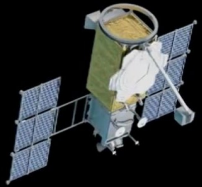


The first results of the TUS orbital detector of ultra high energy cosmic rays and transient luminous events in the atmosphere

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

Lomonosov Moscow State University
Skobeltsyn Institute of Nuclear Physics

Also: JINR (Dubna), Sungkyunkwan U. (Korea), Autonomous U. of Puebla (Mexico)

UHECR-2016, Kyoto

In the beginning,. . .

. . . there were Benson & Linsley:

11.07* Satellite Observation of Cosmic-Ray Air Showers, R.BENSON, TEXAS A & M, and J. LINSLEY, UNIV. OF NEW MEXICO. The arrival trajectories at earth of cosmic rays with energies $>10^{18}$eV afford the possibility of being traced backwards for distances comparable to the dimensions of the Galaxy. Thus they provide a means of testing models of the Galactic magnetic field as well as models of the origin of extra-galactic cosmic rays. It has been shown that large air showers can be observed electronically by means of the stmospheric scintillation light they produce. A practical ground-based system for carrying out air shower observations by this method has been constructed and put in operation by a group at the University of Utah.[1] It is shown here that a satellite based system consisting of a single very large metallized film mirror with an array of photon sensors at its focal plane would have outstanding advantages for the study of cosmic rays at energies above 10^{18}eV.

[Bull. of the American Astronomical Society, 12, 1980, 818]

Mirror: ø36 m

Birth of TUS (Tracking Ultra-violet Setup)

Proceedings of ICRC 2001: 831 © Copernicus Gesellschaft 2001

ICRC 2001

Space experiment "TUS" for study of ultra high energy cosmic rays and the KOSMOTEPETL collaboration

V. V. Alexandrov[1], D. I. Bugrov[1], G. K. Garipov[1], N. N. Kalmykov[1], B. A. Khrenov[1], M. I. Panasyuk[1], A. A. Silaev[1], I. V. Yashin[1], A. Cordero[2], O. Martinez[2], E. Moreno[2], H. Salazar[2], V. M. Grebenyuk[3], M. Finger[3], L. G. Tkatchev[3], J. Linsley[4], O. A. Saprykin[5], V.S. Syromyatnikov[5], L. Villasenor[6], and A. Zepeda[7]

[1]Moscow State University, D.V.Skobeltsyn Institute of Nuclear Physics, , Moscow, Russia
[2]Universidad Autonoma de Puebla, A. Postal 1364, Puebla, Mexico
[3]Joint Institute for Nuclear Research, Dubna, Moscow Region, Russia
[4] University of New Mexico, Albuquerque, New Mexico, USA
[5]Rocket Space Corporation "Energia", Consortium "Space Regatta", Korolev, Moscow Region, Russia
[6]University of Michoacan, A. Postal 2-82, 58040, Morelia, Michiocan, Mexico
[7]Depto de Física, Cinvestav-IPN, 07000, Mexico D. F., Mexico

TUS Design

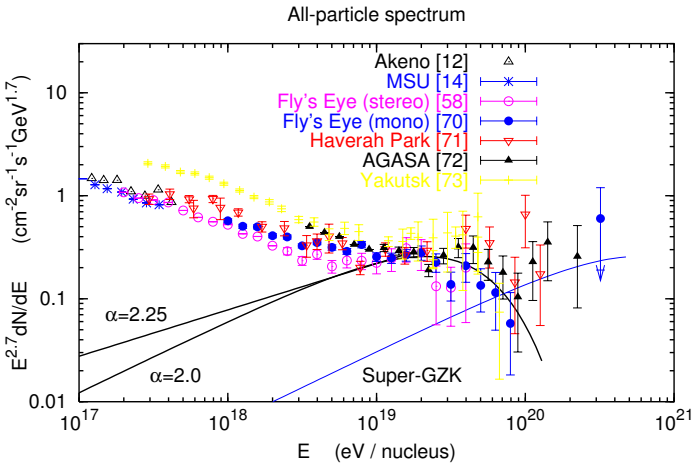
Artists's view of Lomonosov with TUS

Technical parameters:

- Fresnel mirror: 2 m^2, focal distance 1.5 m
- Photodetector: 256 pixels (Hamamatsu R1463) in a 16×16 PDM block
- Field of view: $\pm 4.5^\circ$ $\sim$ 80 km$\times$80 km at sea level at orbit height $\sim$ 500 km
- Four modes of operation with different sampling time: $\tau = 0.8$ μs (EAS), 25.6 μs, 0.4 ms (TLEs), 6.6 ms (micro-meteors)
- Estimated $E_{\rm thr} \sim$ 50–100 EeV

At that time...

...it was unclear if there is a cut-off at energies $\gtrsim$ 50 EeV:



[T. Gaisser, AIP Conf.Proc. 558:27-42, 2001 (arXiv:astro-ph/0011524)]

Purposes of TUS

Early expectations:

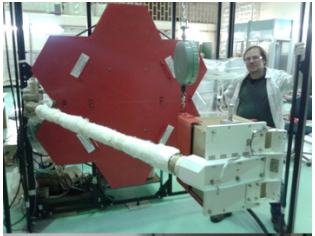
> In 3 years of operation the TUS telescope will have the exposure factor of $6 \cdot 10^3 km^2 sr year$ for the UHECR events with energy $\geq 2 \cdot 10^{20} eV$ and will register of about 20 events with this energy threshold (estimation from the AGASA data). Number of registered events of the lowest energy ($\geq 2 \cdot 10^{19} eV$) is expected to be $\simeq 900$ in the same

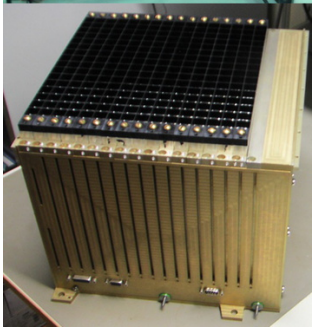
After 2007–2008 [HiRes, Auger], it became clear the goal will not be achieved.

The main purposes of TUS:

- to test the technique of observing UHECRs from space,
- to obtain data on the UV background of the atmosphere (and TLEs) to be used in future missions (JEM-EUSO, K-EUSO, etc.)

Construction





April 28, 2016: The Launch!

What has been observed?

TUS operates since May 19.

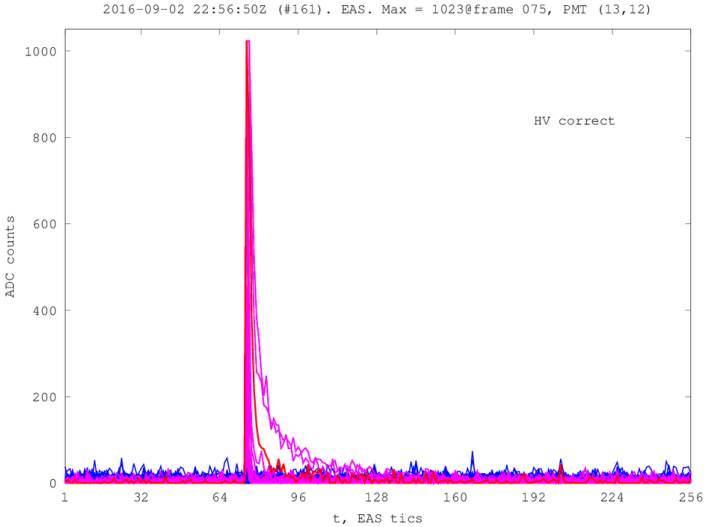
Three modes of operation have been tested:
the EAS mode ($\tau = 0.8\ \mu$s) and both modes for TLE.

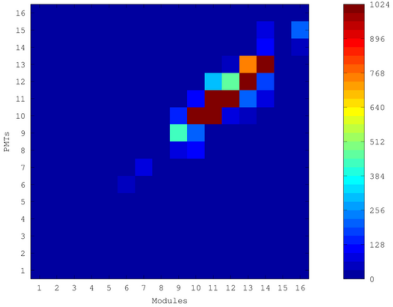
Events registered in the EAS mode can be roughly divided into four groups:

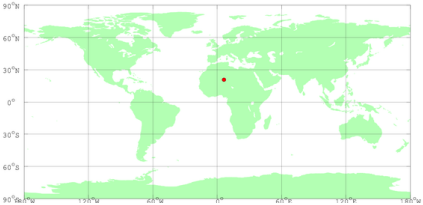
- track-like events ("quick flashes")
- "slow flashes"
- events with "featureless" waveforms
- "unusual" events

PRELIMINARY!!

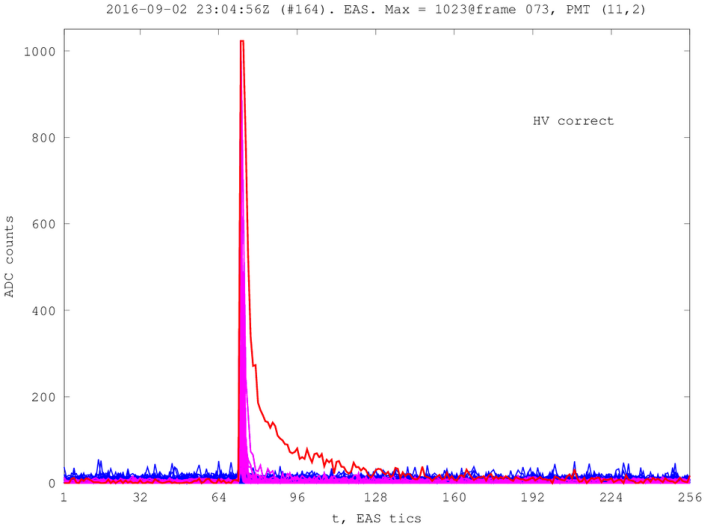
Track-like events (a)

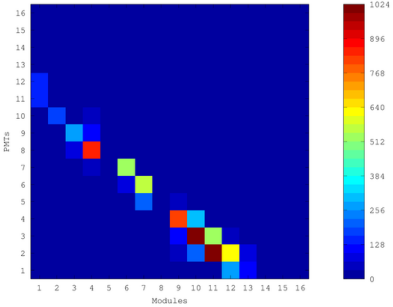




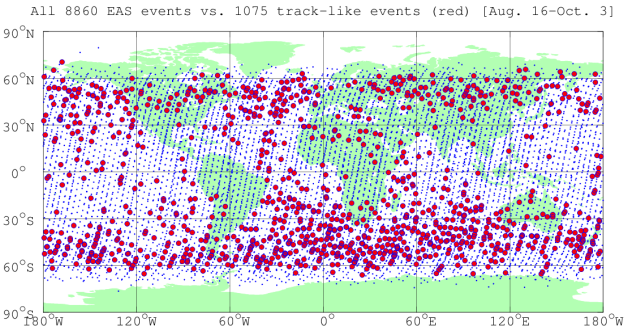


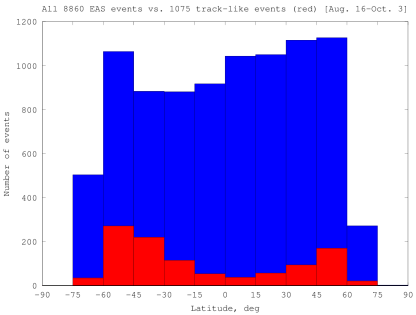
Track-like events (b)



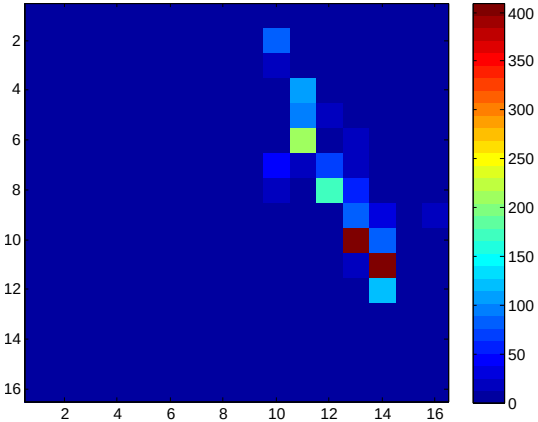


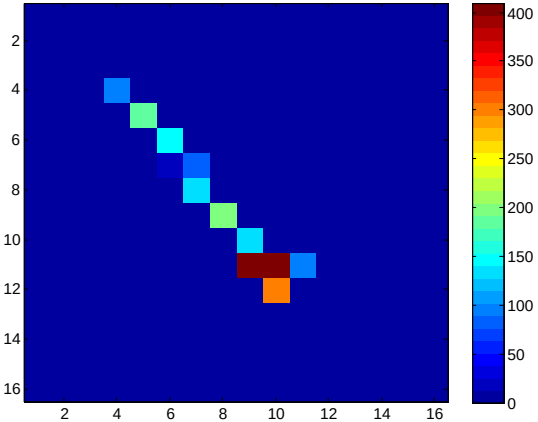
Geography of track-like events





Tracks: cascades by GeV protons hitting the PDM?

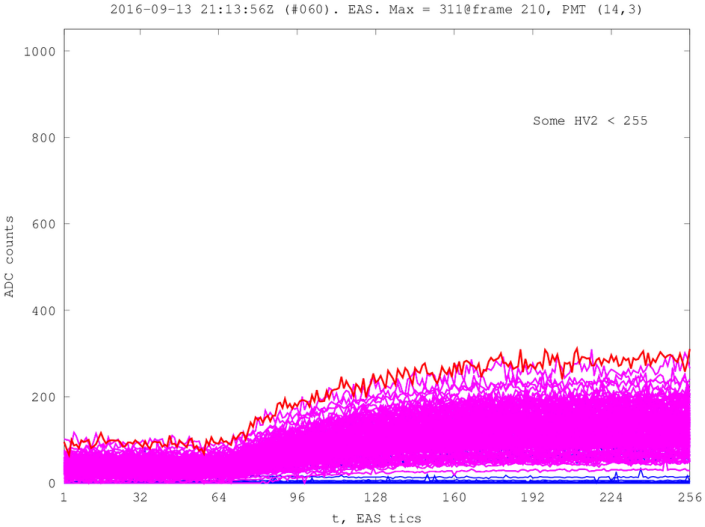


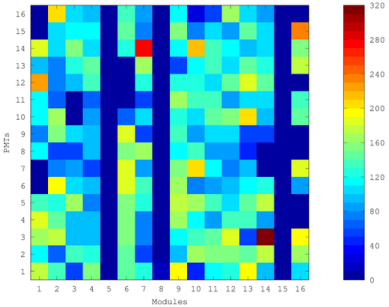


Left: a real track.

Right: a track by a 10 GeV proton (Geant4)

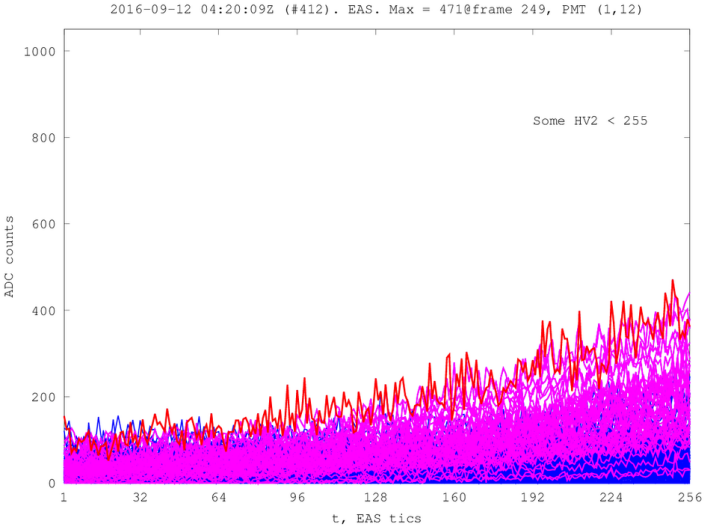
“Slow flashes” (a)

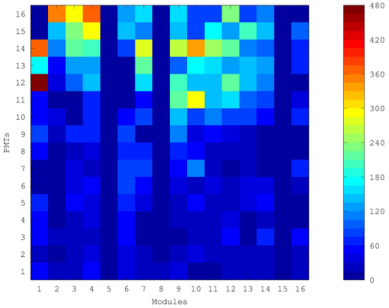


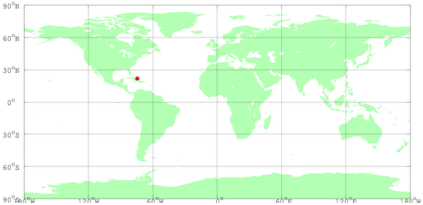


A simultaneous lightning strike in $\sim$ 300 km (WWLLN data)

“Slow flashes” (b)

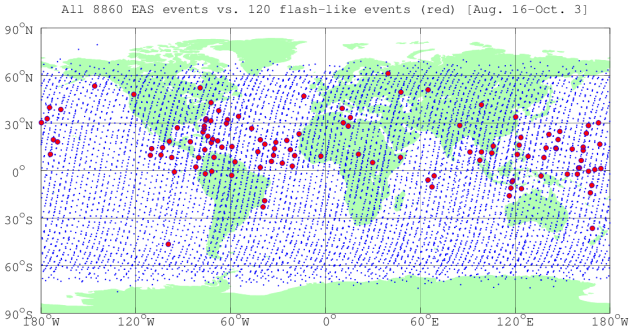


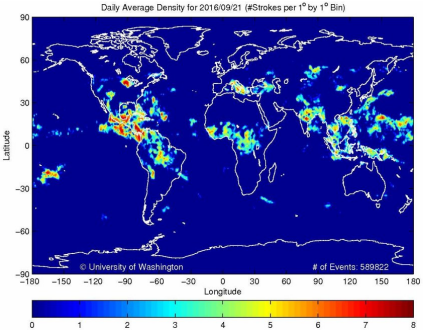




A lightning in $\sim$ 40–50 km from the FoV (WWLLN data)

“Slow flashes” over Earth

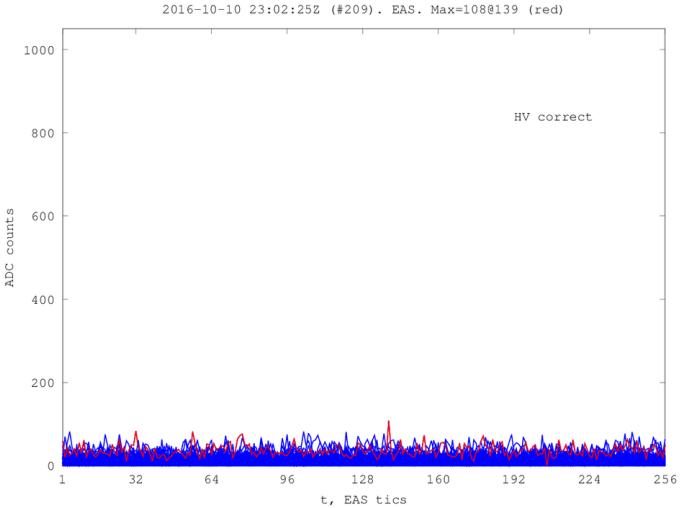


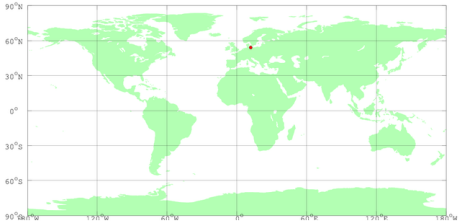


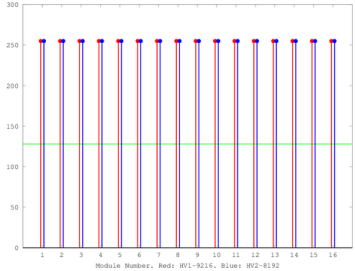
Geographic distribution of flashes (left) vs. distribution of lightning strikes (right).

Important: some flashes have simultaneous lightning strikes at distances $\geq$ 500 km (which means a higher UV background than expected). Scattered UV light?

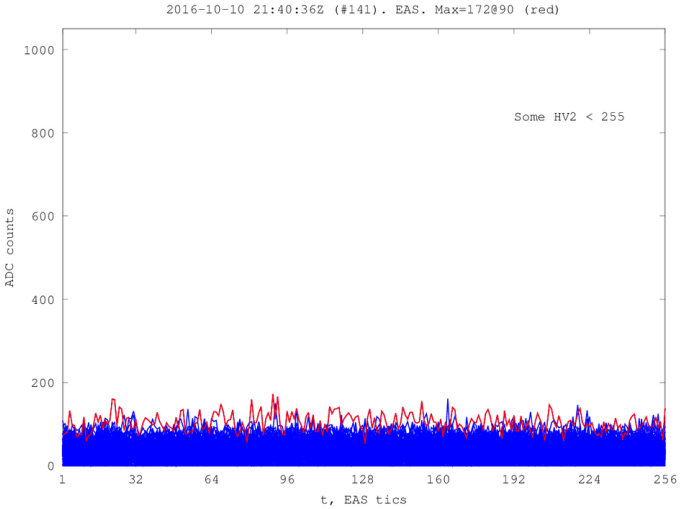
“Featureless” waveforms (a)

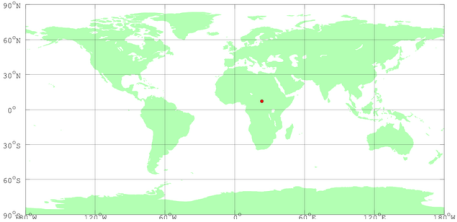


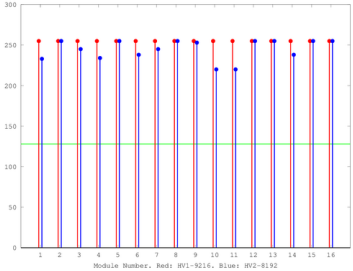




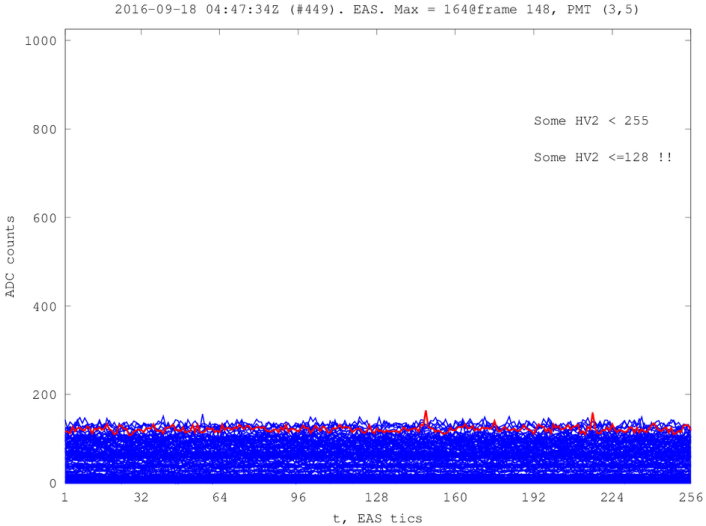
“Featureless” waveforms (b)

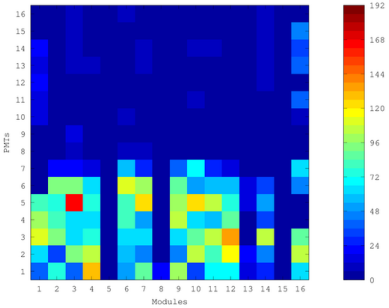






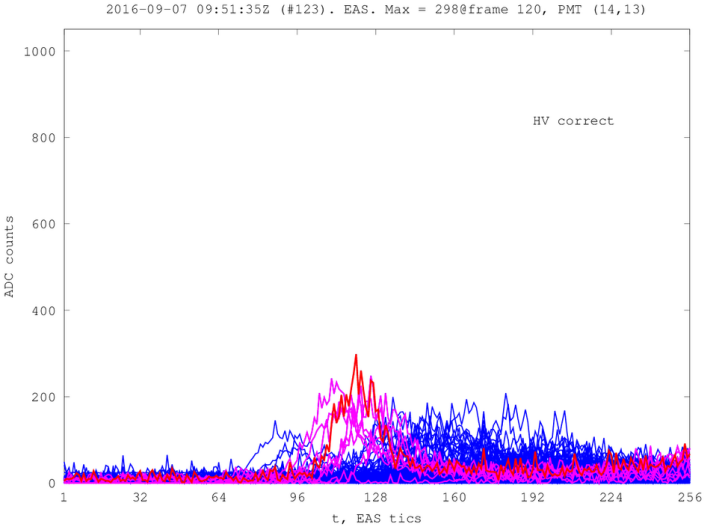
“Featureless” waveforms (c)

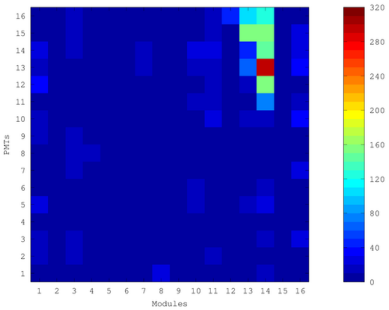


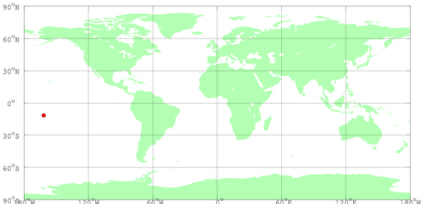


A thunderstorm in $\sim$ 900 km! (WWLLN data)

“Unusual” events (a)

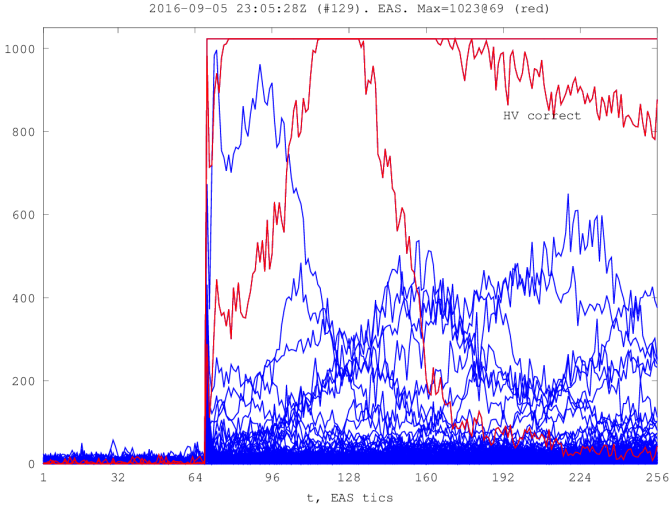






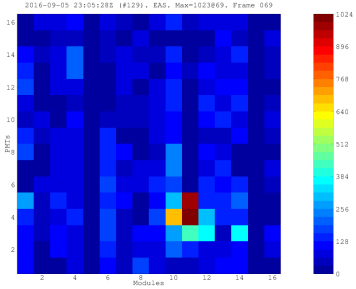
A lightning strike in $\sim$ 180 km $\longrightarrow$ An elve?

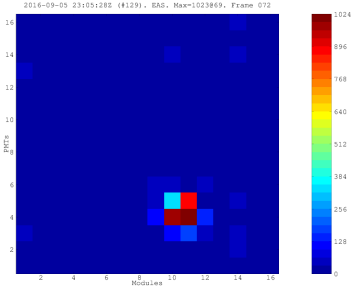
“Unusual” events. One near Sardinia (2016-09-05, 23:05:28 UTC)

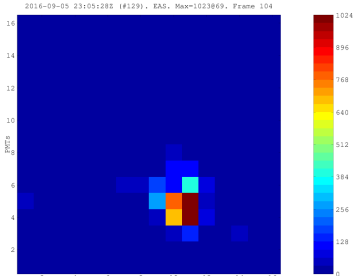


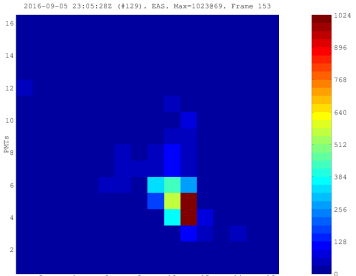
The nearest simultaneous lightning strike in the WWLLN data set was registered in $\sim$ 900 km from this event.

4. “Unusual” events. One near Sardinia (2016-09-05, 23:05:28 UTC)









Summary

- TUS is working on orbit since May 19, 2016
- TUS records ~ 400 "night" events every complete day of work
- Three modes of operation have been tested: one for UHECRs, two for TLEs
- No UHECRs have been registered yet
- A major number of recorded events seem to relate to TLEs in the atmosphere or to GeV particles in space. UV radiation in the atmosphere is more diverse than expected basing on data of the earlier MSU orbital experiments
- An orbital UHECR detector needs a sophisticated trigger in order to filter out events caused by TLEs, human activities and low-energy particles in space
- TUS is not perfect but if it were perfect run, then where does one follow up?