Neutron Monitors detecting cores of Extensive Air Showers (Synergy of solar, galactic, and atmospheric particle physics)

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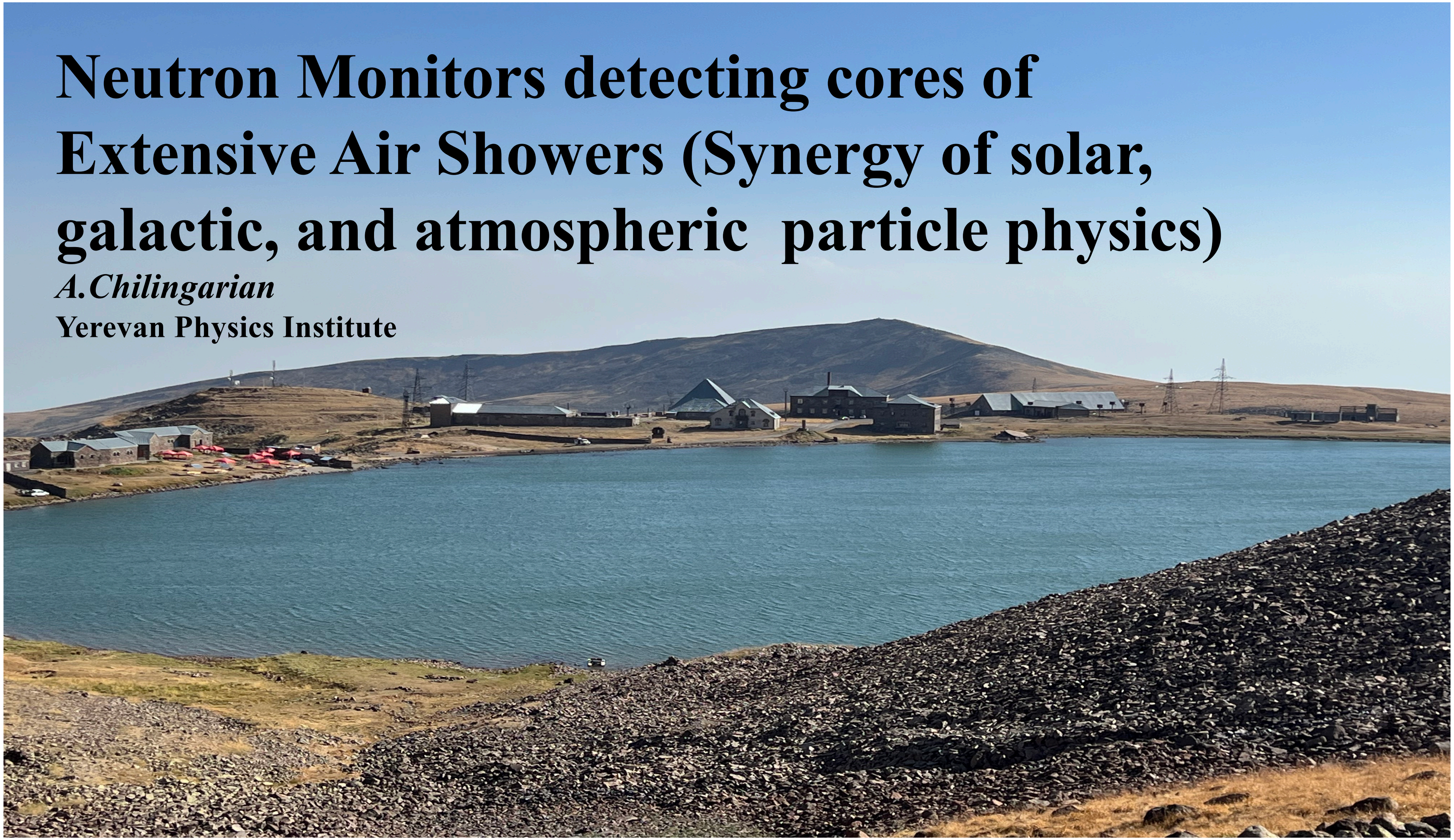
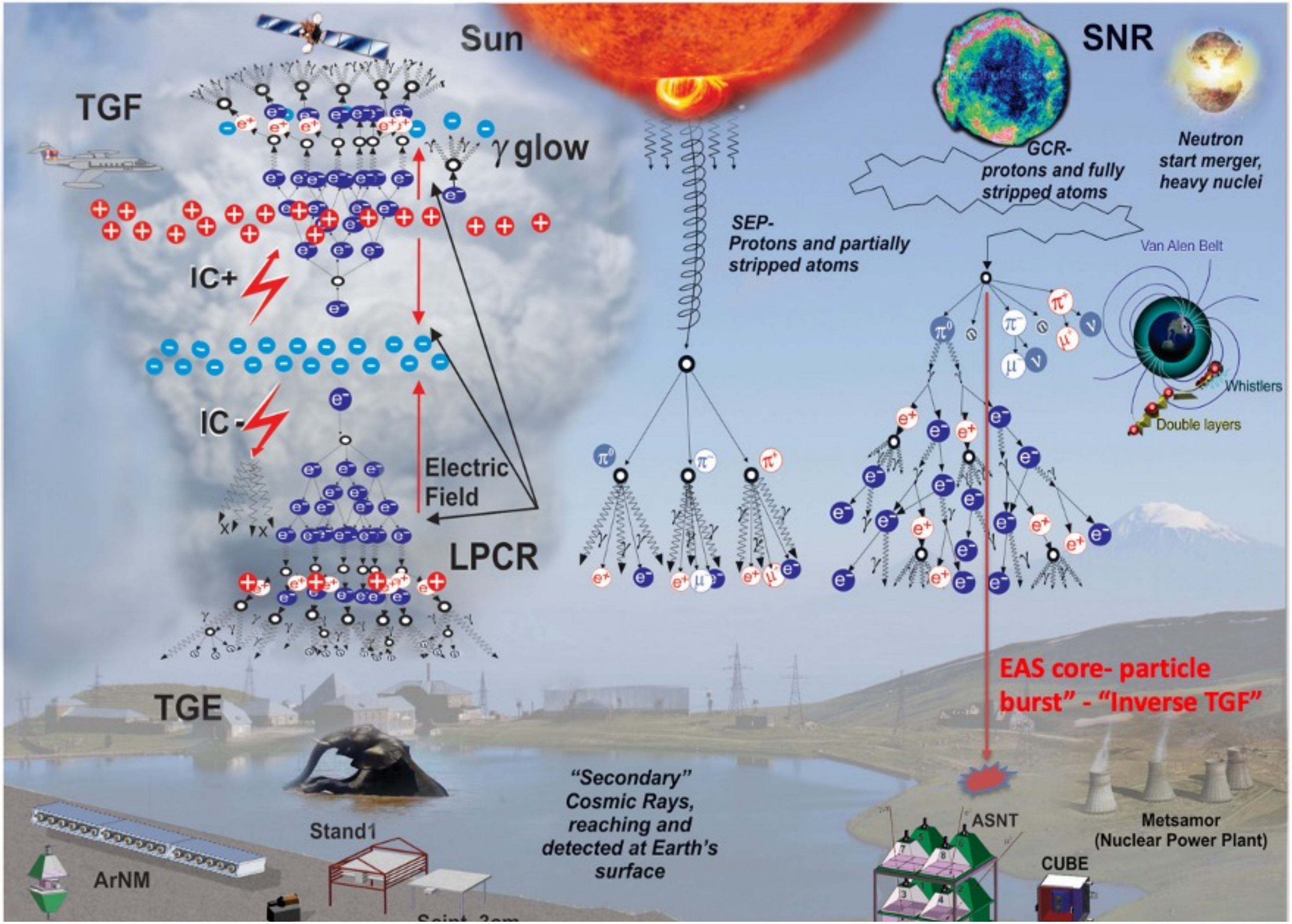


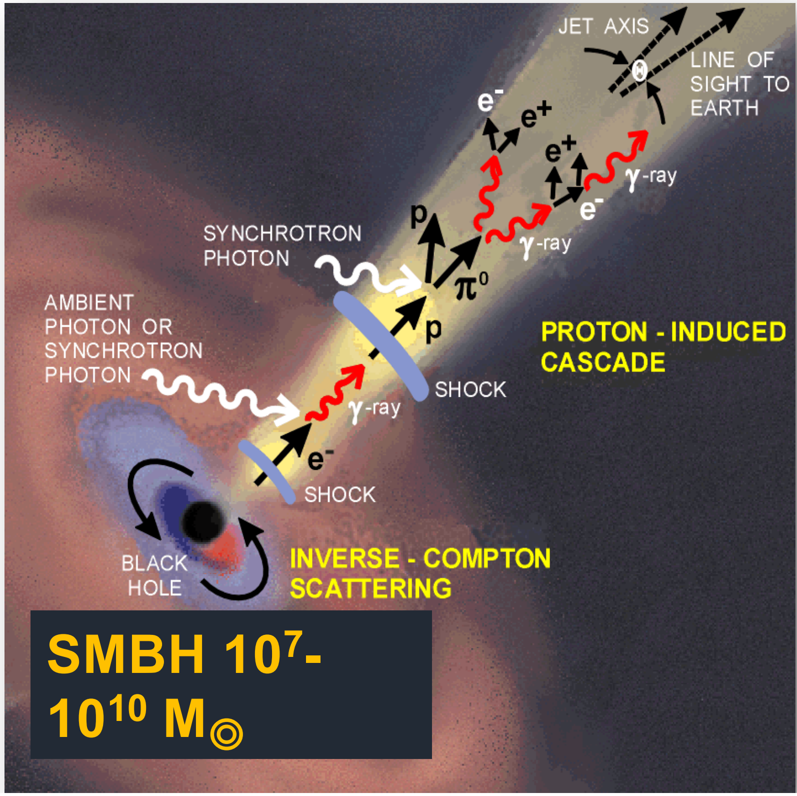
Neutron Monitors detecting cores of Extensive Air Showers. Abstract

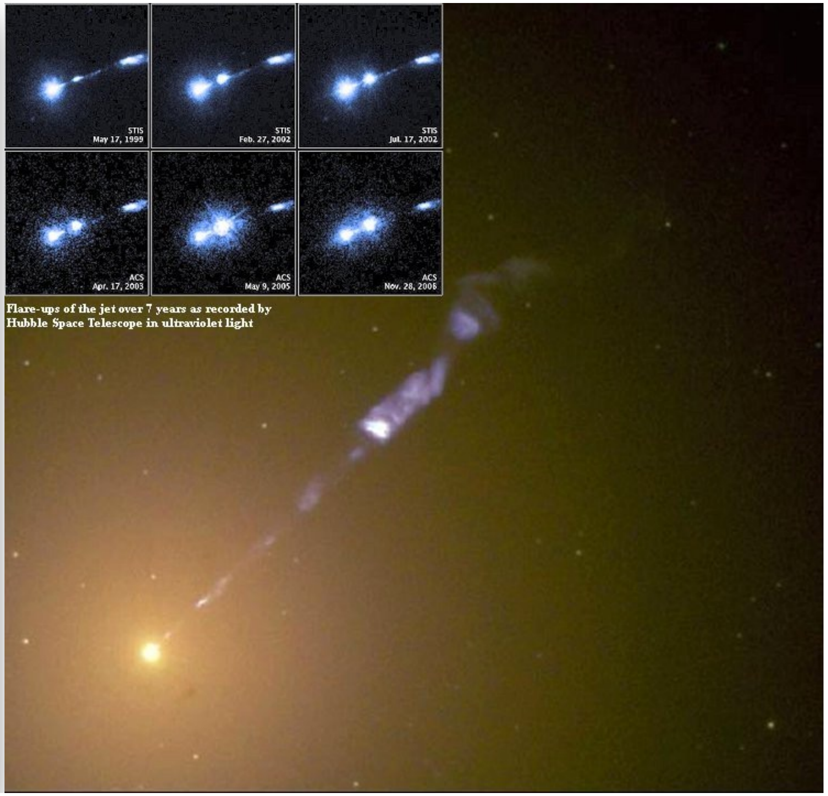
- We identify and analyzed EAS events by the registration of the neutron bursts in the Aragats NM. We relate these bursts to the EAS cores hitting the ground nearby NM. All bursts were observed as sequences of microsecond pulses temporally isolated from other pulses on a time scale of at least 100 µs. The mean burst duration, defined as a time interval between the first and last detectable pulses in the sequence was 2.5 ms +/- 0.6. Thus, NM is enlarging the EAS core particle lifetime (usually not more than 20 – 30 ns) by 5 orders of magnitude by registering multiple secondary neutrons born in the lead absorber and soil by relativistic particles from the EAS core. In this way, NM registers EASs and enables the estimation of primary particle energy by measuring the event multiplicity (number of isolated pulses in NM measured with a dead time of 0.4µs). Although the sensitive area of NM is only several tens of m2, multiyear operation of the NM network will provide sufficient statistics for the research around the knee of all particle energy spectrum (3-4 PeV) and beyond. Additionally, EAS core physics will be revealed.
- The network of nearly ≈ 50 neutron monitors (NM) operates 24/7 around the globe at different altitudes, latitudes, and longitudes for more than 60 years. Maintenance of such detectors is very cheap and they are providing data for many years with minimal intervention from personnel. The data from neutron monitors are collected in databases with open access and a user-friendly interface. After a very simple modernization of NM electronics, it will be possible to recover the energy spectra of galactic cosmic rays with detectors located all around the globe.
- The largest cosmic ray experiments measuring neutron content of EAS confirm the neutron bursts from EAS cores without any relation to lightning occurrences.

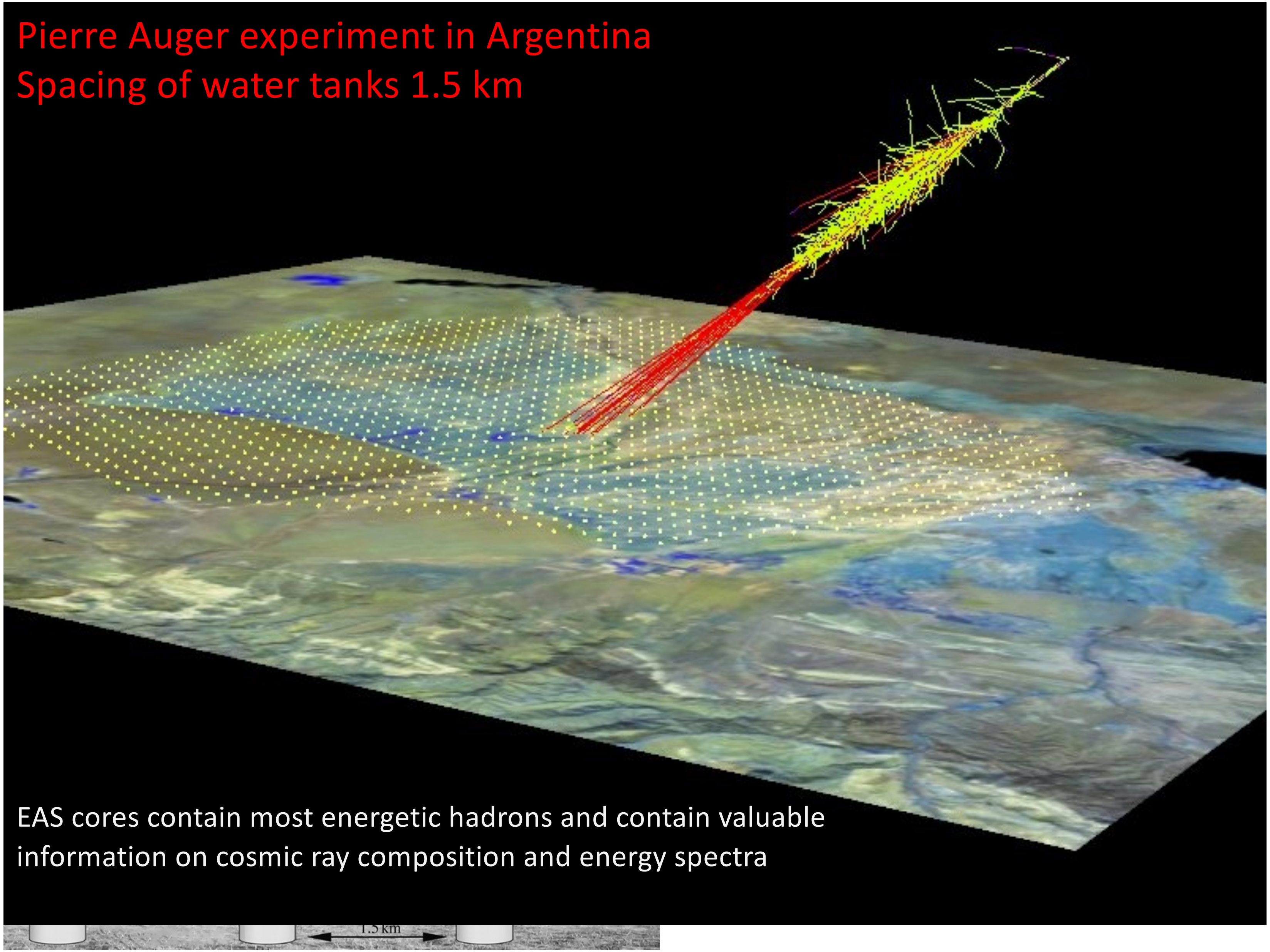

Sun
SNR
TGF
γ glow
GCR-
protons and fully
stripped atoms
Neutron
start merger,
heavy nuclei
SEP-
Protons and partially
stripped atoms
Van Alen Belt
IC+
IC -
Whistlers
Double layers
Electric
Field
LPCR
EAS core- particle
burst" - "Inverse TGF"
TGE
"Secondary"
Cosmic Rays,
reaching and
detected at Earth's
surface
ASNT
Metsamor
(Nuclear Power Plant)
Stand1
CUBE
ArNM

Universe is full of Particle Accelerators

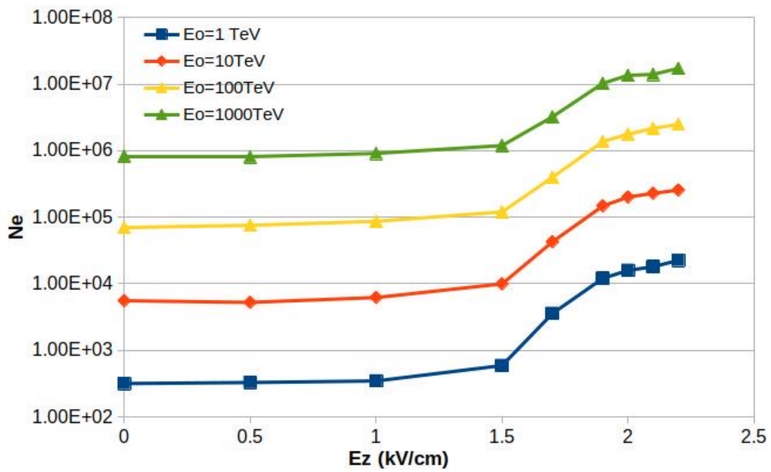
Galaxies that point their jets at us are called “blazars”, Markaryan galaxies



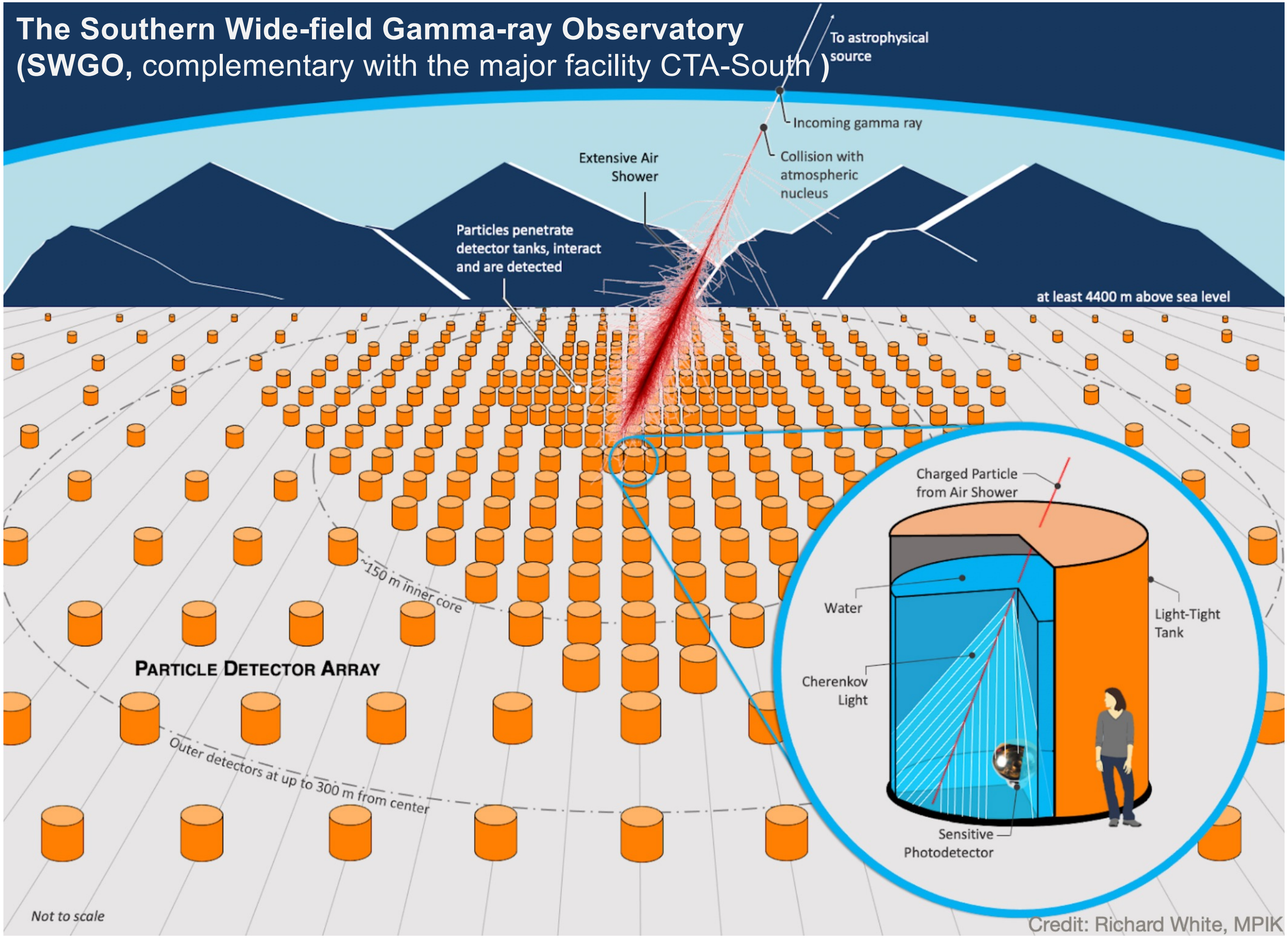


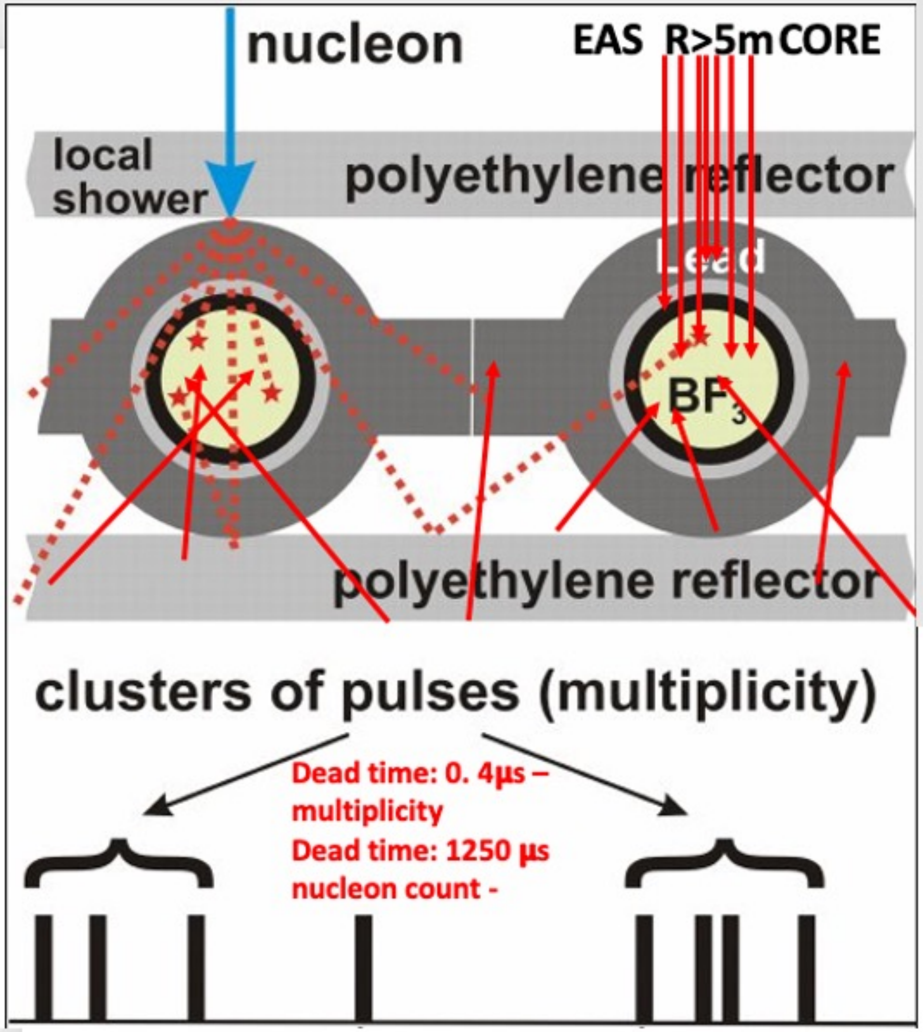

Pierre Auger experiment in Argentina
Spacing of water tanks 1.5 km
EAS cores contain most energetic hadrons and contain valuable
information on cosmic ray composition and energy spectra
1.5 km

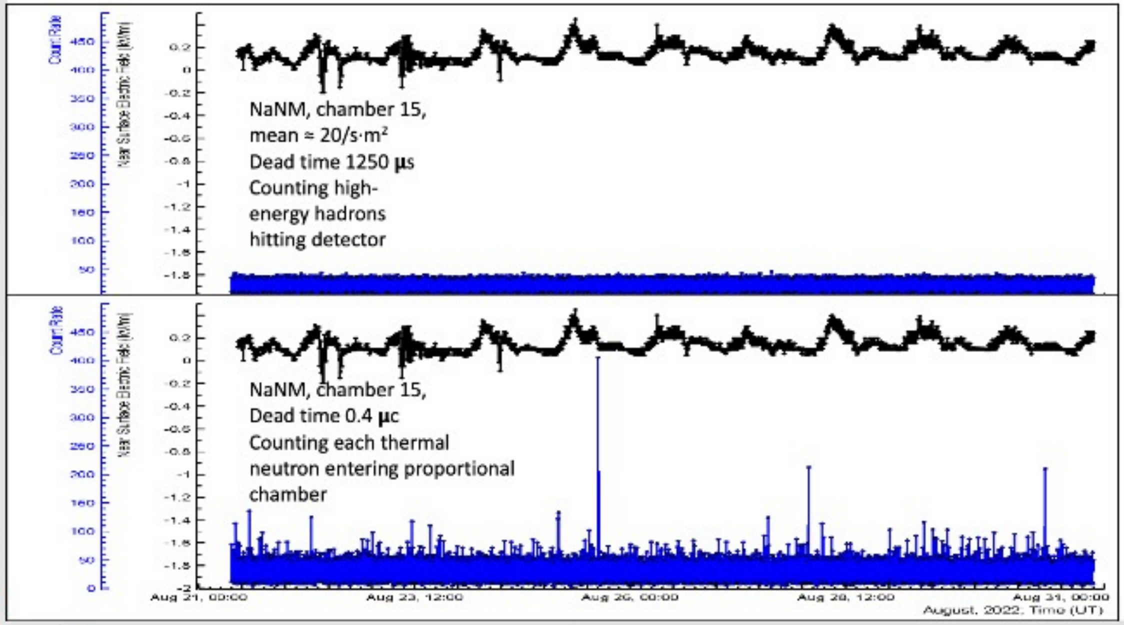
PEVatron detection by LHASSO: possible overestimation of primary gamma ray energies if observations were done during thunderstorms often in Tibetan plateau.

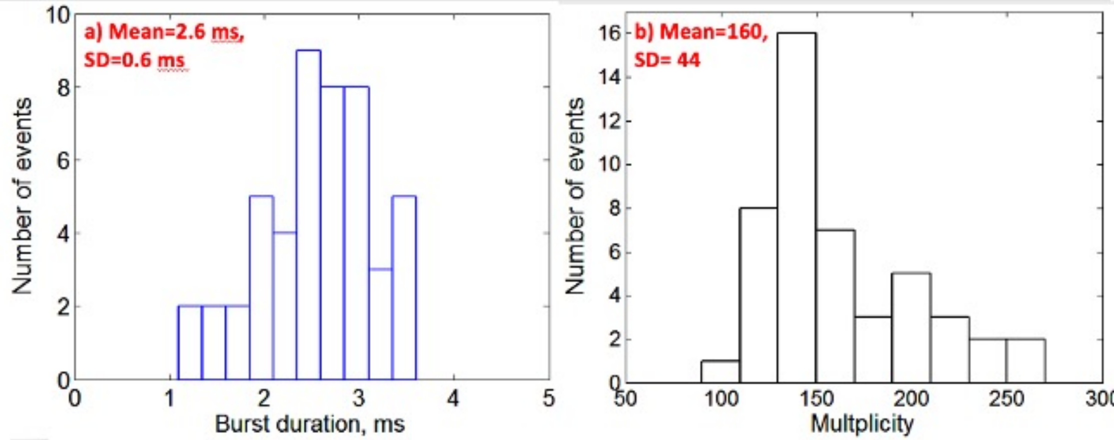


Eo (GeV)	Eest (GeV)
1.00E+03	2.23E+04
1.00E+04	1.34E+05
1.00E+05	6.50E+05
1.00E+06	2.42E+06

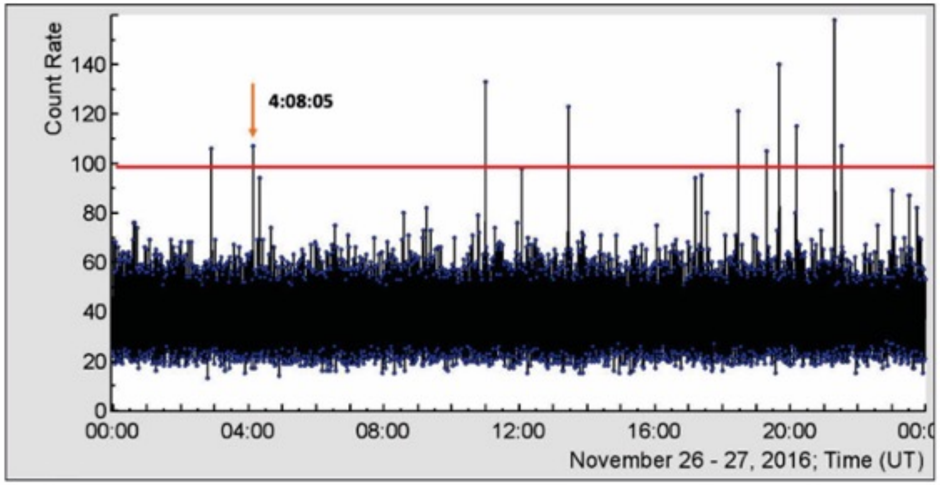

The Southern Wide-field Gamma-ray Observatory
(SWGO, complementary with the major facility CTA-South)
To astrophysical source
Incoming gamma ray
Collision with atmospheric nucleus
Extensive Air Shower
Particles penetrate detector tanks, interact and are detected
at least 4400 m above sea level
~150 m inner core
PARTICLE DETECTOR ARRAY
Outer detectors at up to 300 m from center
Charged Particle from Air Shower
Water
Light-Tight Tank
Cherenkov Light
Sensitive Photodetector
Not to scale
Credit: Richard White, MPIK



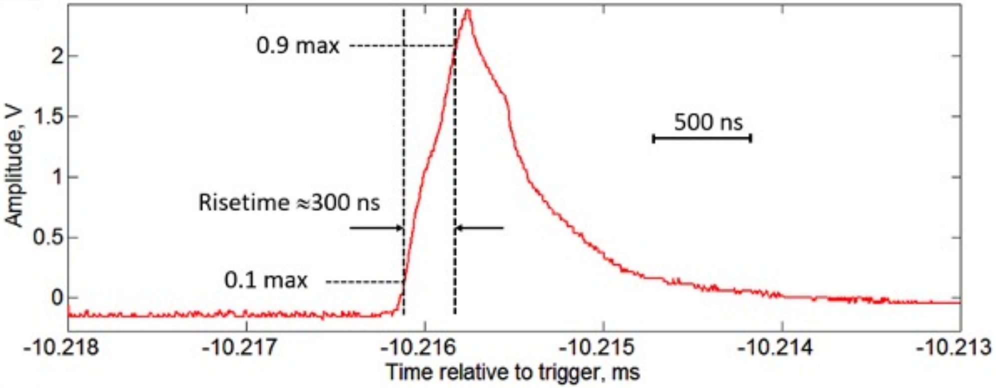




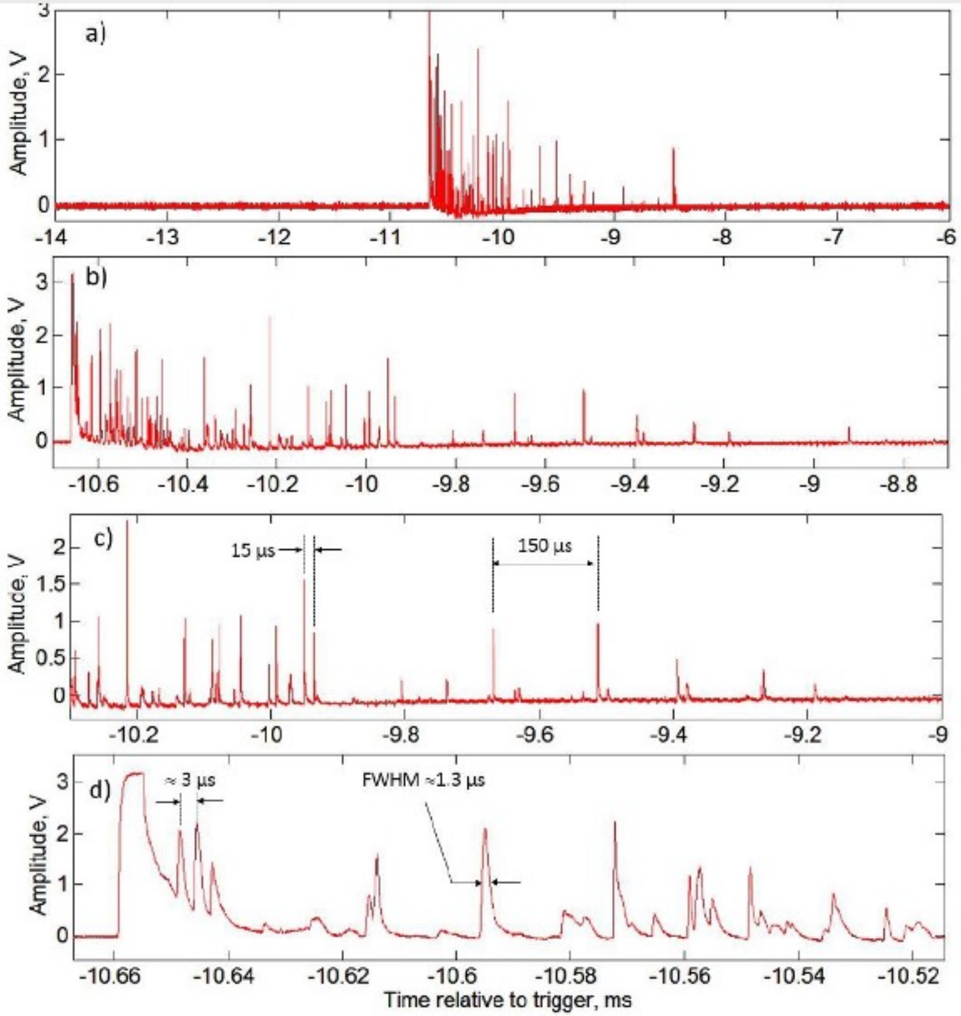
Apatity, Barenzburg, Fine structure of neutron multiplicity on neutron monitors. Yu. V. Balabin, B. B. Gvozdevsk, E. A. Maurchev, et al, Astrophys. Space Sci. Trans., 7, 283-286, 2011.
] Soghomonyan, Suren; Chilingarian, Ashot; Pokhsraryan, David (2021), "Extensive Air Shower (EAS) registration by the measurements of the multiplicity of neutron monitor signal", Mendeley Data, V1, doi: 10.17632/43ndcktj3z.1 https://data.mendeley.com/dat



1-s time series of ArNM multiplicities (proportional counter N2). By the red line the multiplicities above 100 are outlined, by the red arrow – the neutron burst shown in Figures a-c

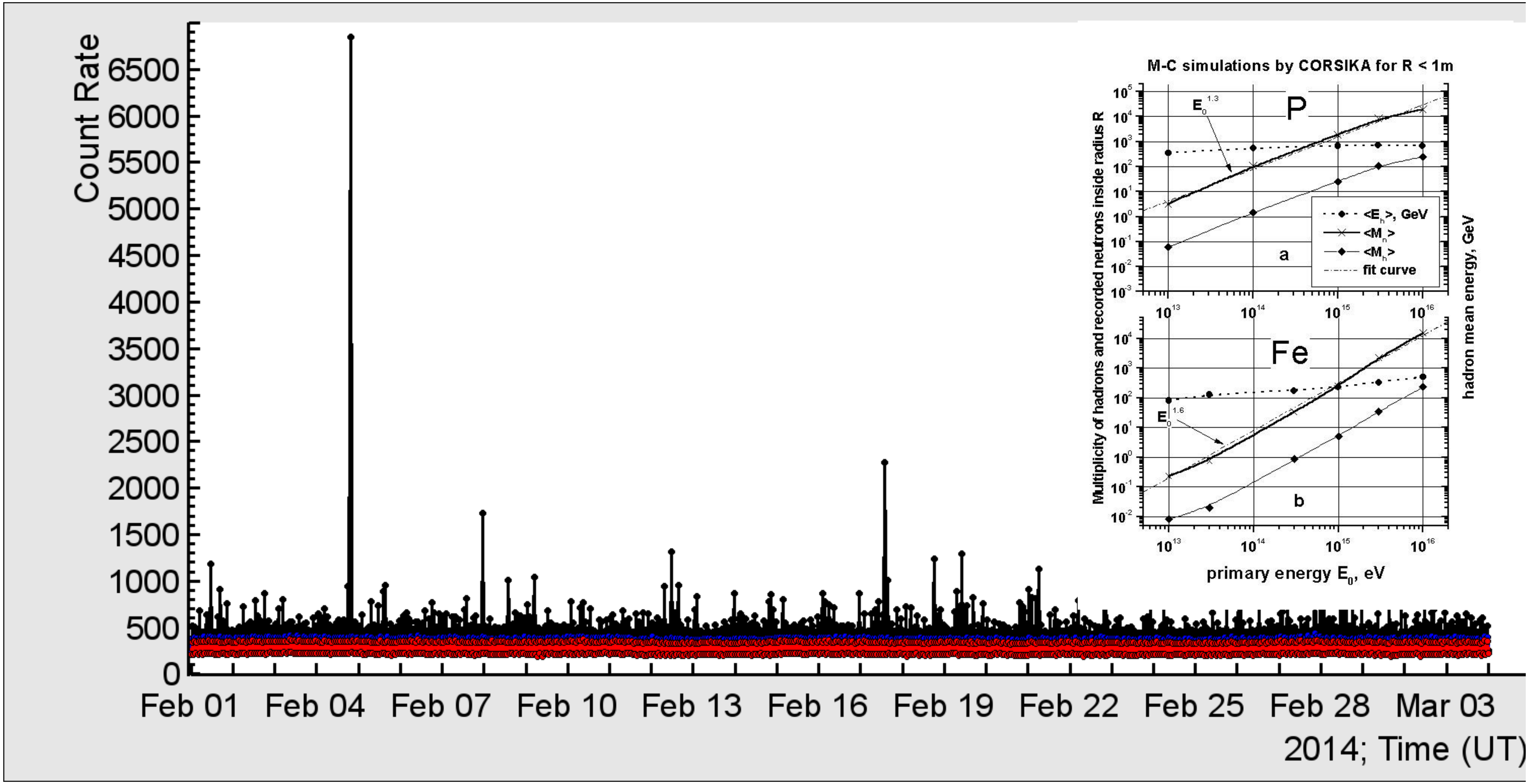


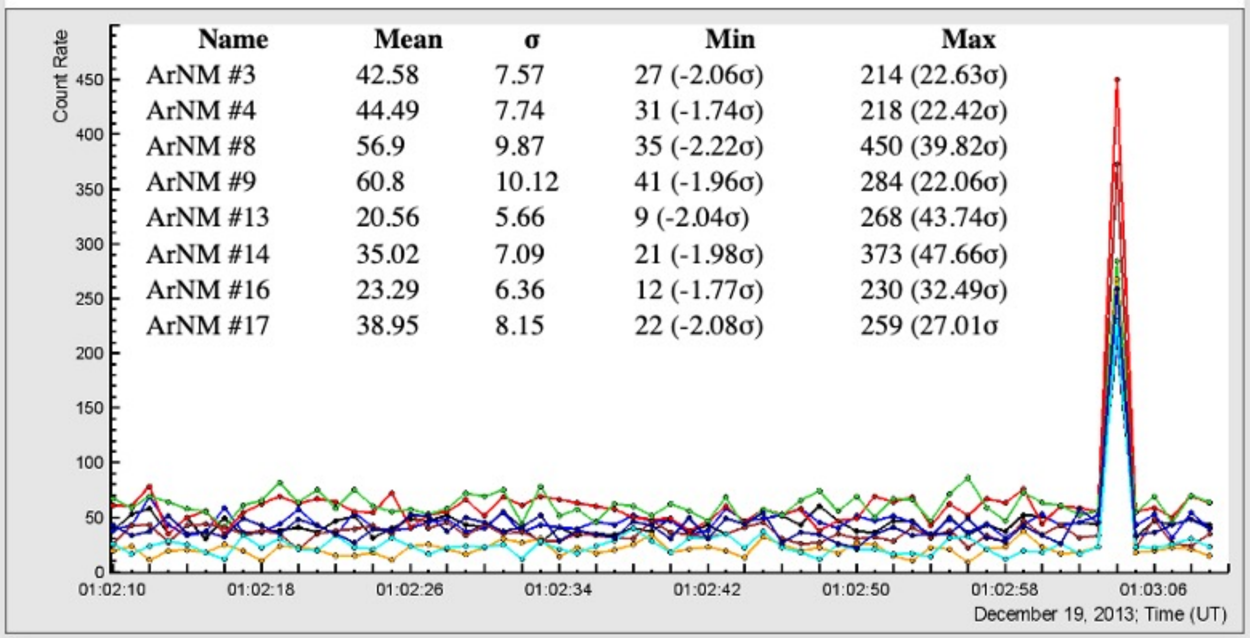
A 5-µs fragment of the oscilloscope record shows a typical pulse shape of the neutron monitor, the risetime (0.1-0.9) is ≈300 ns.



Oscilloscope records of neutron burst that occurred at 4:08:05 on November 26, 2016. The burst duration is ≈ 2.2 milliseconds and the multiplicity is 107 per m². The four panels (a-c) show the records of the burst on different time scales.

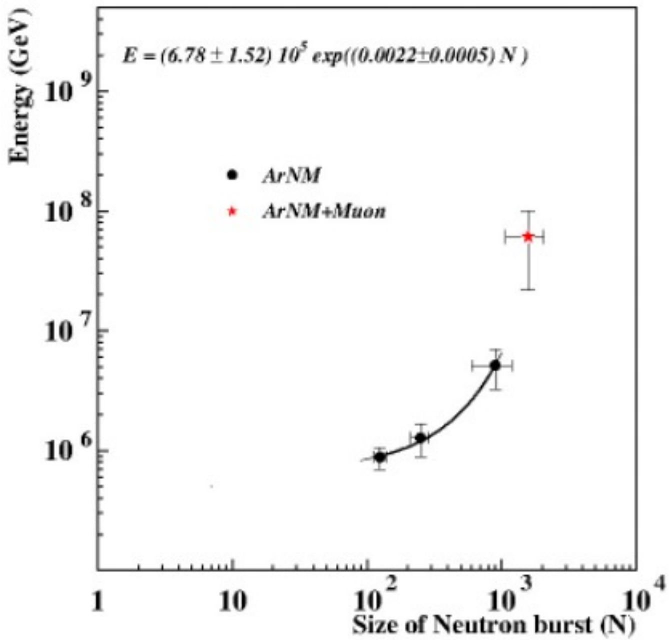
A. Chilingarian, G. Hovsepyan, The synergy of the cosmic ray and high energy atmospheric physics: Particle bursts observed by arrays of particle detectors, New Astronomy, 97 (2022) 101871


Count Rate
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Feb 01
Feb 04
Feb 07
Feb 10
Feb 13
Feb 16
Feb 19
Feb 22
Feb 25
Feb 28
Mar 03
2014; Time (UT)
M-C simulations by CORSIKA for R < 1m
P
Fe
a
b
<E_h>, GeV
<M_n>
<M_h>
fit curve
Multiplicity of hadrons and recorded neutrons inside radius R
hadron mean energy, GeV
primary energy E_0, eV



Name	Mean	σ	Min	Max
ArNM #3	42.58	7.57	27 (-2.06σ)	214 (22.63σ)
ArNM #4	44.49	7.74	31 (-1.74σ)	218 (22.42σ)
ArNM #8	56.9	9.87	35 (-2.22σ)	450 (39.82σ)
ArNM #9	60.8	10.12	41 (-1.96σ)	284 (22.06σ)
ArNM #13	20.56	5.66	9 (-2.04σ)	268 (43.74σ)
ArNM #14	35.02	7.09	21 (-1.98σ)	373 (47.66σ)
ArNM #16	23.29	6.36	12 (-1.77σ)	230 (32.49σ)
ArNM #17	38.95	8.15	22 (-2.08σ)	259 (27.01σ

Time series of ArNM proportional counters registered a large neutron burst at 1:03:4 on 19 October 2013, total multiplicity of 2310 measured by the shortest dead time of 0.4 µs. The multiplicities above 2000 are extremely rare, 1-2 per month; neutron bursts detected by both ArNM and Muon are even rarer, 3-4 per year. The primary particle energies corresponding to these events are well above 10^{16} eV.



The dependence of the multiplicity (size) of neutron burst on energy of primary particle, which initiated EAS (obtained by relation of the frequency of different observed multiplicities (neutron burst sizes) to integral energy spectrum measured by MAKET array. By arrow we show the knee position of the all particle spectrum and by asterisk – the primary particle energy corresponding to the frequency of detecting bursts both in ArNM and muon detector.

Citation: A.Chilingarian A., Hovsepyan G., Kozliner L., Extensive Air Showers, Lightning, and Thunderstorm Ground Enhancements, Astroparticle Physics 82, 21 (2016).

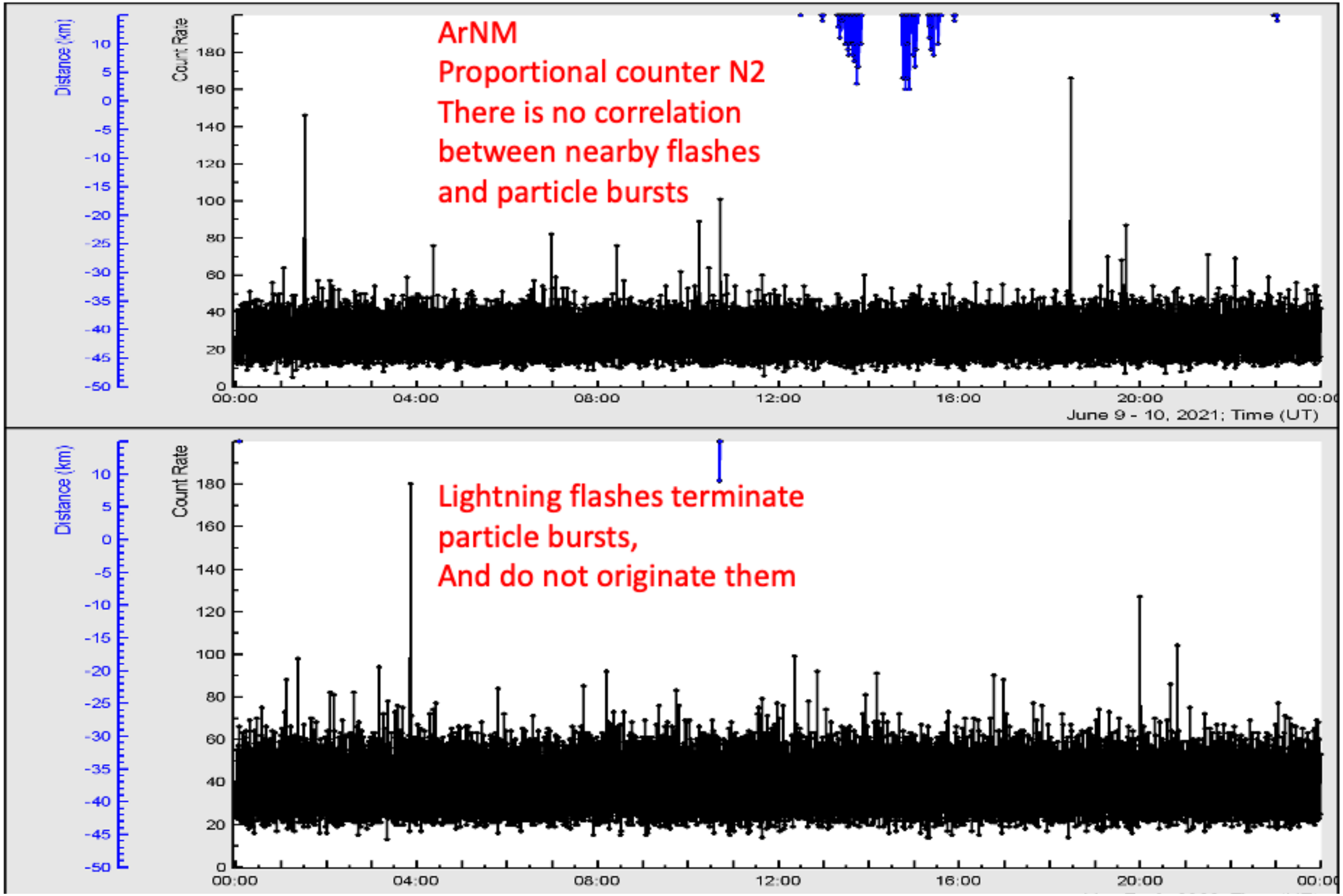
Detectors measuring neutron bursts:

Z. T.Izhbulyakova, A. G. Bogdanov, F. A. Bogdanov, et al., Investigation of the EAS neutron component with the URAN array: first simulation and experimental results, Journal of Physics: Conference Series 1690 (2020) 012071 doi:10.1088/1742-6596/1690/1/012071

A.P.Chubenko, A.L.Shepetov, V.P.Antonova, et al., New complex EAS installation of the Tien Shan mountain cosmic ray station, NIM, 832, 158 (2016) https://doi.org/10.1016/j.nima.2016.06.068

B. Bartoli, P. Bernardini, X.J. Bi et.al., Detection of thermal neutrons with the PRISMA-YBJ array in Extensive Air Showers selected by the ARGO-YBJ experiment, CollaborationsAstropart.Phys. 81 (2016) 49-60

B.-B. Li, V.V. Alekseenko, S.-w Cui, et al., EAS thermal neutron detection with the PRISMA-LHAASO-16 experiment, JINST 12 P12028 (2017) https://doi.org/10.1088/1748-0221/12/12/P12028



ArNM
Proportional counter N2
There is no correlation
between nearby flashes
and particle bursts
Lightning flashes terminate
particle bursts,
And do not originate them
Distance (km)
Count Rate
June 9 - 10, 2021; Time (UT)

Conclusions

- The neutron monitor is enlarging the very short EAS time profile (20 – 30 ns) by ≈ 5 orders of magnitude (2-3 milliseconds) making it possible to use rather a slow device (neutron monitor) for the registration of ultrarelativistic particles from EAS cores.
- After the detailed simulation of the detector response function by modeling the interactions of primary particles in the atmosphere above the detector it will be possible to estimate the energy spectra of primary cosmic ray flux. Sure, the relation "multiplicity – primary energy" is a statistical one, and depends on several unknown parameters of EAS development (core distance, shower age, primary type), however, the NM multiplicity can be related to the energy of the primary cosmic ray hadron hitting the terrestrial atmosphere and initiated EAS. After a detailed simulation of the NM response to EAS cores the statistical relation of multiplicity – primary energy can be established.
- The network of nearly 50 Neutron monitors operate at different altitudes, latitudes, and longitudes for more than 60 years. Maintenance of such a detector is very cheap and they are providing data for many years with minimal intervention of personnel. The data stream is collected in the databases with open access and a user-friendly interface. By using the neutron monitor database (NMDB) after a simple modernization of NM electronics, and after making simulations of the detector response for all included in the network neutron monitors, it will be possible to recover the energy spectra of galactic cosmic rays all around the globe.