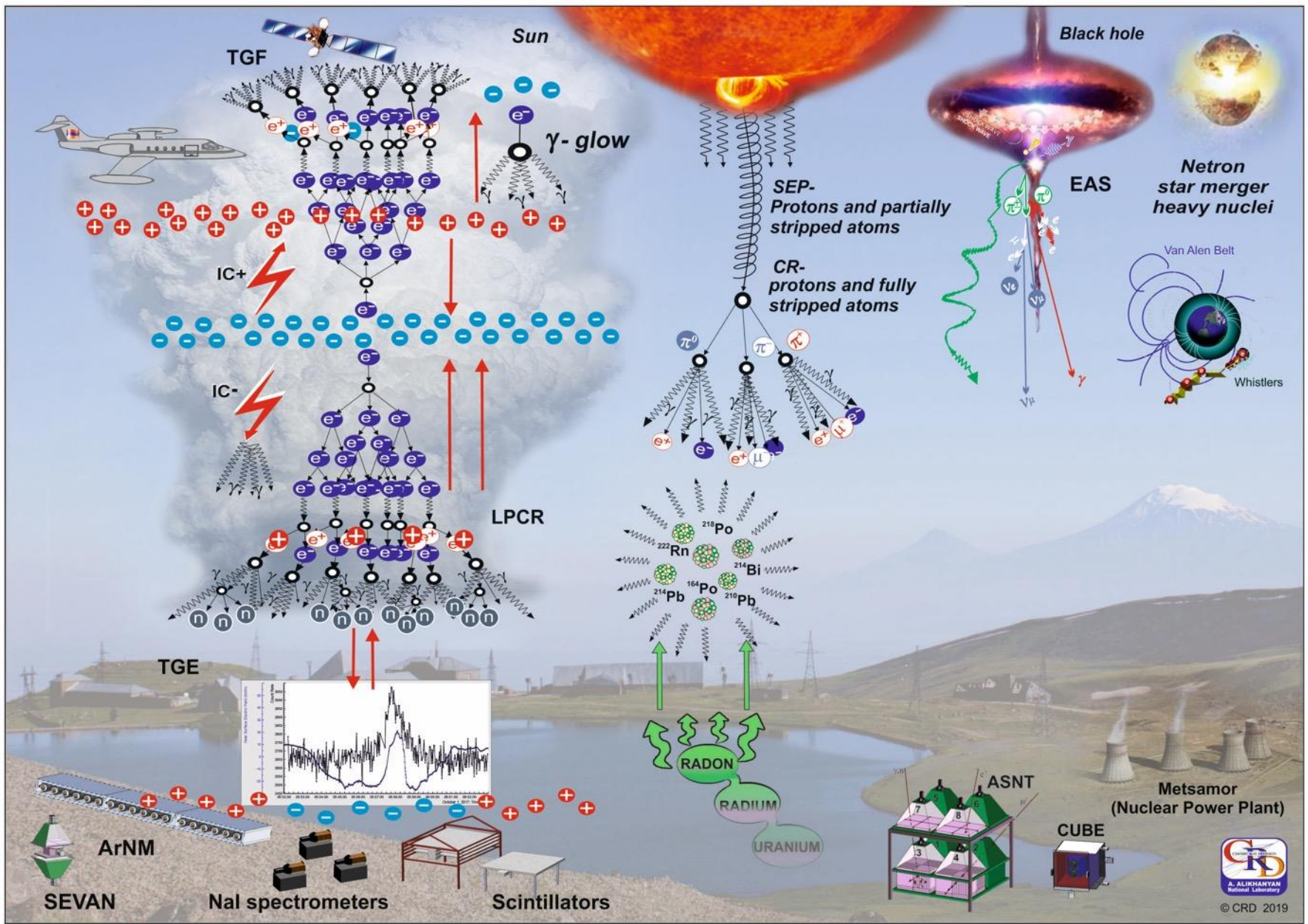


Natural Gamma Radiation and High-energy physics in atmosphere

*Ashot Chilingarian
Yerevan Physics Institute*



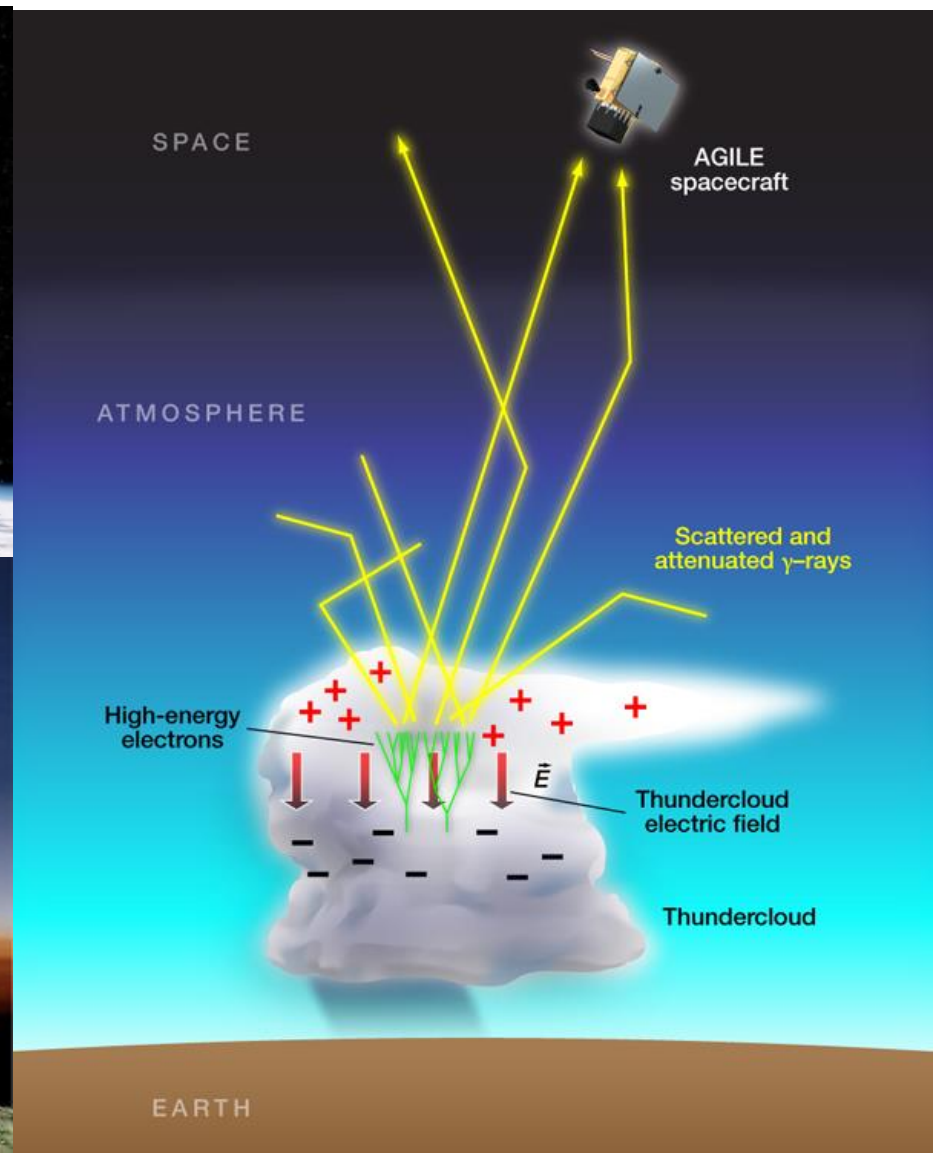
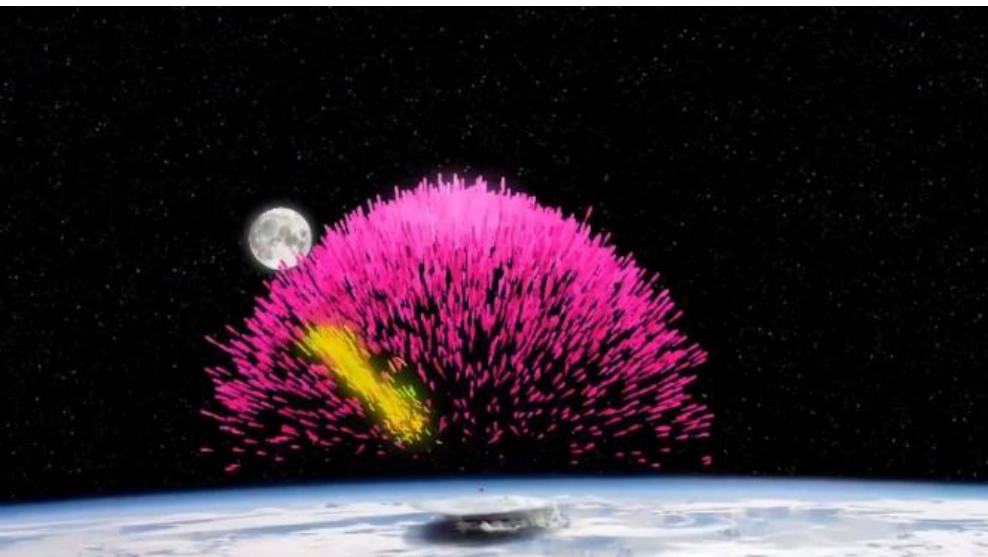
**April 1 2019
Aragats buildings
under snow**



Research of the Natural Gamma Radiation (NGR) High-Energy Physics in Atmosphere (HEPA)

- TGE originated by RB/RREA: Runaway breakdown, Relativistic Runaway Electron Avalanches: up to 50 MeV and more with intensities reaching 10 times CR background, first TGE catalog (2017) published in Nature ResearchReports;
- MOS : gamma rays with energies up to 100 MeV with intensities of 1-2% of CR background, MOS processes confirmed by gamma glows registered by aircraft measurements above 10 km in Florida, Australia and Taxes;
- Role of of Rn progenies in the Long lasting TGEs clarified, Rn and its progenies are attached to aerosols and lifted by electric field to atmosphere. Pb (354KeV) and Bi (609 KeV) measured by NaI network on Aragats;
- Inverse TGFs and TGF afterglows reported by Gapaniese group.
- Optical observation of RREA – direct prove of atmospheric avalanches!
- Interferometer operation on Aragats: \approx 400 triggers registered in 2019

AGILE MCAL: 330 keV – 100 MeV energy range, average altitude 535 km, energy resolution 13% FWHM



The Atmosphere-Space Interactions Monitor (ASIM) is an instrument suite on the International Space Station (ISS) for measurements of lightning, Transient Luminous Events (TLEs) and Terrestrial Gamma-ray Flashes (TGFs).

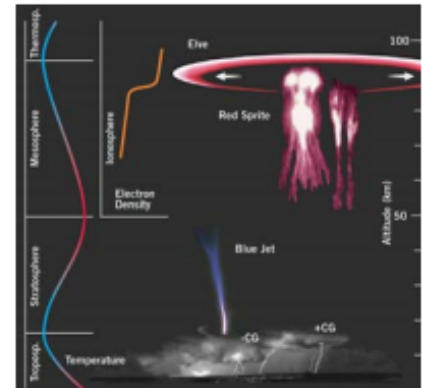


ASIM is the first space mission that carries x- and gamma-ray instrumentation designed to observe TGFs (15 KeV – 20 MeV, $\approx 1\text{m}^2$ area).

ASIM TGF results

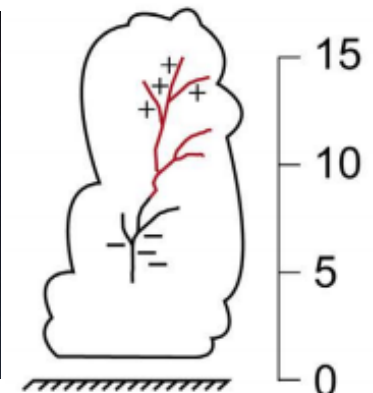
ASIM FIRSTS:

- 3 simultaneous TGFs observations by FERMI and ASIM.
2 with imaging of TGF.
- 15 events with TGF and ELVE from same thundercloud system:
typically 1-200 ms up to 2 second apart - 2 simultaneous (± 80 us)
- 28 events good for imaging
- 94 events with TGF and photometers, solving the sequence of TGF and optical lightning

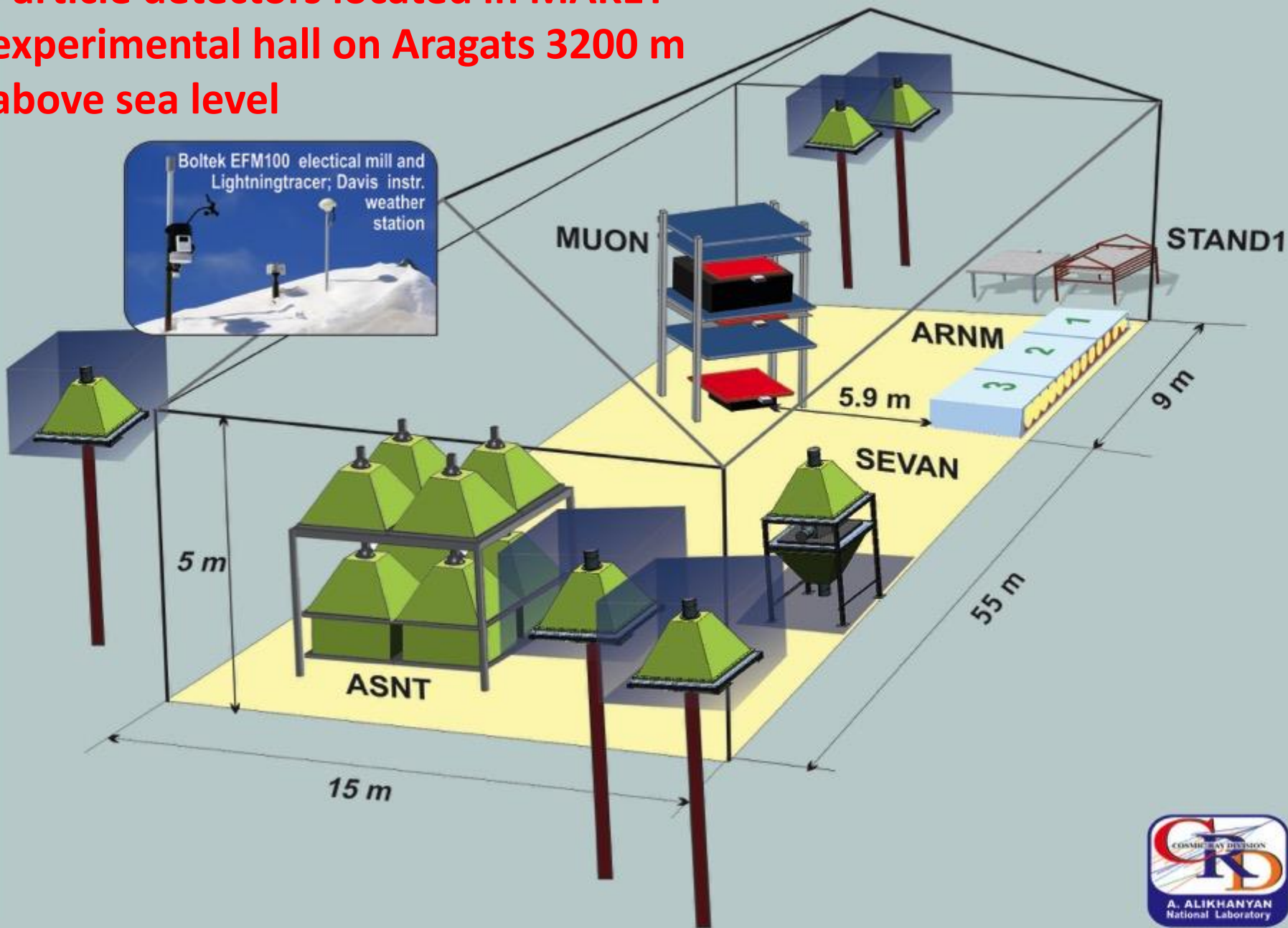


ALSO:

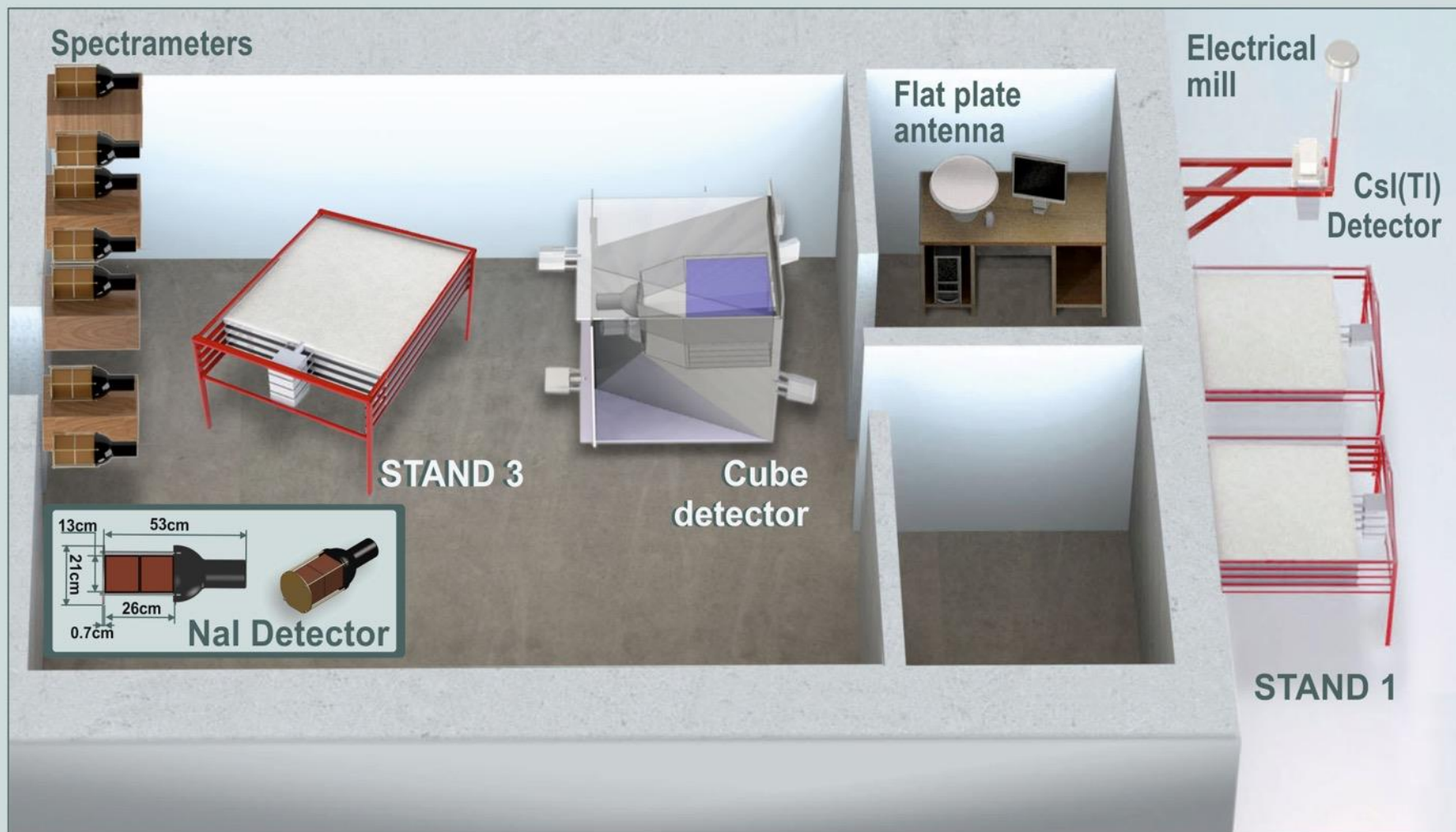
- Many multi-pulse TGFs
- Many bright TGFs
- Lightning induced Electron Precipitation (LEP) events
- Terrestrial Electron Beam (TEB)



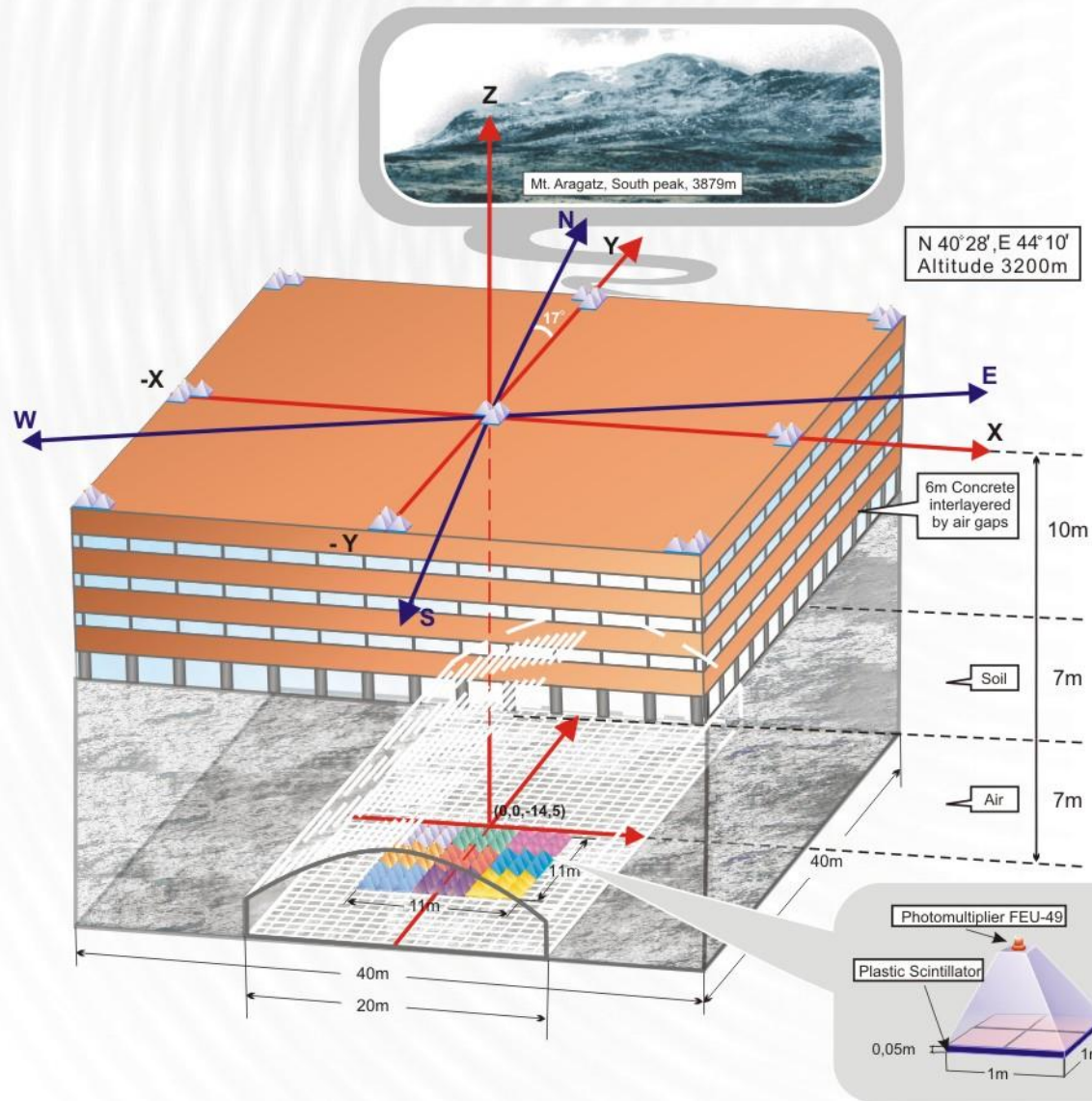
Particle detectors located in MAKET experimental hall on Aragats 3200 m above sea level



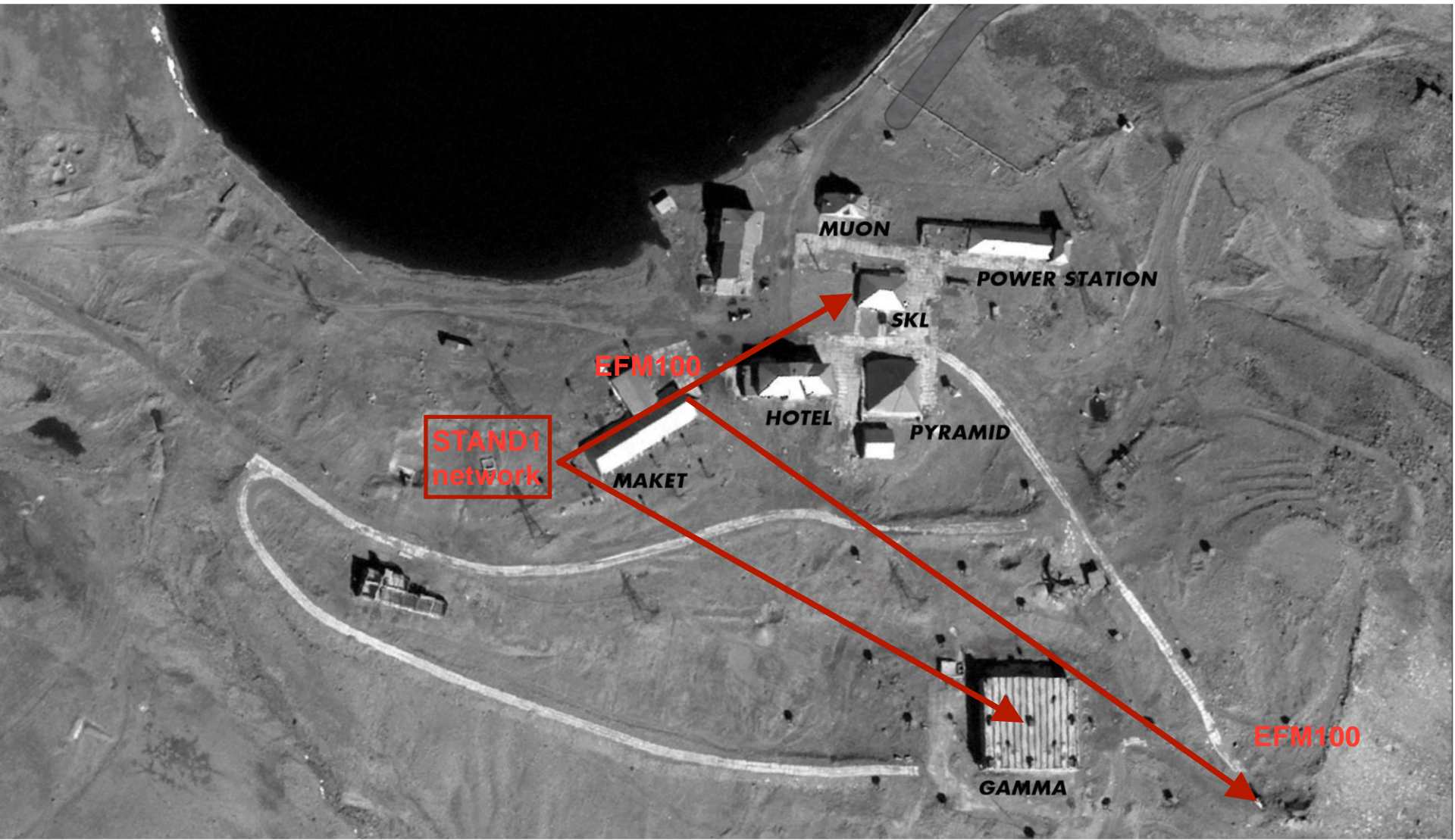
SKL EXperimental Hall



ANI calorimeter-GAMMA array: selection of gamma showers by muon-poor EAS



Thunderstorm observation: origin of lightning flashes and high energy particle bursts. Is it correlation only or causal relation?



KARE Lake



POWER STATION

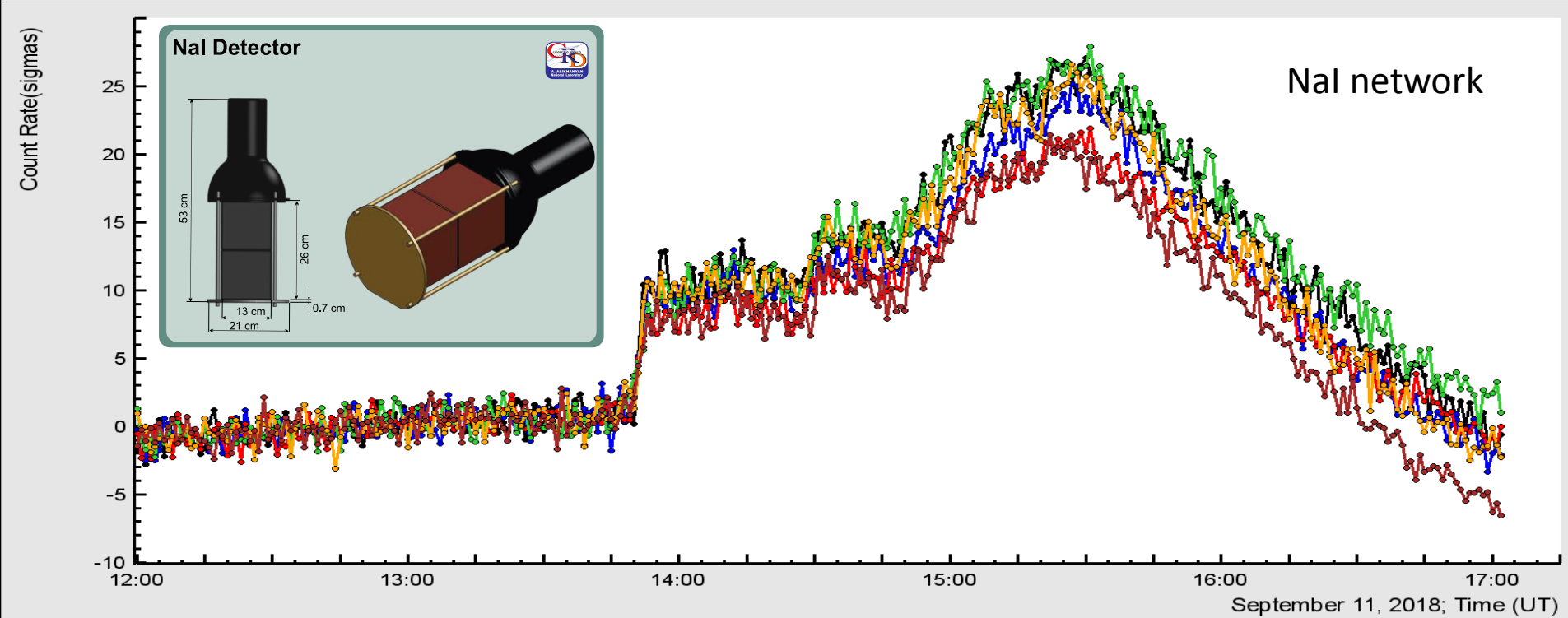
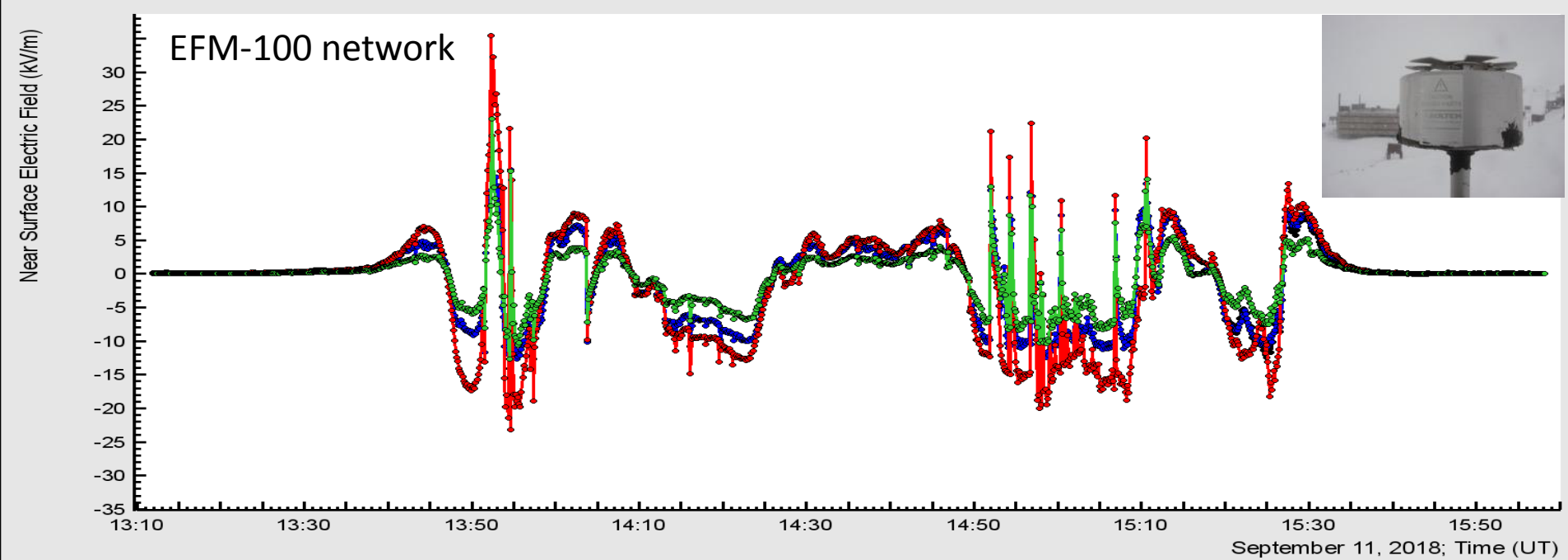
SKL

HOTEL

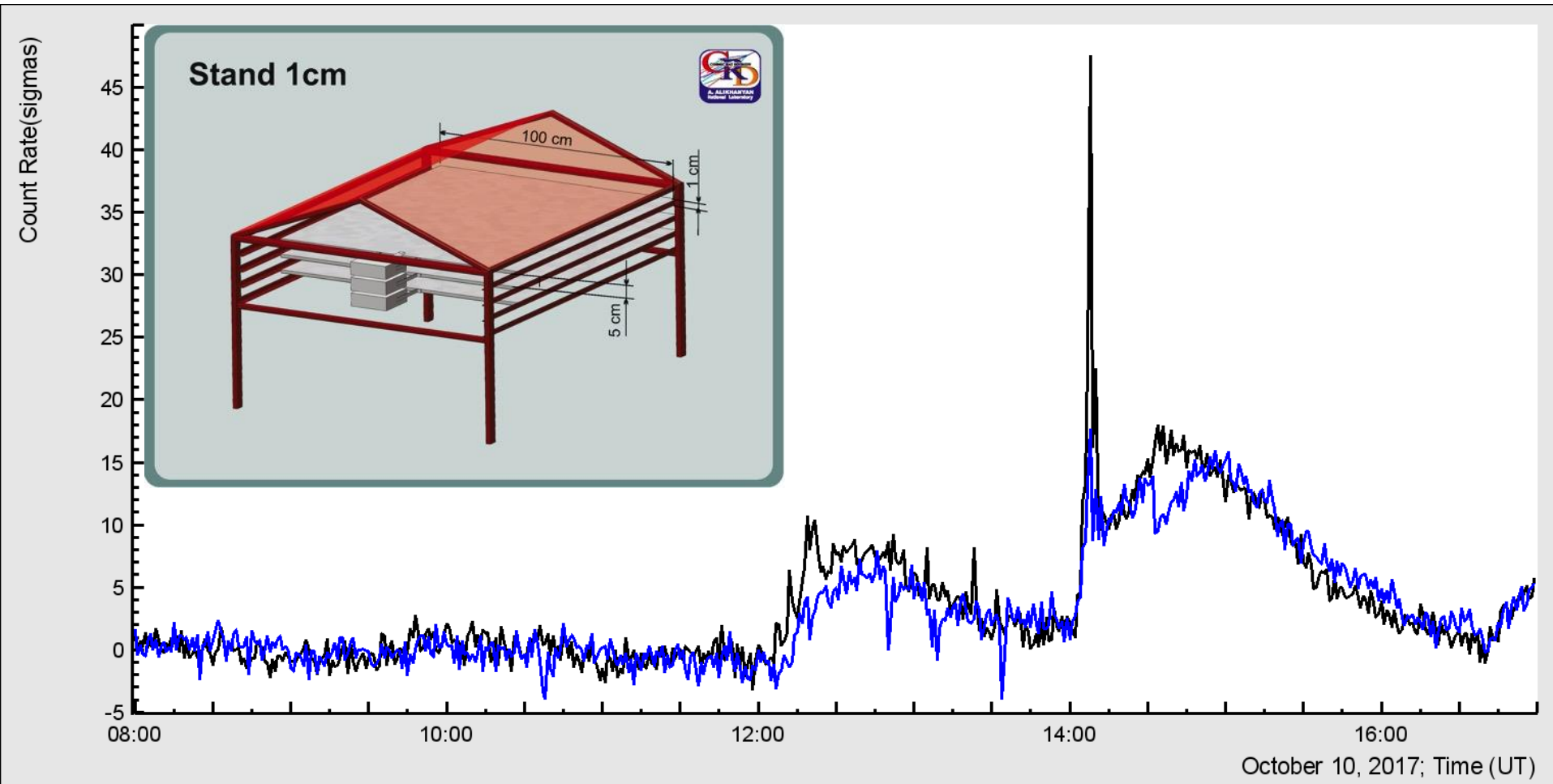
PYRAMID

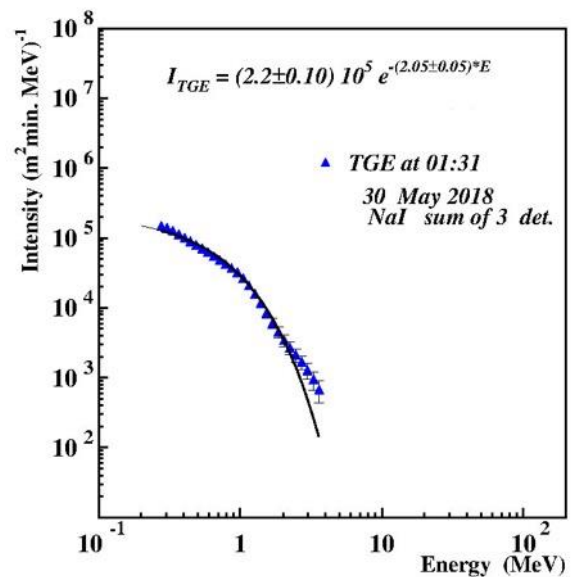
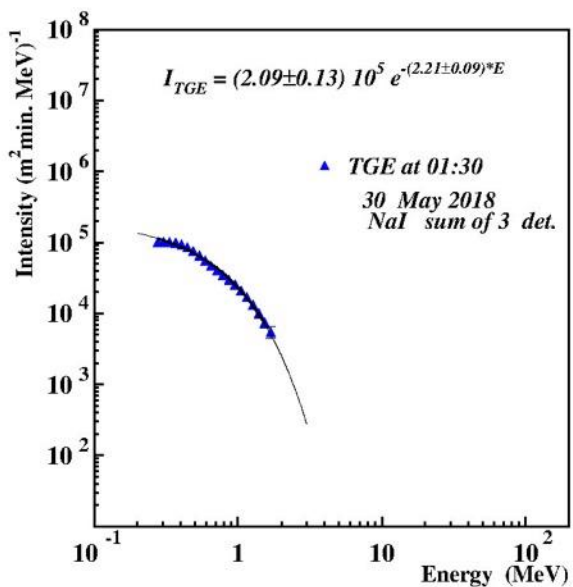
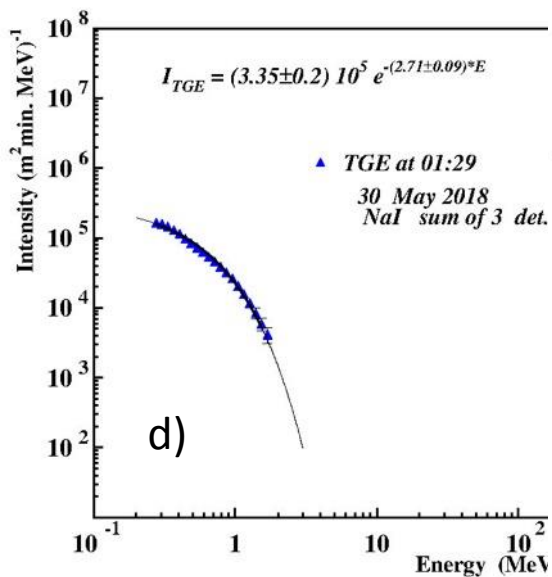
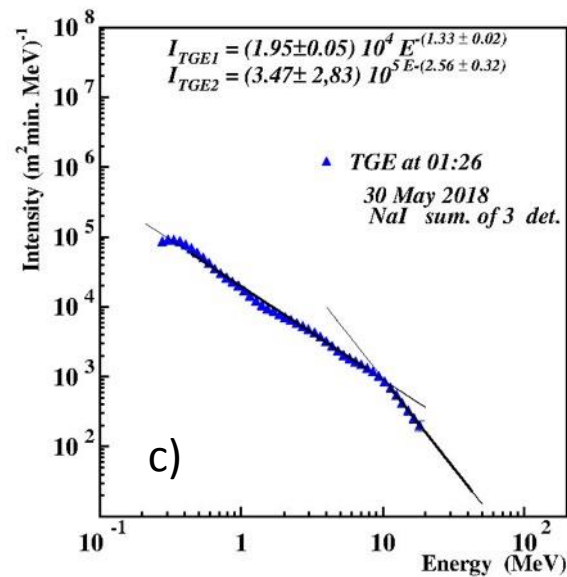
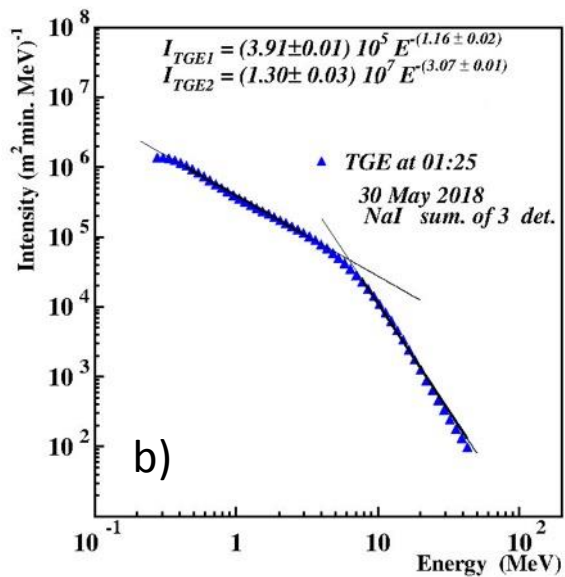
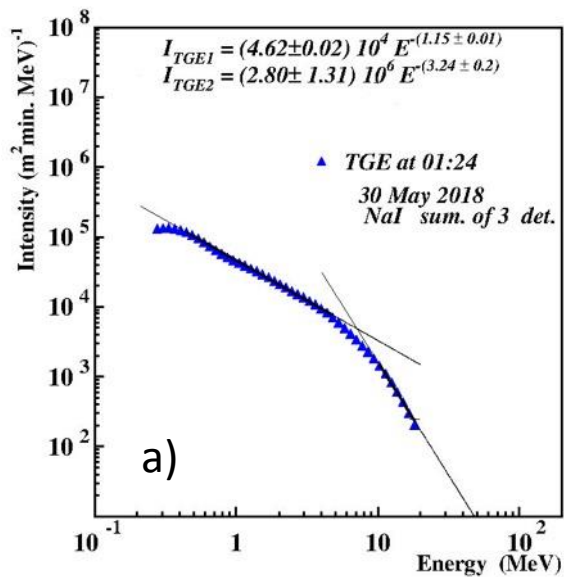


**ARAGATS
Research Station**

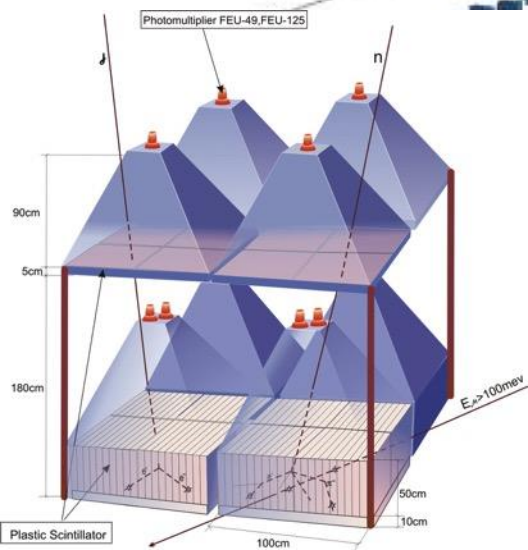
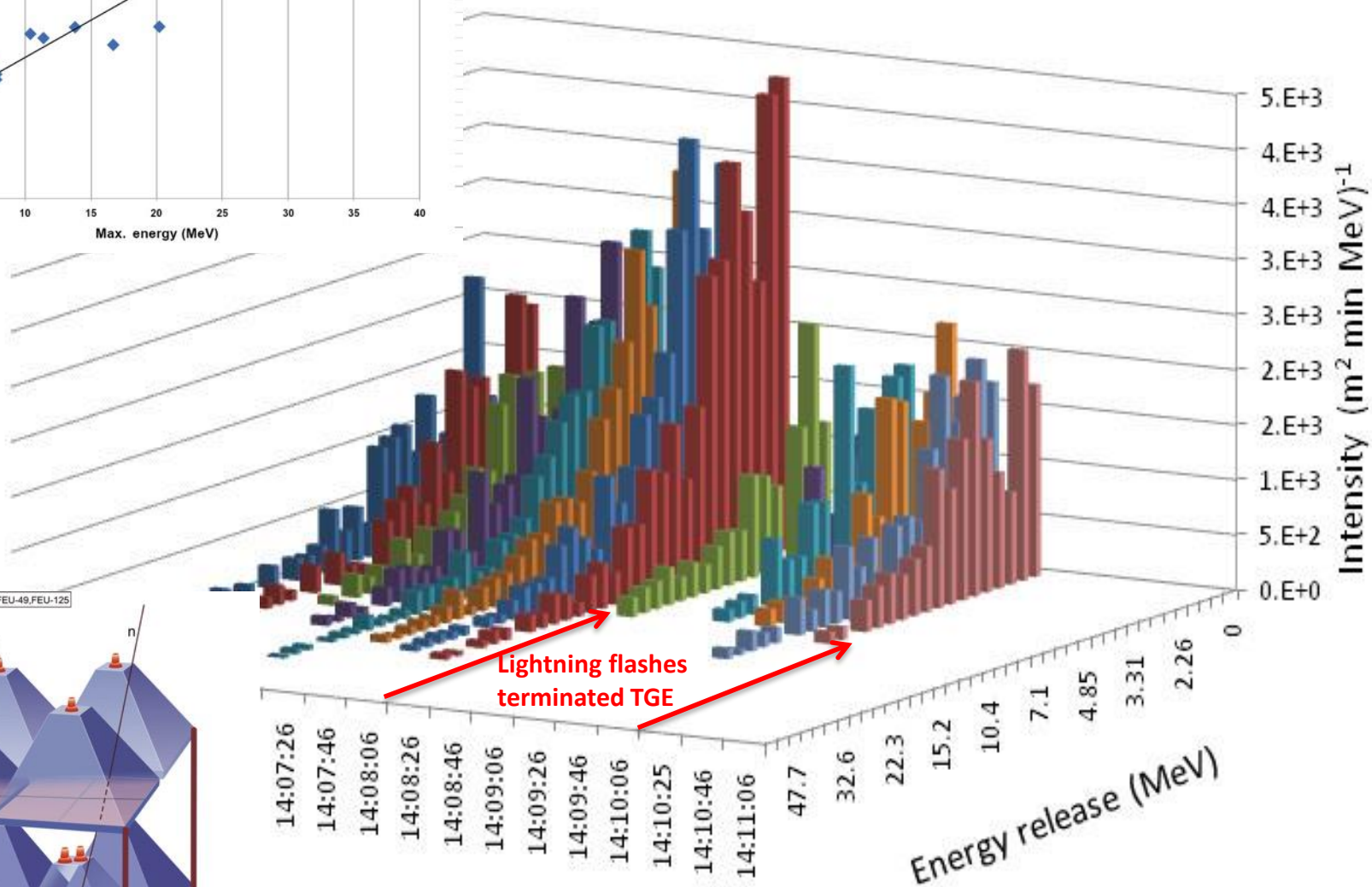
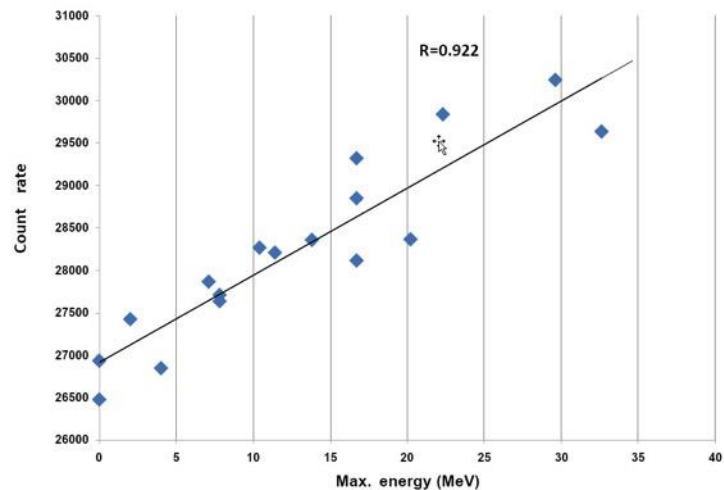


STAND1 (MAKET), stack of 1 cm thick plastic scintillators 100 and 010 combinations



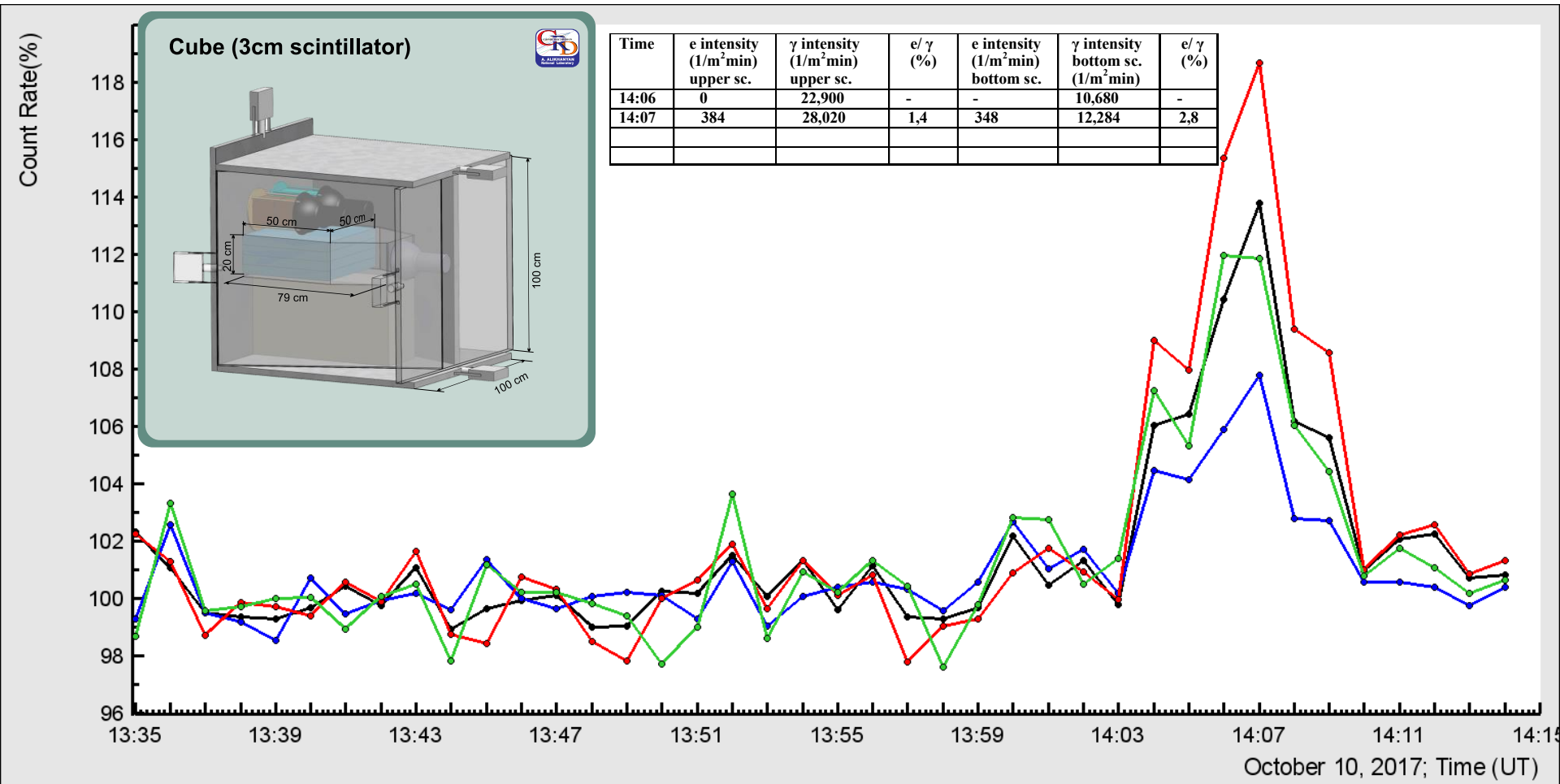


Normal polarity intracloud flashes terminate TGE 2 times

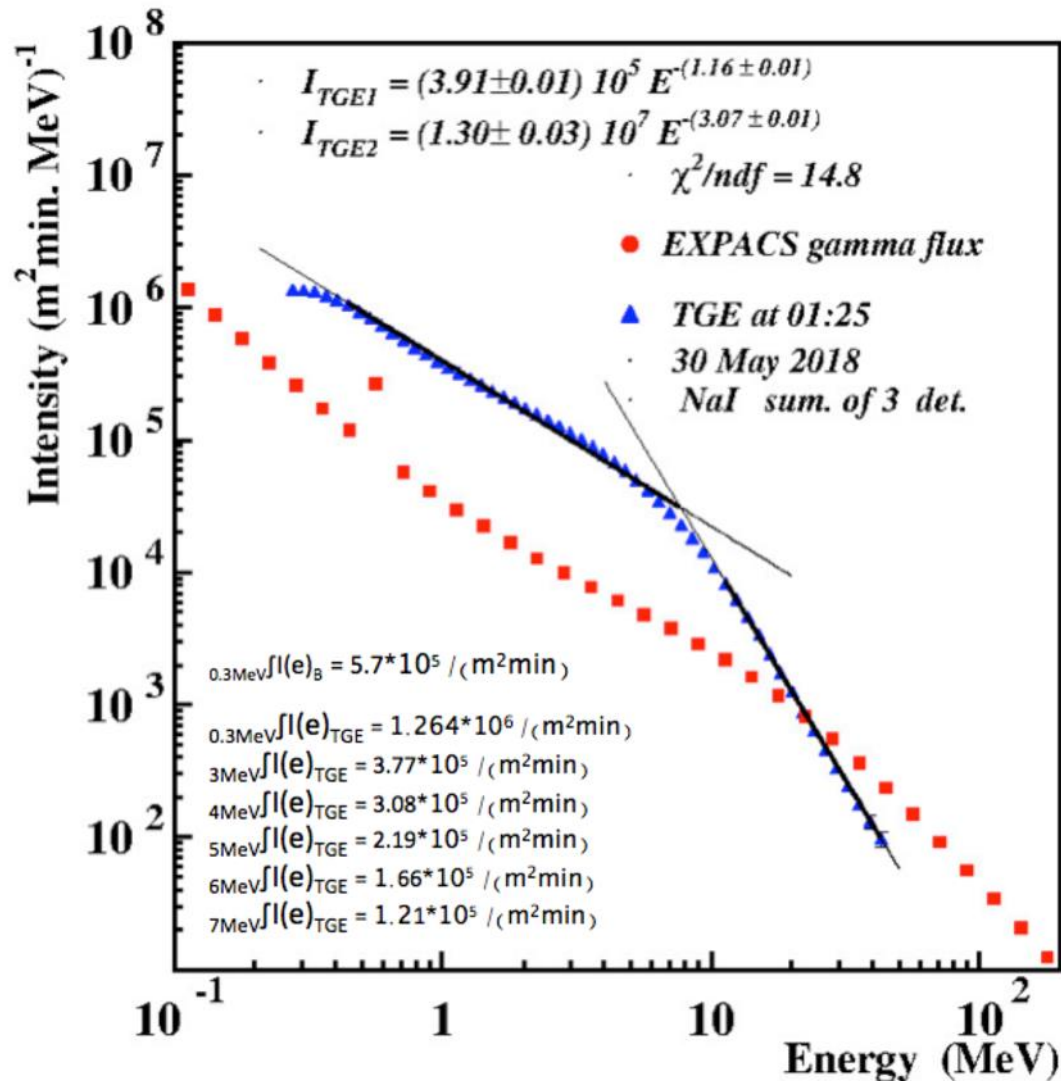


ASNT: 60 cm thick scintillators store energy release histograms each 20 seconds

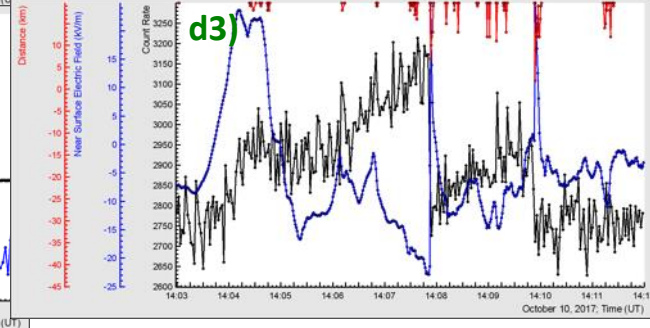
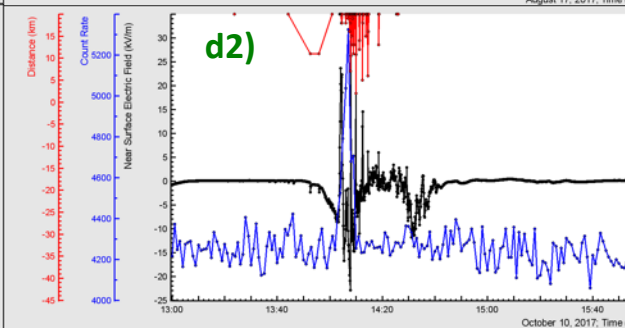
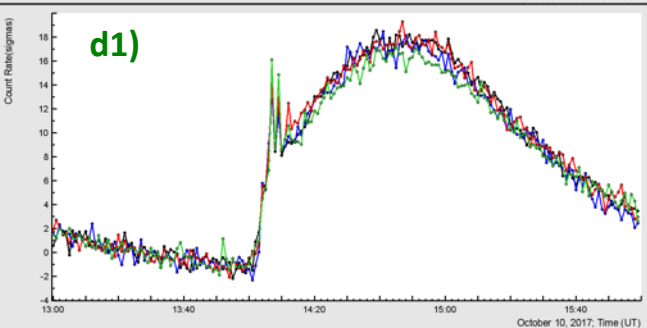
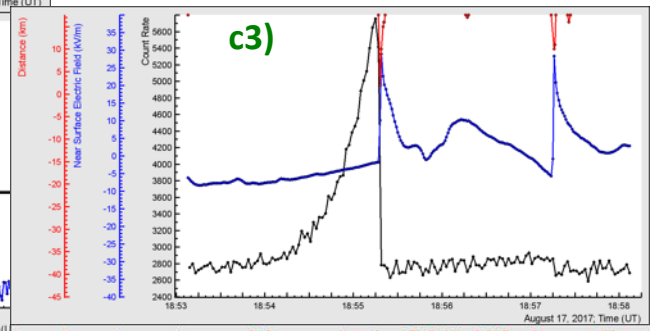
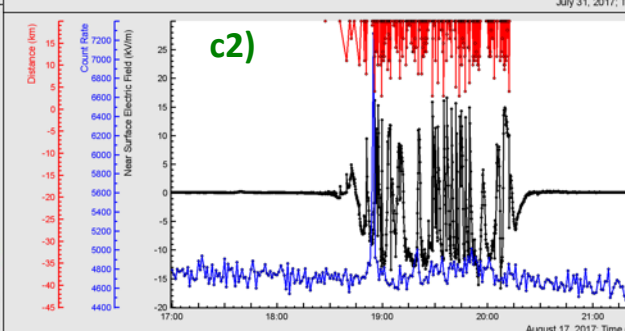
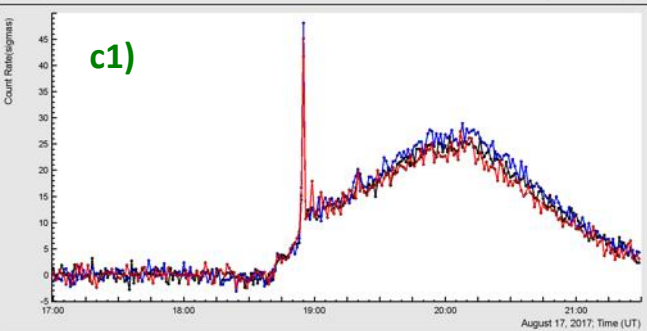
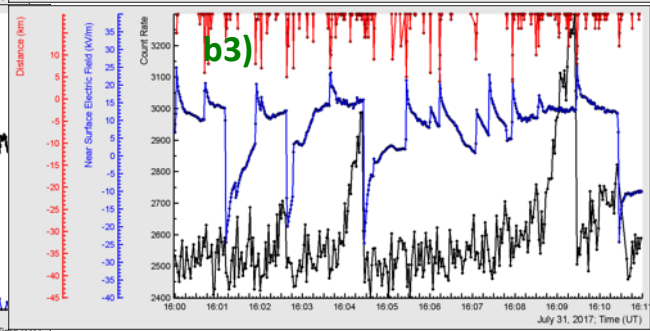
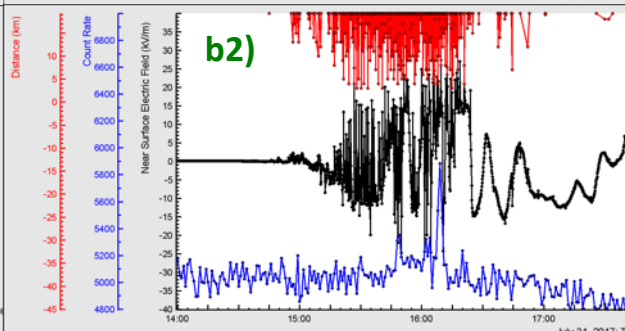
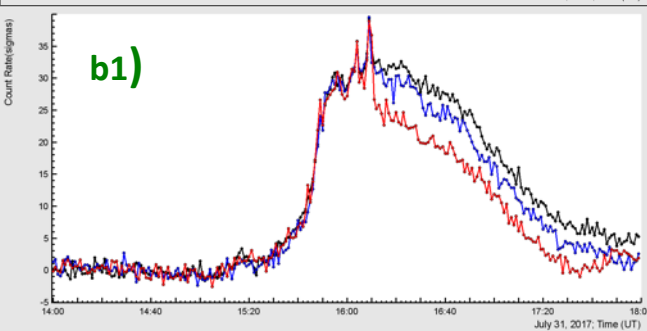
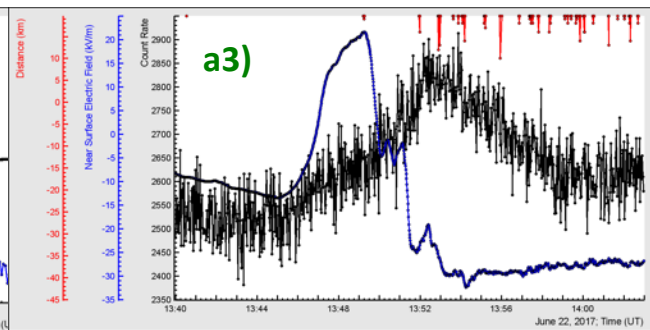
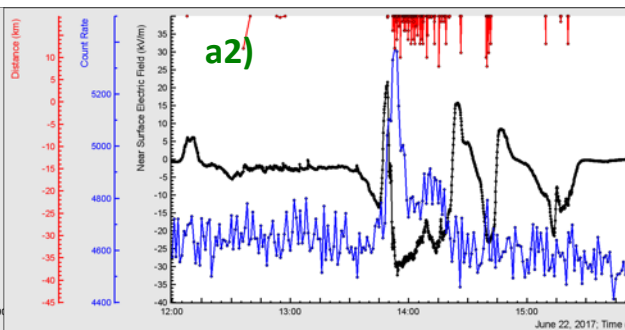
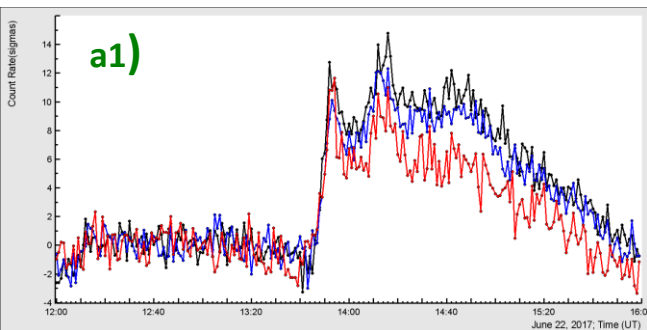
10 October 2017, Recovered fraction of electrons and gamma rays in TGE (cloud height ~ 150m)

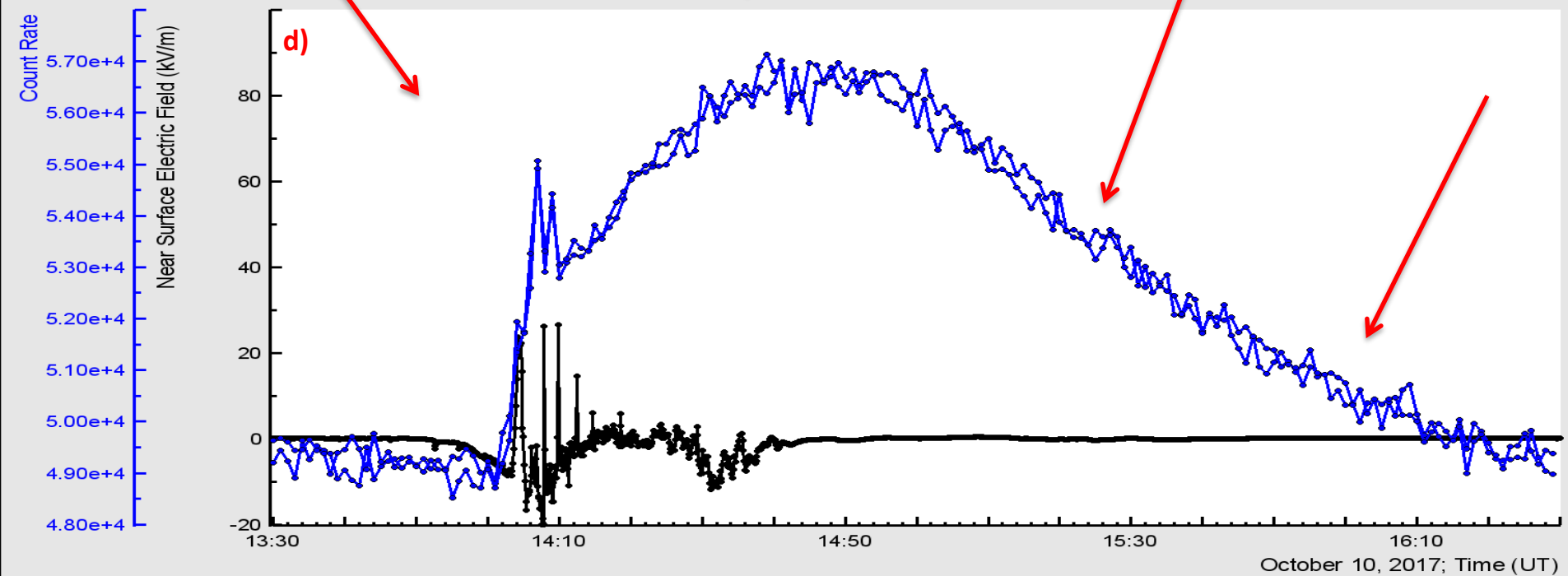
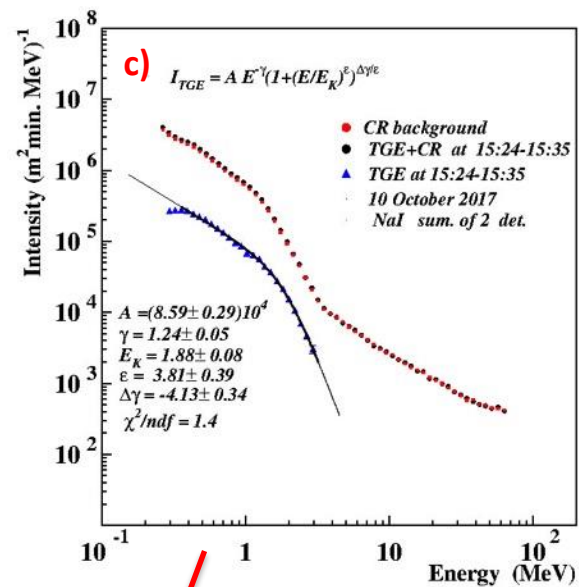
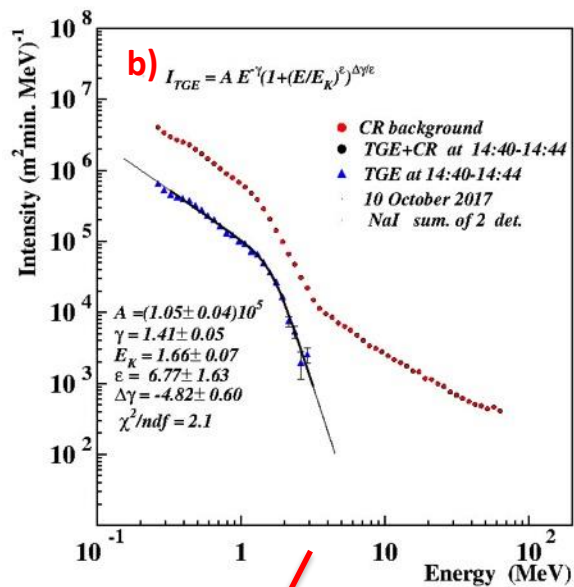
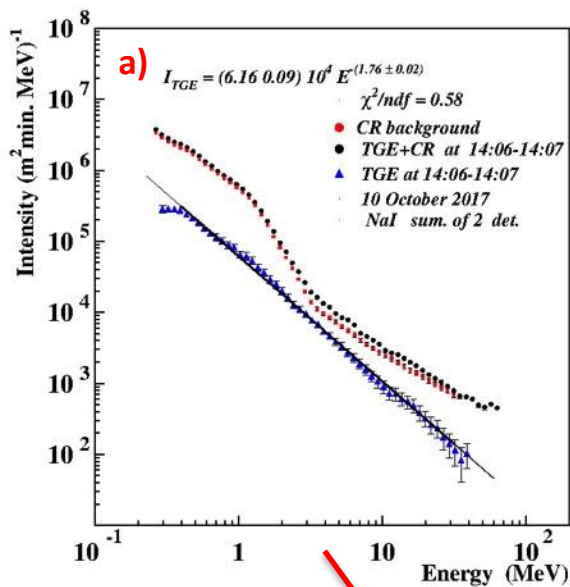


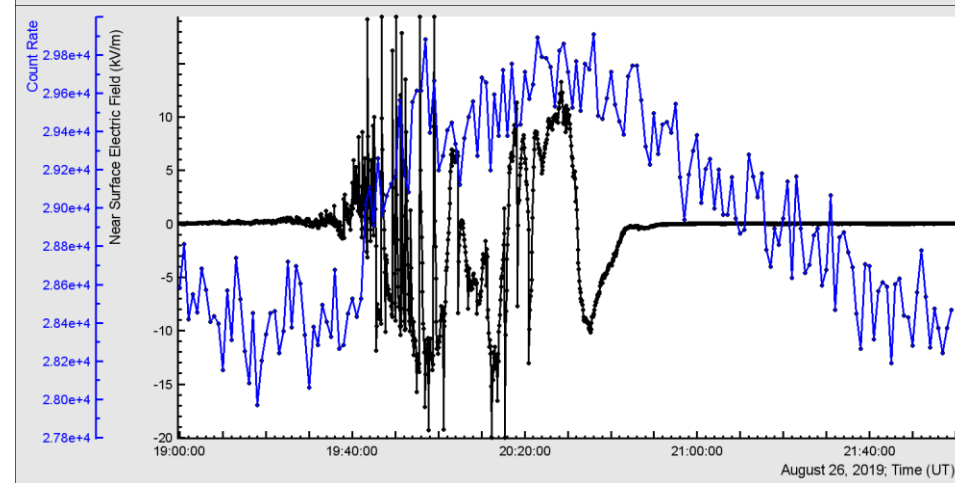
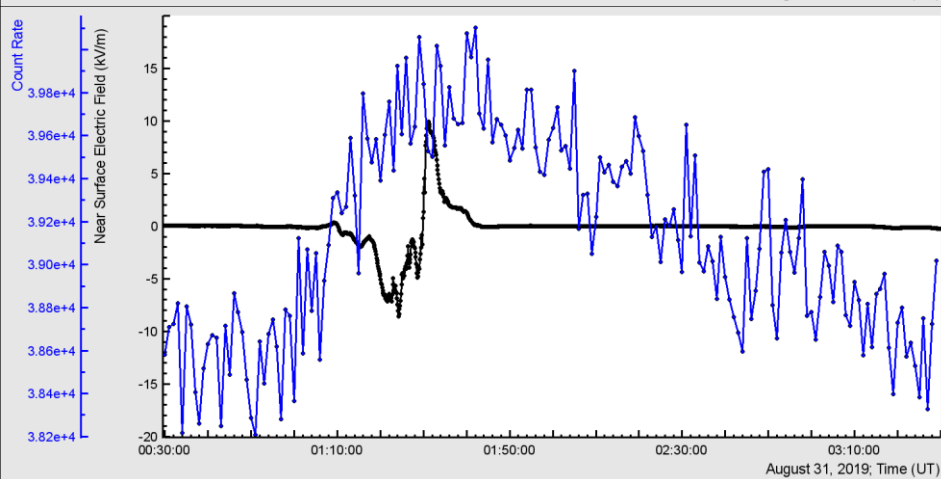
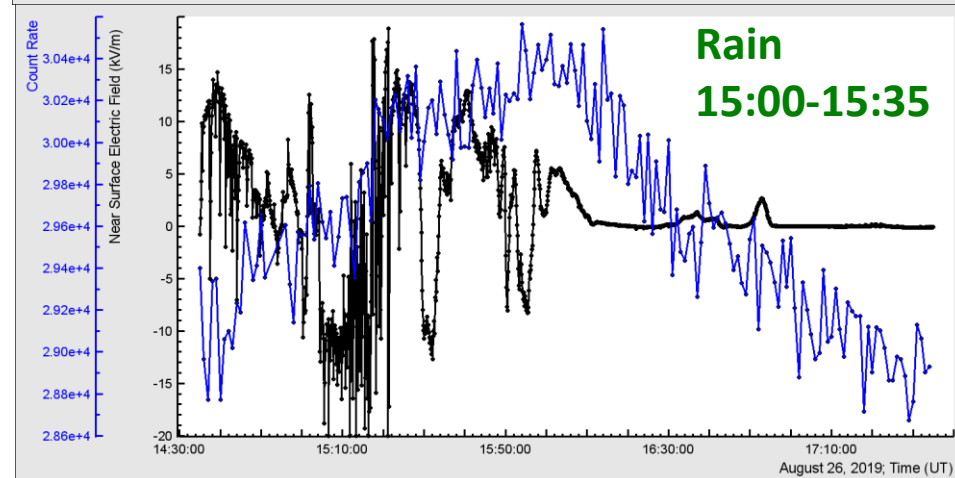
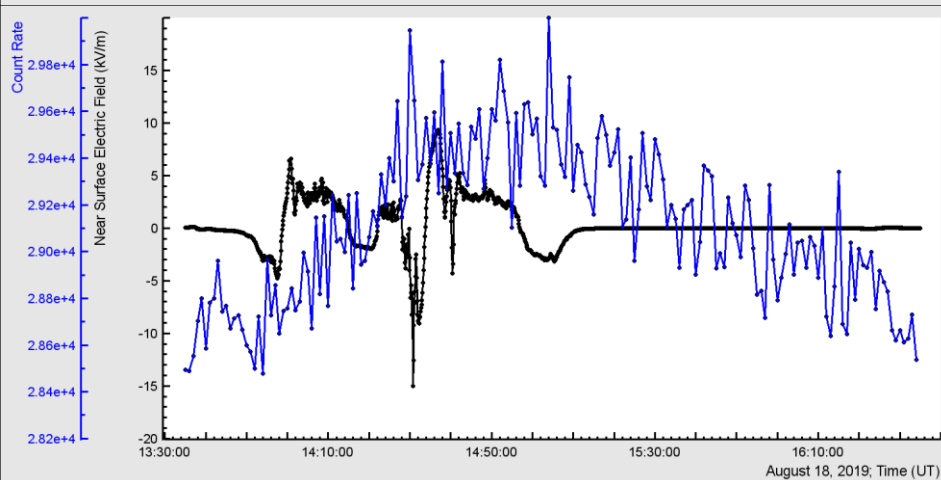
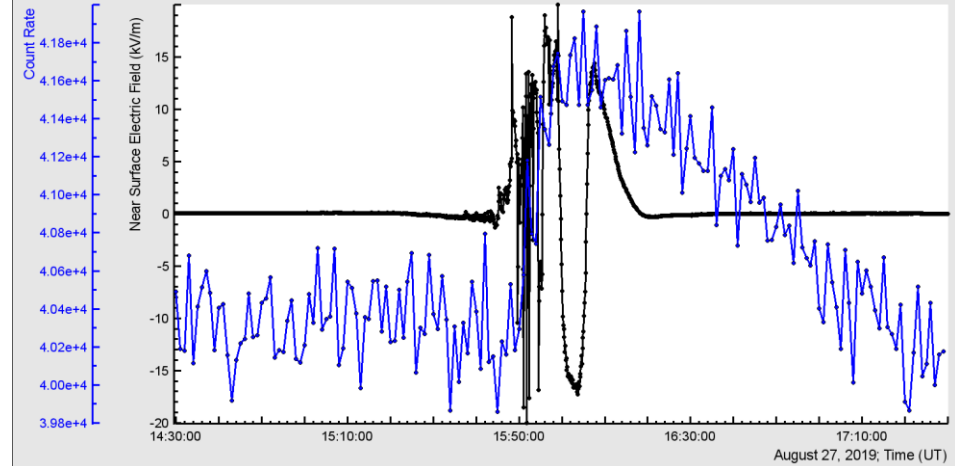
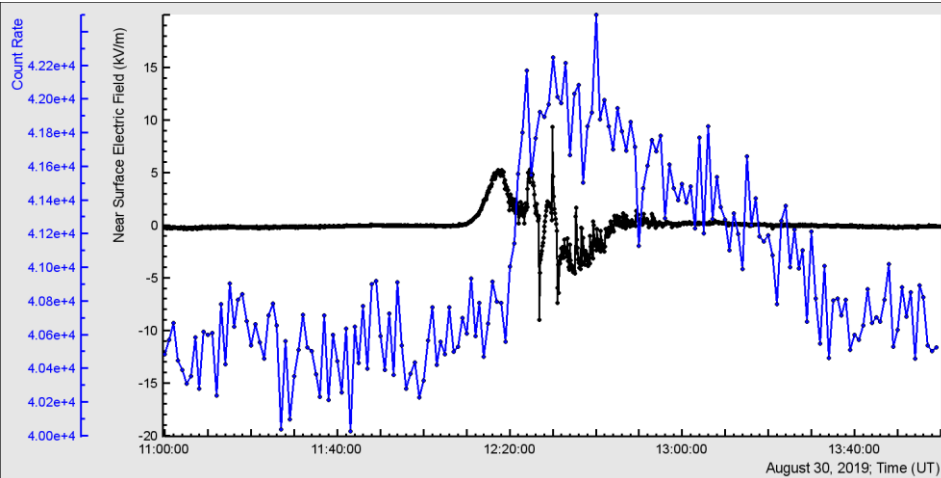
CR background spectrum and TGE spectrum observed on 30 May 2018. In the left bottom corner - values of integral spectrum calculated for different energy thresholds.



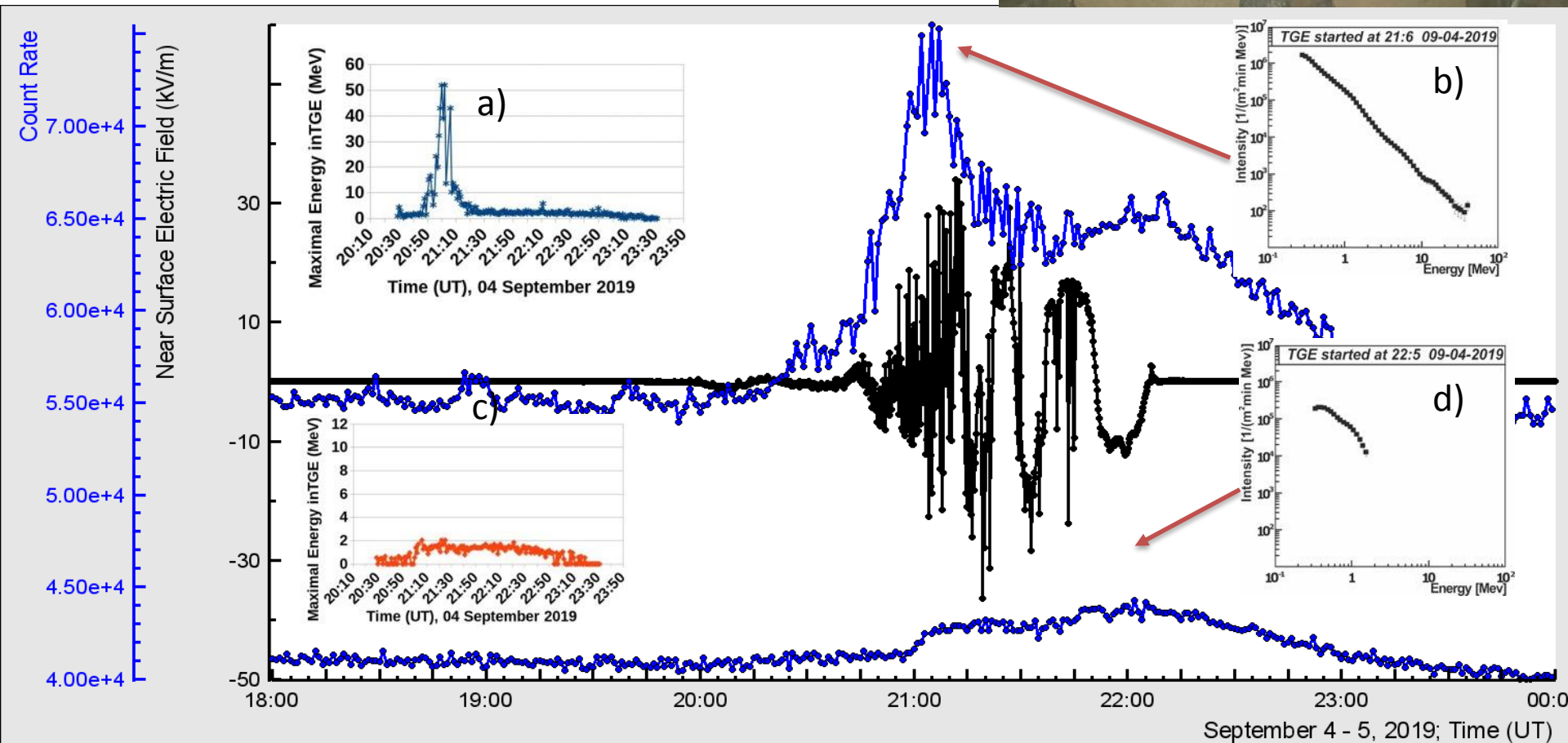
2017 Summer TGEs, Aragats, Armenia



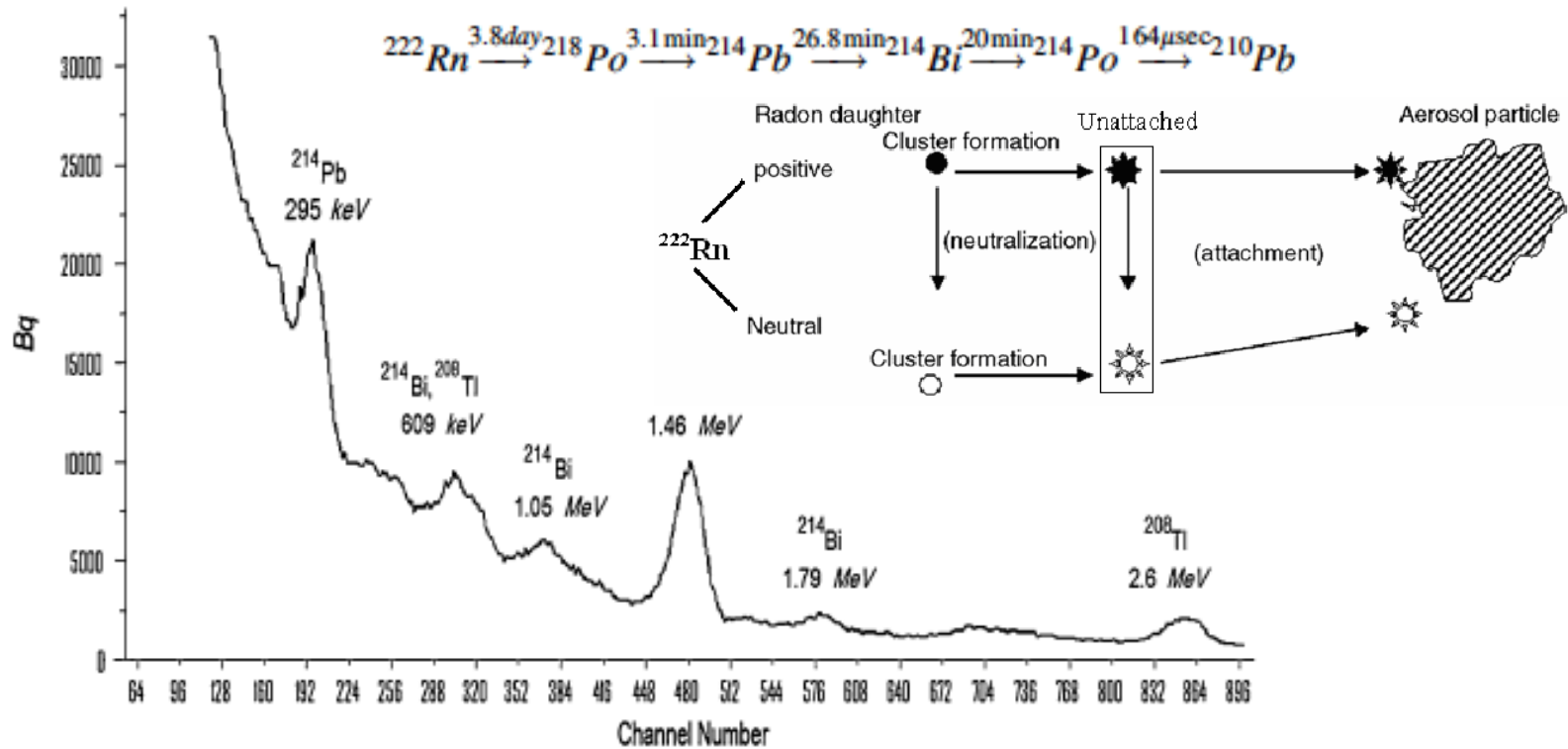




Comparison of TGE registered by NAI 1 (energy spectrum at 15:56 prolonged up to 10 MeV) and 4 (energy spectrum on 15:56 prolonged up to 1.2 MeV)



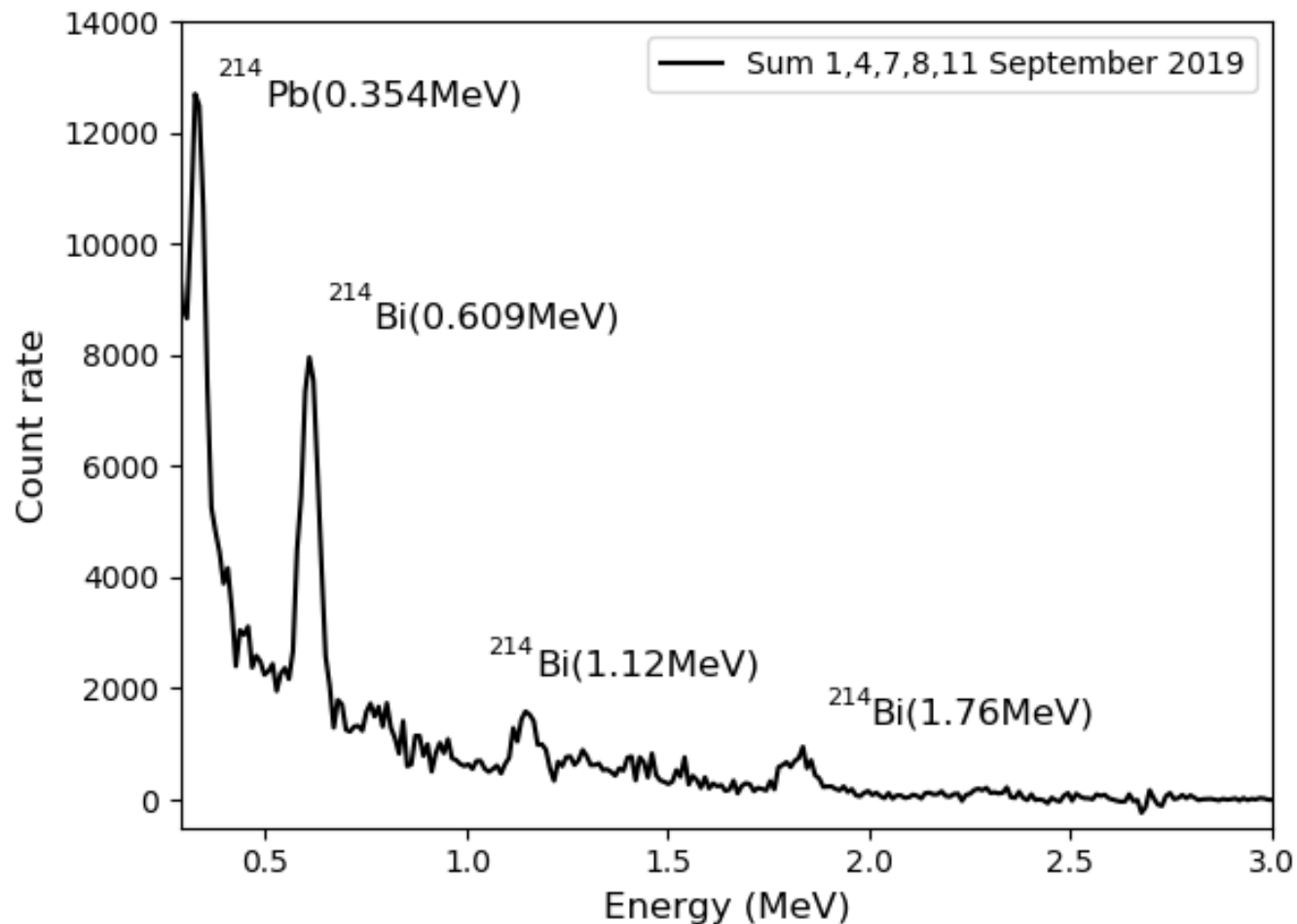
Half live time of ^{222}Rn progenies coincides with TGE measurements!



Opposite to that ^{222}Rn with its much longer half-life $^{222}\text{Ra} = 3.8$ day disperse into the whole atmosphere populating it with progenies from the decay chain:

Owing to their longer half-life ^{214}Pb and ^{214}Bi are the most abundant radon progenies in the atmosphere. The solid radon progenies become airborne and immediately attach to the dust particles, aerosols and water droplets existing in the atmosphere. These particles undergo intensive convection aligning its concentration in the atmosphere (Kumar et al. 1999).

Cumulative spectrum of low energy gamma radiation measured by ORTEC NaI sapectrometer



Inverse TGFs and afterglows

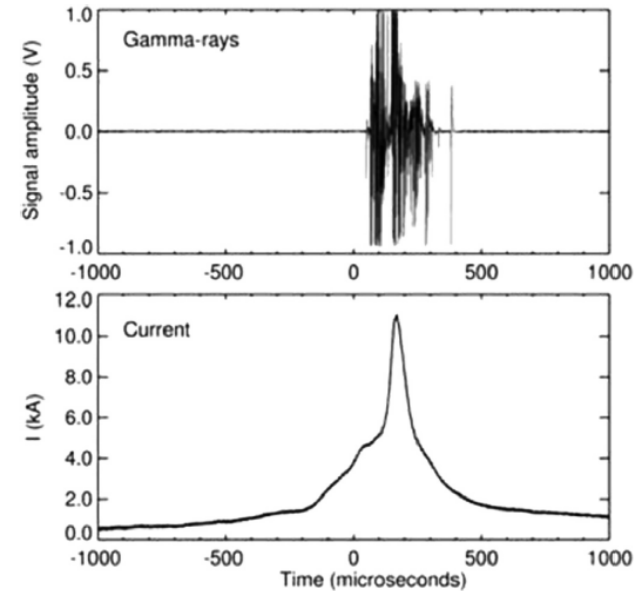
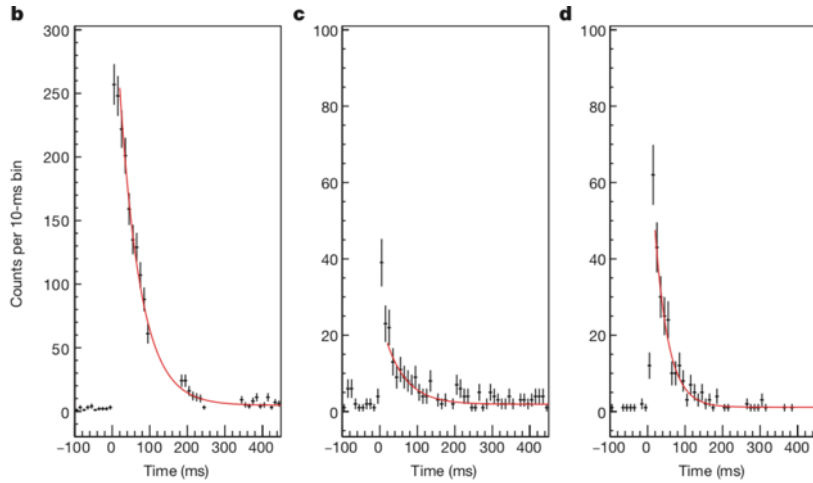
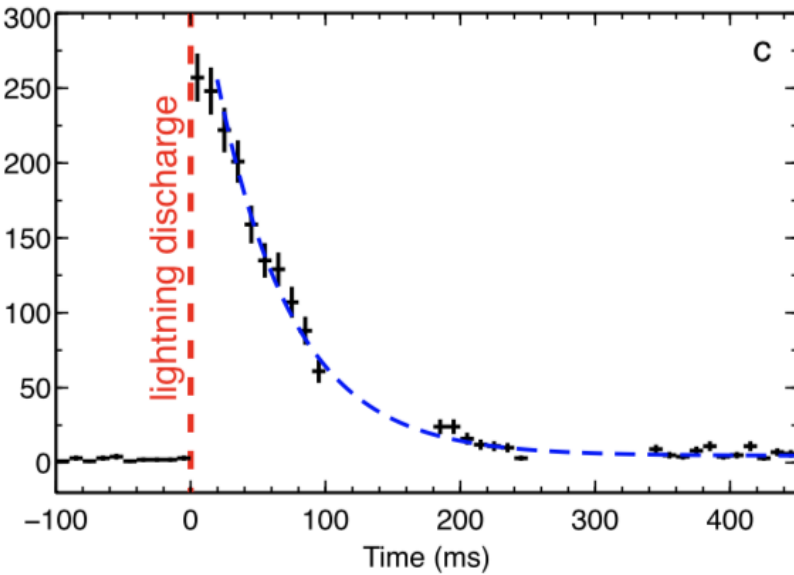
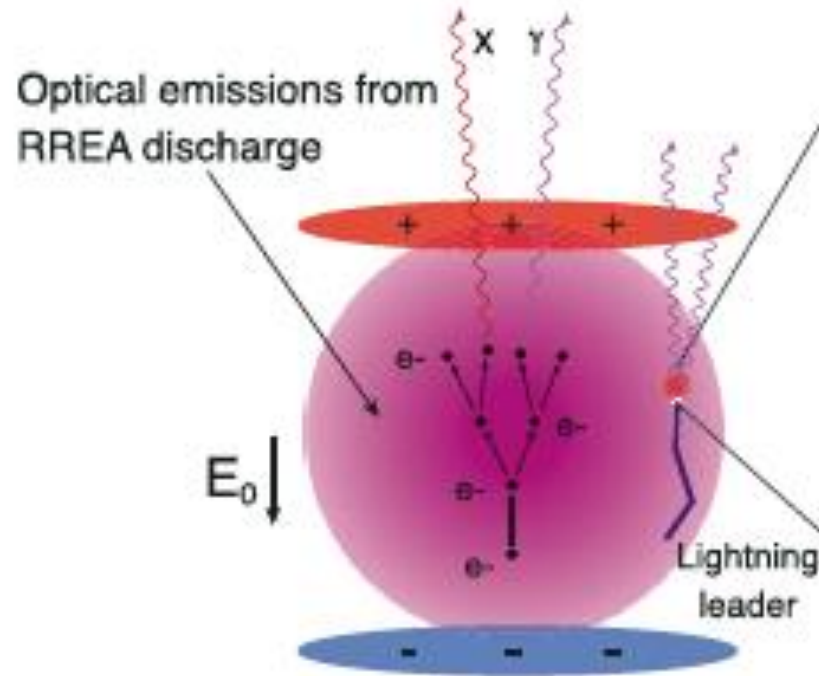


Fig. 7. TGF observed on August 15 2003, shown on a 2 - ms time scale. The top panel shows the gamma-ray data as measured by the 12.7-cm NaI detector. The bottom panel shows the electric current data, measured at the lightning channel base. The TGF began when the channel-base current was about 4.5 kA. Adapted from Dwyer et al. (2004).

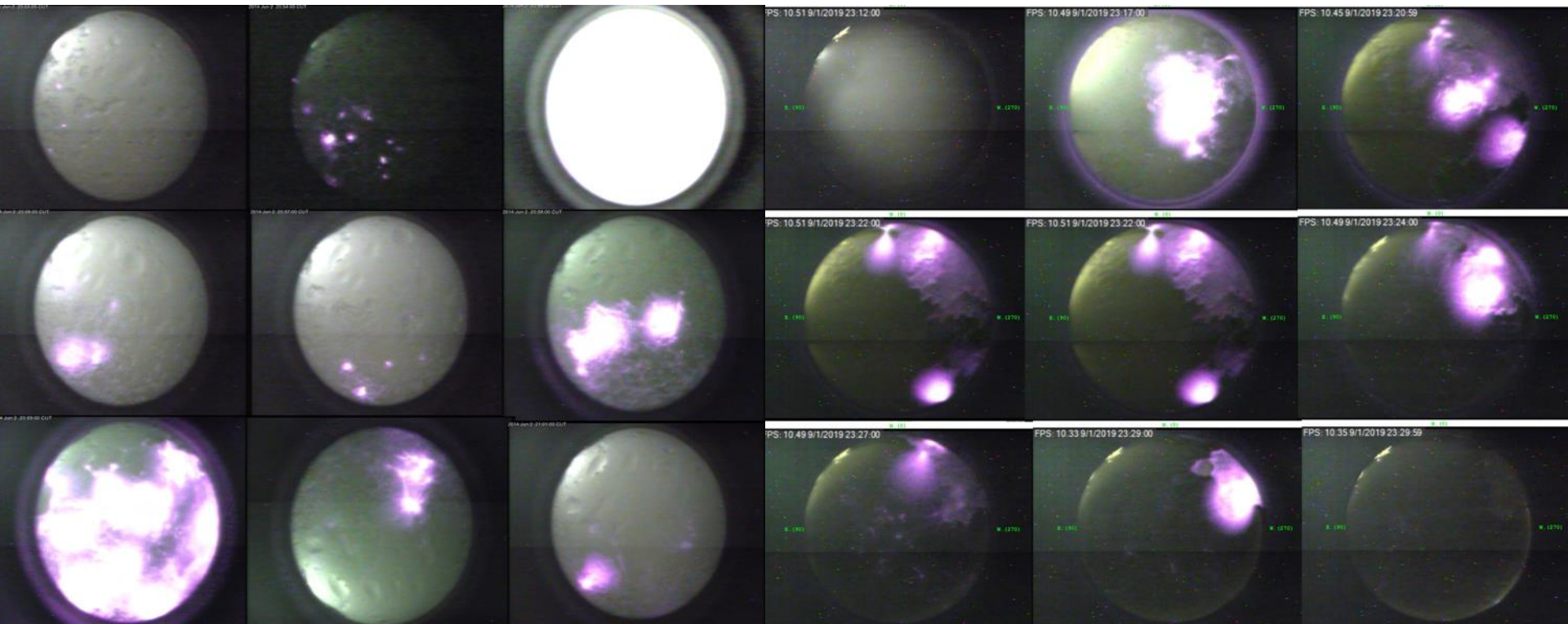


Wei Xu, Sebastien Celestin, and Victor Pasko, Optical emissions associated with terrestrial gamma ray flashes

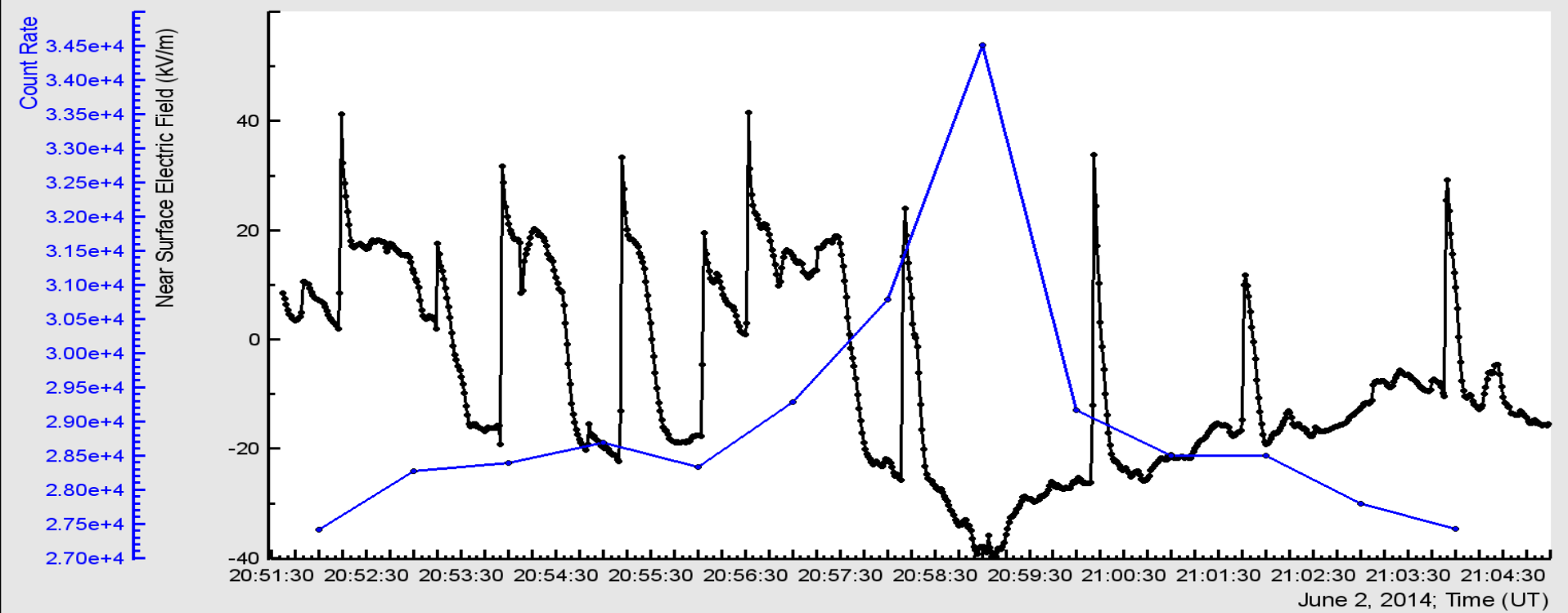
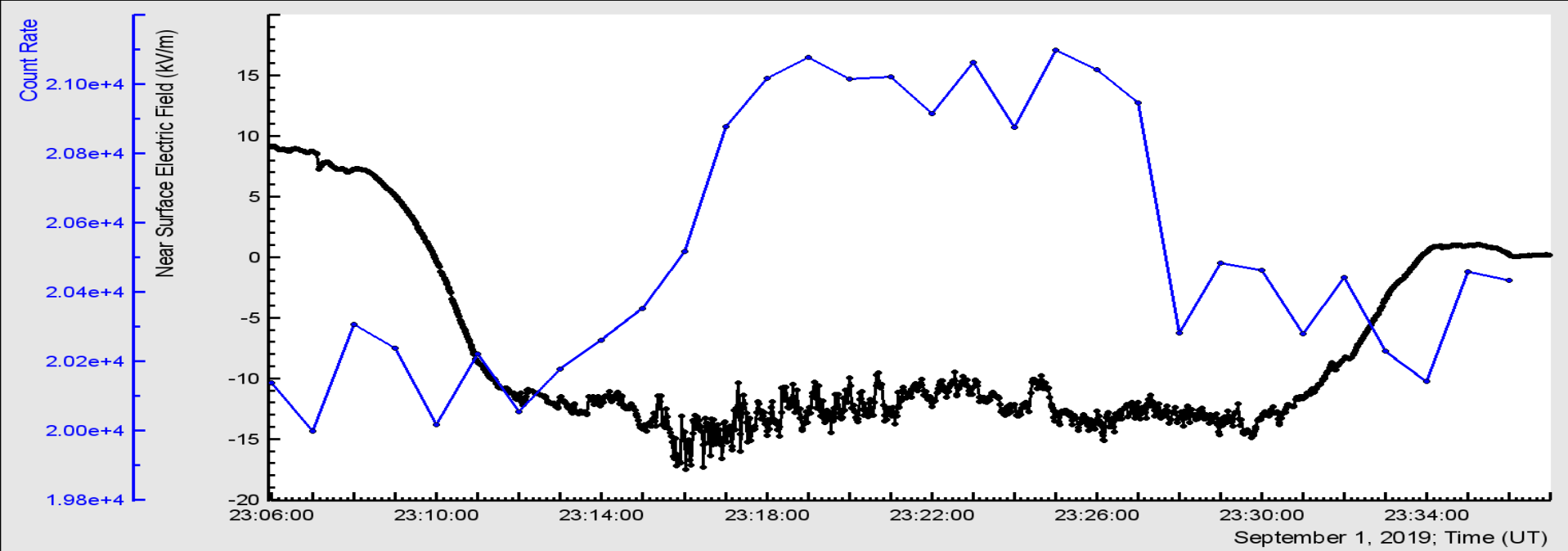


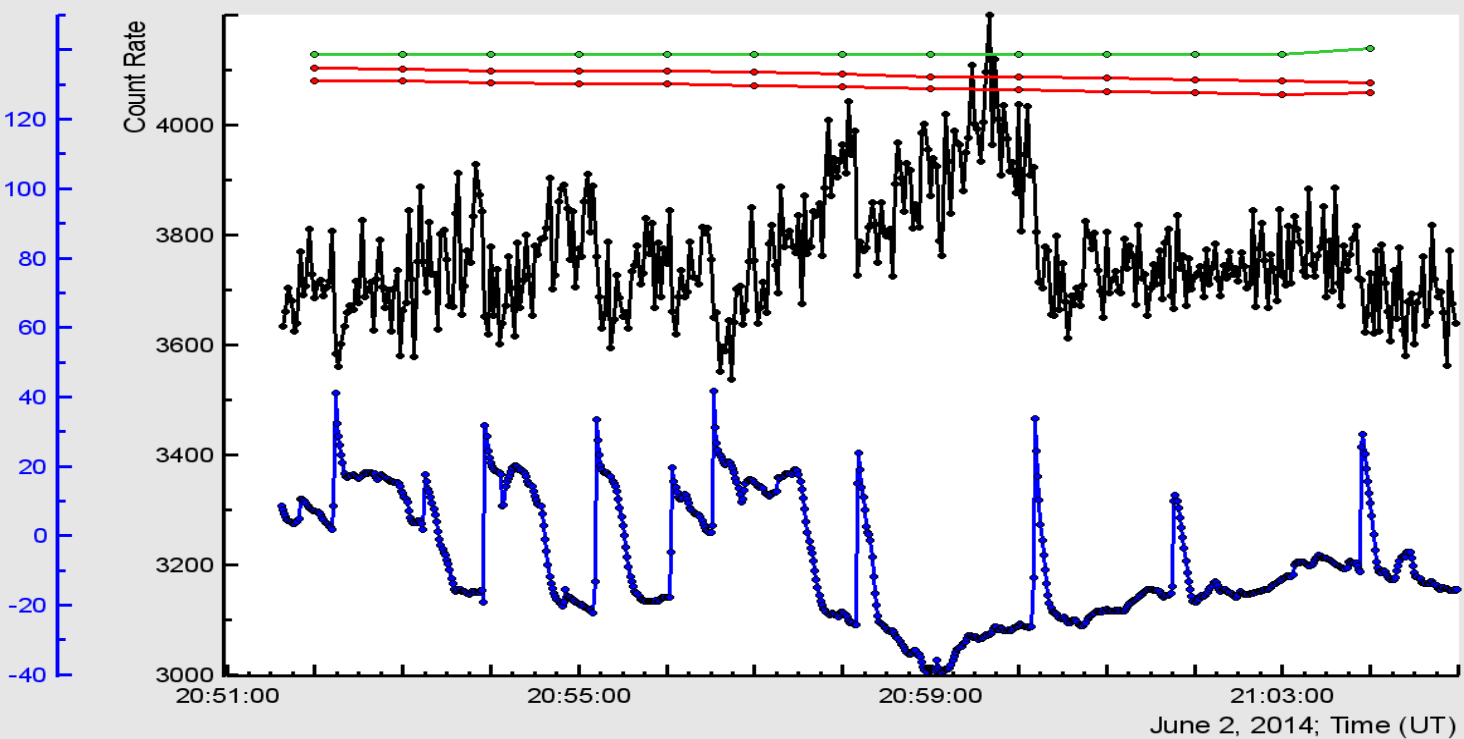
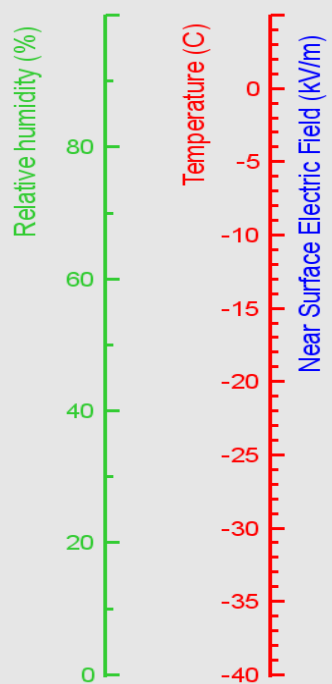
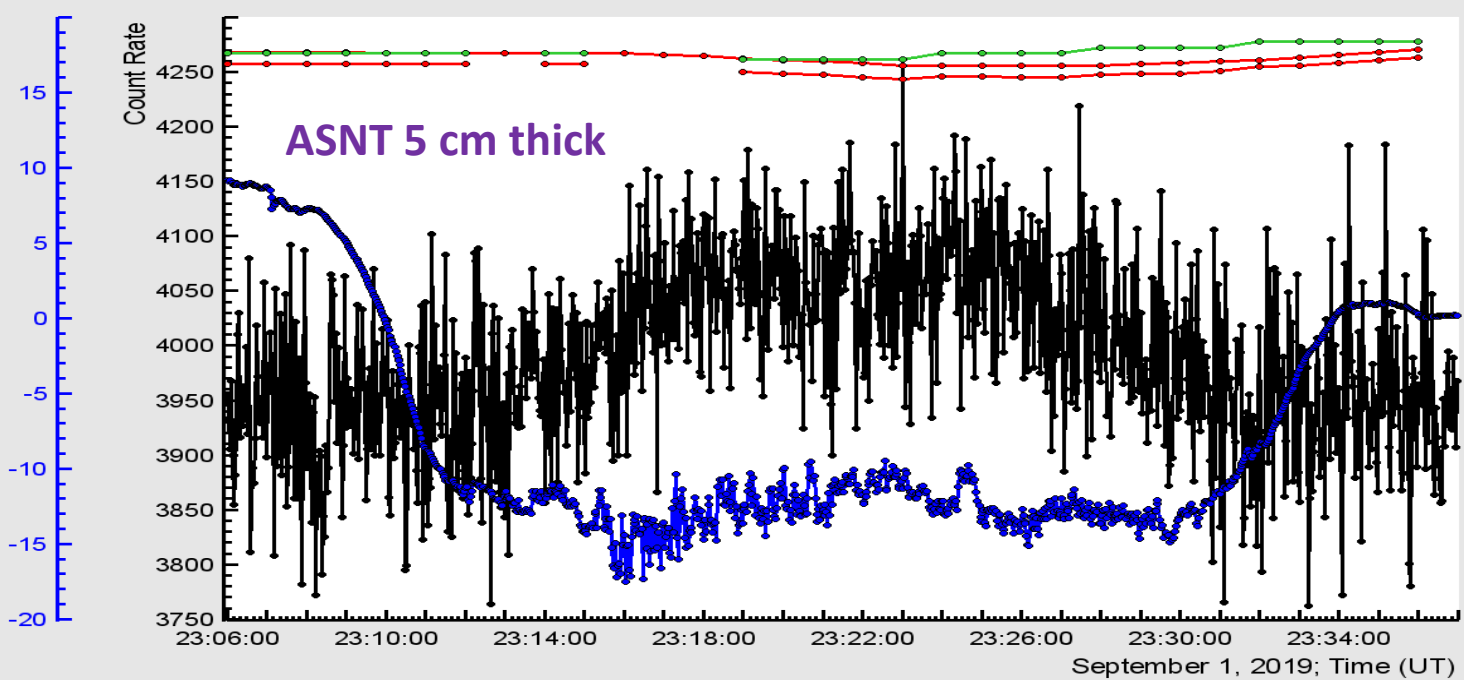
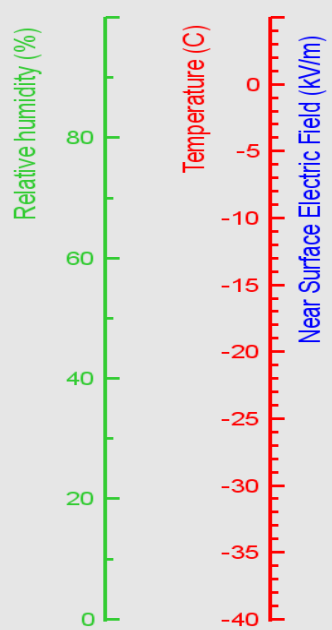
From the knowledge of the electron energy distribution, we have quantified the optical emissions that are possibly generated during the production of TGFs. Modeling results indicate that TGFs are most likely accompanied with detectable levels of optical emissions.

Optical images of RREA



2 June 2014 glow, 8 minutes lightning flashes 1 September 2019, 15 minute glow no flashes





VHF interferometer (24-82 MHz) for lightning location

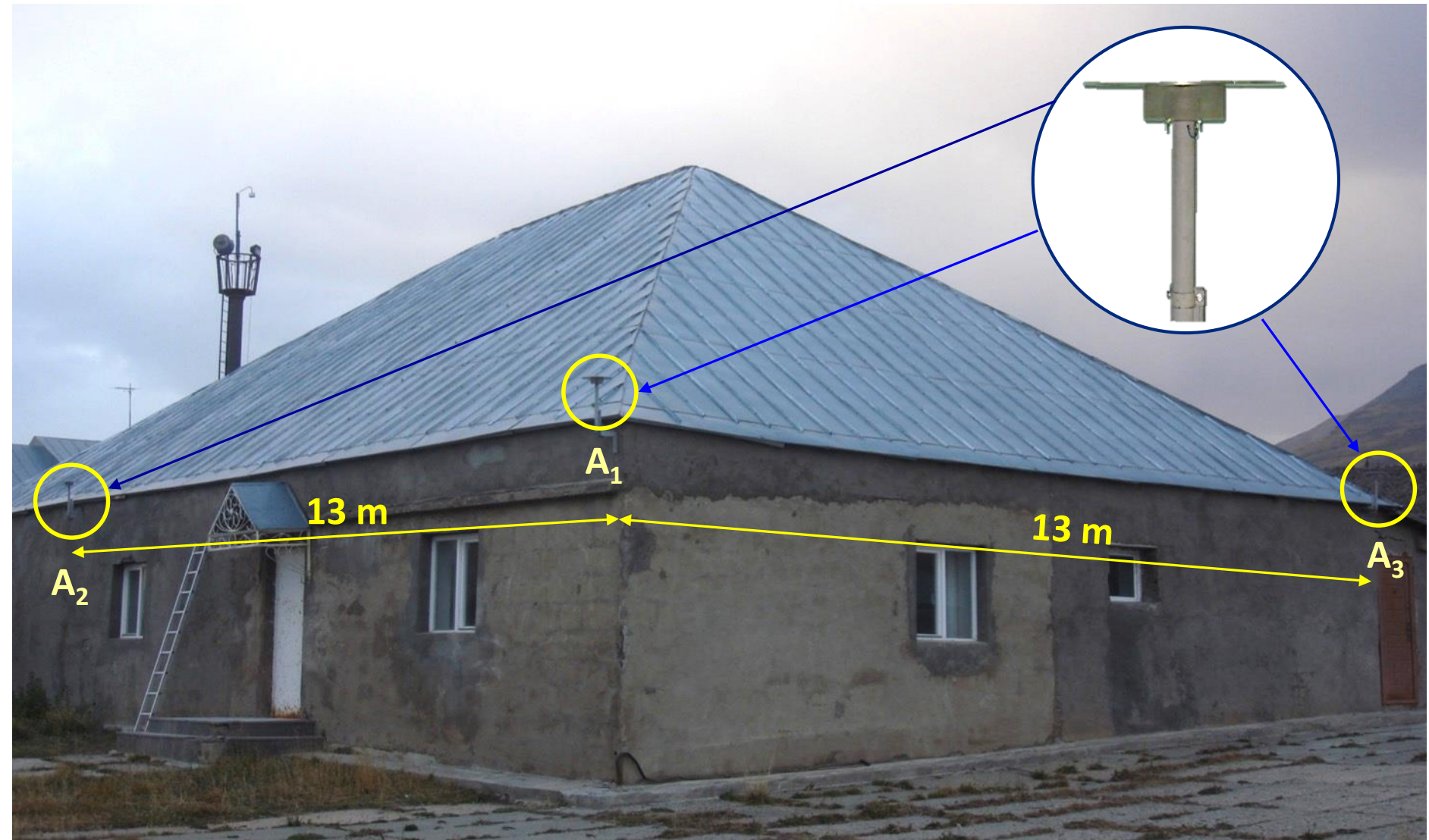


An instrument which determines the direction to a lightning-produced radio point source with microsecond time resolution by correlating the signal received at two or more antennas

Interferometer

- Nearly 400 lightning flashes detected in 2019 (100 ~ 270 in 2018). I will take several months to analyze all data acquired during 2019.
- Analysis software tuned; different modes of filtering tested;
- Cabling improved. Signal/Noise ratio significantly enhanced by installing low noise broadband amplifiers;
- Analysis of interferometer data combined with analysis of data of fast wideband electric field and near-surface electrostatic field , as well as the WWLLN data is in progress.

Three flat plate antennas of VHF interferometer installed at SKL hall of Aragats station



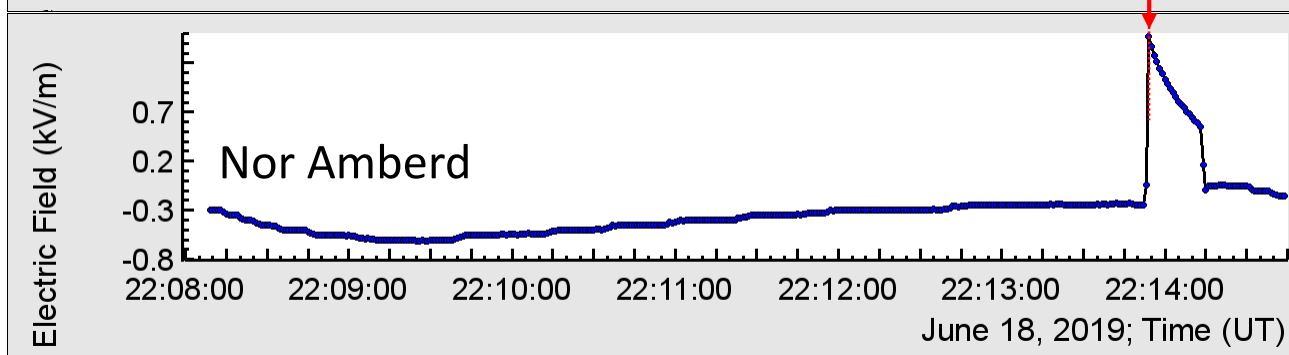
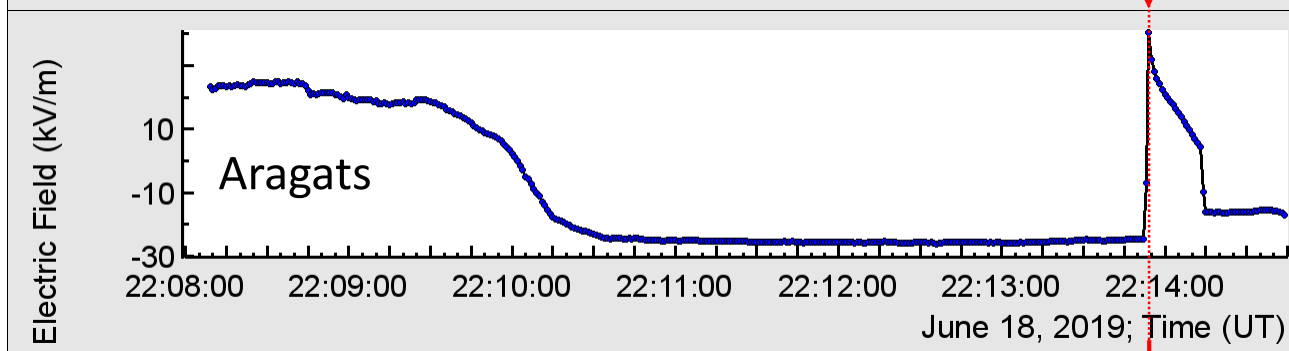
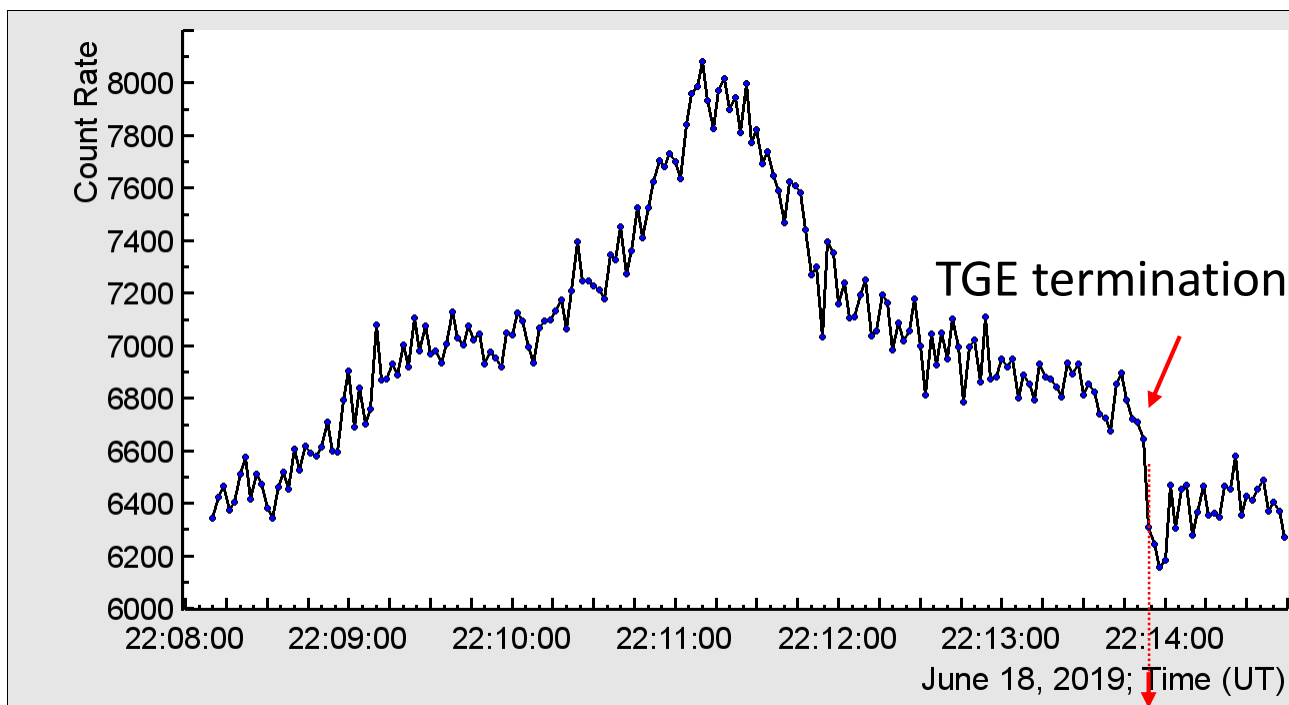
June 18, 2019, 22:13:53.661

TGE terminated by –CG lightning flash

TGE shown in next slide was recorded by the ASNT detector, coincidence One 60cm-Zero 5cm. Electrostatic field change ΔE is positive in Aragats and Nor Amberd, polarity reversal was not detected. Fast electric field record shows wide pulses, that can be attributed to RS pulses of –CG. Identification: -CG

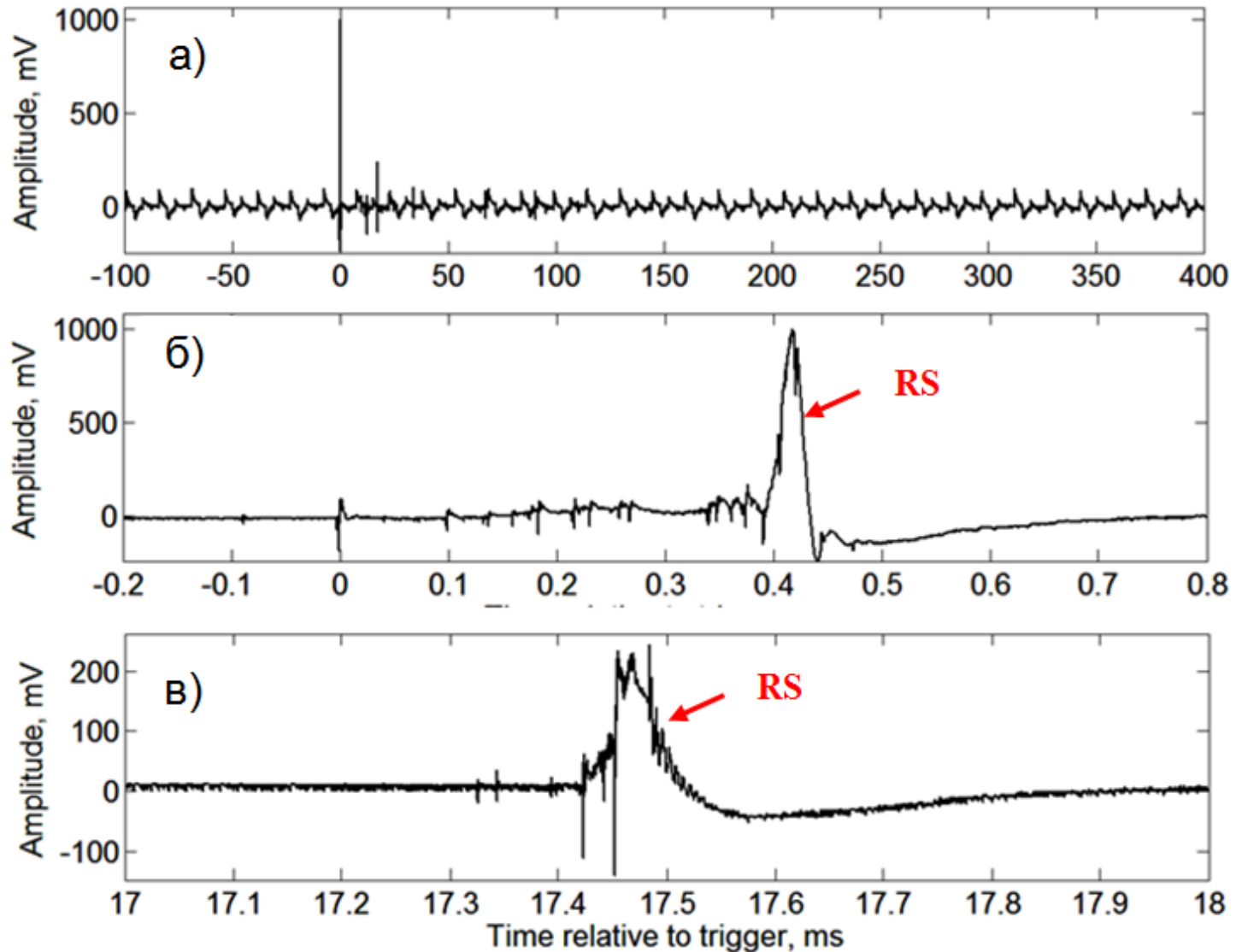
Detected also by WWLLN:

Date	Time	Latitude	Longitude	ResErr	Nsta	Distance	Bearing
18-Jun-19	22:13:53.662	40.5039	44.1846	14.7	10	3.6	3.6
18-Jun-19	22:13:53.662	40.5089	44.1771	11	5	4.2	-5.5



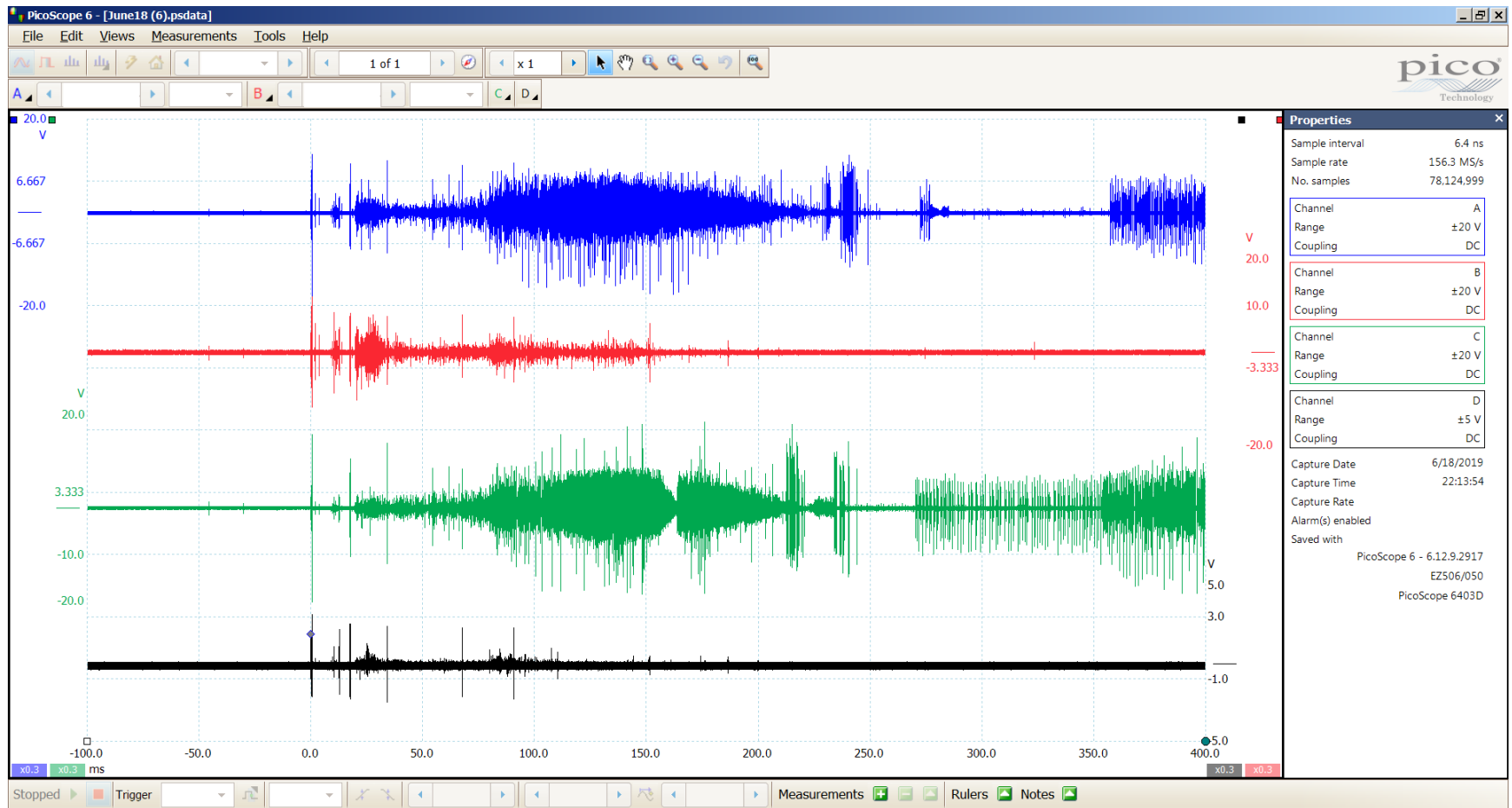
June 18, 2019, 22:13:53.661

Fast electric field



June 18, 2019, 22:13:53.661

VHF interferometer record

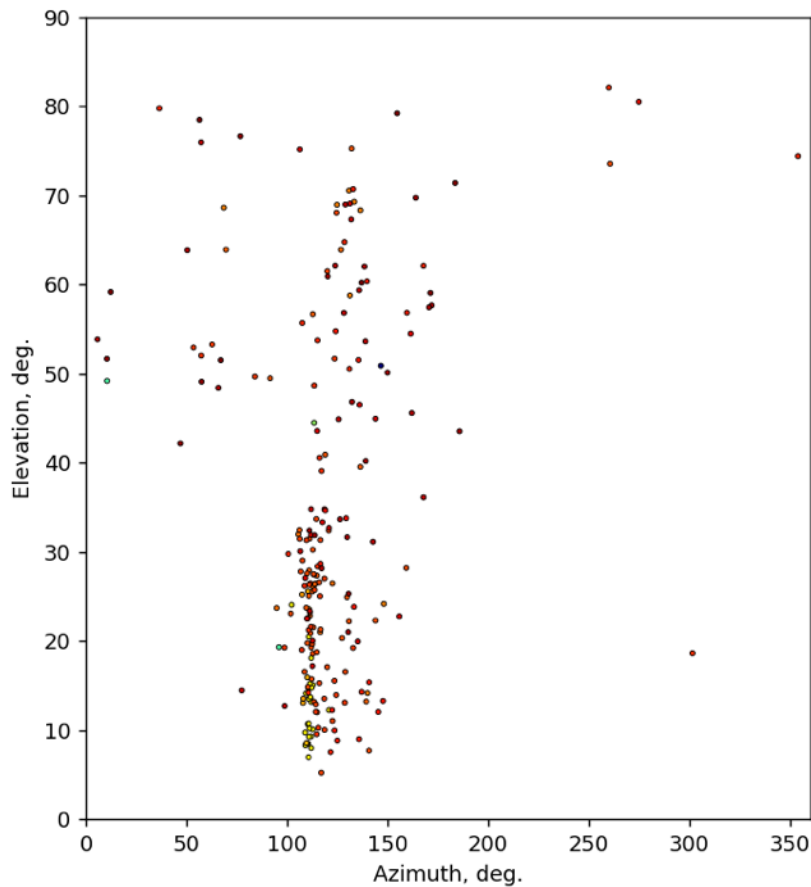


June 18, 2019, 22:13:53.661

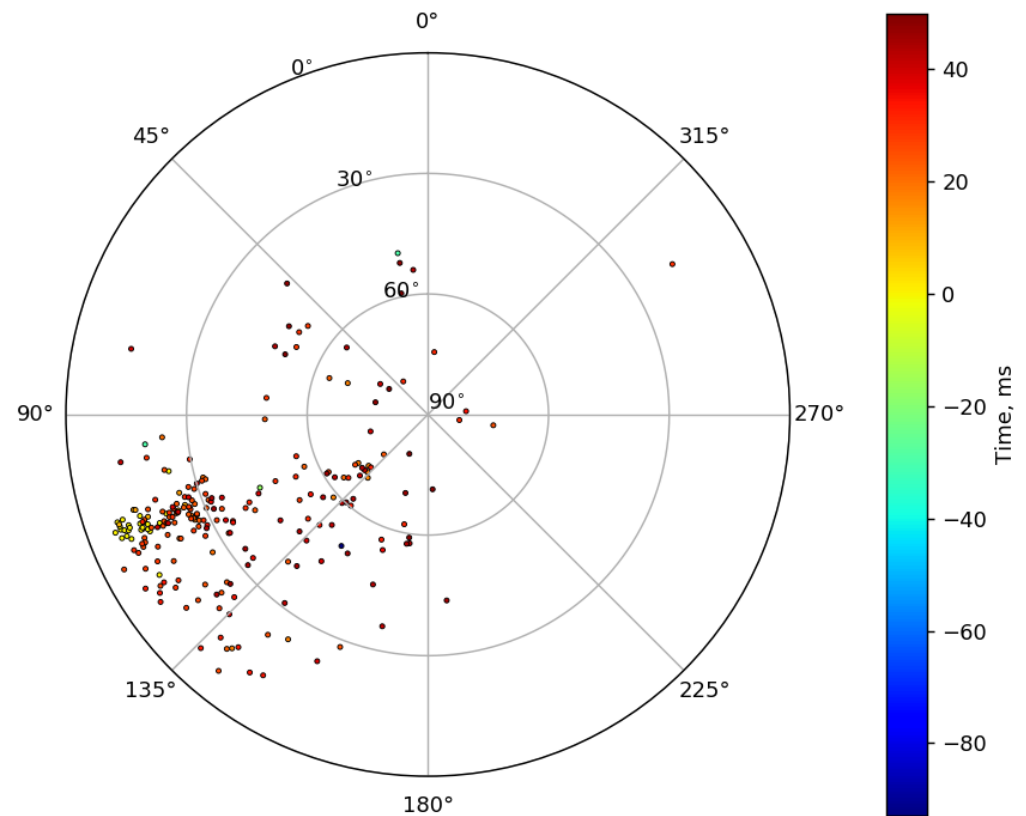
Cloud-to-ground lightning detected by interferometer

Time window: from -100 ms before trigger to 50 ms after trigger

Color indicates time



Rectangular sky plot

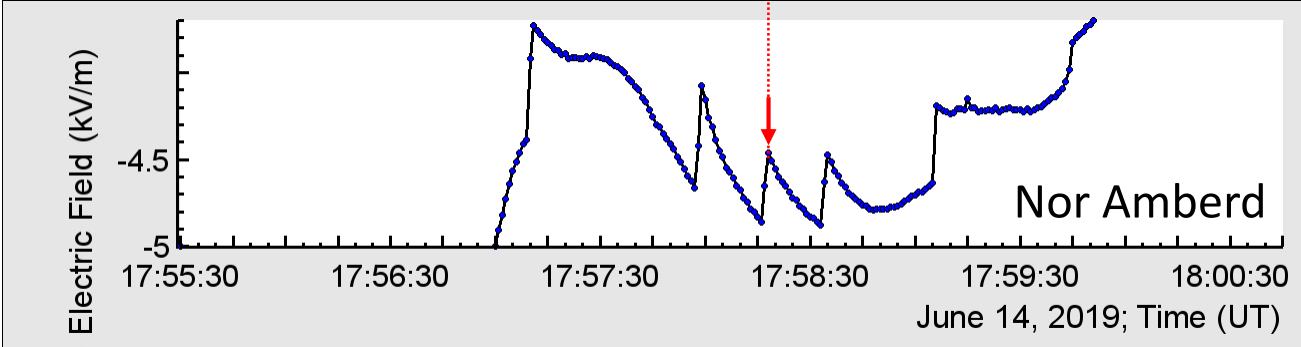
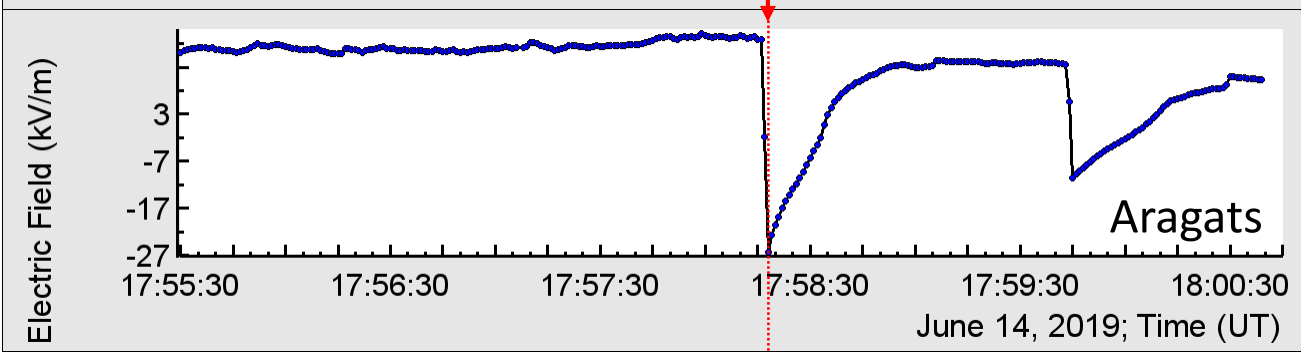
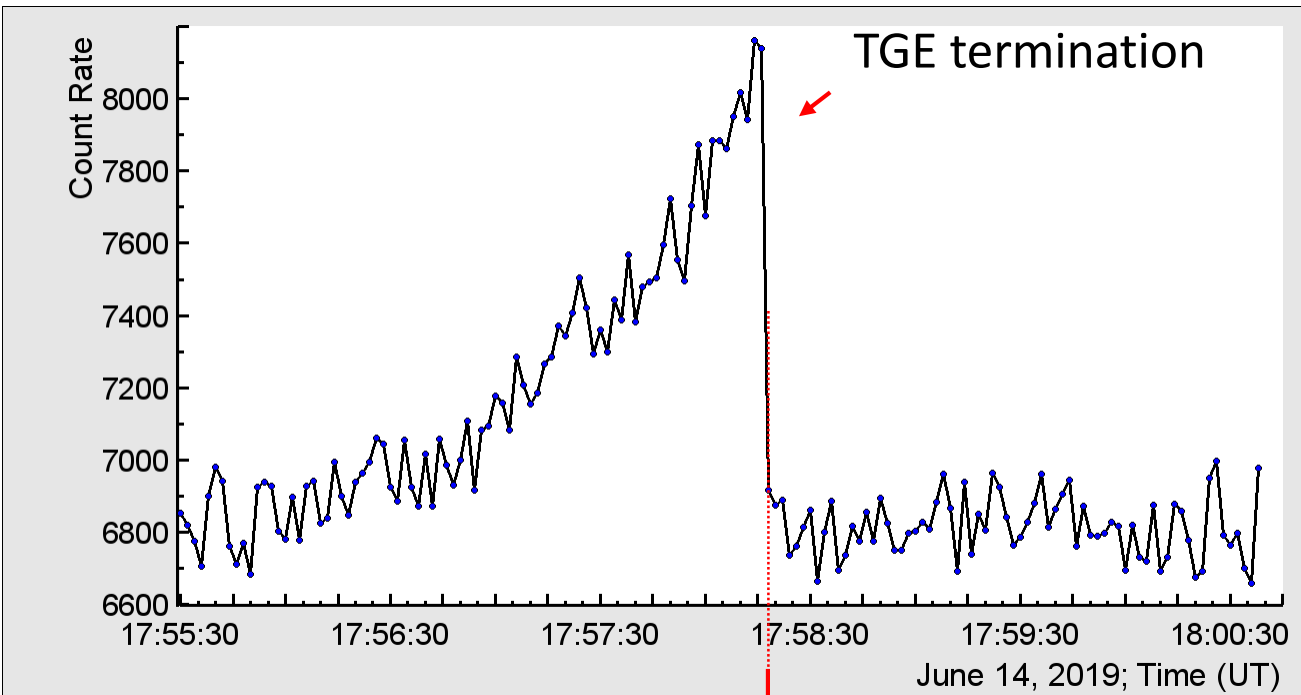


Polar sky plot

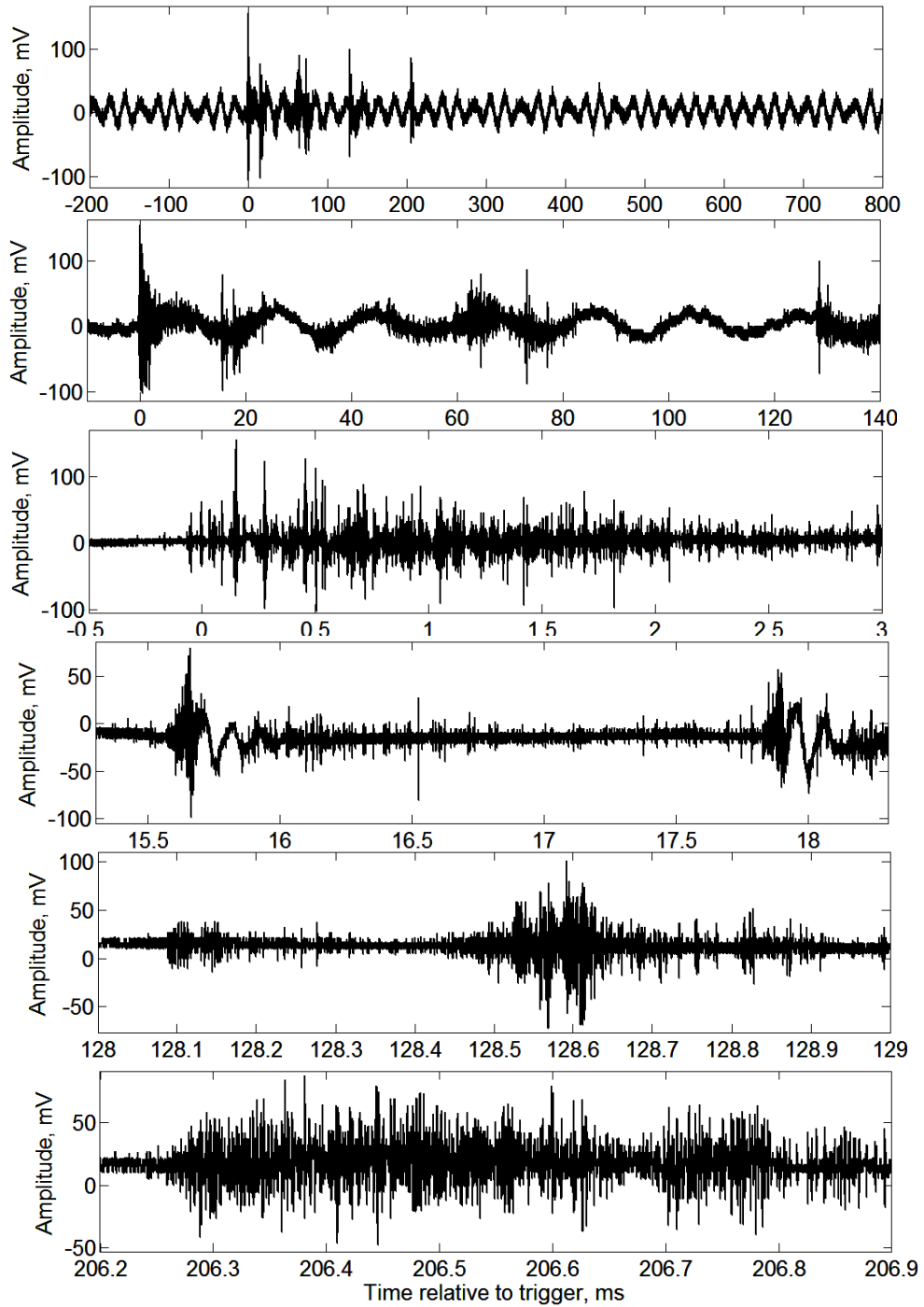
June 14,2019, 17:58:17.473

TGE termination by inverted-polarity IC
ASNT detector, coincidence One 60cm-Zero 5cm

Electrostatic field ΔE change is negative in Aragats and positive in Nor Amberd, that is polarity reversal of ΔE is detected. Larger ΔE corresponding to closer station is negative. Fast electric field record contain only short pulses indicative of cloud discharge. Identification of lightning type: inverted-polarity IC

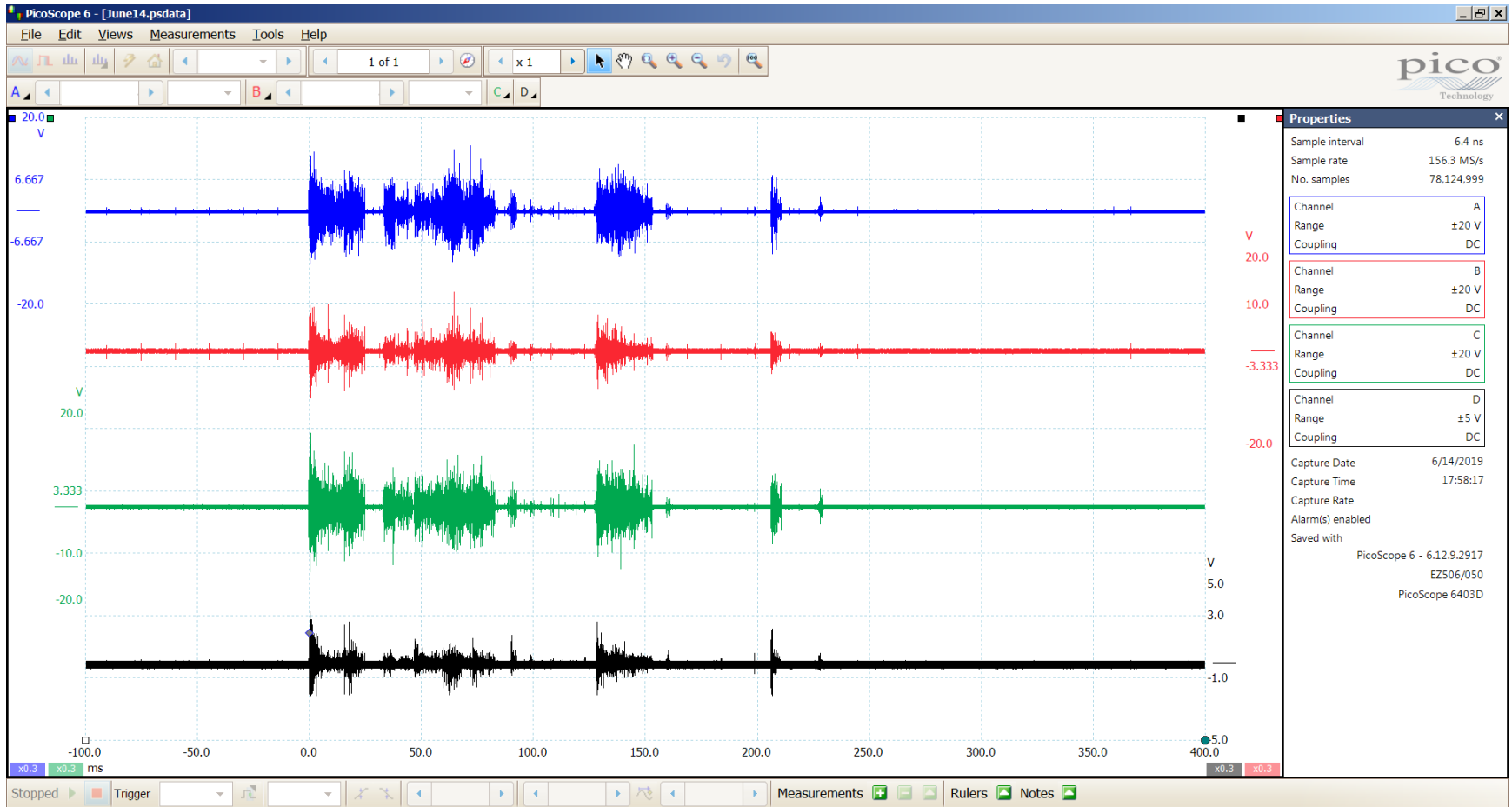


June 14, 2019 17:58:17.473 Picoscope N3 MAKET



June 14, 2019, 17:58:17.473

TGE termination

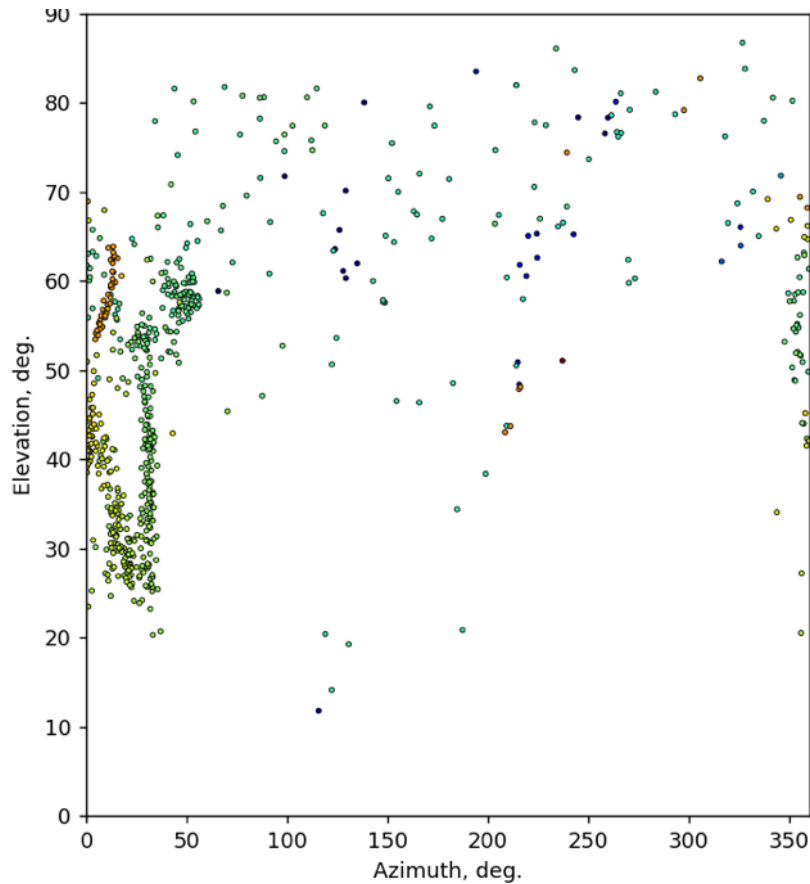


June 14, 2019, 17:58:17.473

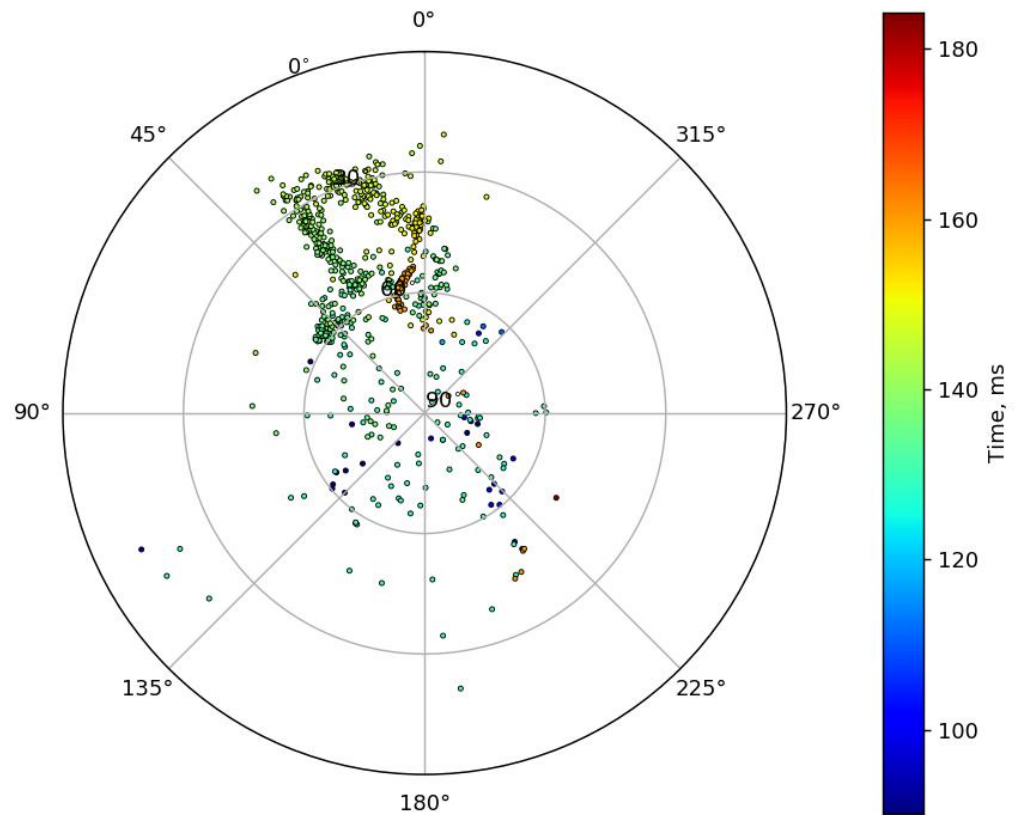
Inverted IC flash detected by interferometer

Time window: from 90 ms to 190 ms after trigger

Color indicates time



Rectangular sky plot



Polar sky plot