Atmospheric Gamma-Ray Time Profiles Measured During Thunderstorms in Moscow Region and at Aragats Station

Vitaly Bogomolov

SINP MSU

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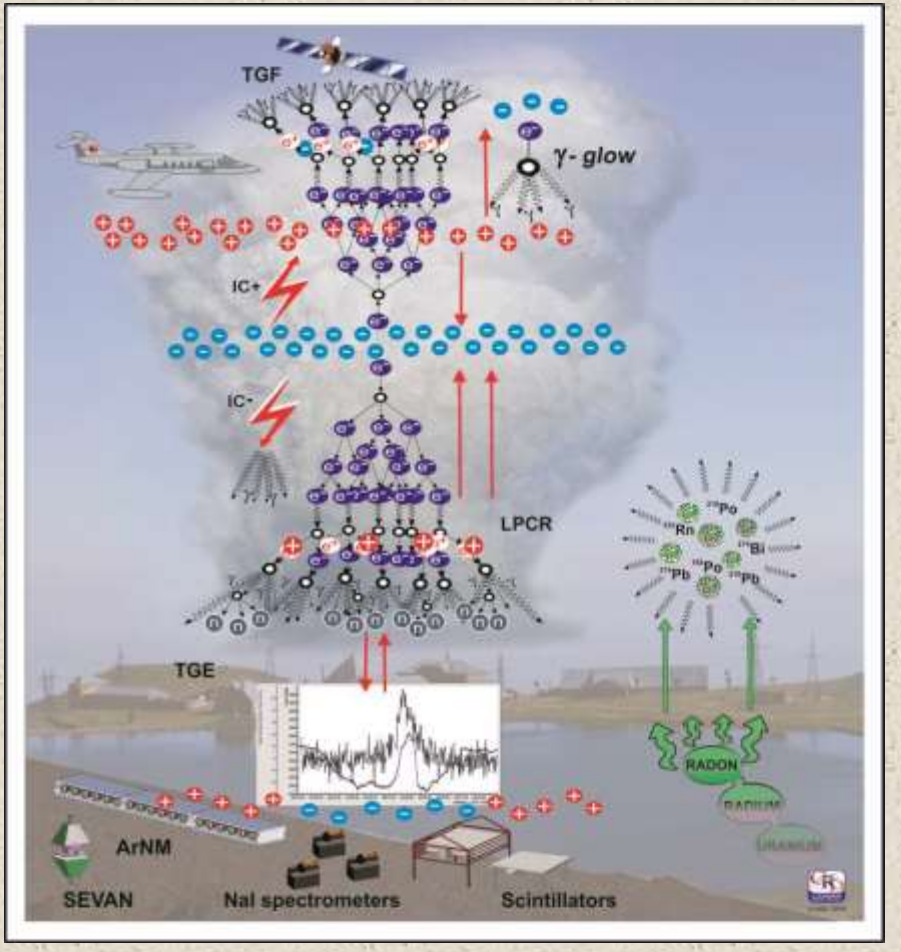
Sources of the observed gamma radiation:

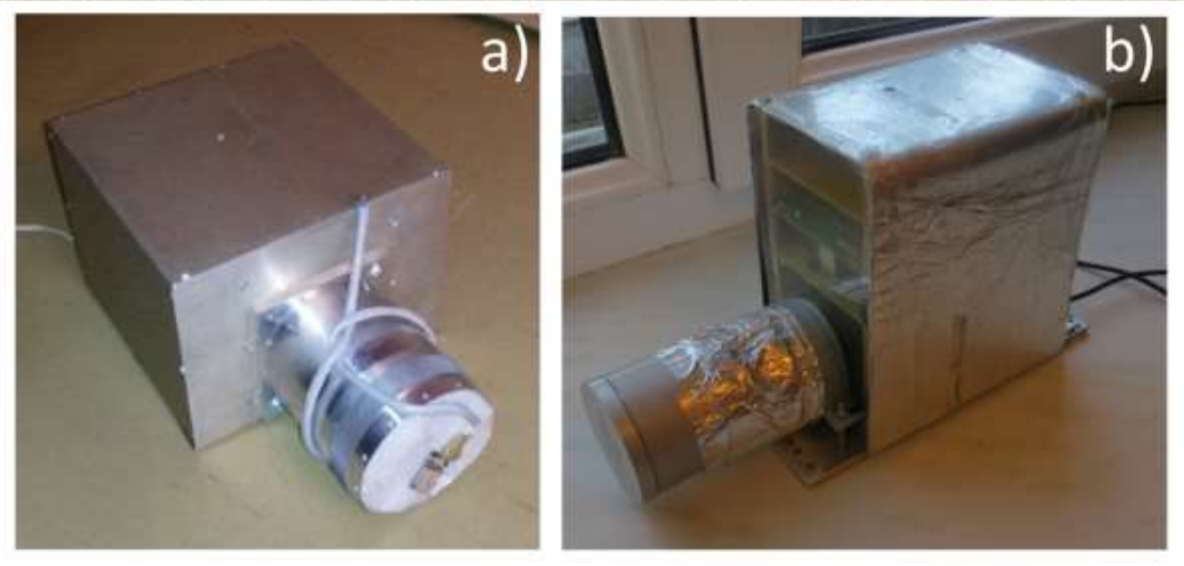
- Cosmic rays
- Natural radioactivity
  a. Constant radiation (K-40, Tl-208)
  b. Variable radiation (Rn-222 with daughter isotopes)
- Bremsstrahlung of the electrons, accelerated in the atmospheric electric fields



Principles of the instrument design:

- Scintillator spectrometers based on NaI(Tl) or CsI(Tl)
- Electronic circuits allowing to analyze the pulse shape in order to exclude the gamma event imitation from lightning
- Recording of the data about every interaction in the detector with fine time and spectral resolution
- All collected data are recorded to the SD card for farther analysis
- Exact binding to the world time via GPS

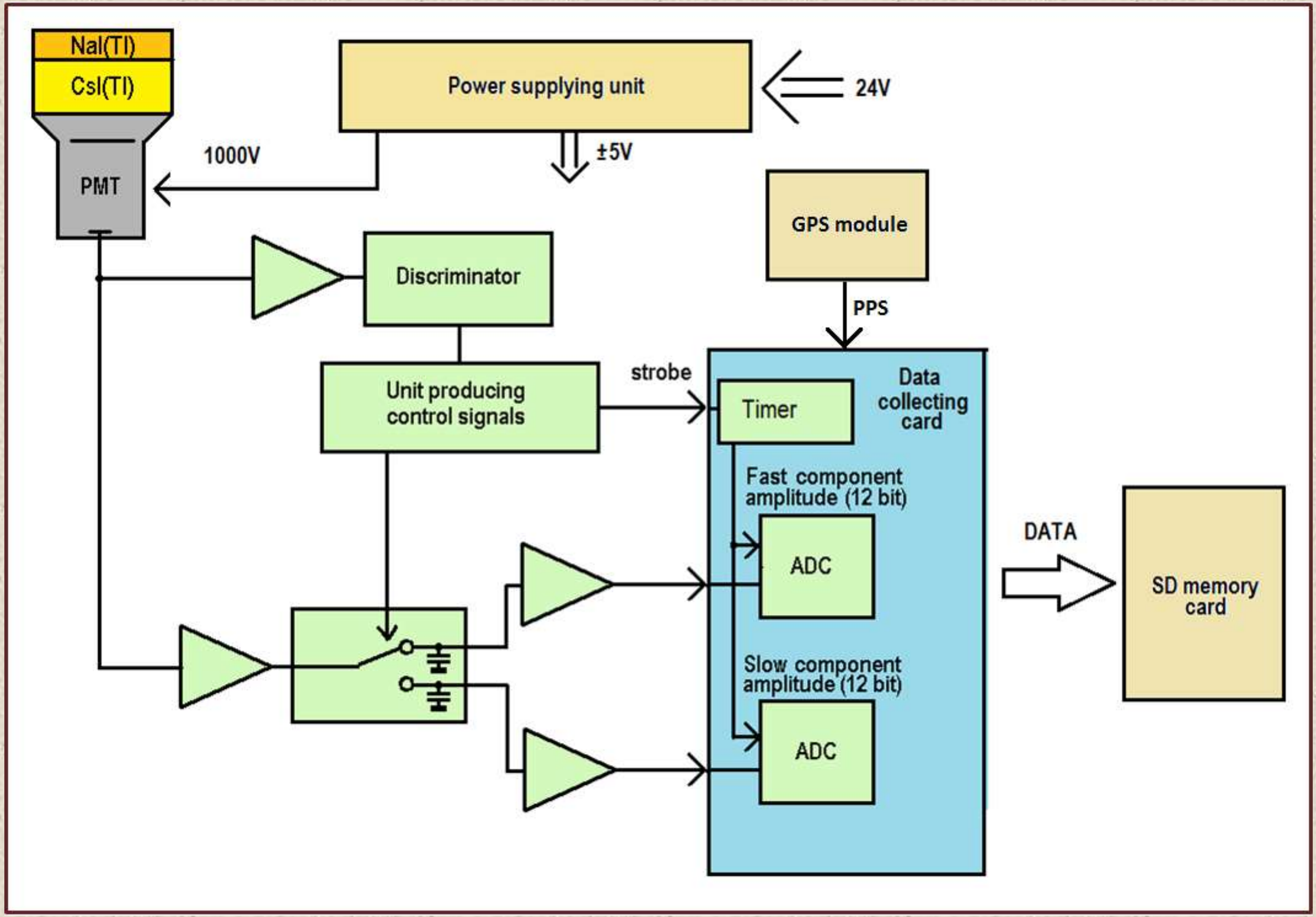
Spectrometers used in this work:



Detector: CsI(Tl) 80x80 mm
PMT: Hammamatsu R1307
Energy range: 30 keV-6 MeV
Resolution 7.2% for 662 keV

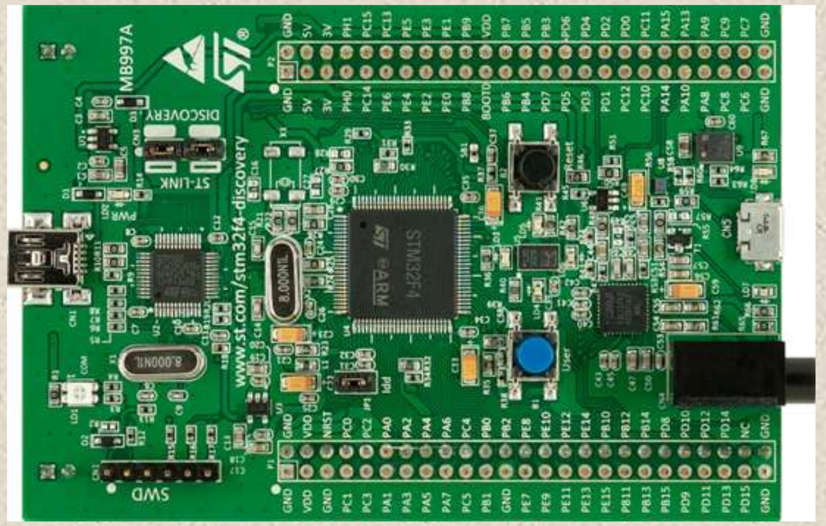
Detector: NaI(Tl) 50x50 mm
PMT: FEU-176
Energy range: 30 keV-7 MeV
Resolution 12% for 662 keV

Design of instrument electronics



Digital electronics and data format

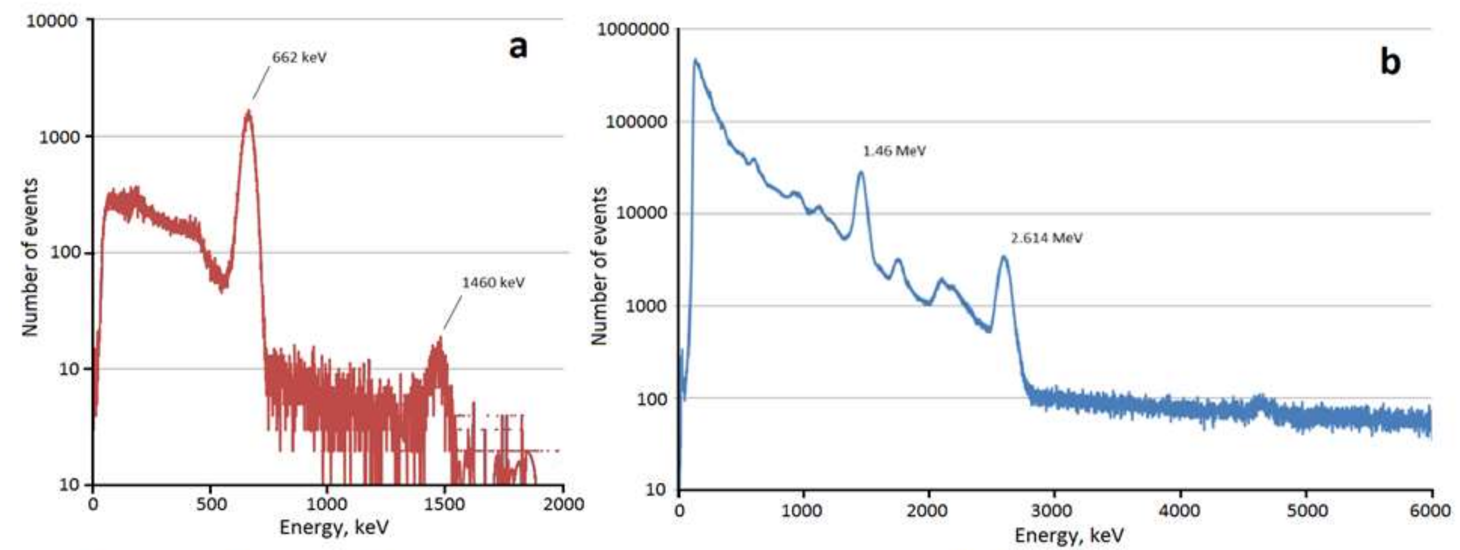
- Producing time data with accuracy 15 mcs. Stability of internal timer is ~1s/day and synchronyzation via GPS every second
- Forming data frames each second.
- Producing ~15mcs timer data starting at the beginning of the frame
- Interrupt on the request from analog card and digitize pulses of fast and slow components
- At the beginning of a frame digitize signal on the additional analog input



Board STM32F4 DISCOVERY with Cortex M4 microcontroller

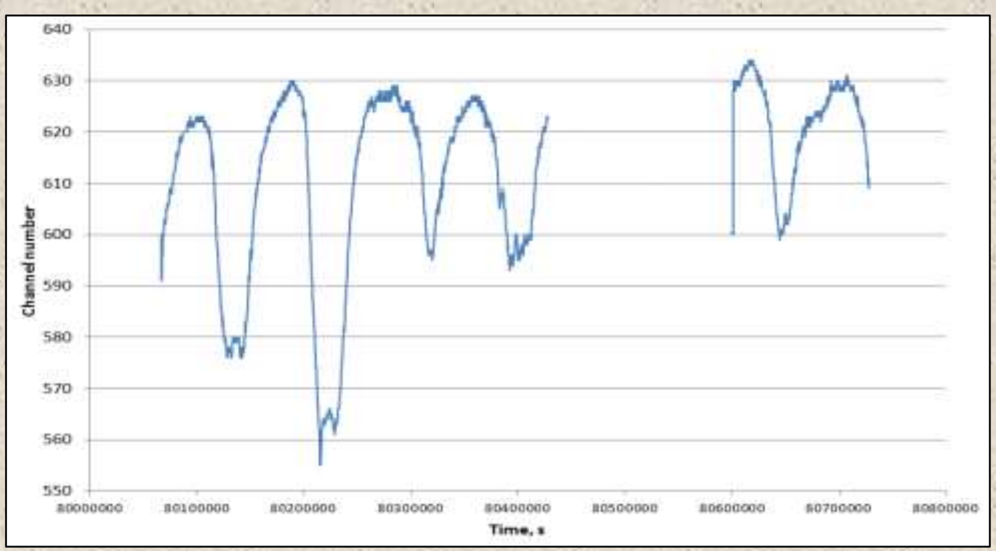
7b - Frame start marker - E4 57 B4 C0 3F 66 99
4b – Frame number
6b - Time – YY MM DD hh mm ss
2b – Number of events in the frame
4b – Number of counts of 15mcs timer during the frame
2b – ADC data for external analog input
N*(3b+3b) – Data records: ADC data + timer value
4b – Frame end marker – CC 11 00 00

Calibration and data analysis



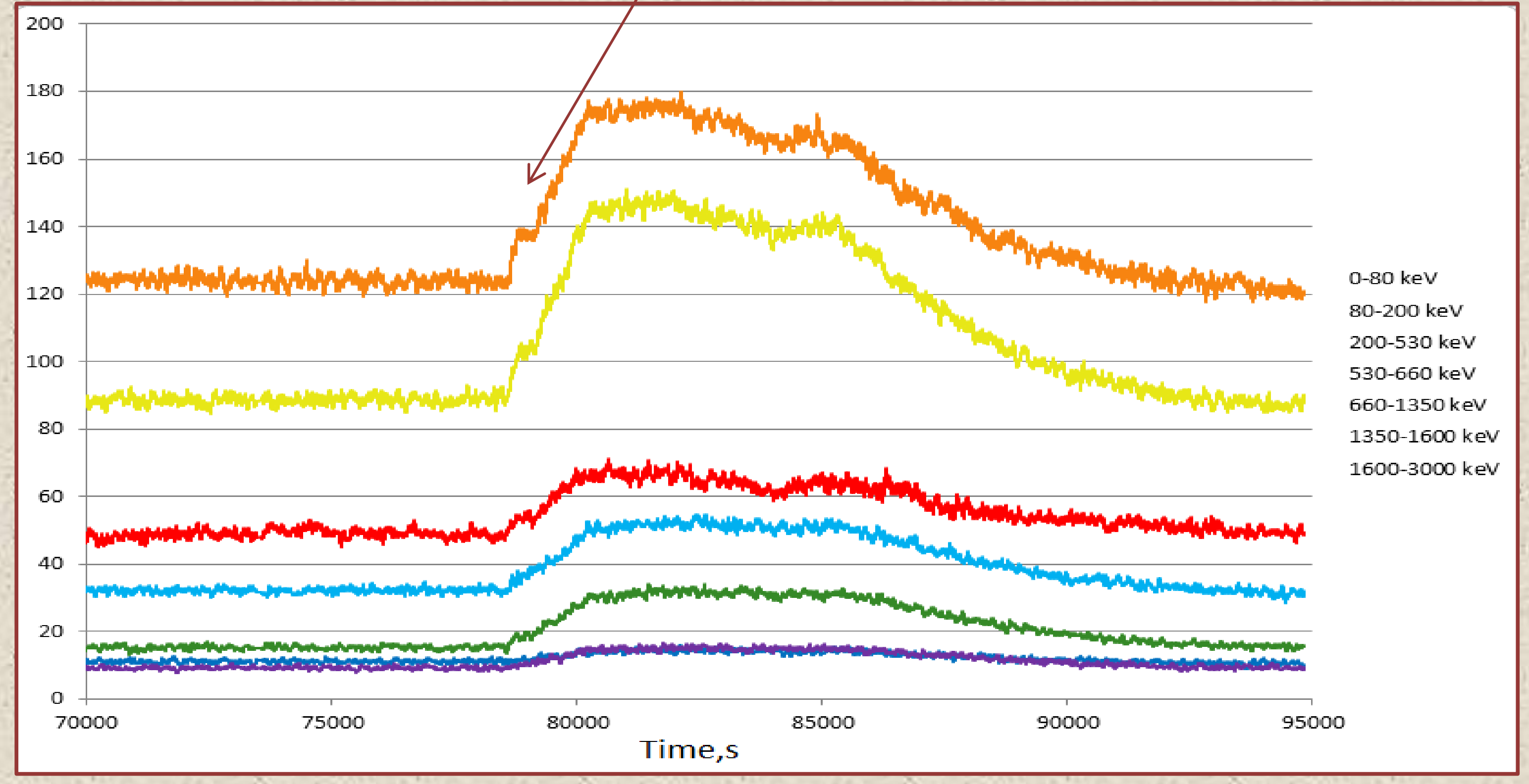
Spectrum of Cs-137 (*a*) and background spectrum (*b*) obtained with the 80 mm diameter CsI(Tl) detector. Lines at 1.46 MeV and 2.614 MeV correspond to the naturally occurring isotopes ^{40}K and ^{208}Tl.

During the data processing every 5 minutes the position of 1.46 MeV gamma-ray line of natural isotope K-40 was determined in order to correct the variations of the detector readings caused by the temperature dependence of the scintillator characteristics.

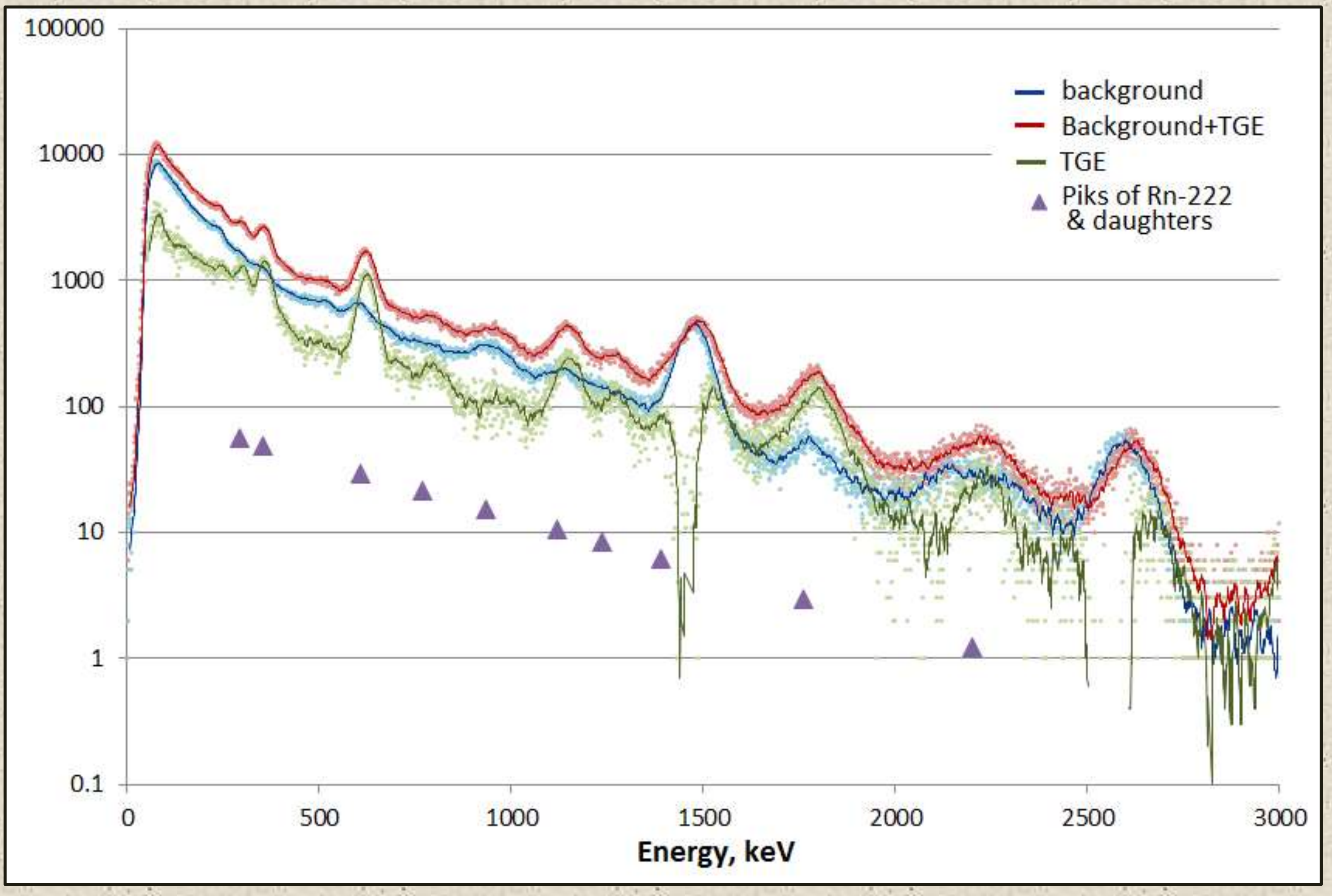


Measurements at the sea level (50 km from Moscow)

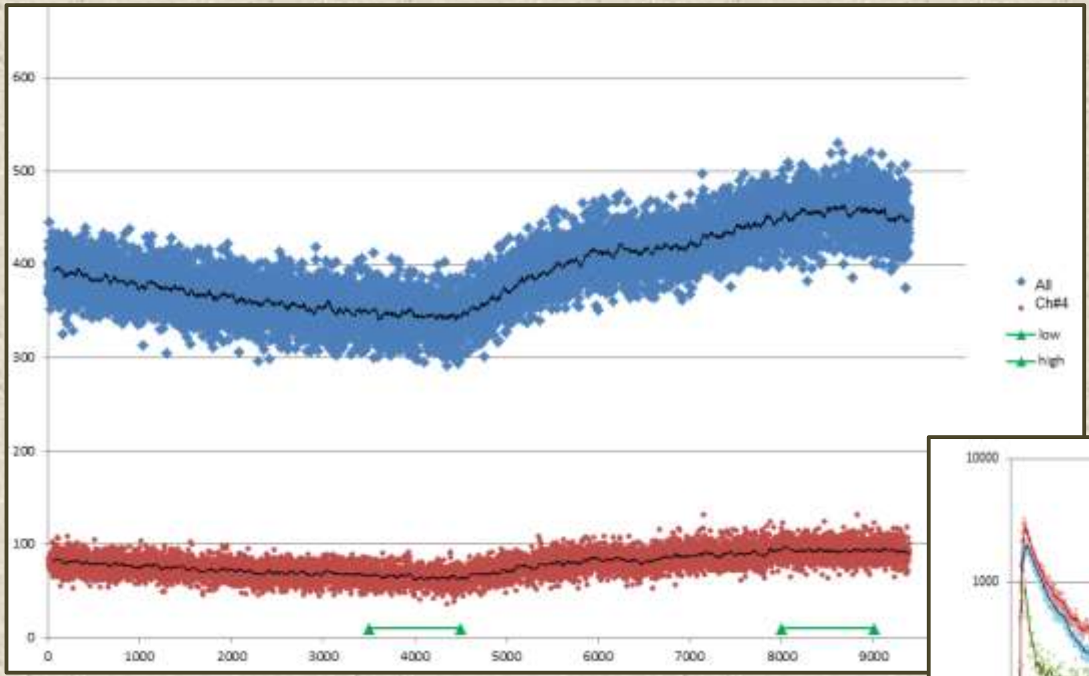
27 of September, 2015 г.
Conditions: fine weather, then the shower with thunderstorm started, then the rain stopped for 5 minutes, then the rain started again for ~2h.

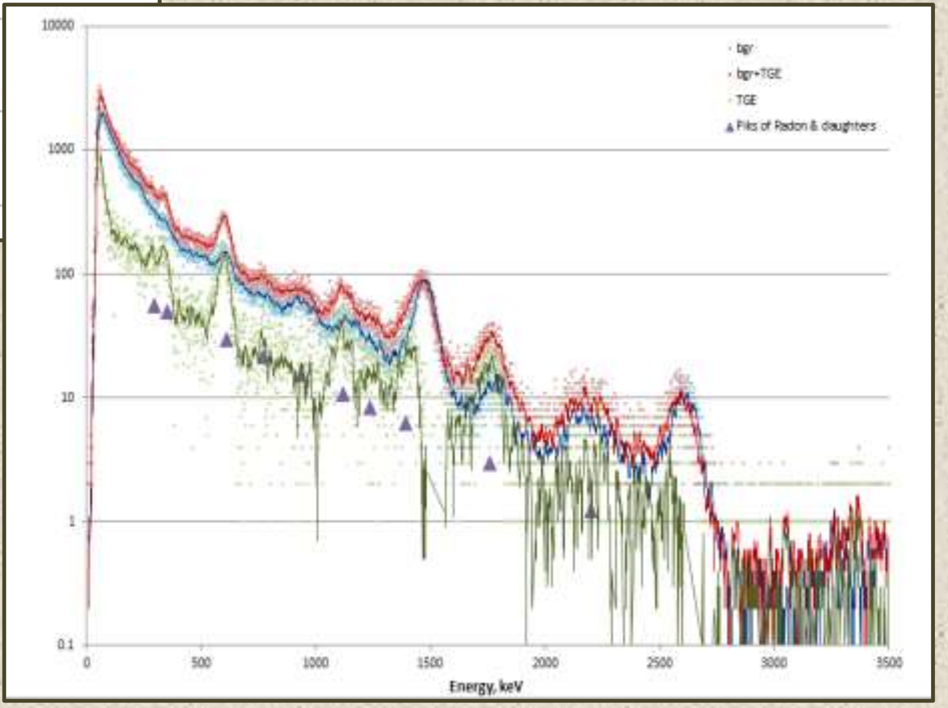


Energy spectrum of the TGE 27.09.2015

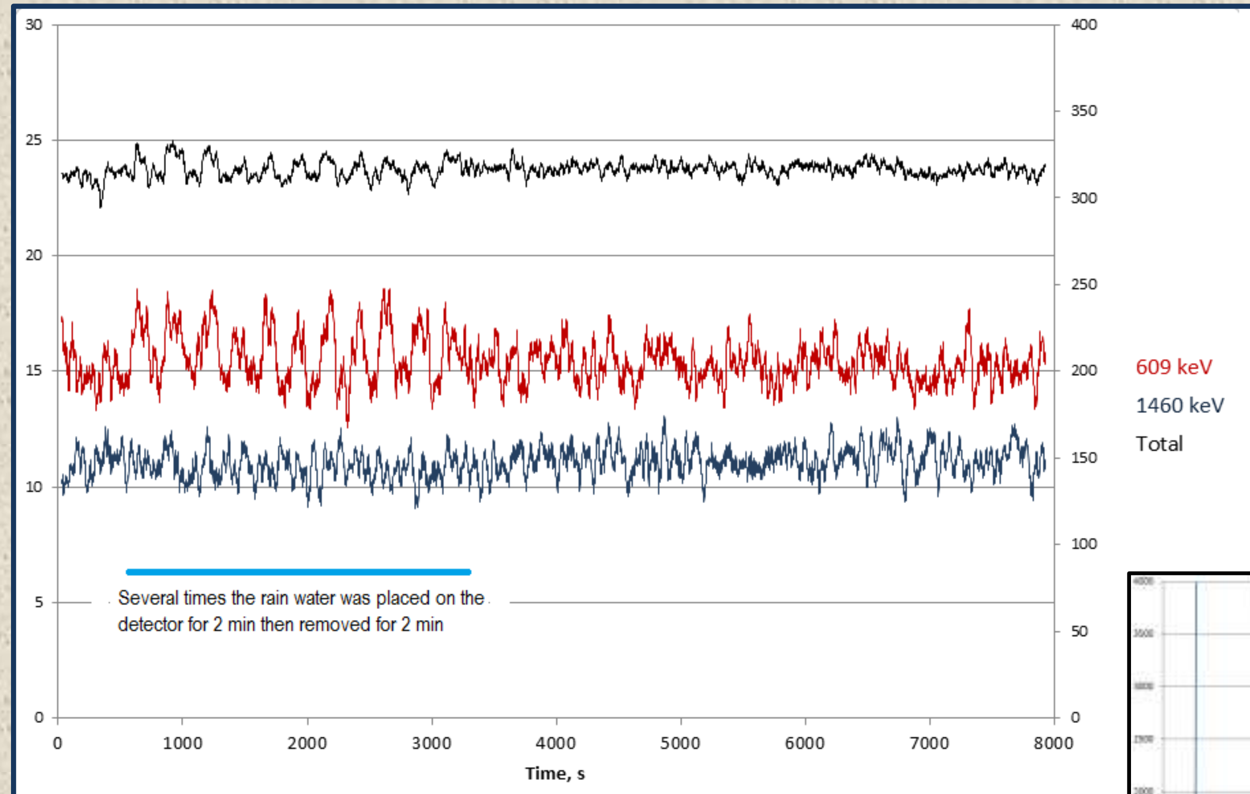


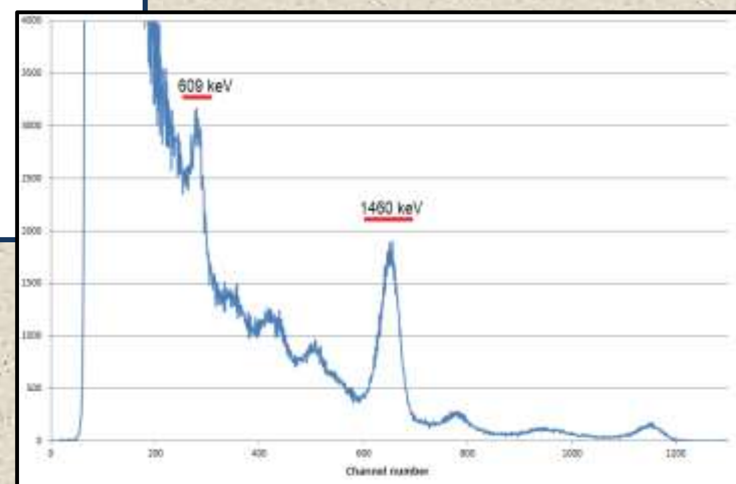
05 of September 2015.
Conditions: small rain without thunderstorm



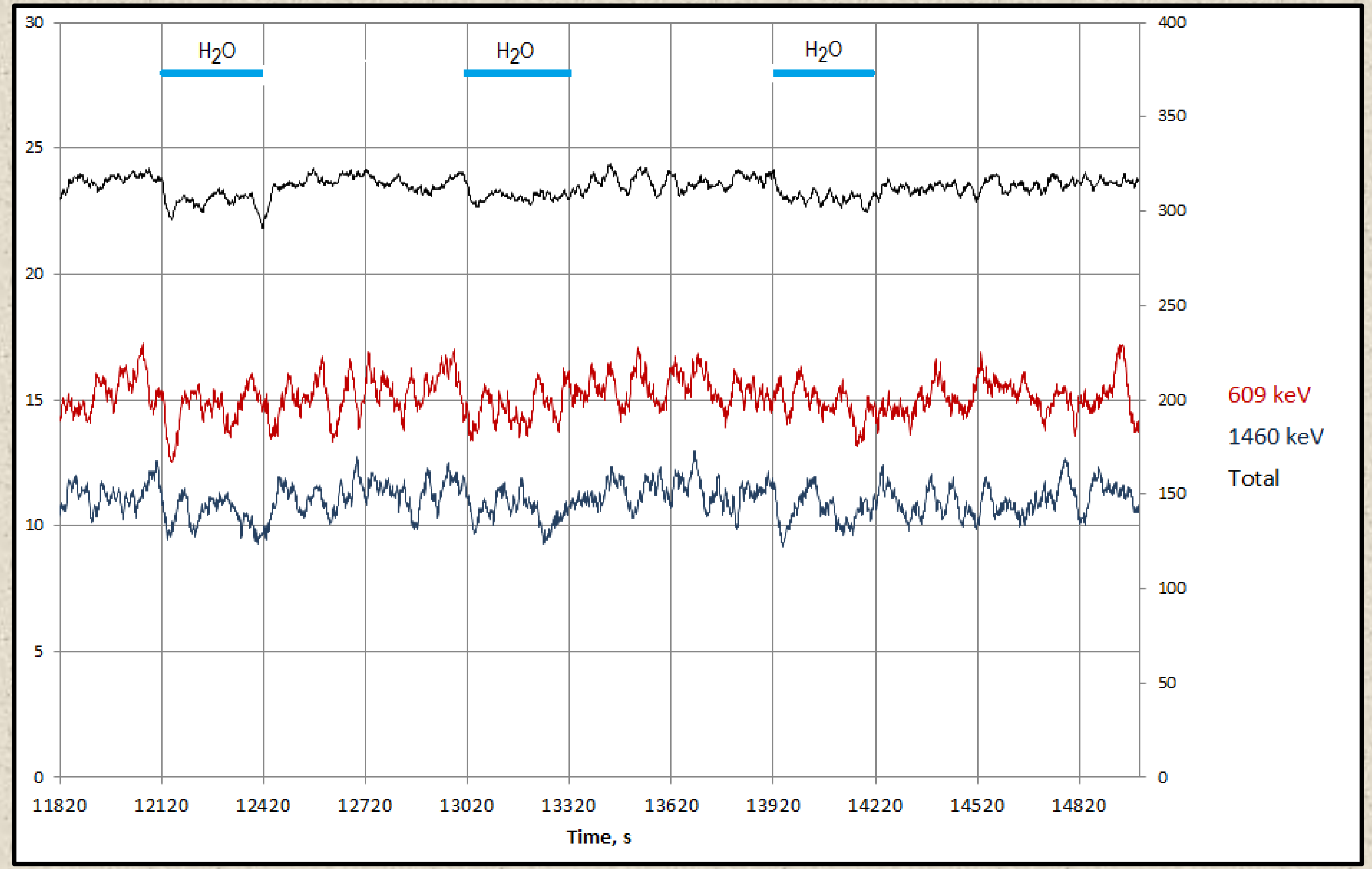


Radiation from the rain water collected in Moscow during the thunderstorm

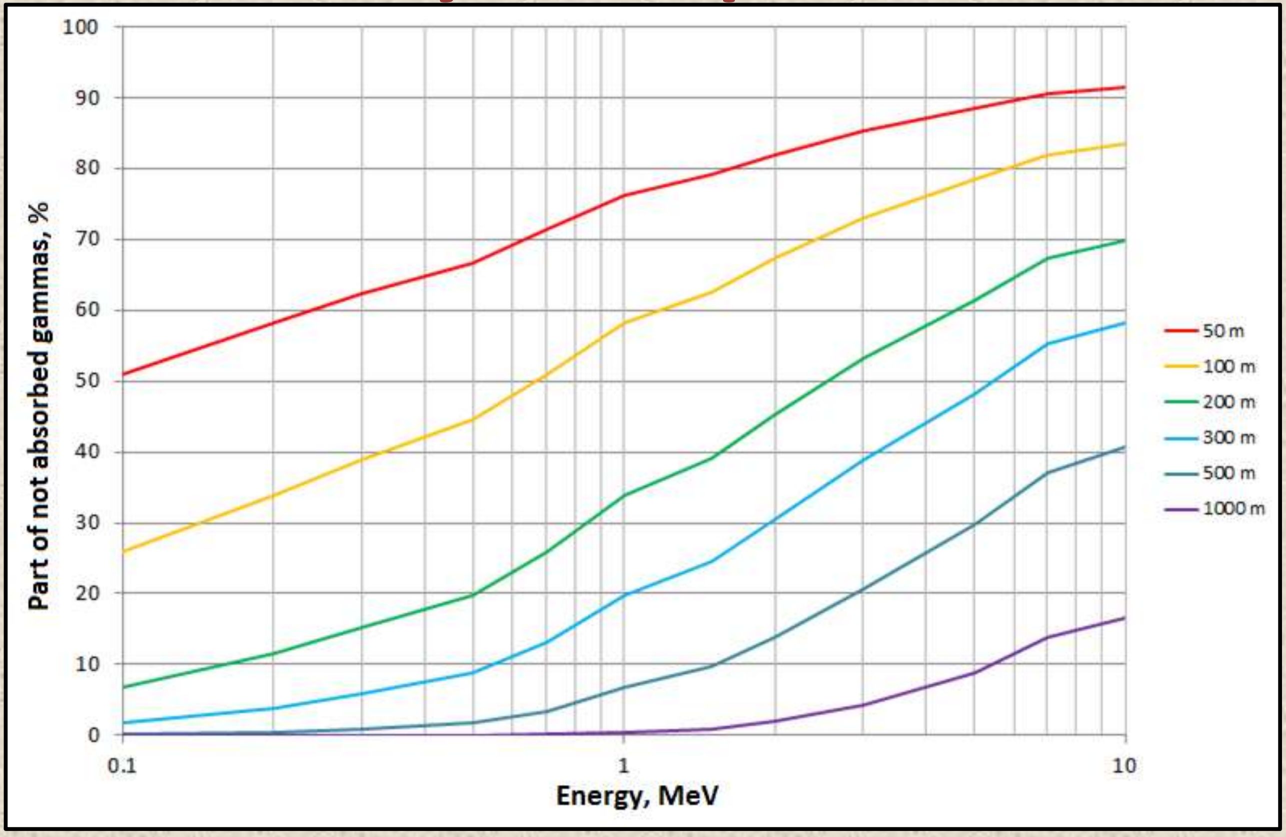




The vessel with water from the water-supplying tube was placed several times to the detector. Some decrease of readings was observed



Gamma-ray absorption in the air

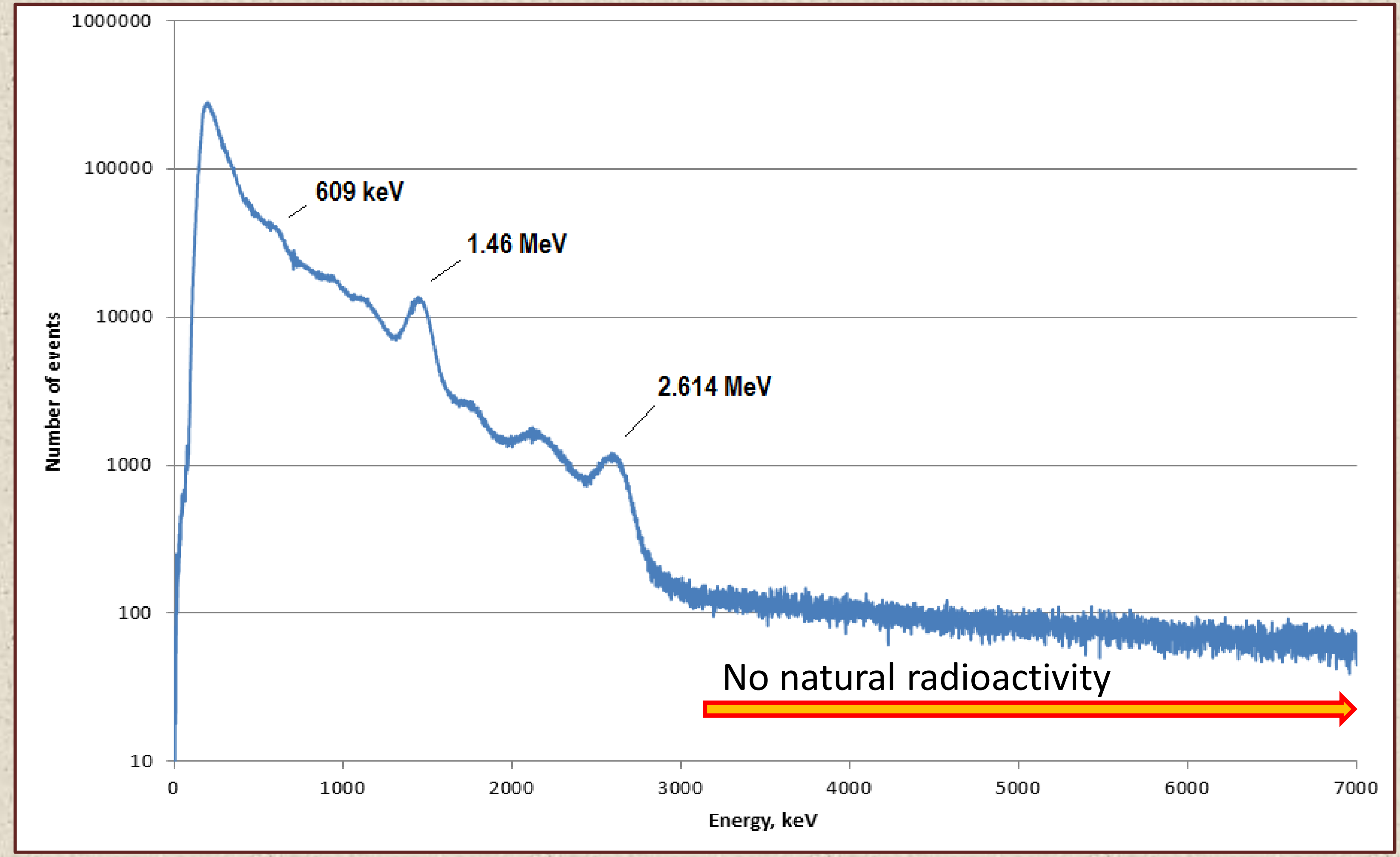


No significant increases of the gamma-ray flux with energy >3 MeV were observed during thunderstorms in Moscow region. It can be explained by the great absorption of the gamma-radiation in the air. One must take into account that the distance between the cloud and the instrument in this case is about several kilometers.

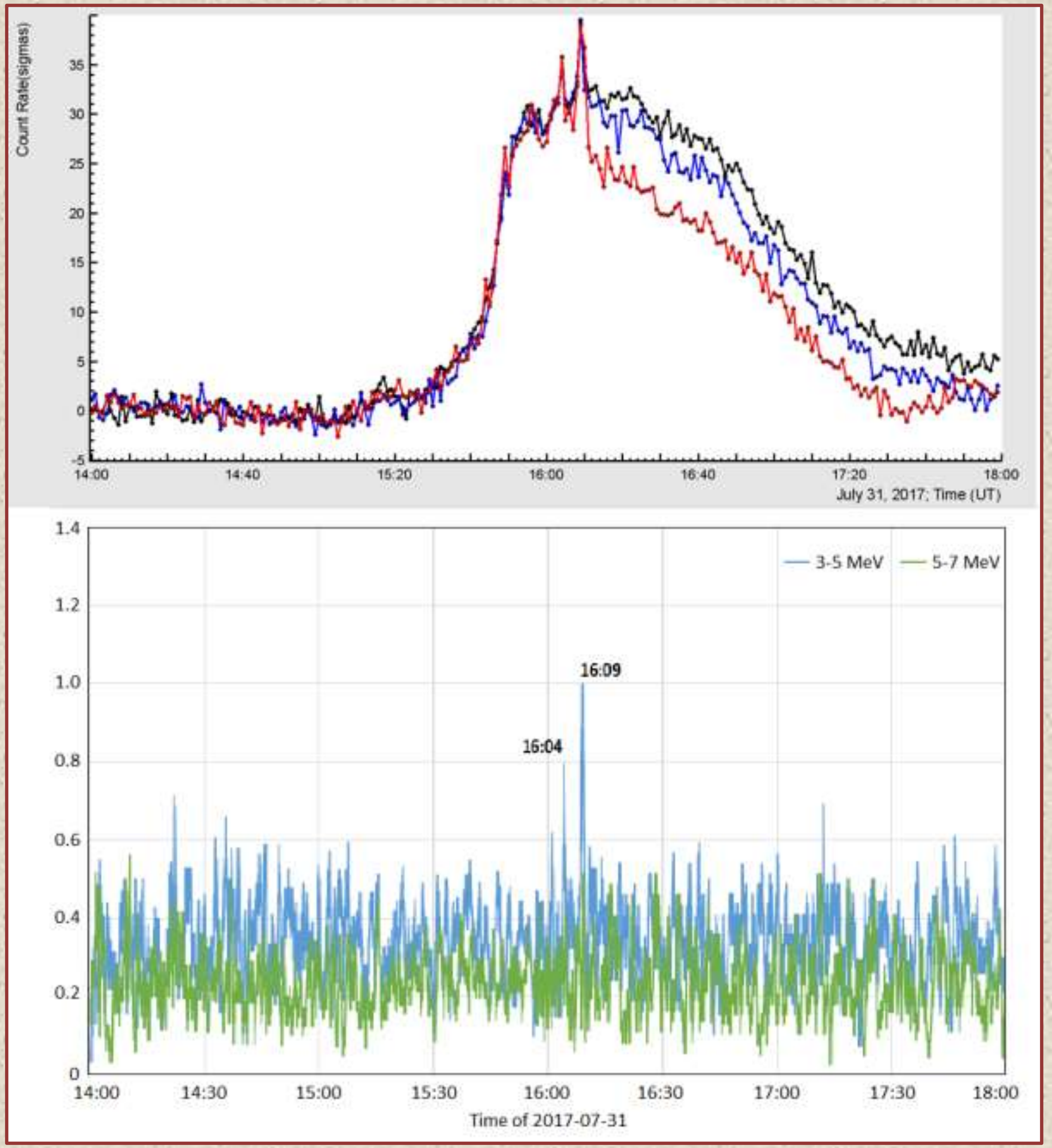
Upper limit (3 sigma) = 2.4 $*10^{-4}$ $cm^{-2}{}_{*}s^{-1}$

Observations of TGEs with SINP MSU spectrometer placed on Aragats

Gamma-ray background spectrum measured from 13.08.2017 to 20.08.2017 at Aragats station.



Observation of TGE 31.07.2017

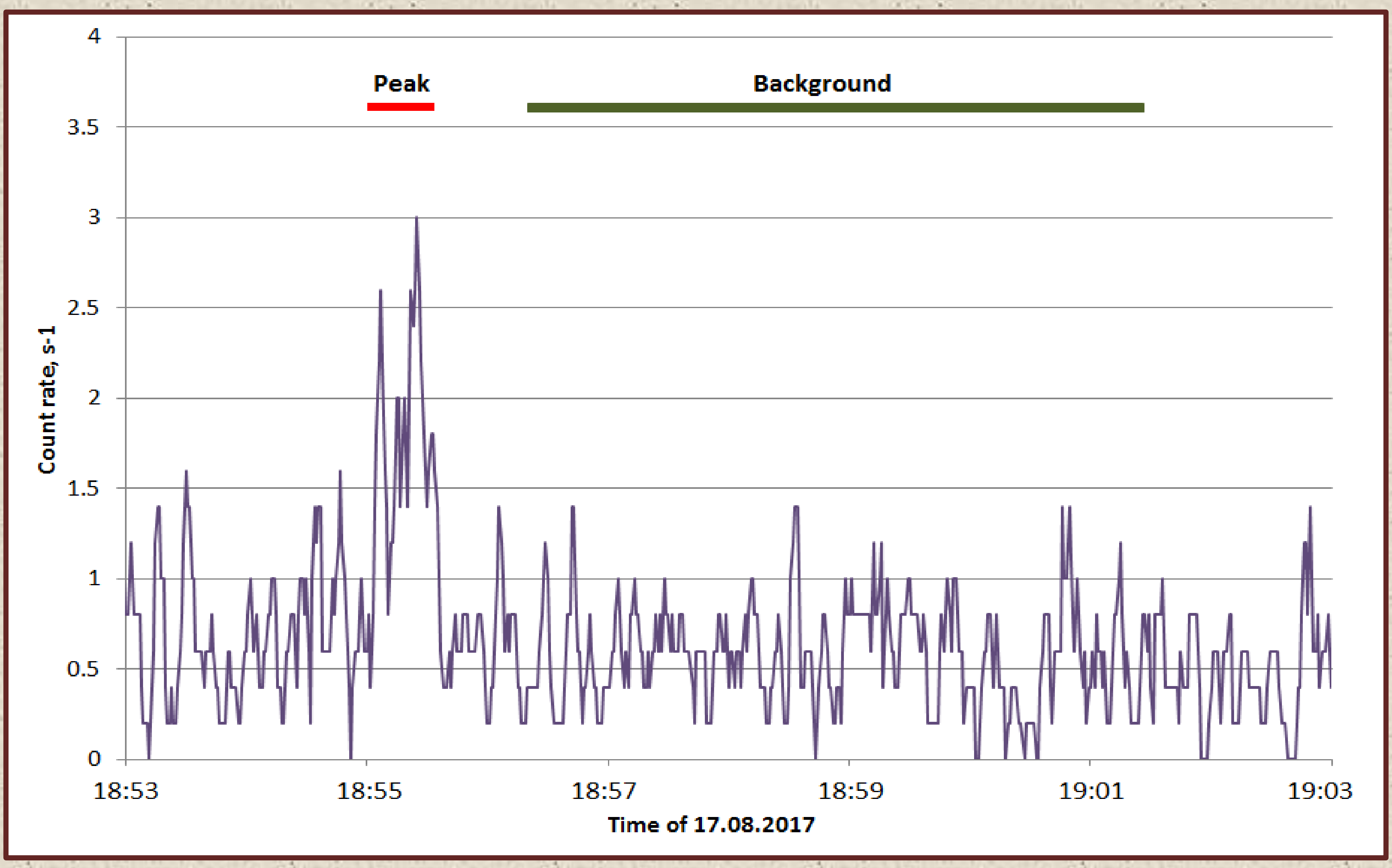


Upper panel – the data from A.Chilingarian group
Low pannel – readings of SINP MSU spectrometer in the high energy channels

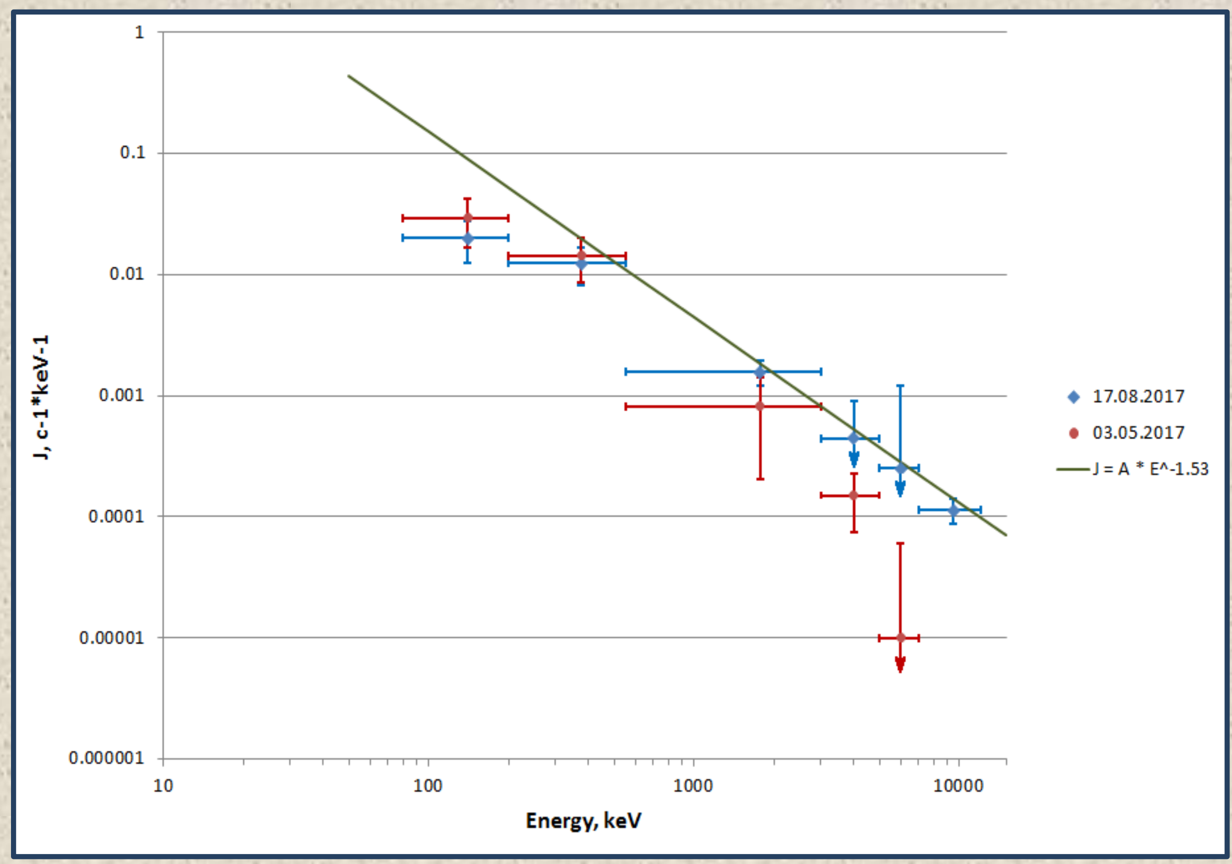
Time sequence of the gamma-spectrometer readings on 17.08.2017

The hard narrow peak of TGE 17.08.2017 in details.

In order to obtain energy spectrum the mean values of the flux were calculated for the intervals marked as “peak” and “background”



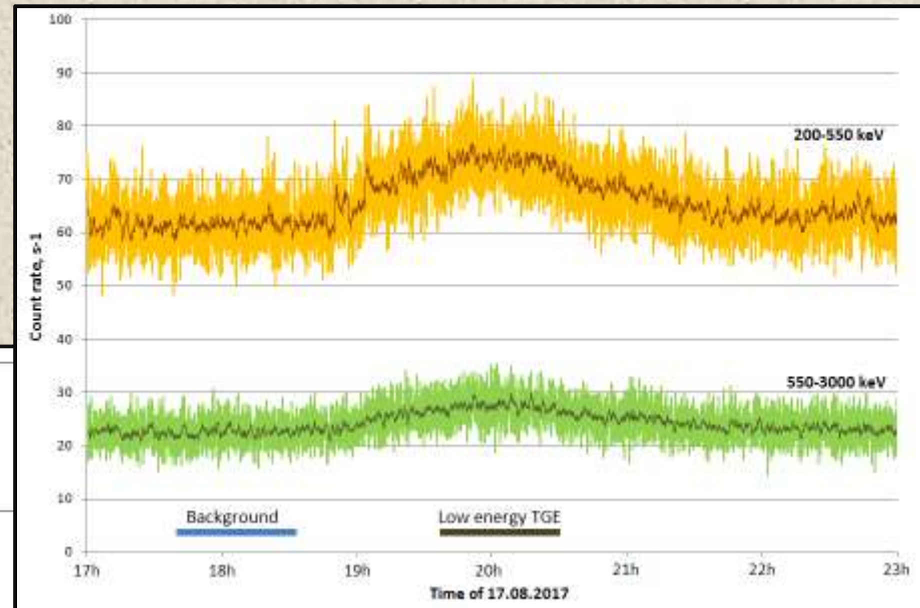
Energy release spectra during the hard narrow peaks of TGEs 17-08-2017 and 03-05-2017

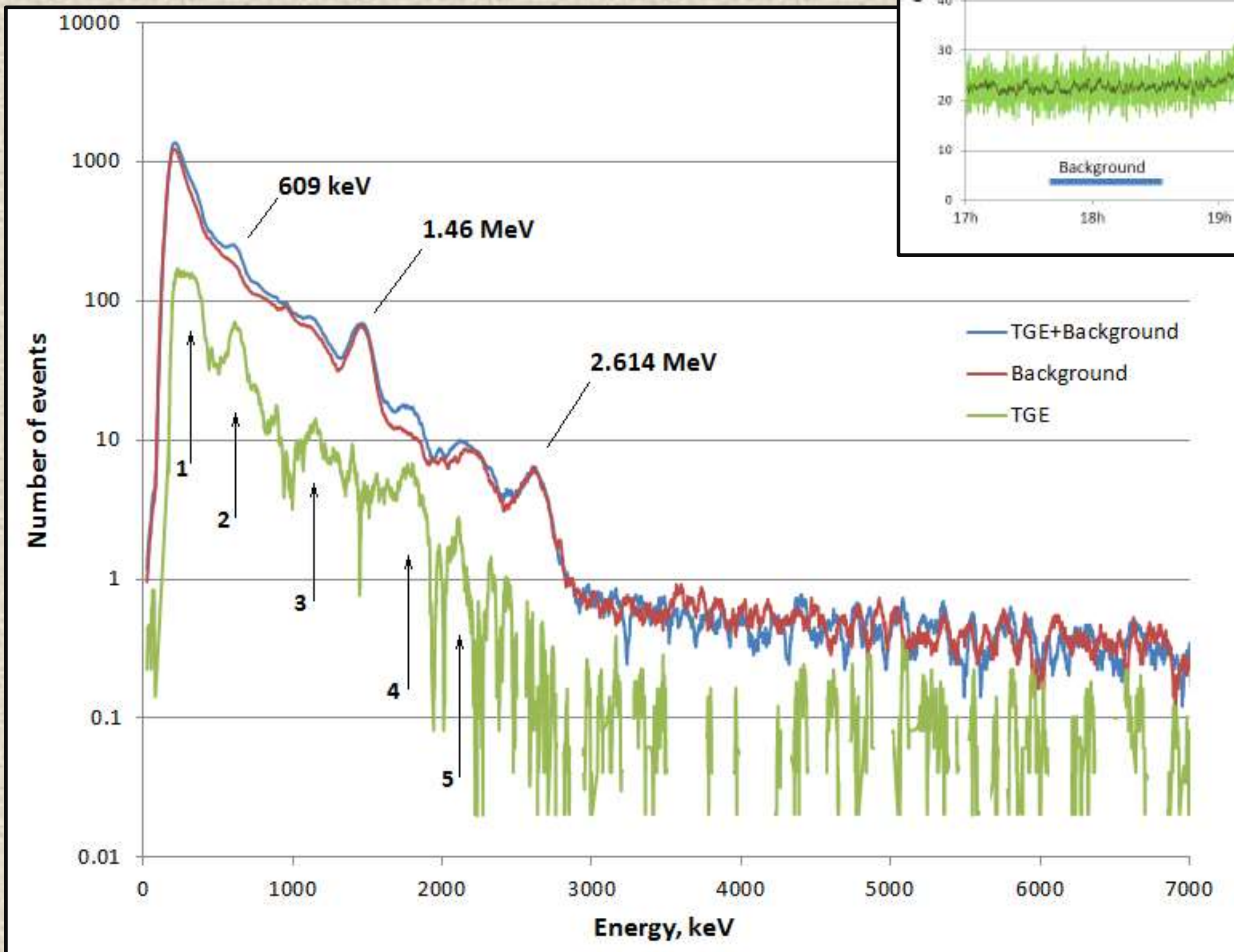


The parameters of power-law approximation were taken from the "NaI network" data, presented by A.Chilingarian. The value "A" was multiplied to the ratio of the sensitive areas of the instruments.

The correction for low efficiency of 5 cm NaI(Tl) in high energy part of the spectrum was not done. Very good coincidence of the energy release spectra measured by the instruments of different thickness can be explained by direct detection of the accelerated electrons exceeding the detection of secondary gammas. Difference of the spectra for May, 3 and August, 17 can be caused by the difference of the distance to cloud base in these two cases.

Energy release spectrum during the long-soft phase of TGE 17-08-2017



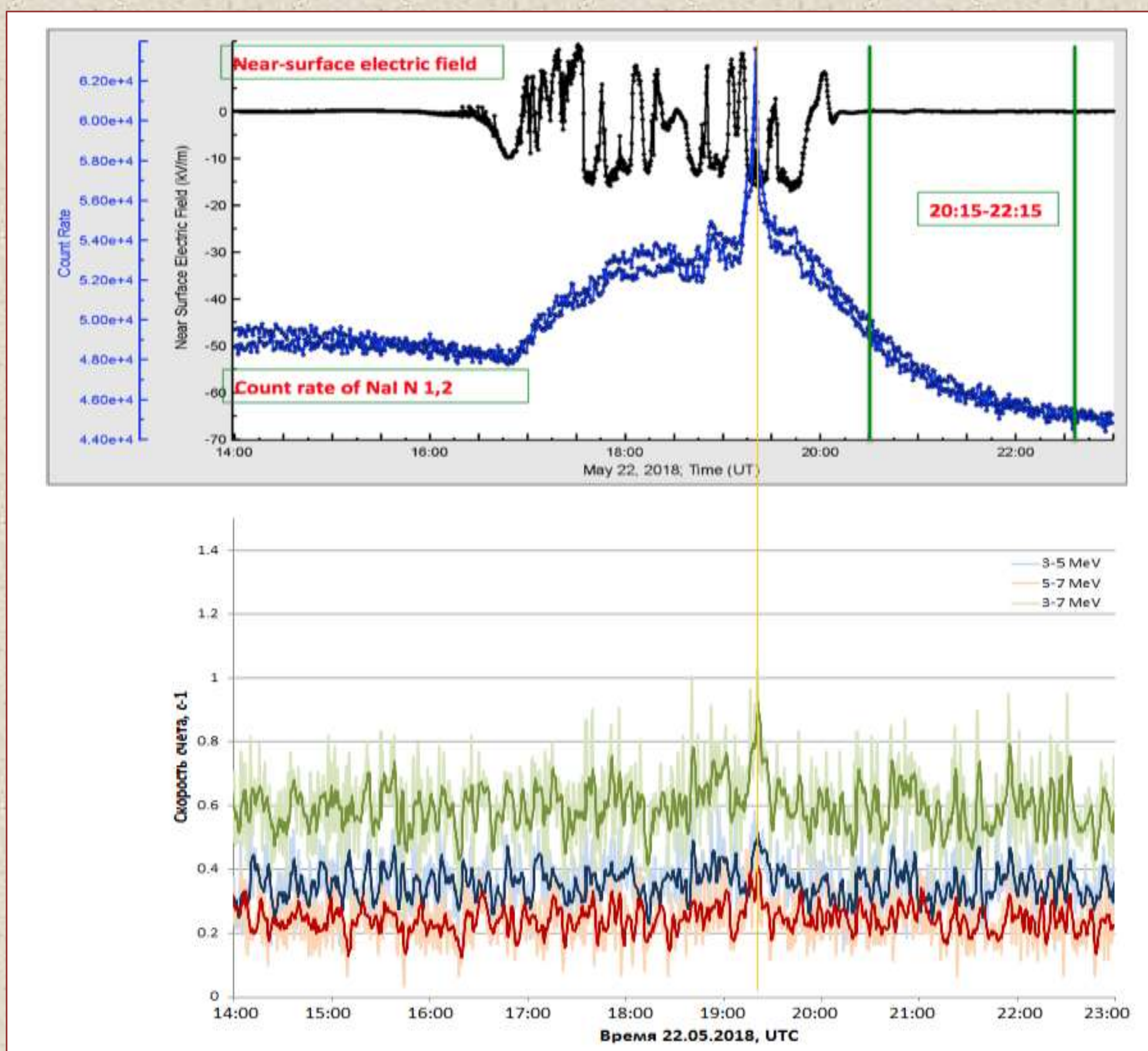


The spectrum of the long phase of TGE contain a number of gamma-ray lines associated with Rn-222 and its daughters). No significant change of the flux in range E>3 MэВ was observed during this phase

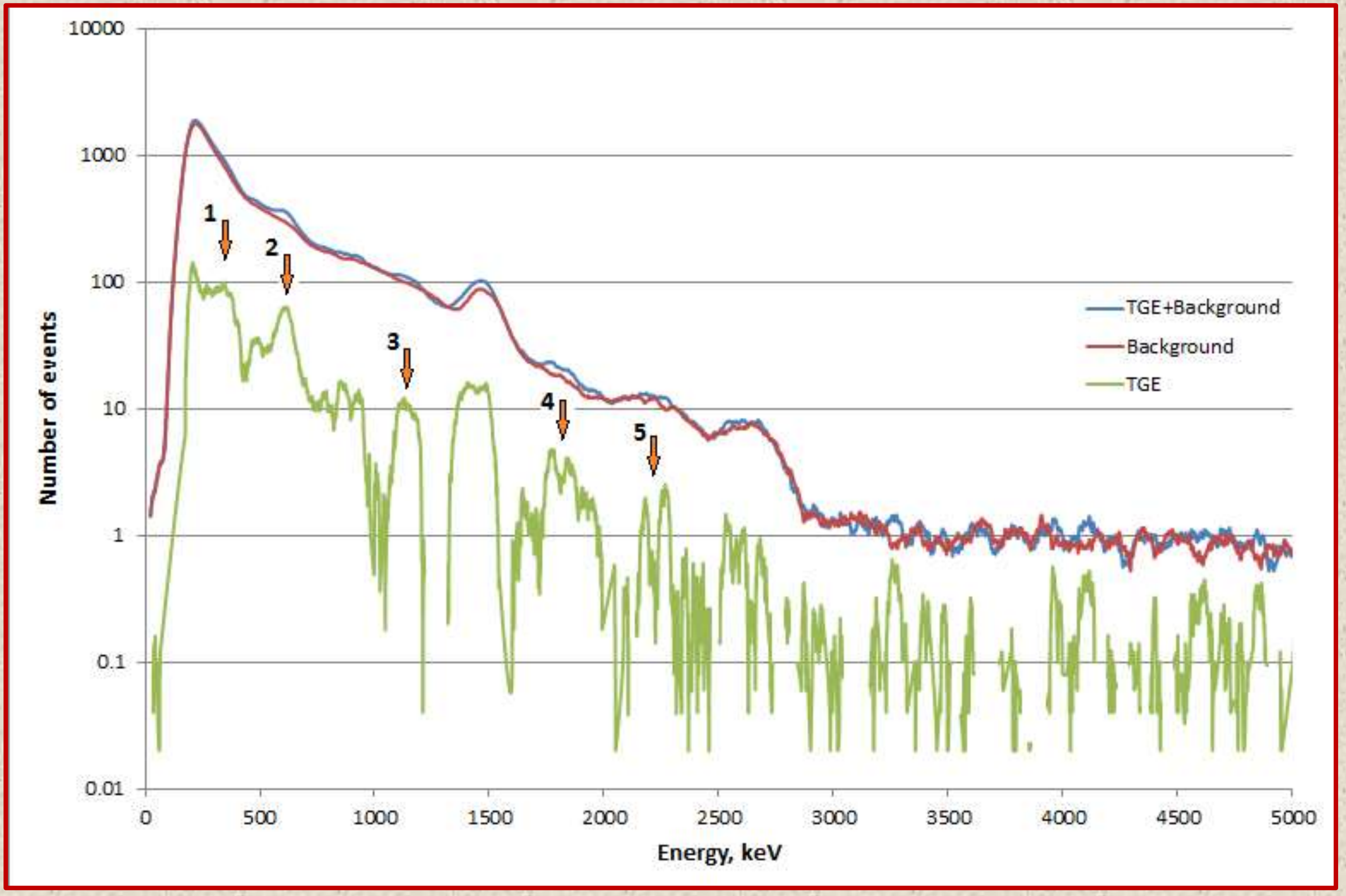
Time profile of TGE on 22 of May, 2018 (Aragats station)

Measurements by A.Chilingarian group

Measurements with 5 cm NaI(Tl) In hard energy channels



Energy release spectrum during the TGE 22-05-2018



Arrows point to the position of the gamma-ray lines produced by Rn-222 with its daughters

Intermediate conclusion:

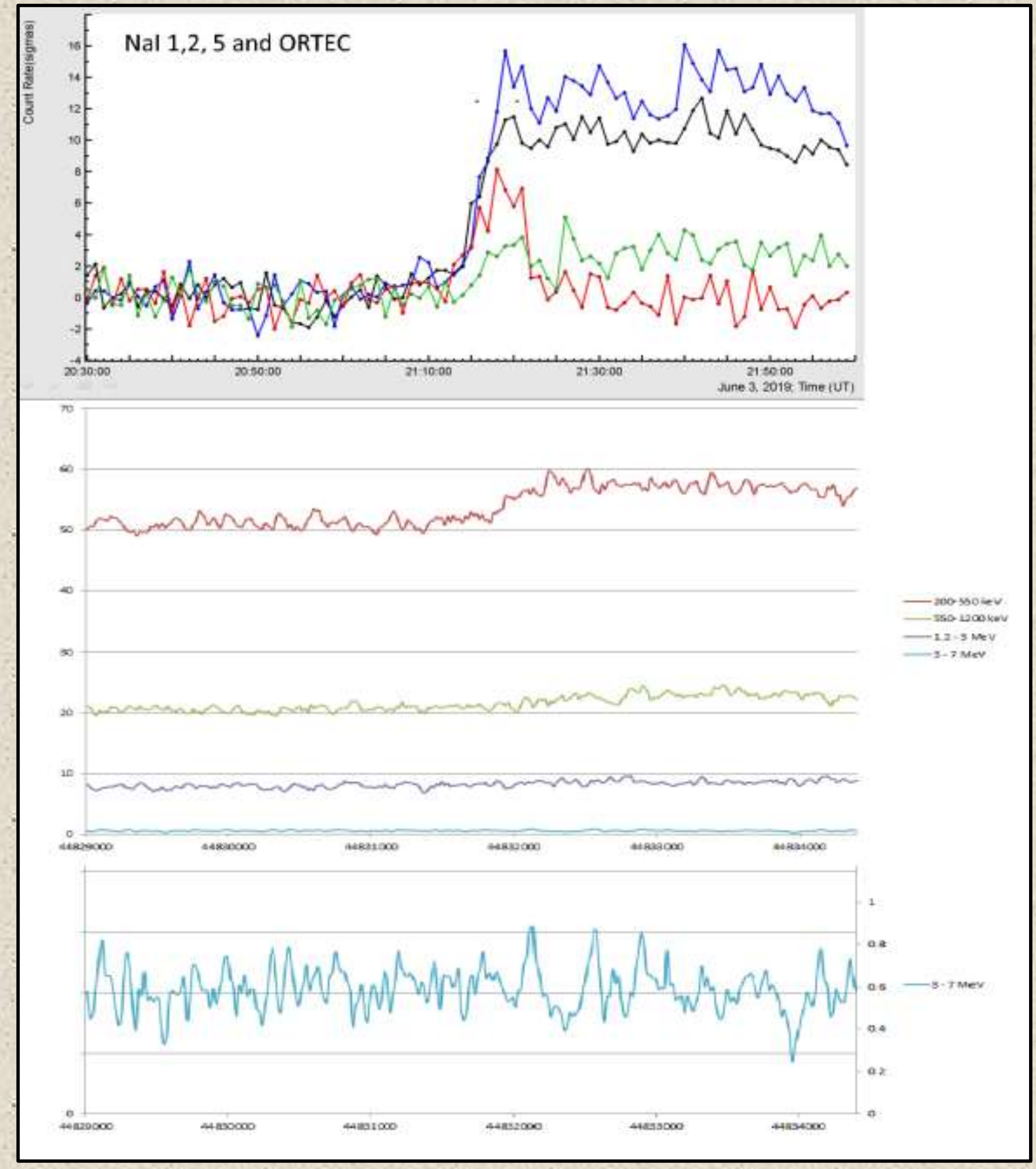
- Increases in gamma-ray spectrometer readings during thunderstorms are usually long, up to several hours, smooth increases in the low energy region (E<3mev), against which short (0.5 – 10 minutes) peaks with energy E>3 MeV can be present
- A significant part of the slow increase in gamma-ray spectrometer readings at E<3 MeV can be explained by variations in Rn-222 daughters, which can be caused by changes in weather conditions (precipitation, etc. factors). This is supported by a number of observed gamma-lines of Bi-214 and Pb-214 being Rn-222 daughter isotopes
- The hard radiation observed in the mountains can be interpreted as the emission of electrons accelerated in a thundercloud. The relationship between inhibitory gamma ray registration and direct electron registration requires further analysis.

Measurement results and riddles of the 2019 summer

Next slides will demonstrate the results of the measurements with 5 cm NaI(Tl) instrument on Aragats in 2019 in comparison with NaI network, ORTEC and other instruments.

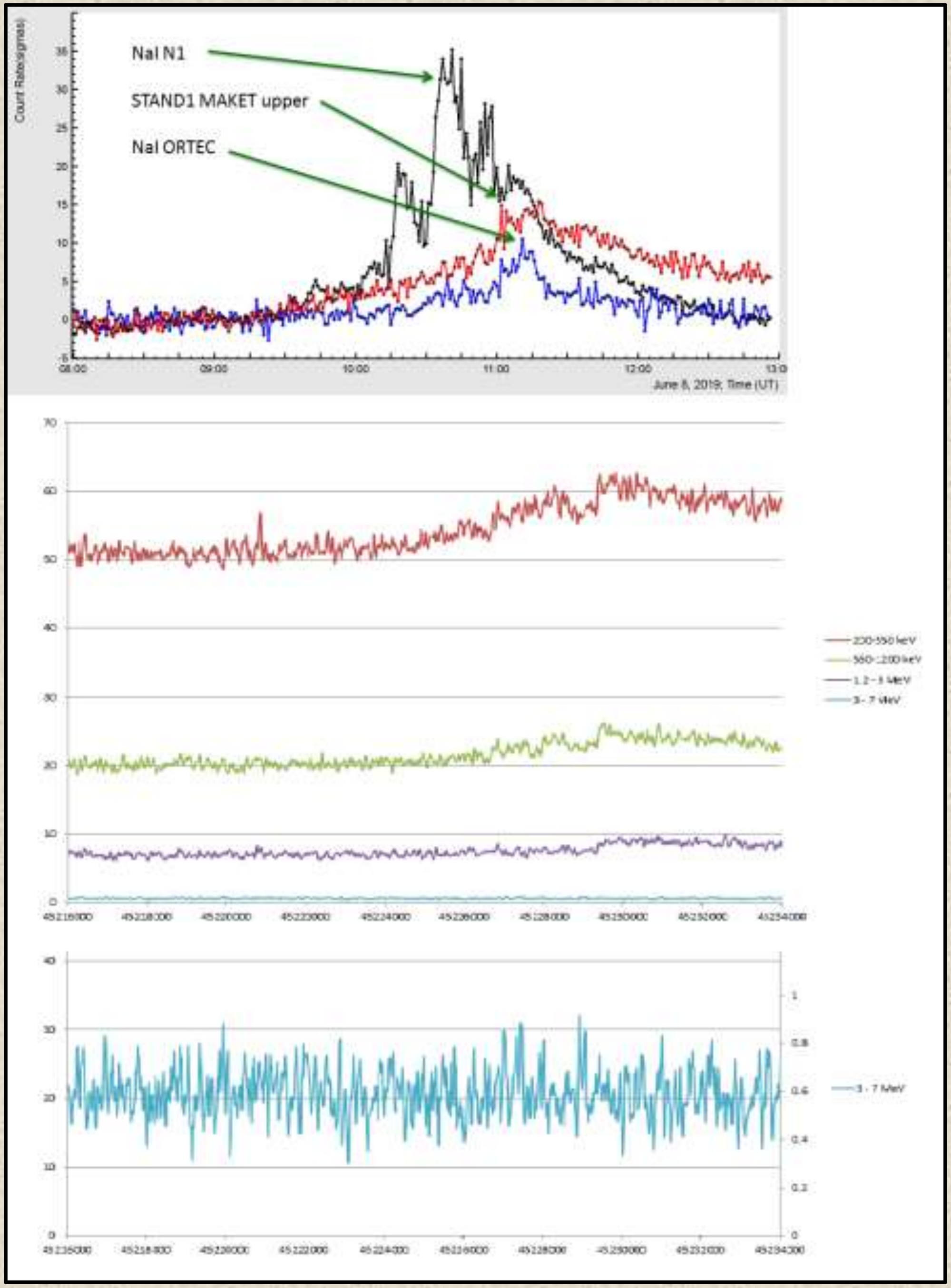
Sensitive area of 5 cm NaI(Tl) is 16 times less than one of 12.5x25 cm NaI network detector. Efficiency in E>3 MeV range is ~2 times less so we expect the readings in hard TGE peaks to be 30 times less

June 3, 2019

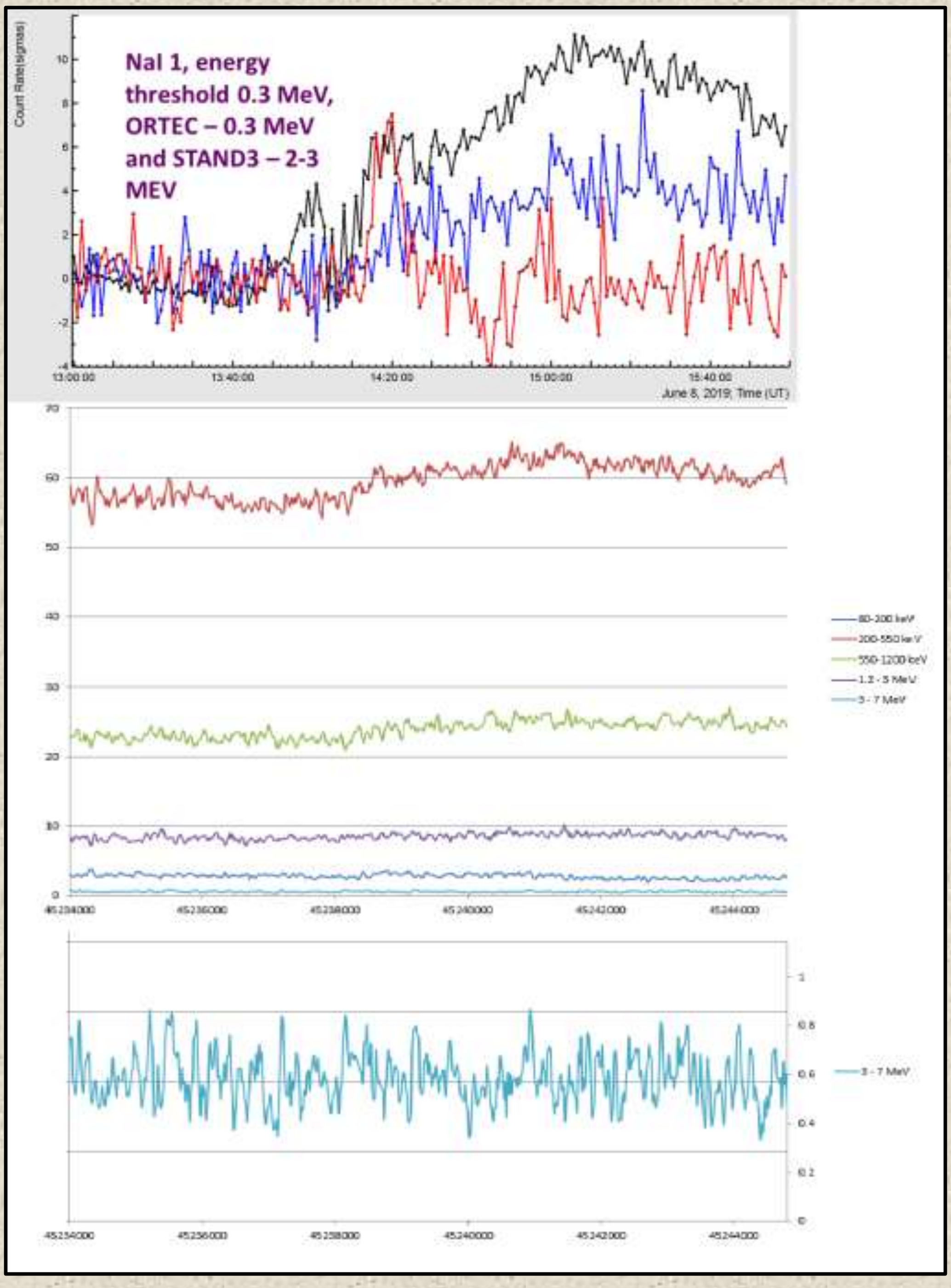


NaI 1,2, 5 and ORTEC
Count Rate(sigmas)
20:30:00
20:50:00
21:10:00
21:30:00
21:50:00
June 3, 2019; Time (UT)
200-550 keV
550-1200 keV
1.2 - 3 MeV
3 - 7 MeV

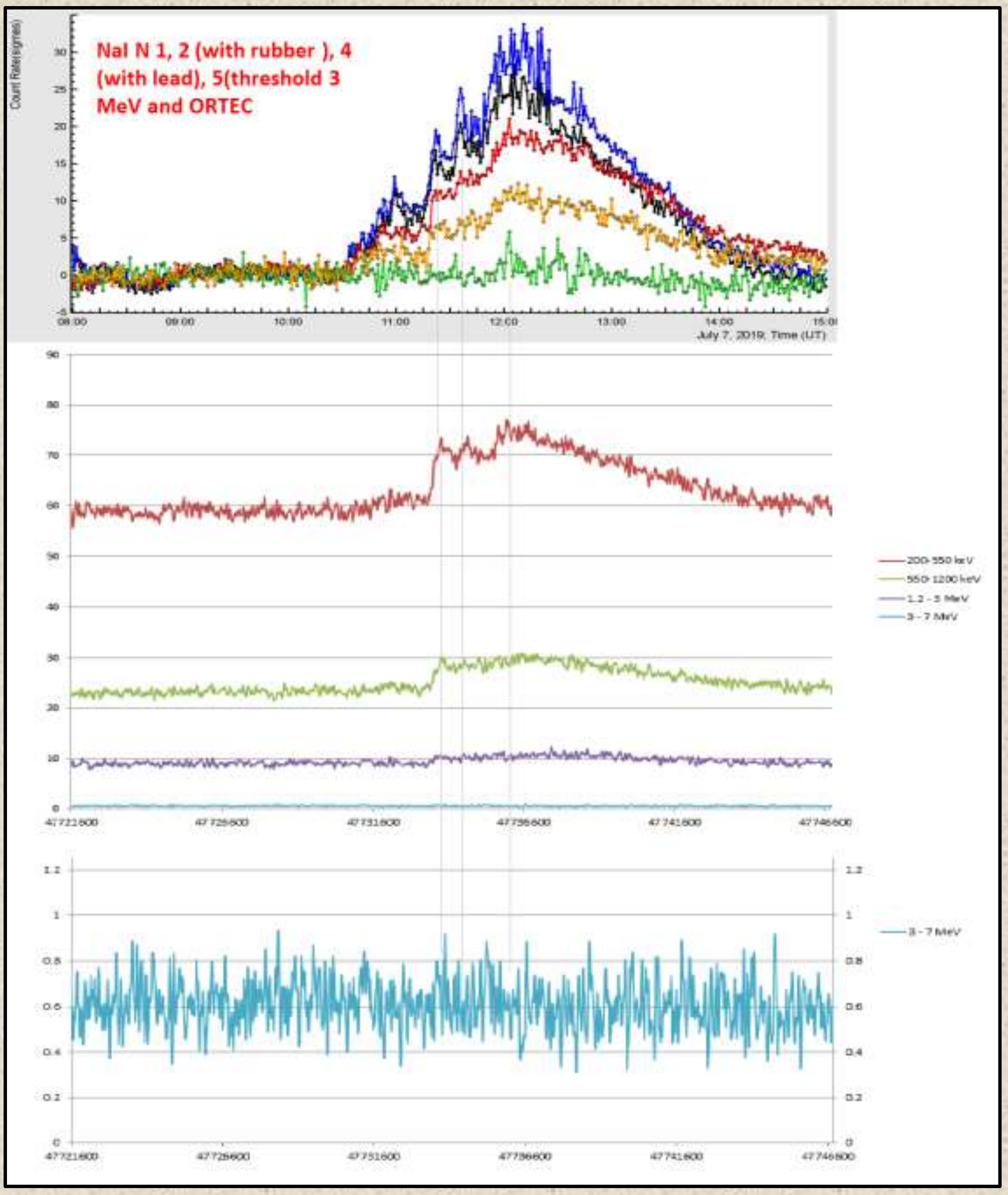
June 8, 2019
TGE at ~10h



June 3, 2019
TGE at ~14h

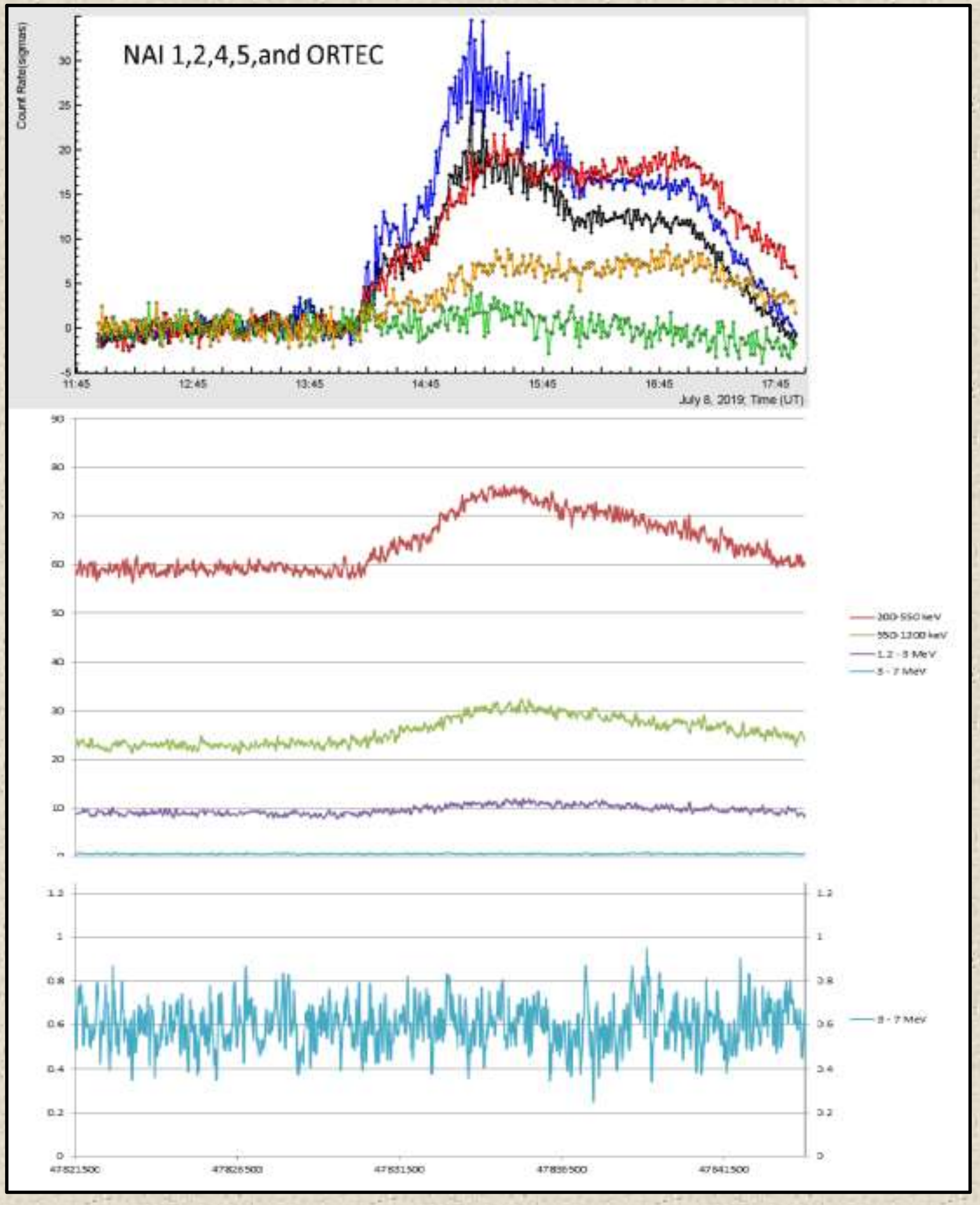


July 7, 2019



NaI N 1, 2 (with rubber), 4
(with lead), 5(threshold 3
MeV and ORTEC
July 7, 2019, Time (UT)
200-550 keV
550-1200 keV
1.2 - 3 MeV
3 - 7 MeV
3 - 7 MeV

July 8, 2019



NAI 1,2,4,5,and ORTEC
Count Rate(sigmas)
July 8, 2019; Time (UT)
200-550 keV
550-1200 keV
1.2 - 3 MeV
3 - 7 MeV

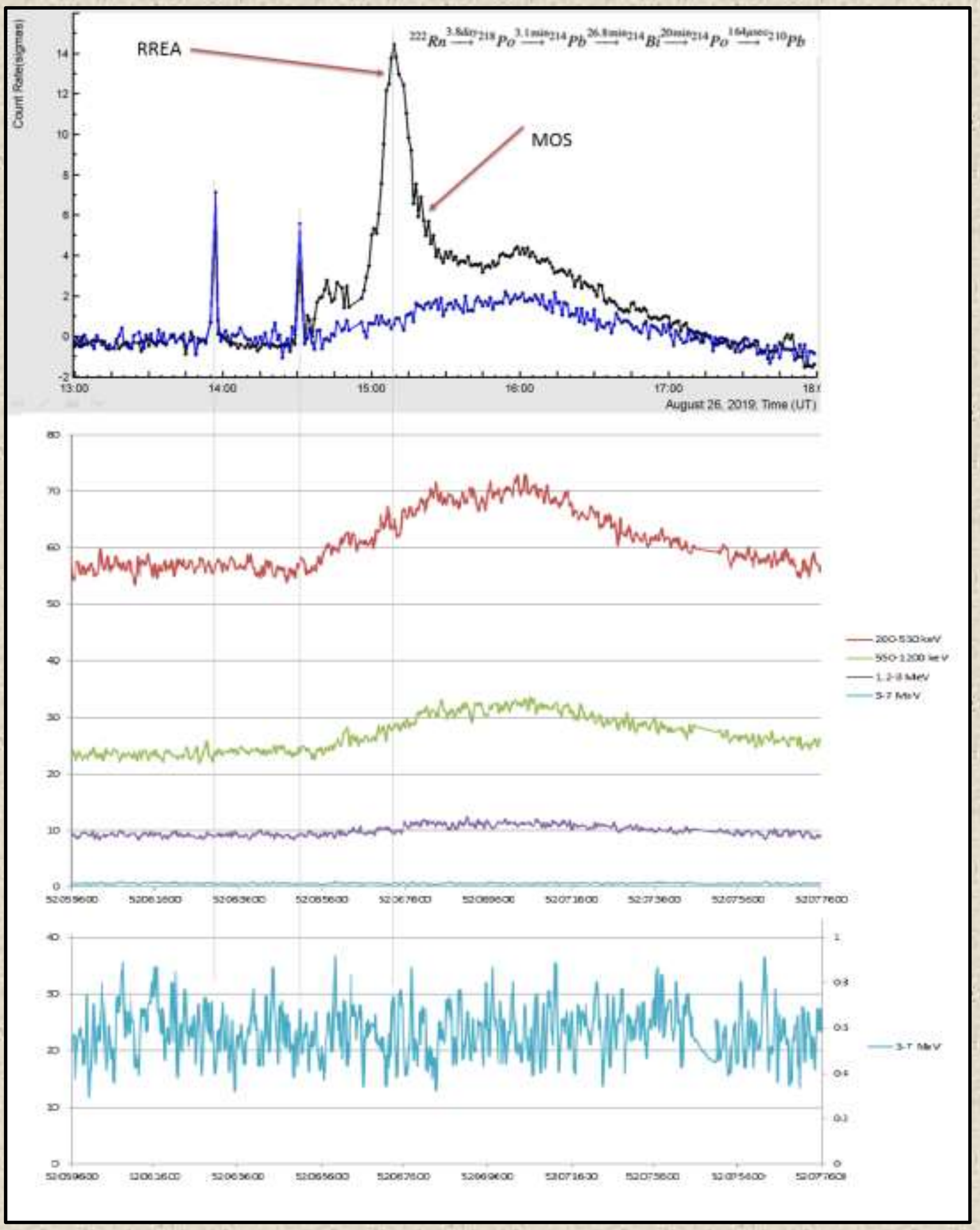
August 26, 2019

Expected response of 5cm NaI(Tl) detector

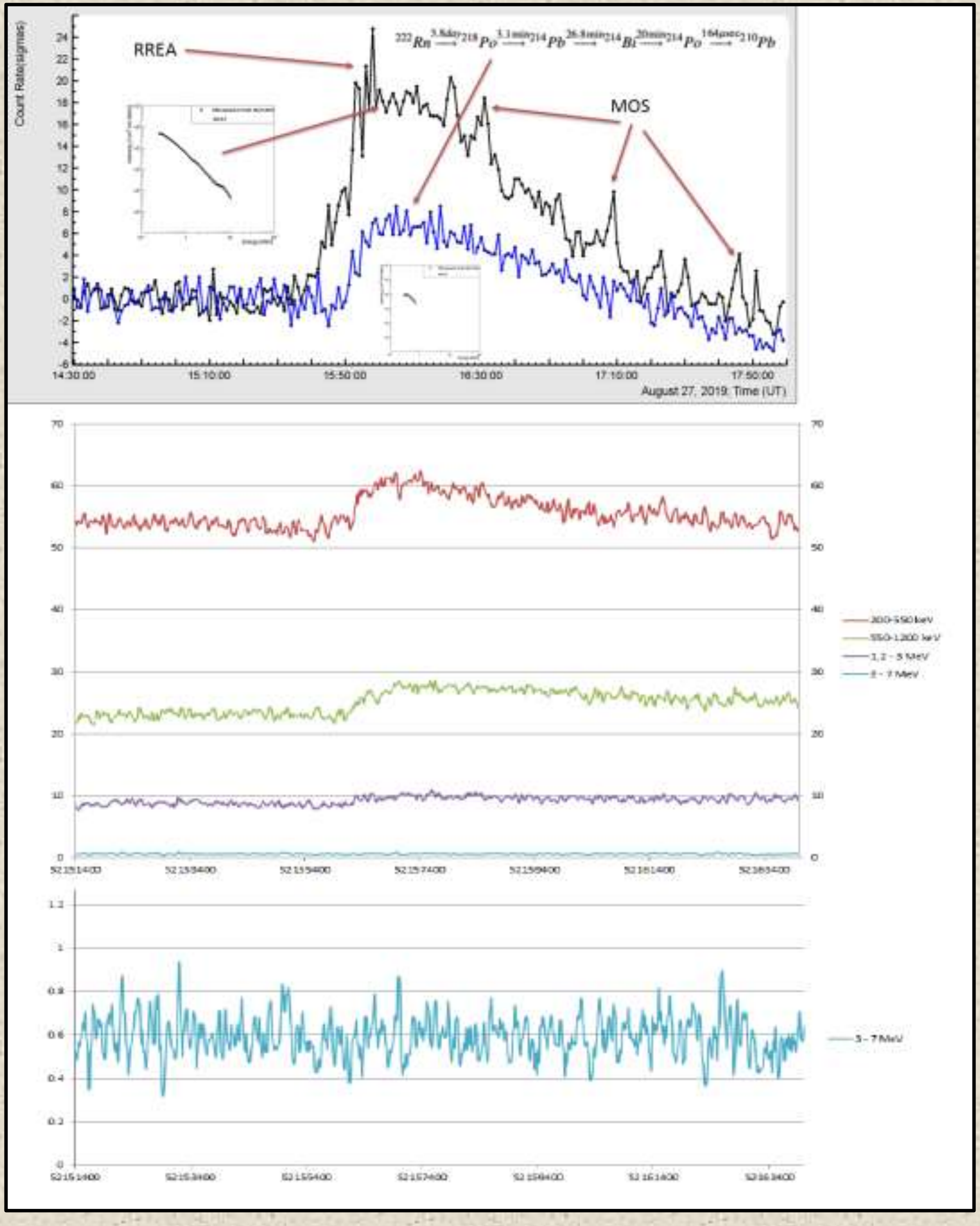
Background rate of NaI network detector is ~50000 min^{-1}, so sigma is ~225 min^{-1}

7 sigma is 1575 min^{-1}=26.25 c^{-1}.

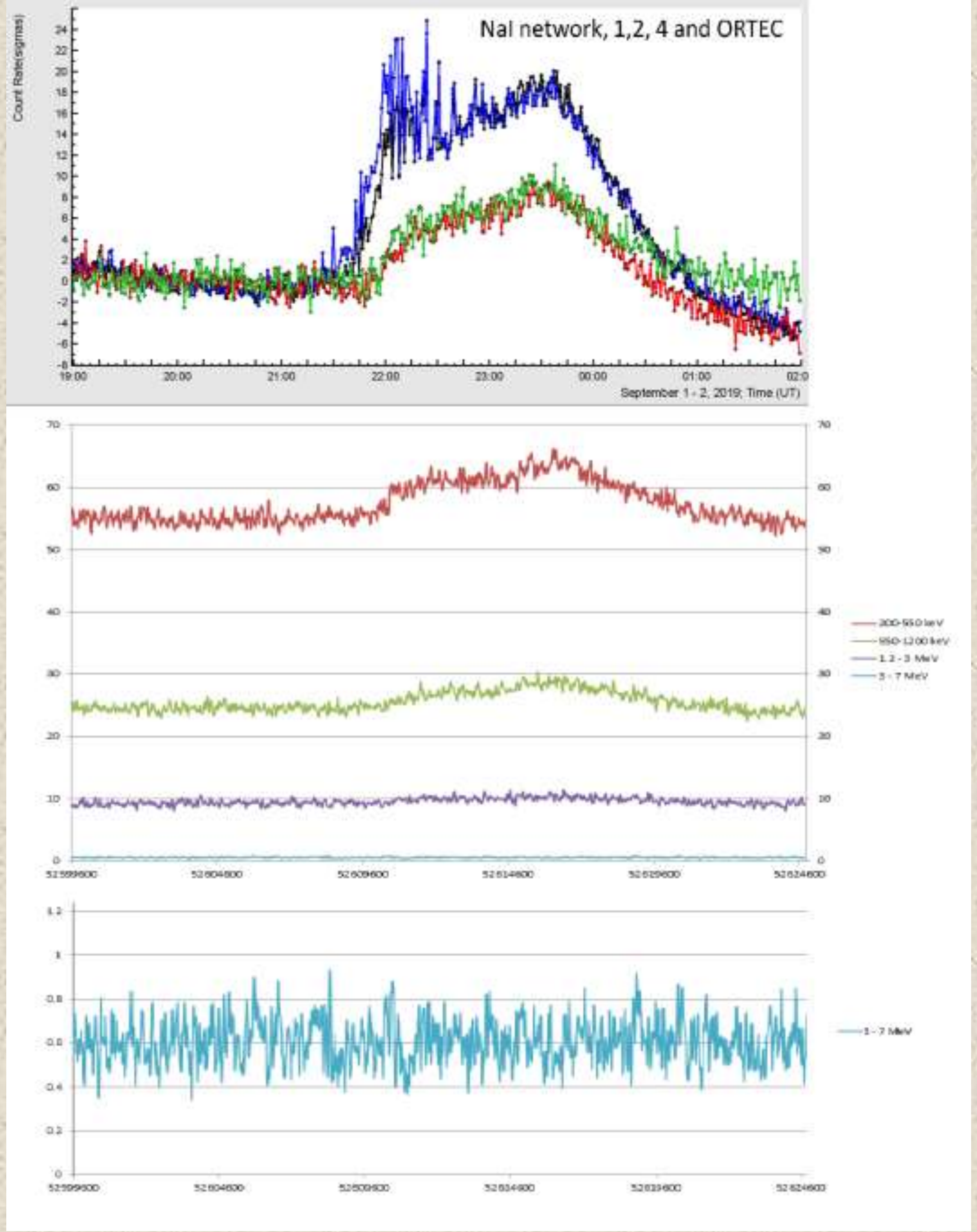
We expect readings 30 times less so the expected peak is 0.875 s^{-1}



August 27, 2019



September 1-2, 2019



For the conclusion:

Several questions are waiting for an answer:

- Why do similar instruments sometimes have qualitatively different time behavior of readings?
- What kind of particles do we detect in short-hard peaks? Are the accelerated electrons sometimes detected directly?
- Where the Rn-222 and its daughters Bi-214 and Pb-214 are located? How do they appear near the instrument during thunderstorms?
- How do the Bi-214 and Pb-214 disappear? Is the time of soft TGE decay the combination of half-life times of these isotopes?
- Mapping of the cloud in hard radiation is useful in order to locate the place of the gamma-ray source

Thank You!