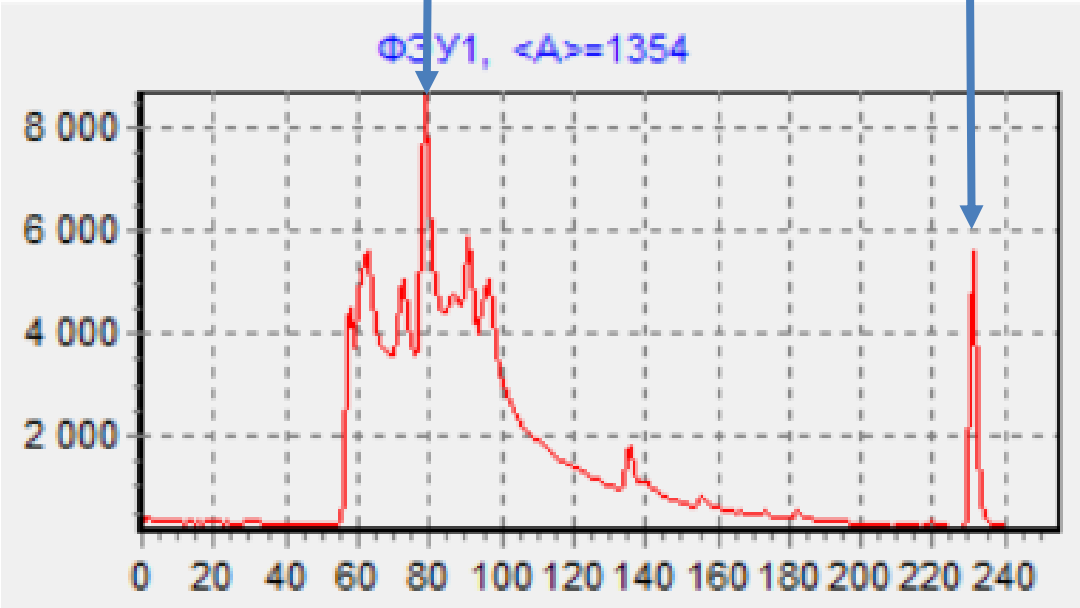


Example of good coincidence (temporal structure)

2016/6/28	5	18	25,642693	12,782	-89,9408	15	6	73293,2	0	1
2016/6/28	5	18	25,642703	12,784	-89,8766	9,4	6	66585,2	33120,2	4
2016/6/28	5	18	25,642734	12,889	-89,8925	11	6	87608,1	54218,9	5
2016/6/28	5	18	25,642792	12,91	-89,6601	6,5	5	0	0	0
2016/6/28	5	18	25,757921	12,854	-89,9115	18	8	21241,7	1293,43	3
2016/6/28	5	18	25,75793	12,876	-89,9228	12	6	16519,1	5264,08	3
2016/6/28	5	18	25,757932	12,884	-89,8833	12	8	4603,36	2953,61	5
2016/6/28	5	18	25,819322	12,857	-89,8845	19	14	1799,34	1468,55	9
2016/6/28	5	18	25,81936	13,002	-89,8504	8,7	5	6105,87	3805,28	3

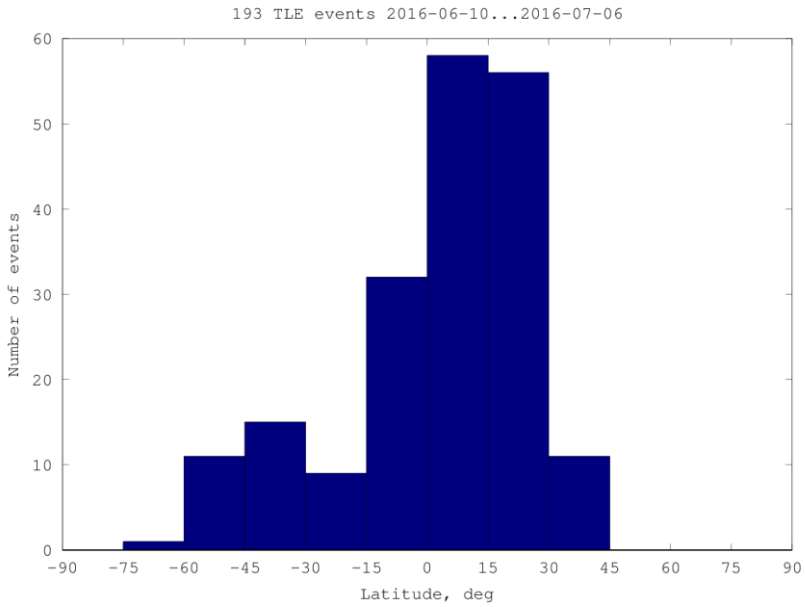
9 WWLLN lightning

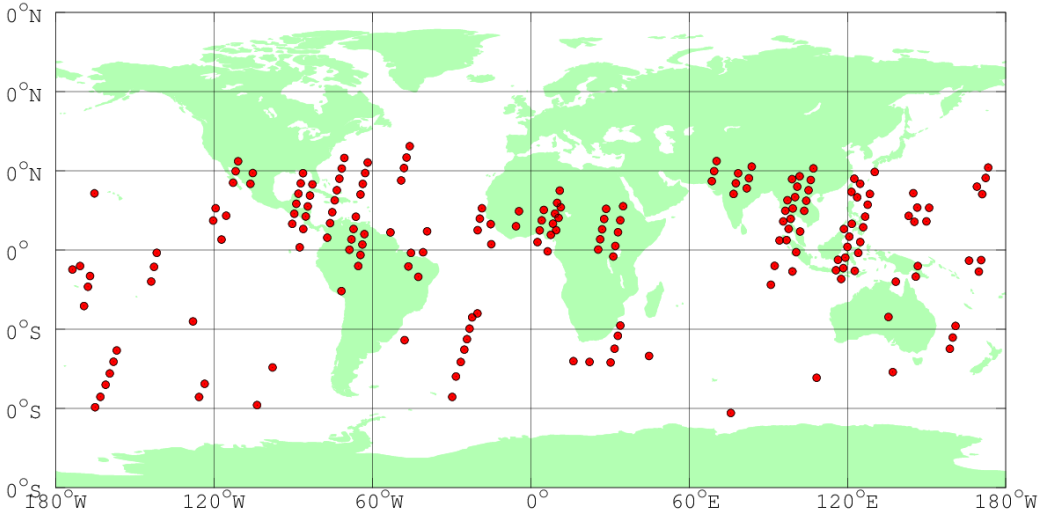
dT = 62 ms



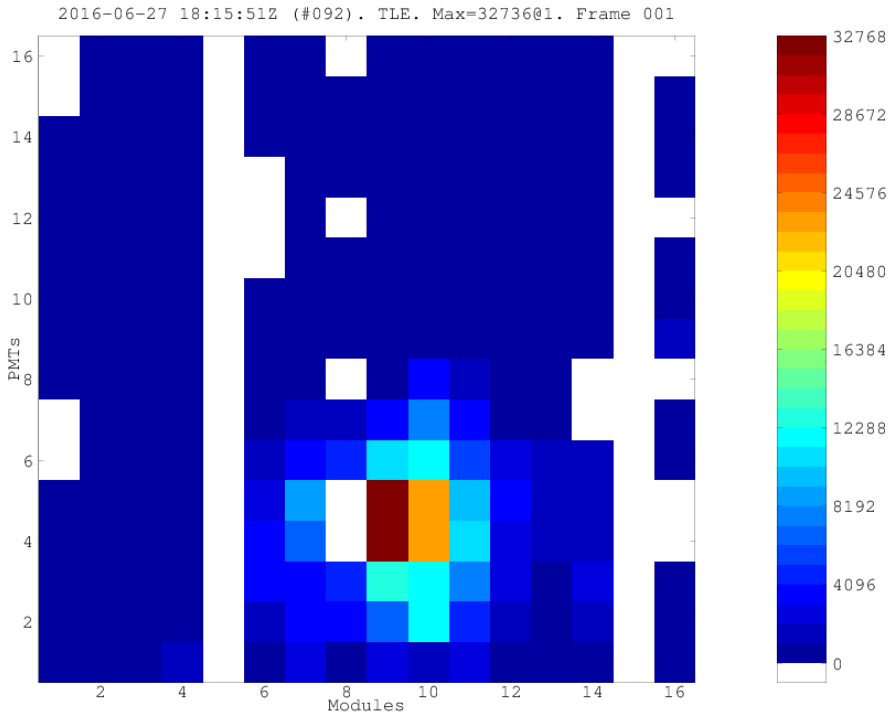
TUS event waveform

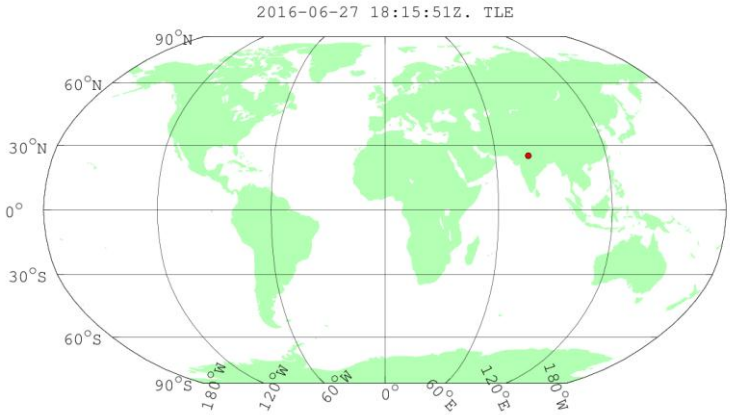
Geographical distribution of TLEs





Local event with complicated temporal and spatial dynamics



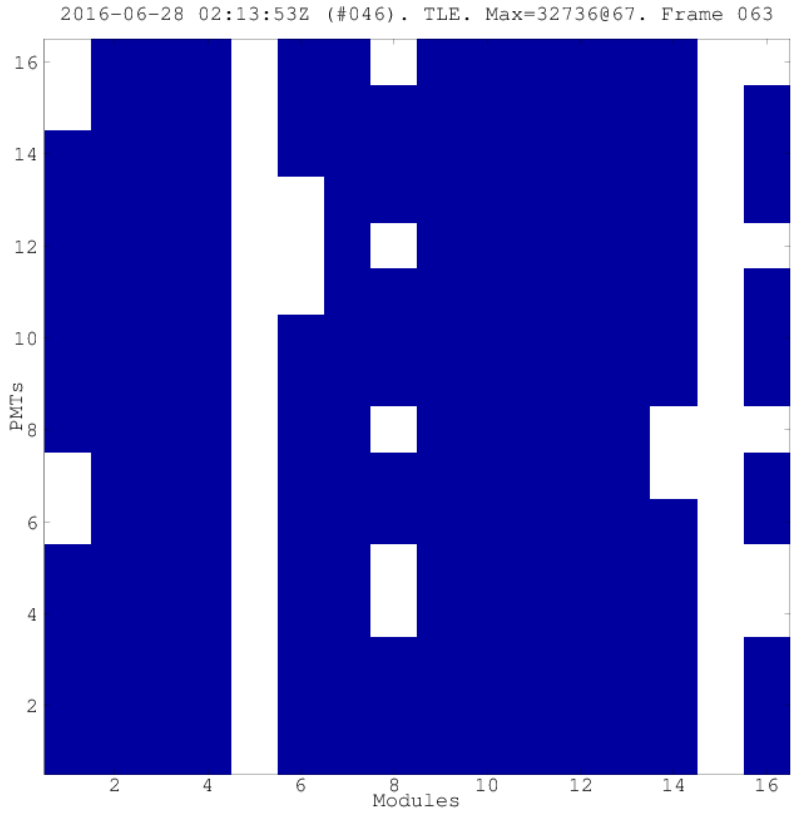


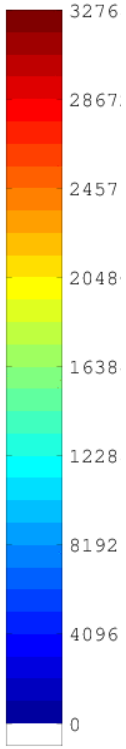
TUS event

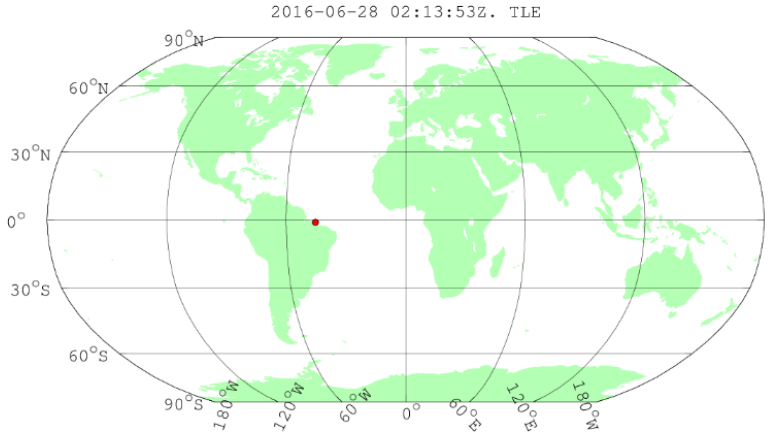
Lat	Long	Date	time	WWLLN dist
25.289	77.76	160627	181551	630.678

WWLLN data

2016/6/27,18:15:58.793534, 24.6834, 078.9702, 24.7, 5, 1290.64, 622.20, 4







TUS event

Lat	Long	Date	time	WWLLN dist
-1.094	-45.328	160628	**02:13:53**	3547.14

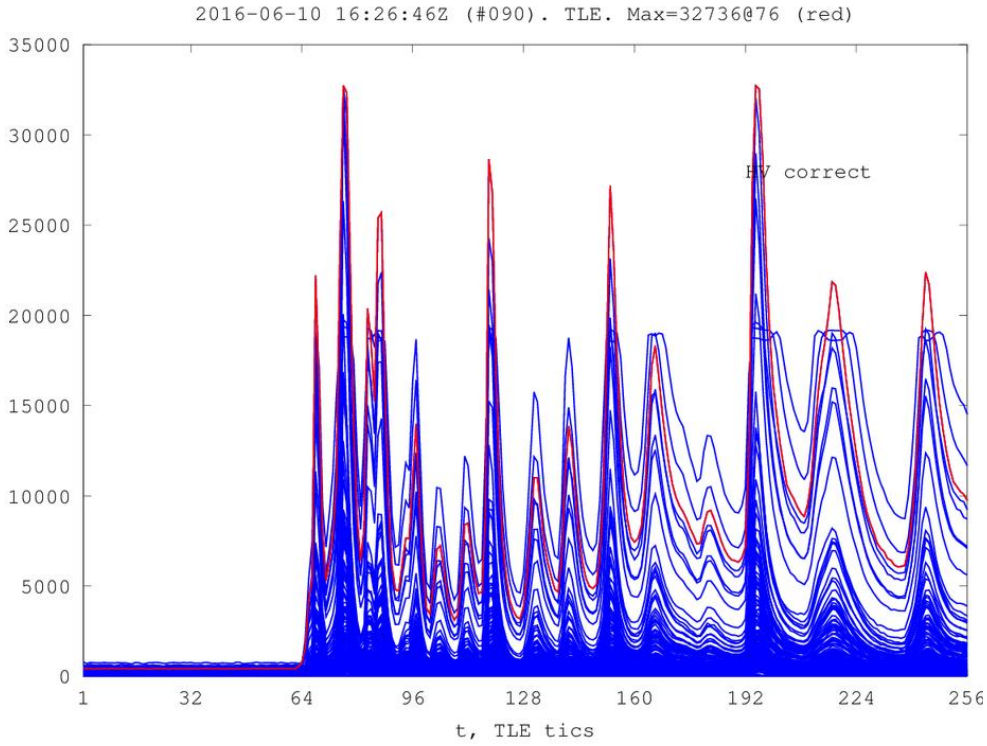
Very powerful event with interesting spatial dynamics!
But closest lightning 3547 km away!!!

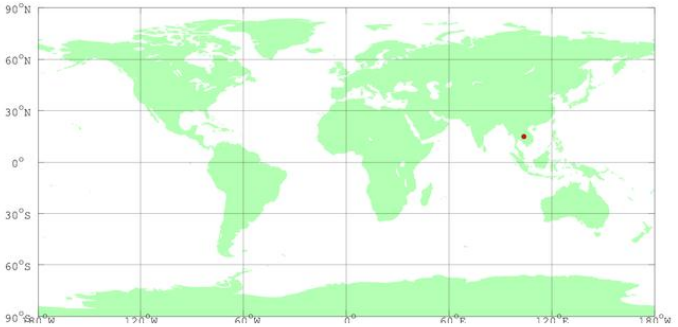
2016/6/28,**02:15:13**.731153, -01.3733, -045.5059, 14.6, 10, 1490.13, 581.46,7
2016/6/28,02:15:13.814221, -01.3783, -045.4825, 12.0, 5, 409.60, 18.92,5
2016/6/28,02:15:13.731163, -01.3765, -045.4984, 20.4, 6, 1493.72, 40.46, 2

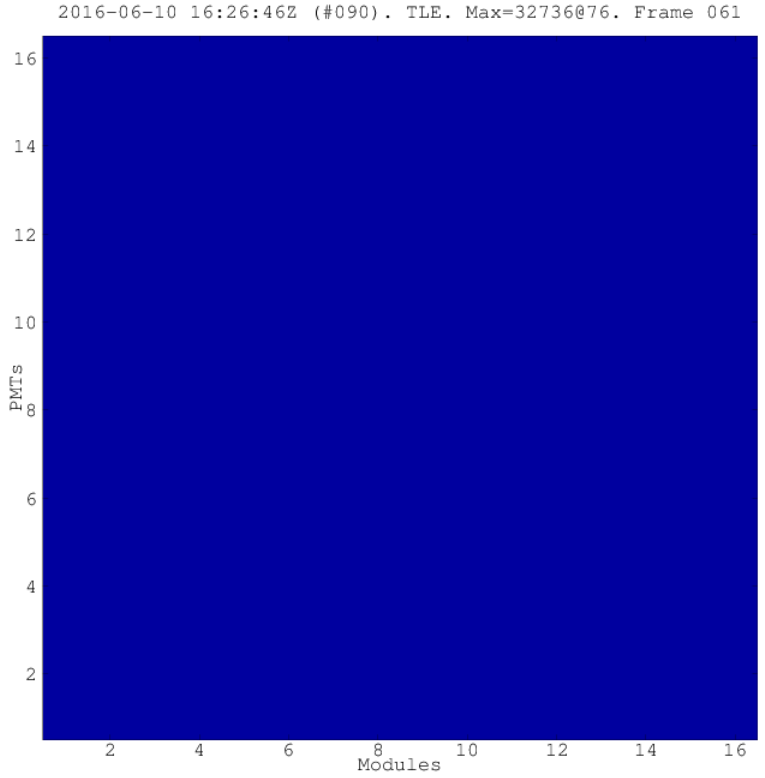
Conclusion

- Detector TUS works successfully during first months and passed flight tests.
- First measurements of various UV flashes in the atmosphere are carried out in two time scales (with temporal resolution: 0,8 μs and 0,4 ms). First phenomenological classification is developed.
- Detector TUS is sensitive to lightning discharges far from geometrical FOV and low energy charged particles.
- A number of very fast events moving across the FOV were measured which are most probably - elves.
- Several powerful flashes inside FOV were observed without coincidence with any lightning measured by WWLLN. There events should be considered more carefully and compared with other lightning location networks.


Thank you for your attention!





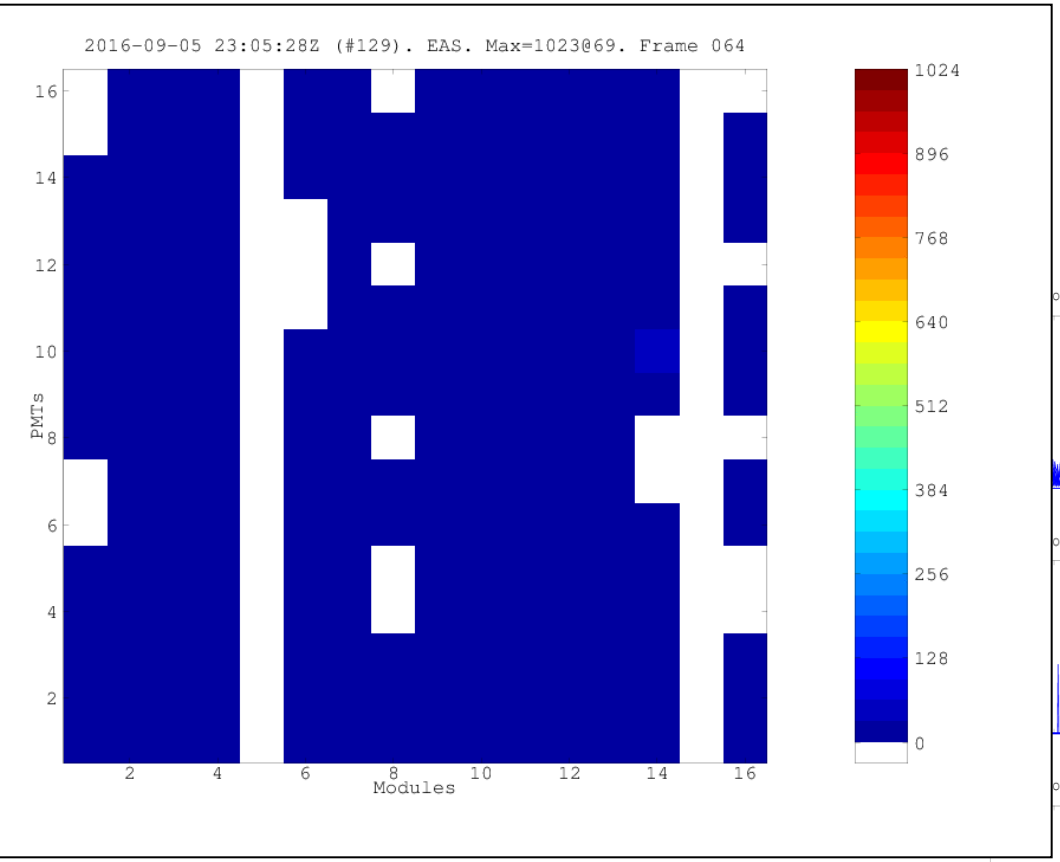


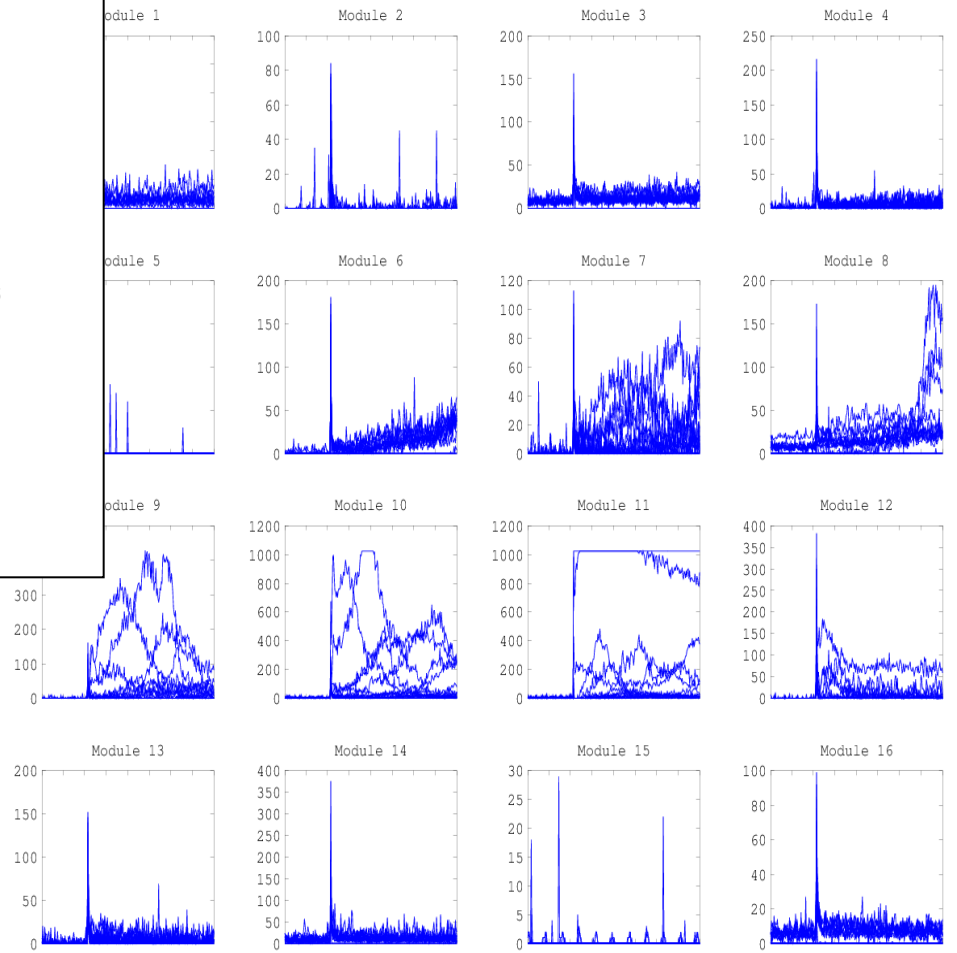
TUS event

Lat	Long	Date	time	WWLLN d
14.851	103.655	160610	162646	1343.08

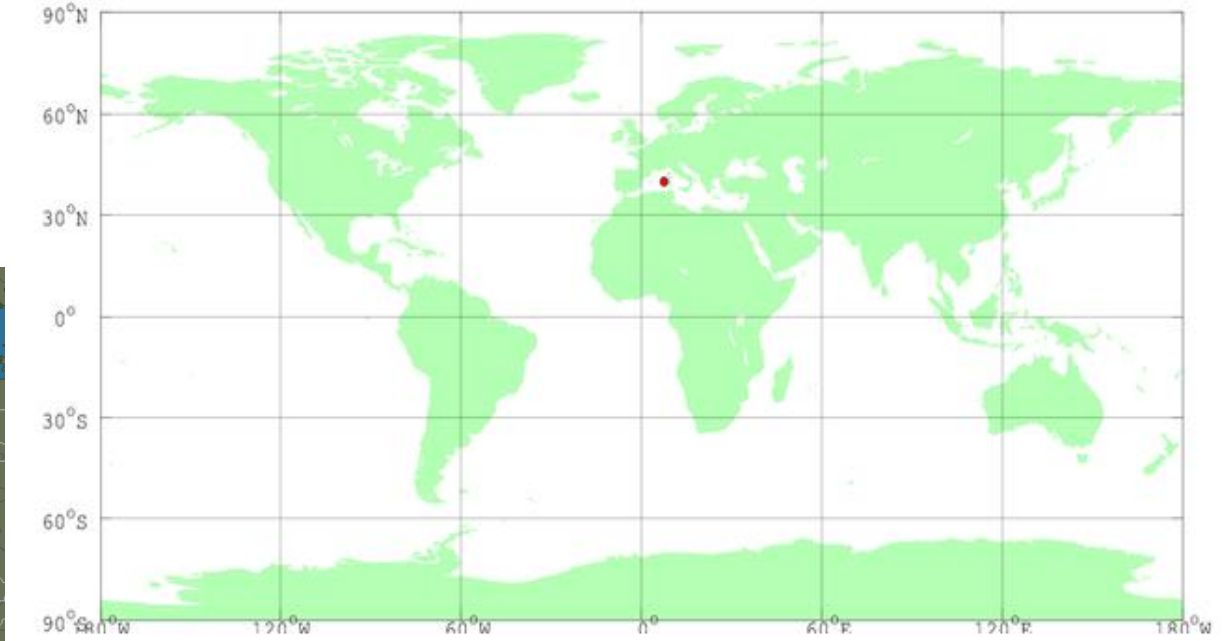
2016/6/10,16:32:10.960288, 15.3753, 103.6186, 22.9, 5, 5039.43, 877.25, 5

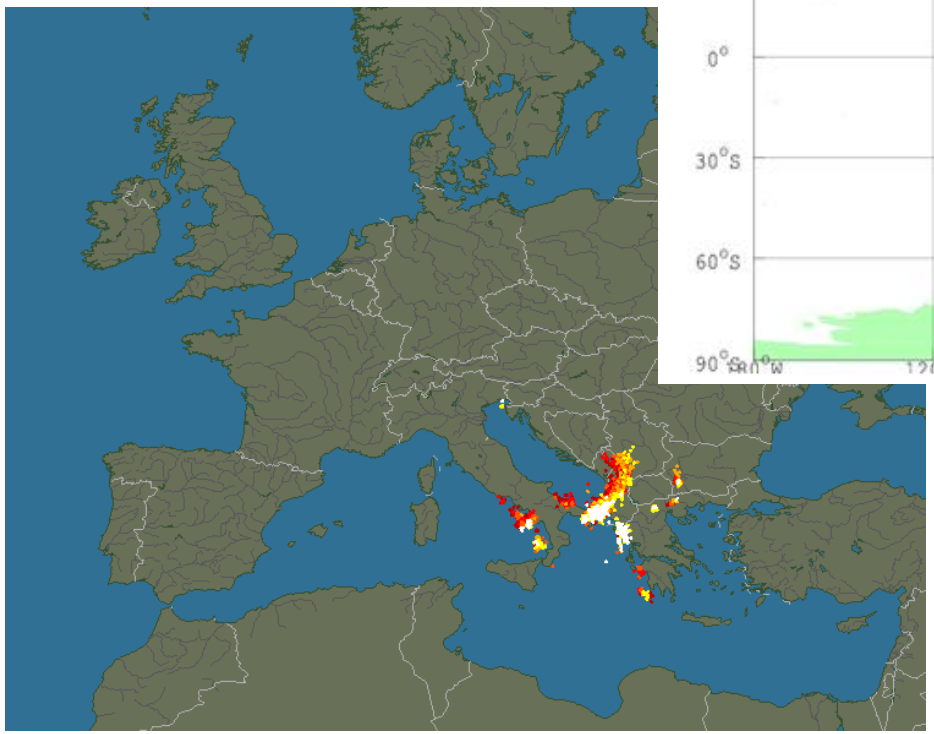
Fast movement of spot across FOV (2)

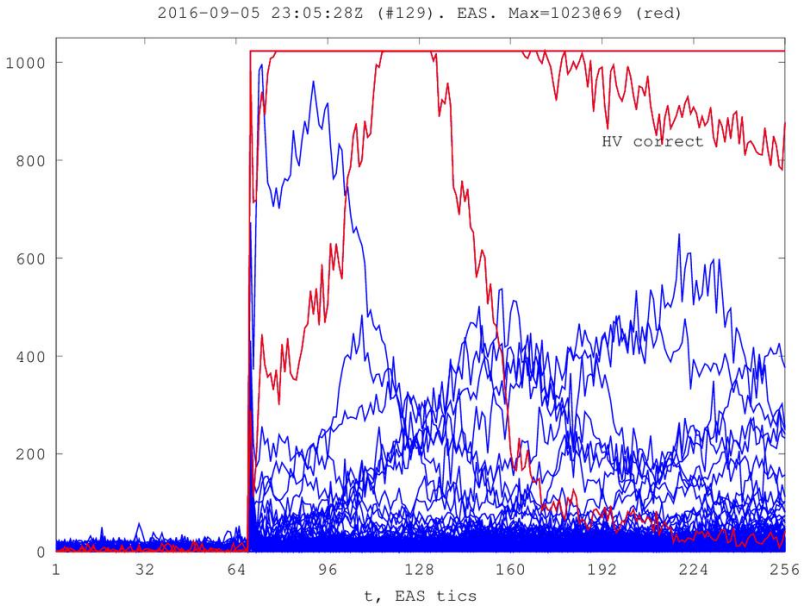




Extremely bright transient pulse (<1ms) and expanding slow signal





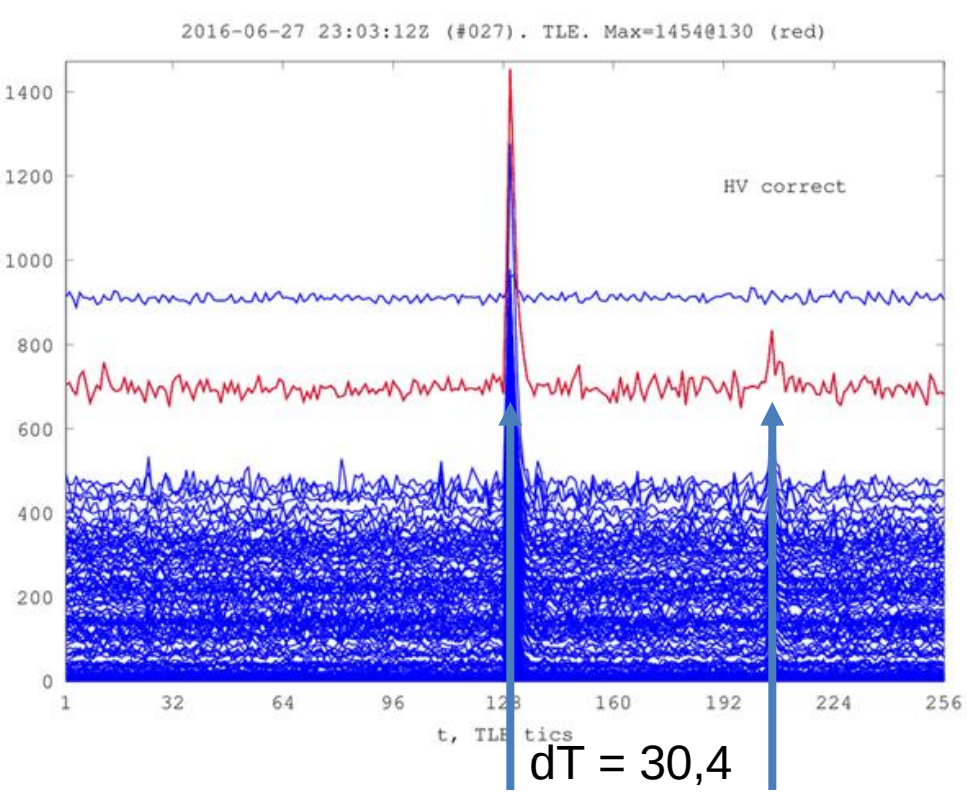


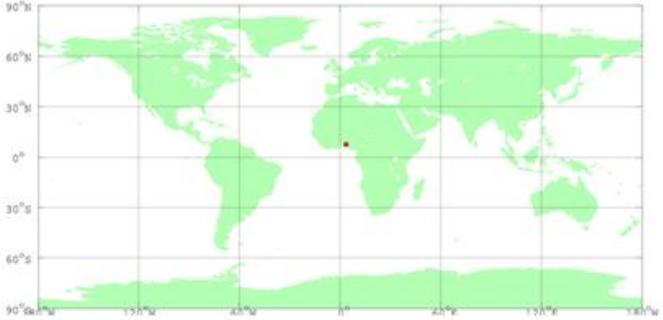
TUS event

Lat	Long
39.896	7.434

Ближайшее событие по WWLLN – 1500 км и слабое!

2016/9/5,23:05:27.461718, 40.3159, 018.0717, 11.6, 5, **73.70**, 21.80, 5





Example of good coincidence but with larger distance (250 km)

TUS event

Lat	Long	Date	time	WWLLN dist
7.445	3.433	160627	230312	**248.532**

2016/6/27,23:03:12.117205, 08.8520, 001.6525, 12.7, 6, 3477.59, 1146.97, 6	
2016/6/27,23:03:12.117203, 08.8302, 001.6610, 09.6, 7, 3532.27, 686.18, 5	-0,002
2016/6/27,23:03:12.148273, 08.8330, 001.6311, 16.5, 7, 752.04, 45.55, 5	**31,07**
2016/6/27,23:03:12.244090, 08.8416, 001.6307, 11.4, 8, 585.70, 83.85, 5	48,968
2016/6/27,23:03:12.197241, 08.8761, 001.6935, 07.8, 5, 973.33, 94.80, 5	46,849

Number of coincidences for different area of search