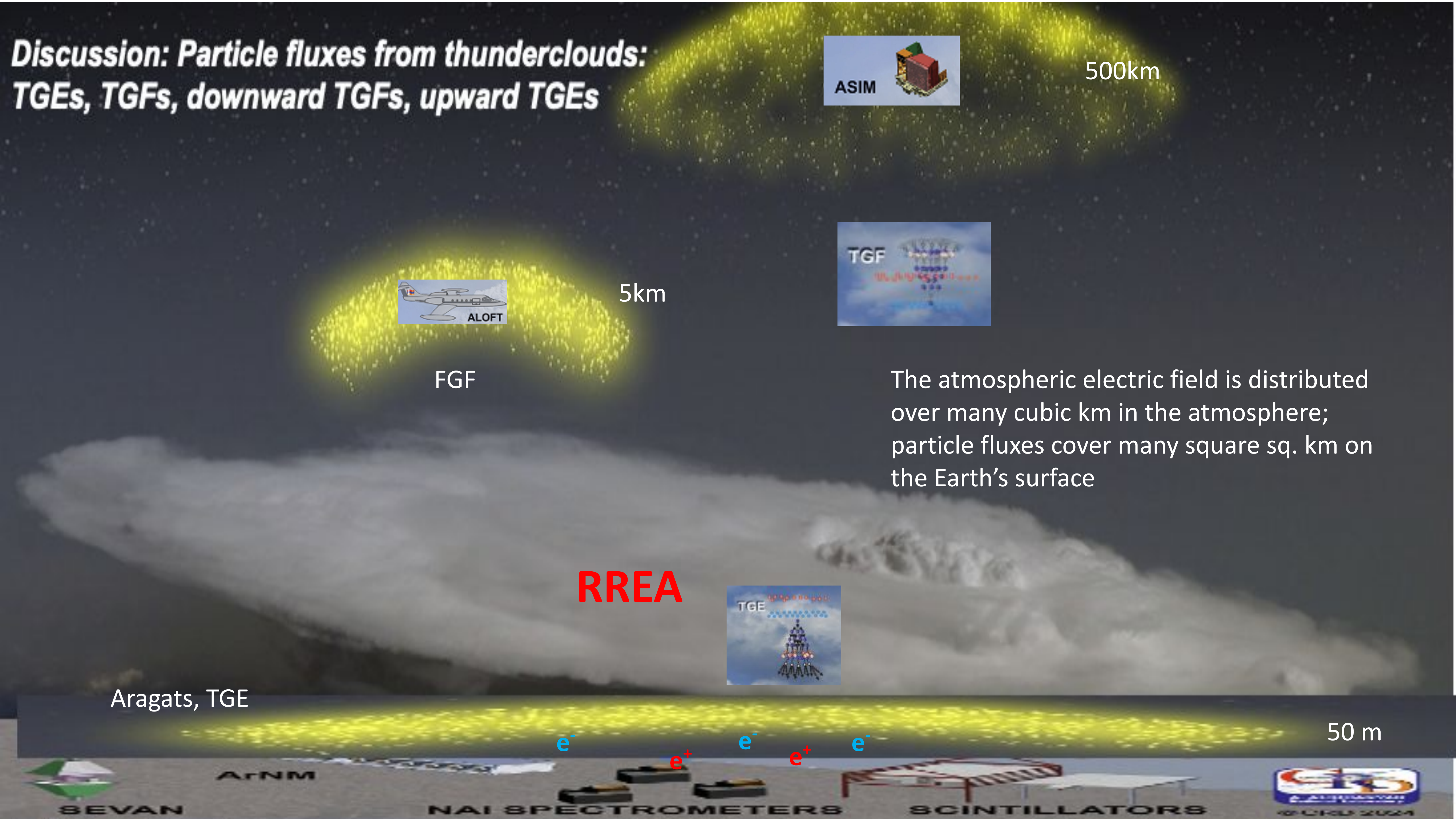
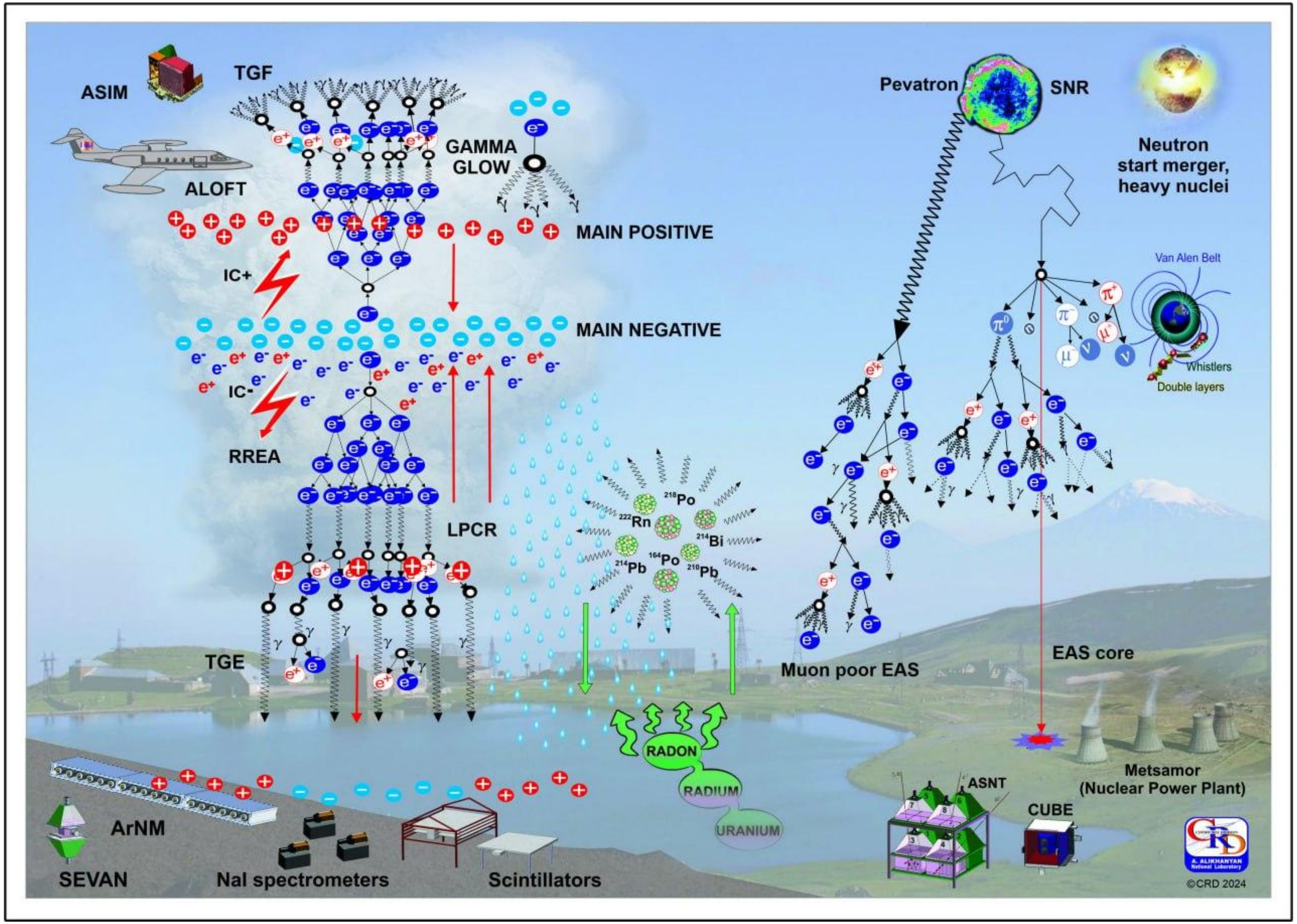
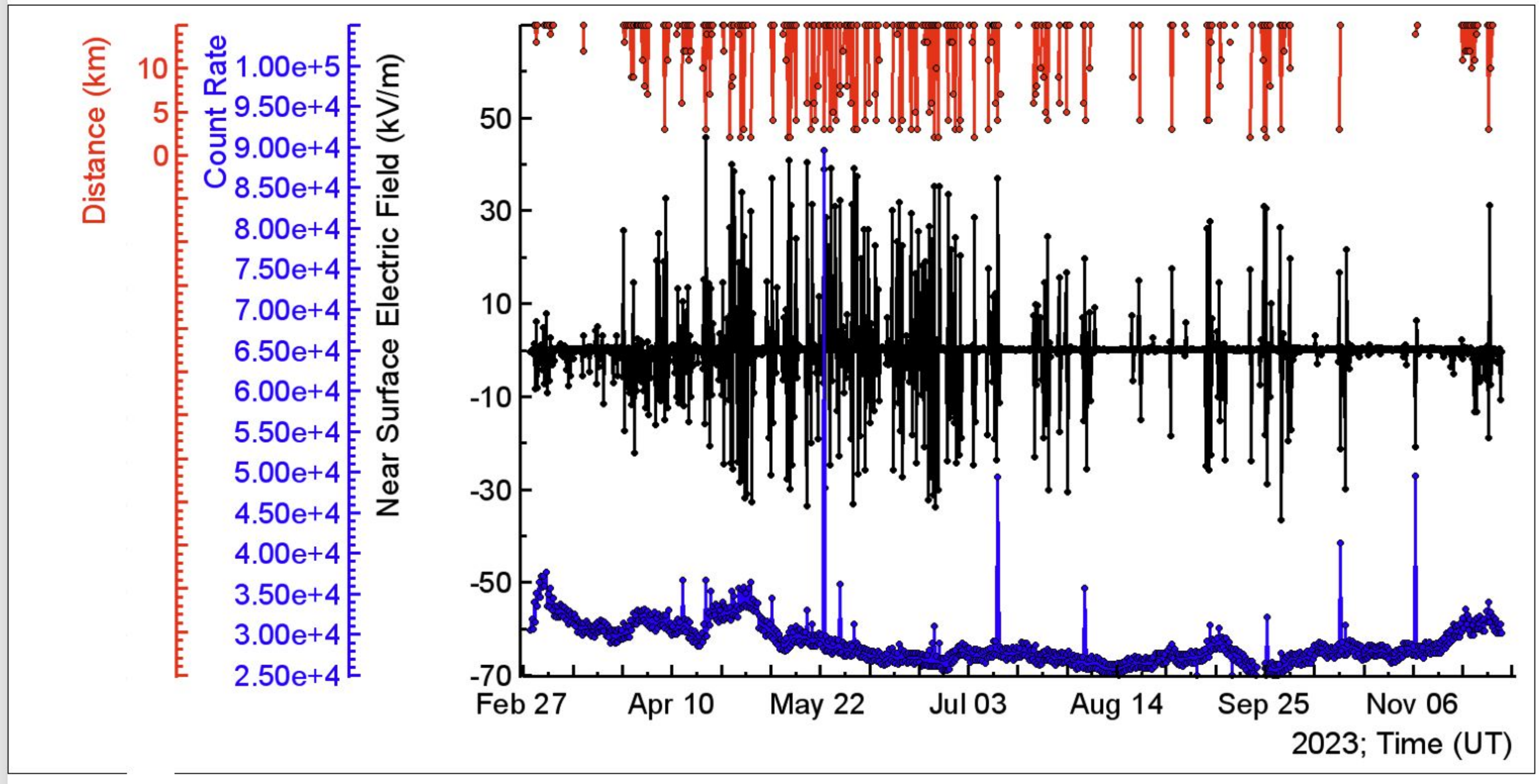

Discussion: Particle fluxes from thunderclouds:
TGEs, TGFs, downward TGFs, upward TGEs
ASIM
500km
5km
ALOFT
FGF
TGF
The atmospheric electric field is distributed over many cubic km in the atmosphere; particle fluxes cover many square sq. km on the Earth's surface
RREA
TGE
Aragats, TGE
50 m
e-
e+
e-
e+
e-
ArNM
SEVAN
NAI SPECTROMETERS
SCINTILLATORS

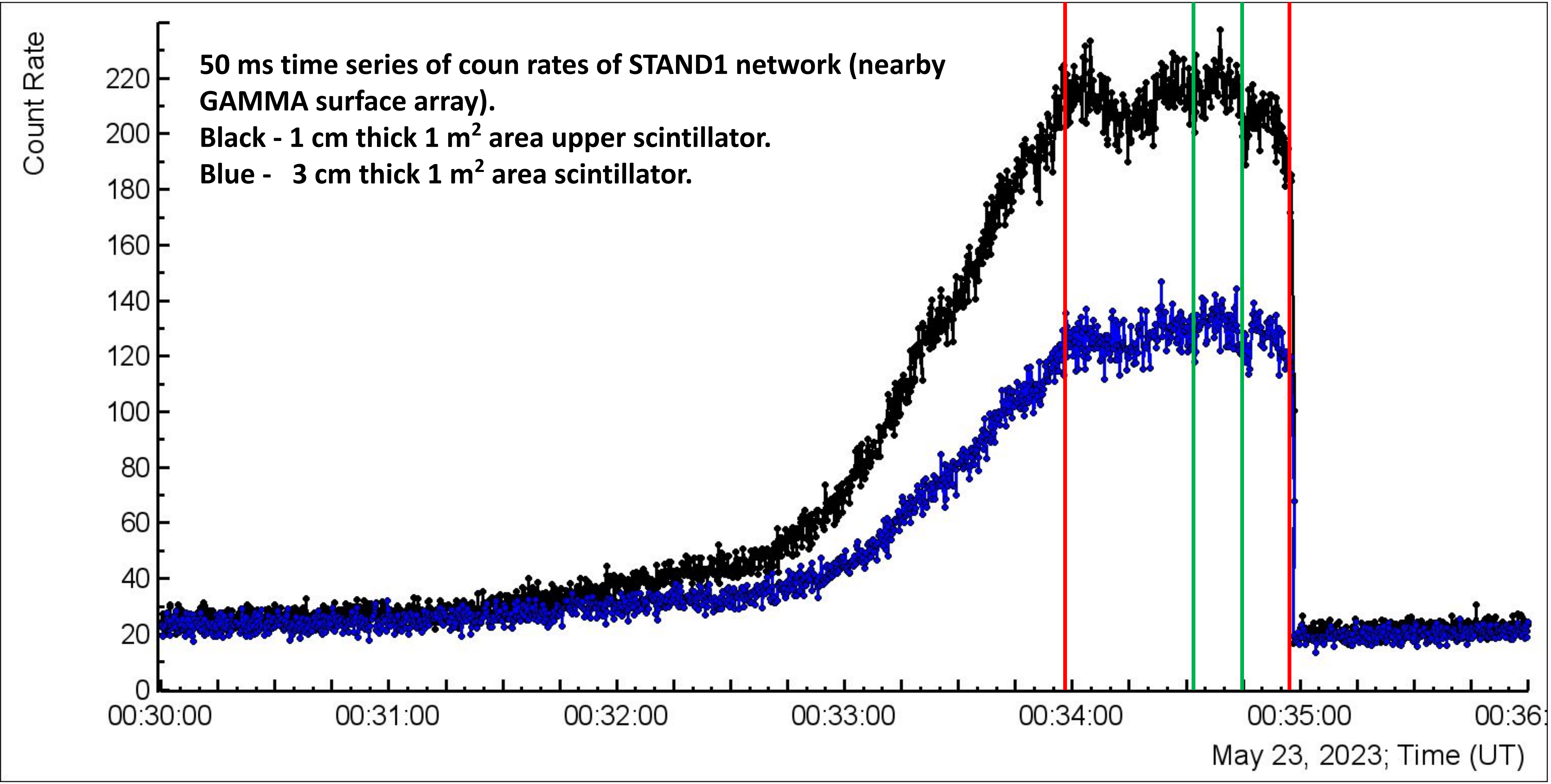
Particle fluxes from space and cloud accelerators and from Radon progeny radiation (circulation effect)



Geophysics networks (particles, fields, and meteorology). STAND1, EFM 100, DAVIS, LLN

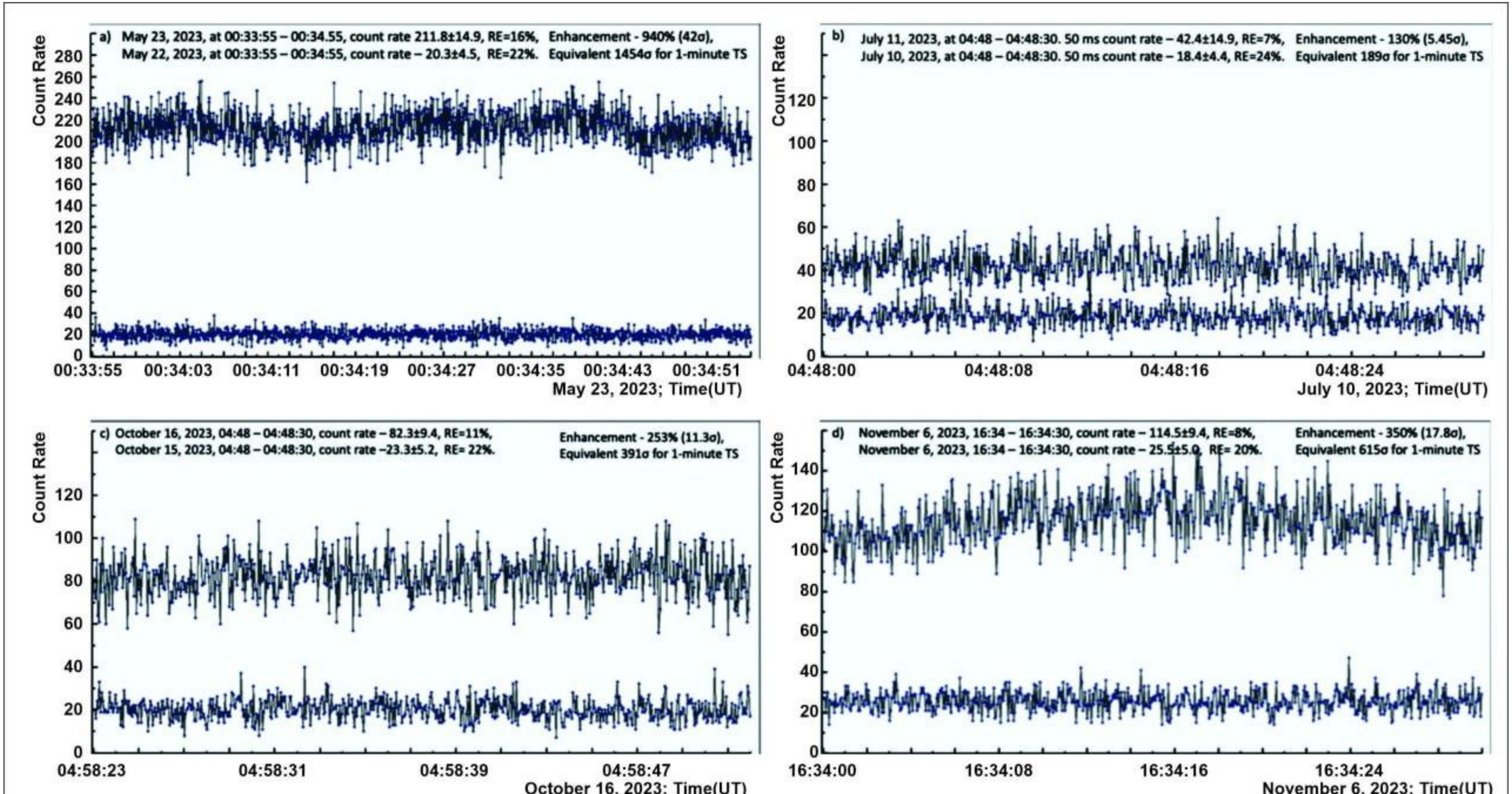
Black shows disturbances of the NSEF measured by EFM 100 electric mills produced by the BOLTEK firm; blue shows a time series of 1-minute count rates of a STAND3 plastic scintillator with a 1 m^2 area and 3 cm thickness (1000 coincidence, signal only in the upper scintillator); red shows distances to lightning flashes.



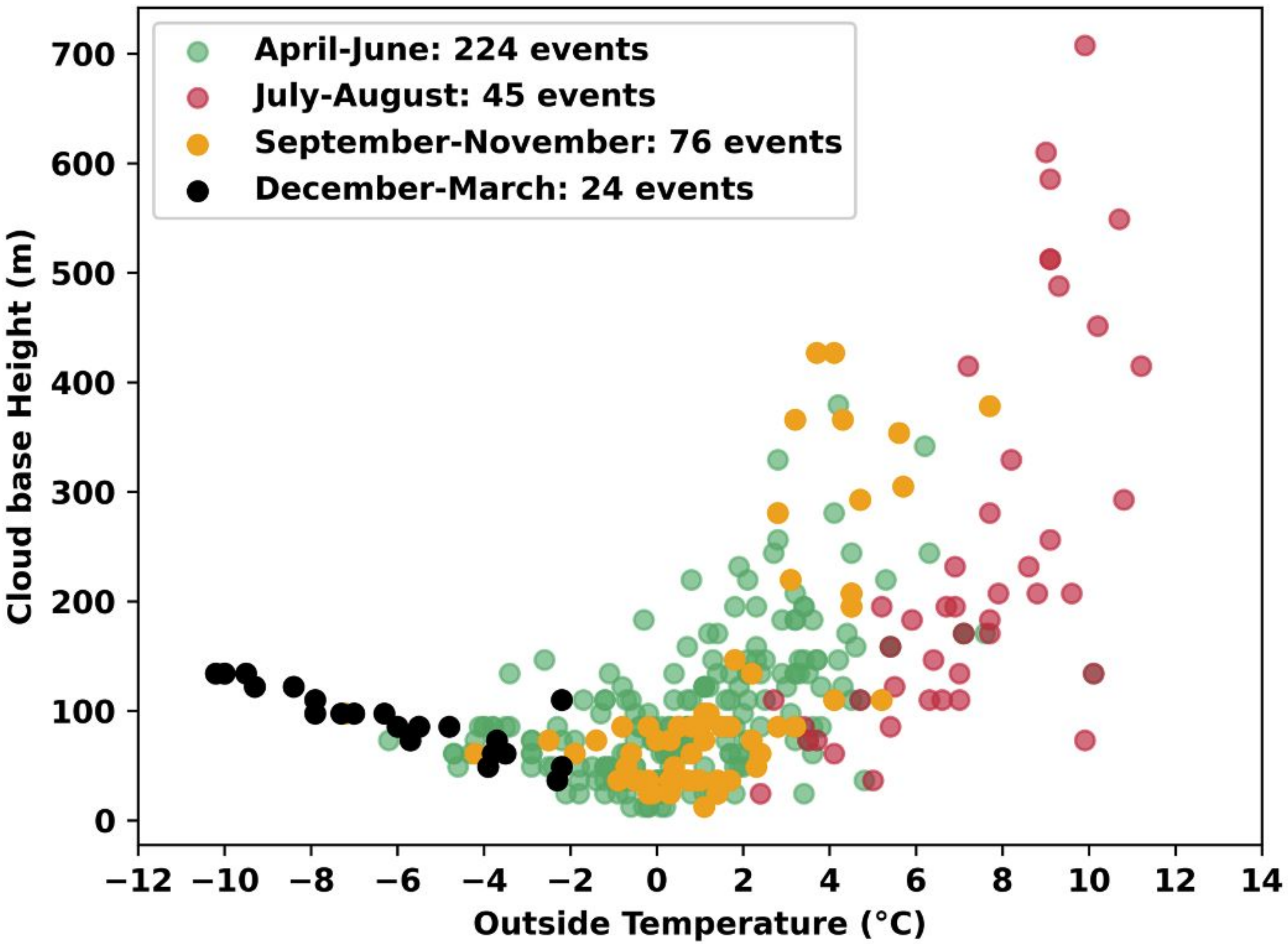

50 ms time series of coun rates of STAND1 network (nearby GAMMA surface array).
Black - 1 cm thick 1 m² area upper scintillator.
Blue - 3 cm thick 1 m² area scintillator.
Count Rate
0
20
40
60
80
100
120
140
160
180
200
220
00:30:00
00:31:00
00:32:00
00:33:00
00:34:00
00:35:00
00:36:
May 23, 2023; Time (UT)

50 ms time series of count rates of the STAND1 network's GAMMA scintillator's upper scintillator.

The upper curve on each frame corresponds to TGE and the lower curve to the background, measured one day earlier and at the same time as TGE. In each frame, the mean count rate, the



Scatter plot between outside temperature and cloud base height



Most of the TGEs occurred in Spring and Autumn (80%) when the outside temperature is in the limits of -3°C до +3C° and clouds are low above the surface.

Discussion: Particle fluxes from thunderclouds: TGEs, TGFs, downward TGFs, upward TGEs

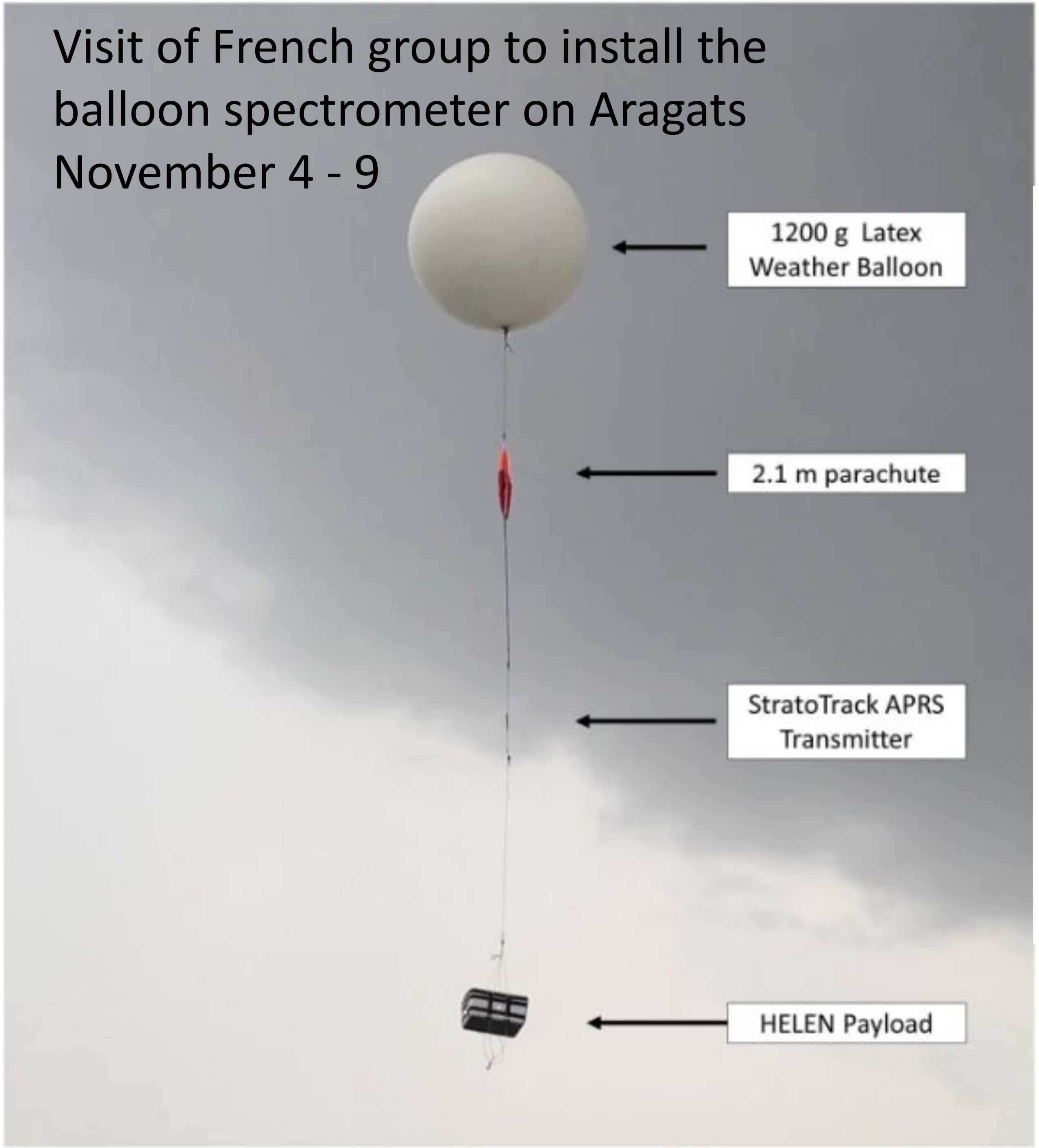
- Despite more than three decades of measurements, simulations, and extensive analysis, the relationship between atmospheric discharges and particle fluxes in the upper atmosphere remains poorly understood and, at times, contradictory. Progress in this field hinges on distinguishing between primary physical processes and measurement-based terms and integrating these concepts into a unified framework. Such a framework should reflect the key drivers of these phenomena, such as the **relativistic runaway electron avalanche (RREA),** along with related observational events like terrestrial gamma-ray flashes (TGFs), thunderstorm ground enhancements (TGEs), gamma glows, and the hypothetical "downward TGF."
- **TGFs**, or terrestrial gamma-ray flashes, were first reported by Fishman et al. (1994). These are brief bursts of gamma radiation detected by orbiting gamma-ray observatories, lasting between tens and hundreds of microseconds. TGFs originate from thunderstorms at altitudes of 10 to 15 kilometers, typically in equatorial regions, and are detected by spacecraft positioned 400 to 700 kilometers above the source.
- **TGEs**, or thunderstorm ground enhancements, described by Chilingarian et al. (2010, 2024), represent intense and prolonged particle fluxes observed on the Earth's surface. These fluxes are closely associated with thunderstorms and elevated atmospheric electric fields, allowing for detailed study of the particle fluxes that reach the surface.
- In contrast, **gamma glows** are bursts of gamma radiation detected in the atmosphere by balloon or aircraft-based instruments. These events persist for tens of seconds to several minutes and are usually concluded by lightning.
- Several research groups have also recently reported millisecond-long radiation bursts associated with lightning activity at the Earth's surface, referred to as **"downward TGFs."**

Origin of particle fluxes from thunderclouds: TGEs, TGFs, downward TGFs, upward TGEs, Flikgering gamma gamma-ray flashes (FGFs)

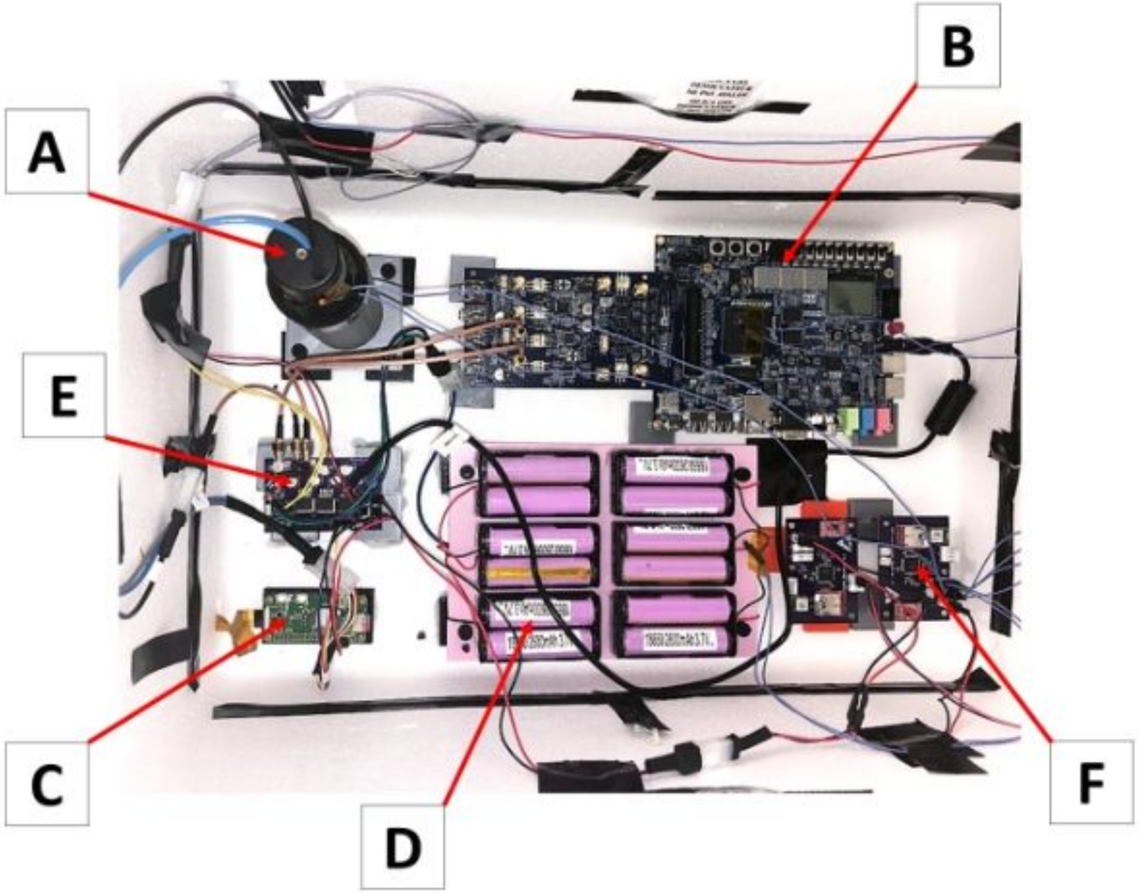
NASA ER-2 aircraft (Spy U2 from 60th shut down in 1960, Powers – pilot). MacDill Air Force
Base in Tampa, Florida, USA. A total of ten flights (3–8 h each) at 20-km
altitude were performed above active thunderstorms. The airborne scientific payload consists of five independent gamma-ray detectors, 30 photometers, three electric-field sensors, two radars, and two passive radiometers. Pilot was instructed to return to the same location as long as gamma-ray glows were detected.

Bismuth-Germanium-Oxide instrument from the University
of Bergen. All detectors have different geometric areas ranging from 0.09 to 225 cm^2 to provide four orders of magnitude dynamic range in flux sensitive in the energy range 300 keV to >30 MeV and have a 28-ns time-tagging accuracy.
iSTORM spectrometer’s energy range is 0.3- 5 MeV.
iSTORM consists of 32 1-inch-diameter CeBr3 scintillating crystals with silicon photomultiplier

Visit of French group to install the balloon spectrometer on Aragats November 4 - 9

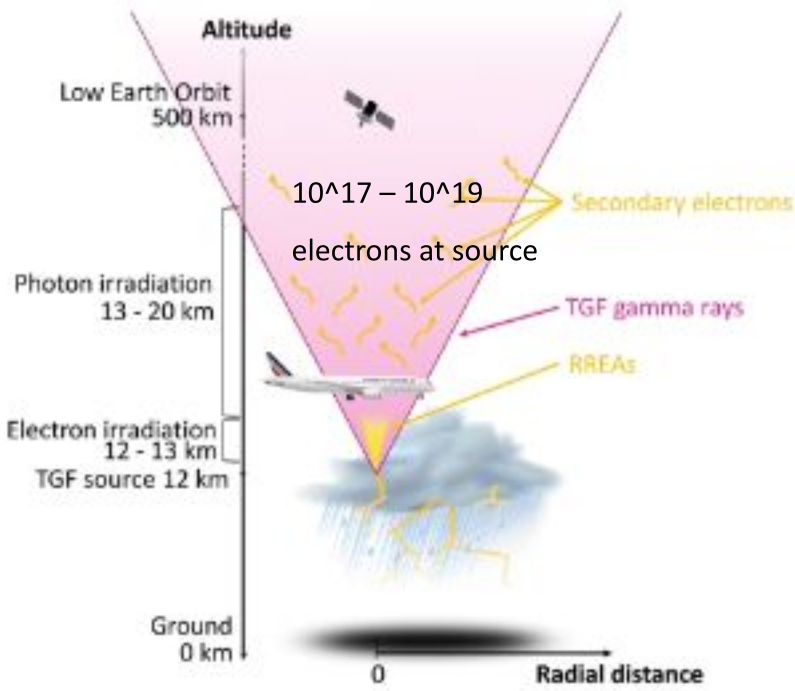


TGFs,Gamma-RayGlows,andDirectLightningStrike RadiationObservedDuringaSingleFlightofaBalloon-BorneGamma-RaySpectrometer, The University of Alabama in Huntsville, Huntsville, AL, USA

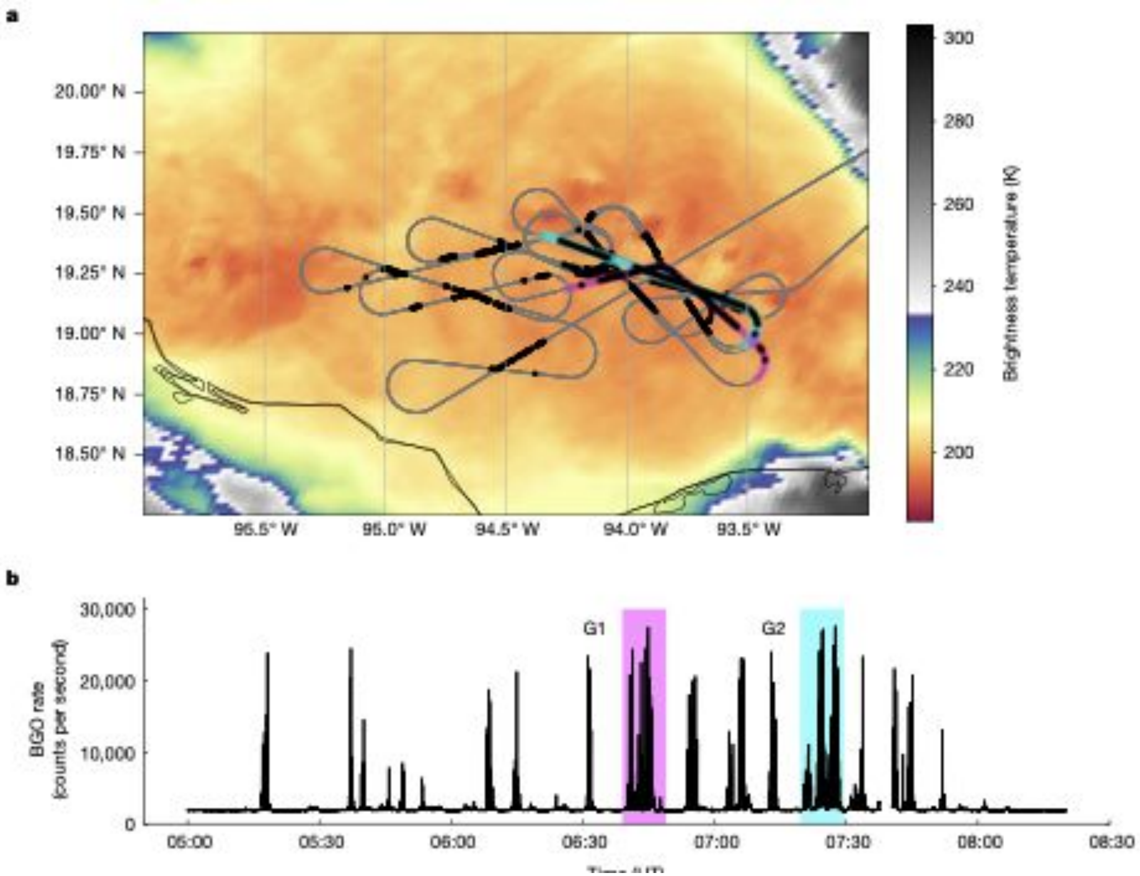


(A) LYSO: Ce scintillator crystal coupled with a Hamamatsu R6095PMT, (B)DE-10 Standard Development Board with ADC Card for Processing radiation pulse data, (C)Raspberry Pi-based optical camera capturing 1080p video for lighting flashes, (D)18650 Battery power supply, (E)Power distribution board, (F)Environmental data acquisition board recording temperature, GPS timing/location, and payload orientation.

Paradigm change. TGFs originate not from point sources not from lightning. A strong electric field originates particle fluxes. Radiation covers many cubic km in space and many sq. km at Earth's surface

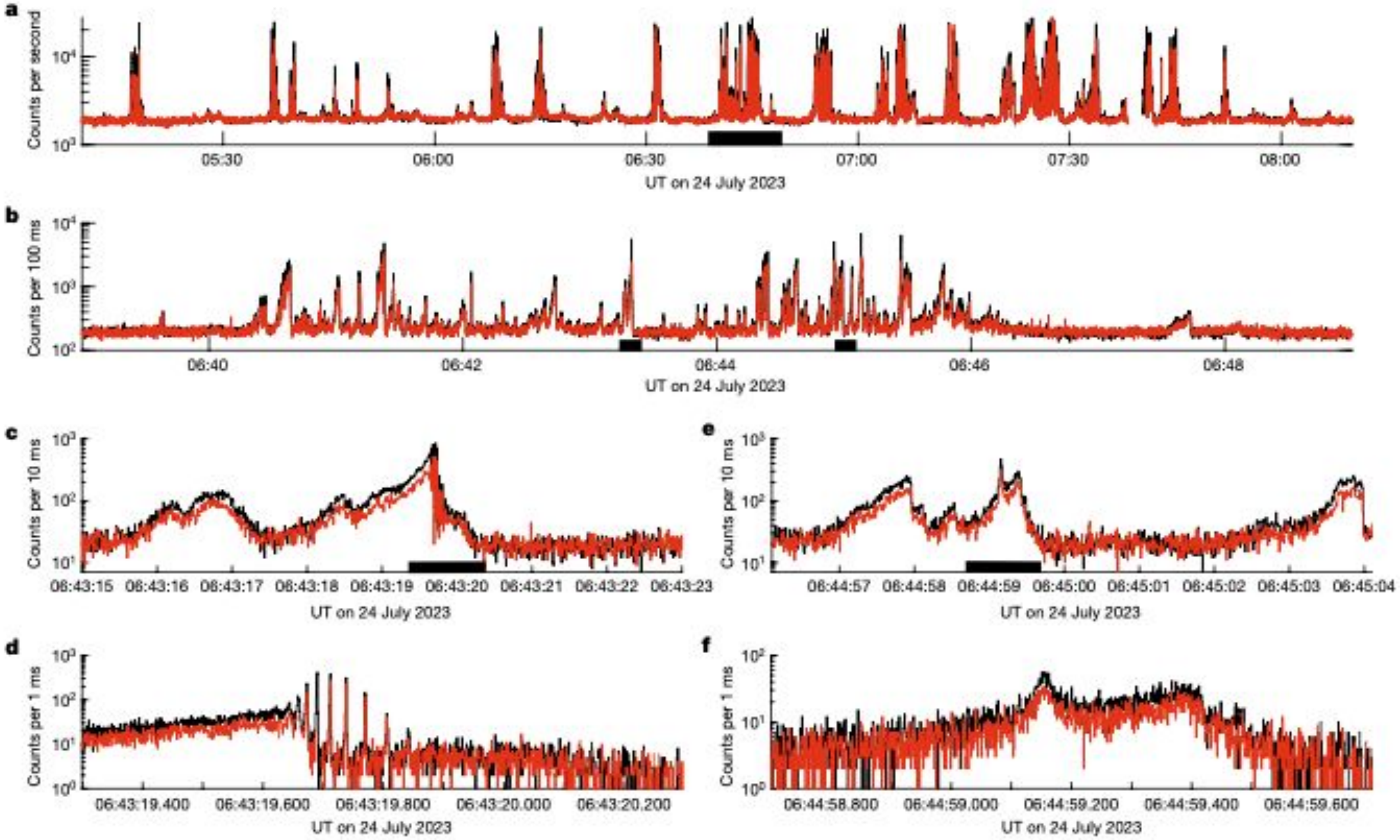


Tropical thunderclouds over the ocean and coastal regions emit gamma rays for hours over areas up to a thousand square kilometers with increases of 10–30 times the background. (Marisaldi, et al., 2024)

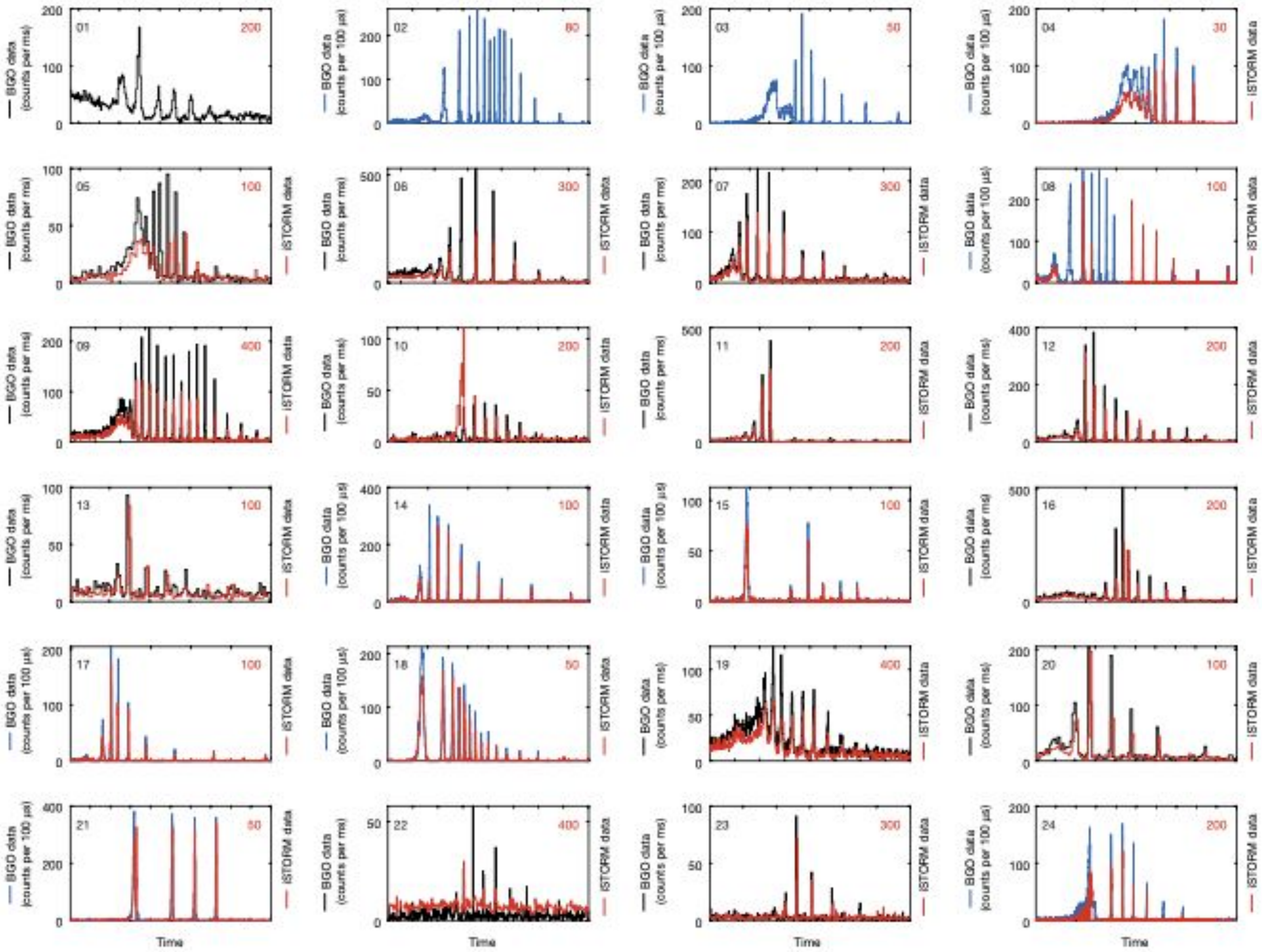


Picture credit: Pallu, M., Celestin, S., Trompier, F.,& Klerlein, M. (2021). Estimation of radiation doses delivered by terrestrialgamma ray flashes within leader-based production models. JGR : *Atmospheres*,*126*, e2020JD033907.

BGO and iSToRM spectrometers detection: particle fluxes observed during five of the ten flights spent 2–3 h above active gamma-glowing thunderclouds



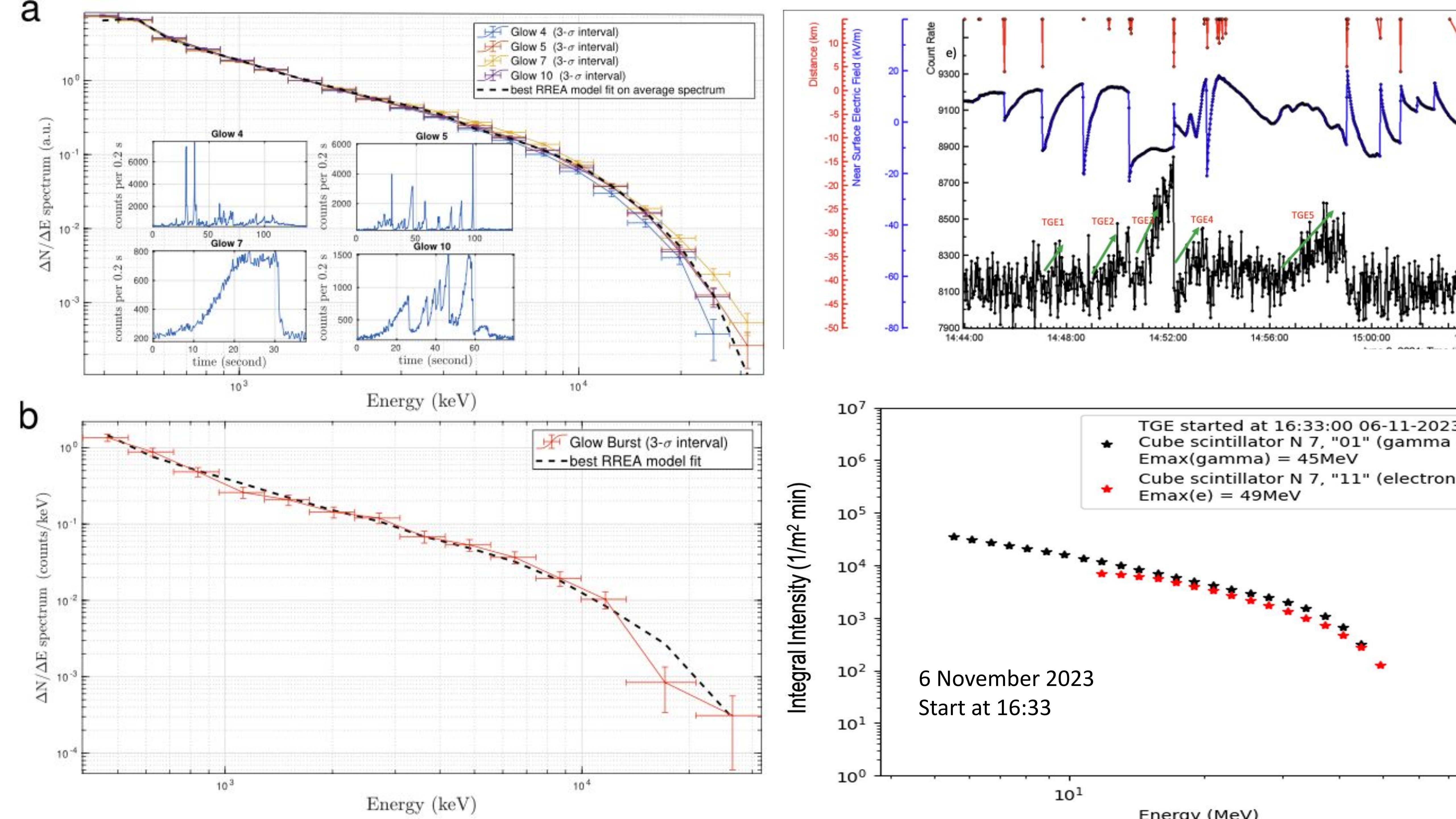
Marisaldi M., Østgaard N., Mezentsev A., et al. 2024, Highly dynamic gamma-ray emissions are common in tropical thunderclouds, Nature 634, 57.



Flickering gamma-ray flashes (FGFs).

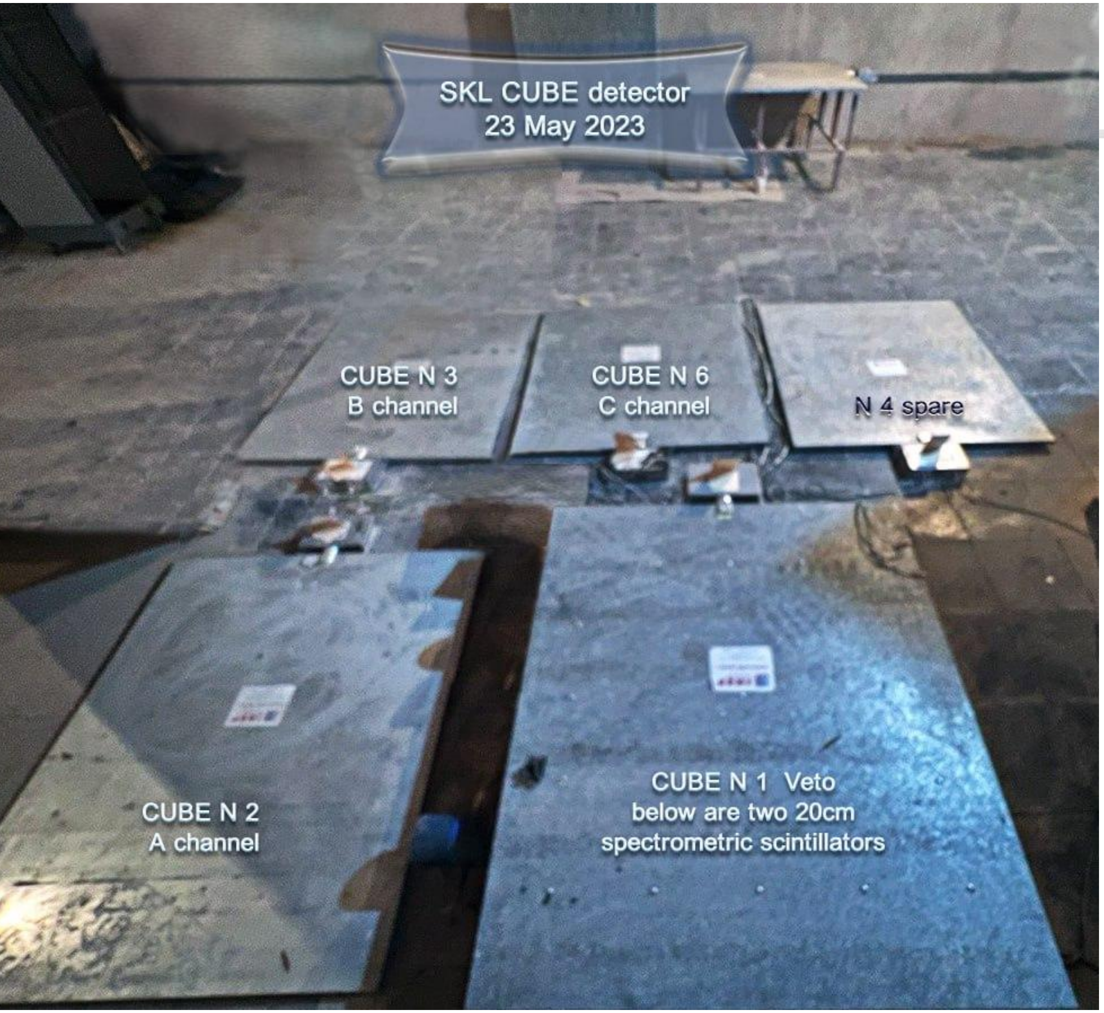
FGFs resemble the usual multi-pulse TGFs but have more pulses; each pulse lasts longer than ordinary TGFs. FGF durations span from 20 to 250 ms, which reaches the lower boundary of the gamma-ray glow duration. FGFs are radio and optically silent, which makes them distinct from normal TGFs.

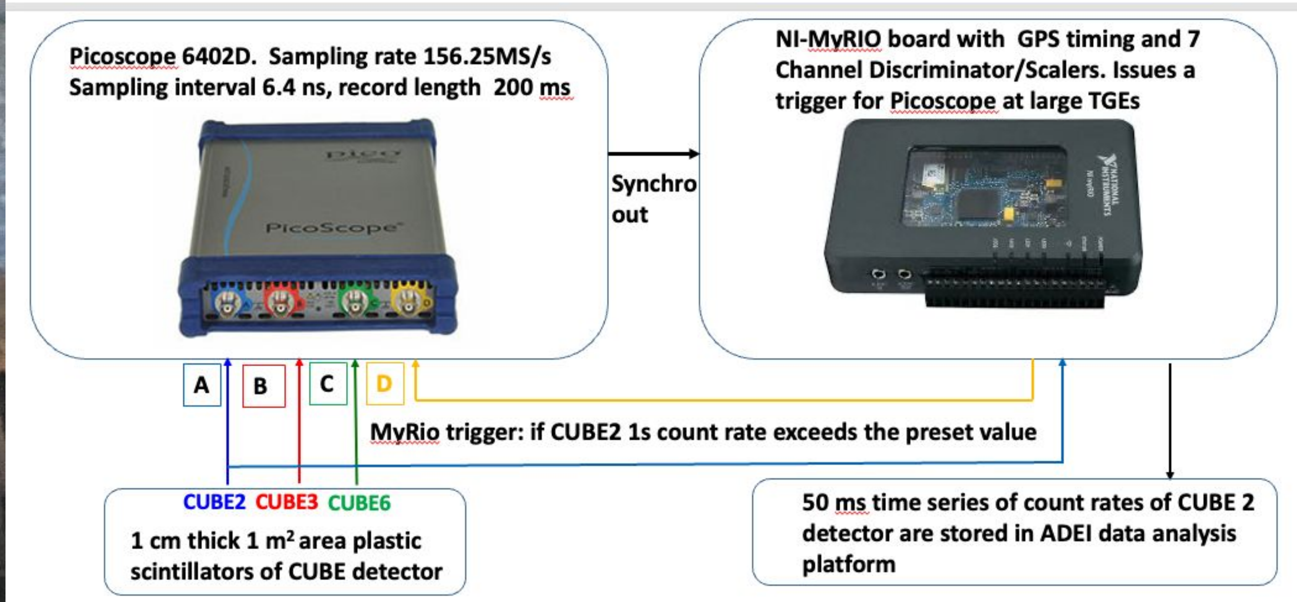
Østgaard N., Mezentsev A., Marisaldi M., et al. 2024, Flickering gamma-ray flashes, the missing link between gamma glows and TGFs, Nature 634, 53.



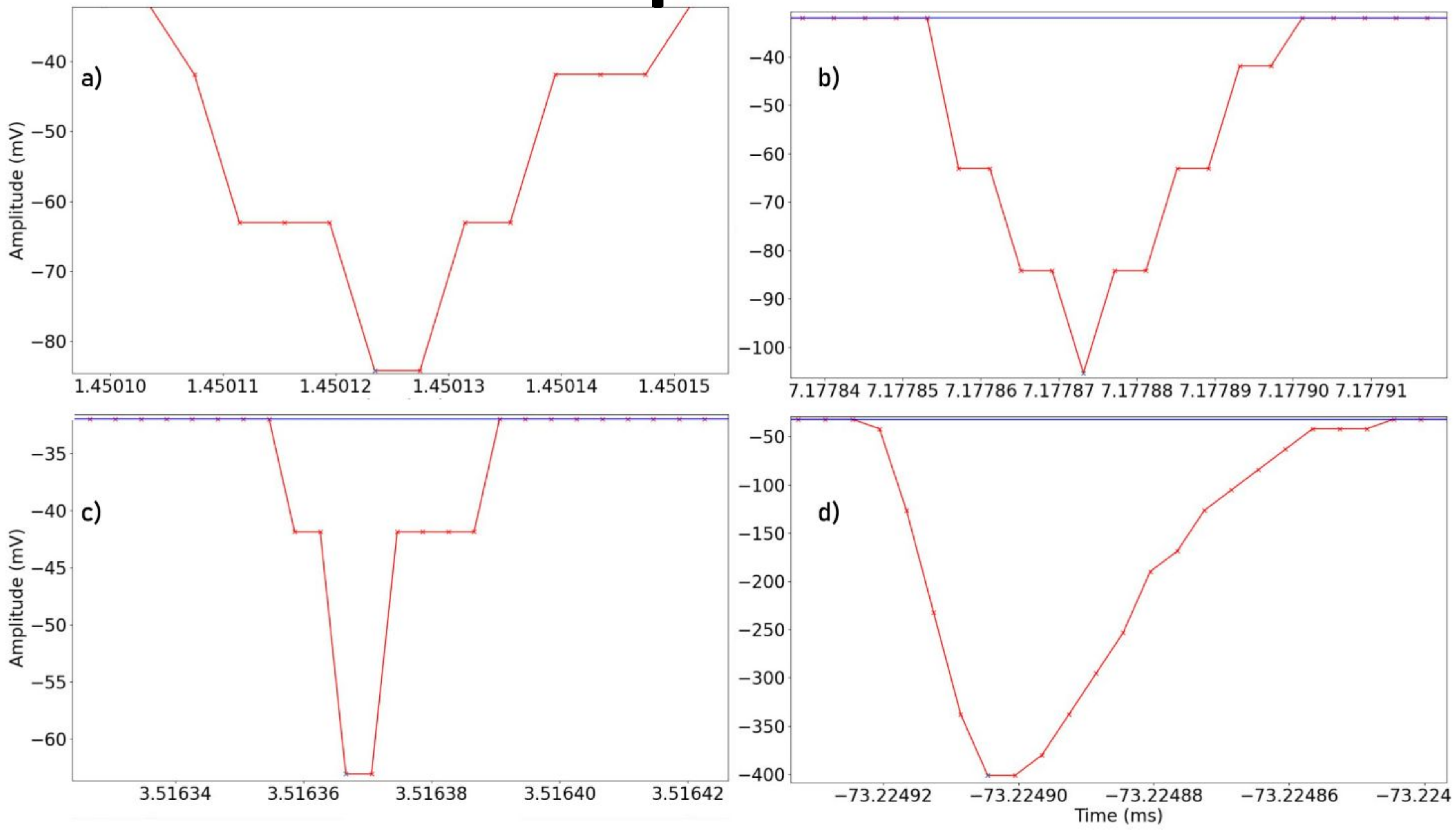
a
Glow 4 (3-σ interval)
Glow 5 (3-σ interval)
Glow 7 (3-σ interval)
Glow 10 (3-σ interval)
best RREA model fit on average spectrum
ΔN/ΔE spectrum (a.u.)
Energy (keV)
Glow 4
Glow 5
Glow 7
Glow 10
counts per 0.2 s
time (second)
b
Glow Burst (3-σ interval)
best RREA model fit
ΔN/ΔE spectrum (counts/keV)
Energy (keV)
Distance (km)
Near Surface Electric Field (kV/m)
Count Rate
e)
TGE1
TGE2
TGE3
TGE4
TGE5
14:44:00
14:48:00
14:52:00
14:56:00
15:00:00
TGE started at 16:33:00 06-11-2023
Cube scintillator N 7, "01" (gamma
Emax(gamma) = 45MeV
Cube scintillator N 7, "11" (electron
Emax(e) = 49MeV
Integral Intensity (1/m² min)
6 November 2023
Start at 16:33
Energy (MeV)

Space-temporal structure of the thunderstorm ground enhancements (TGEs)



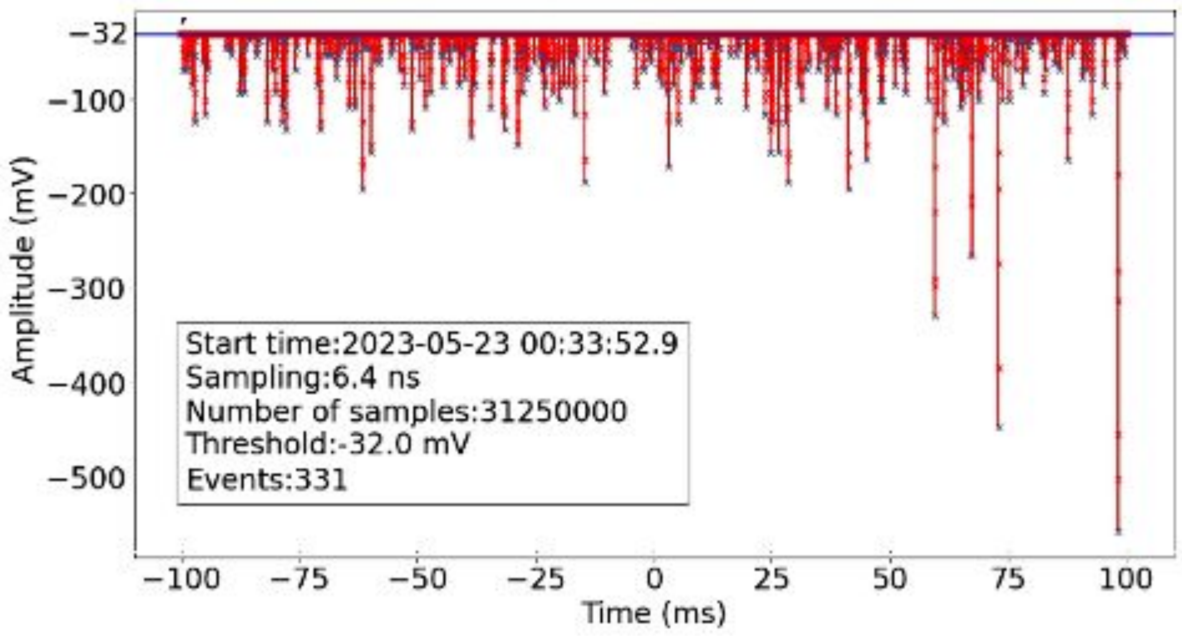


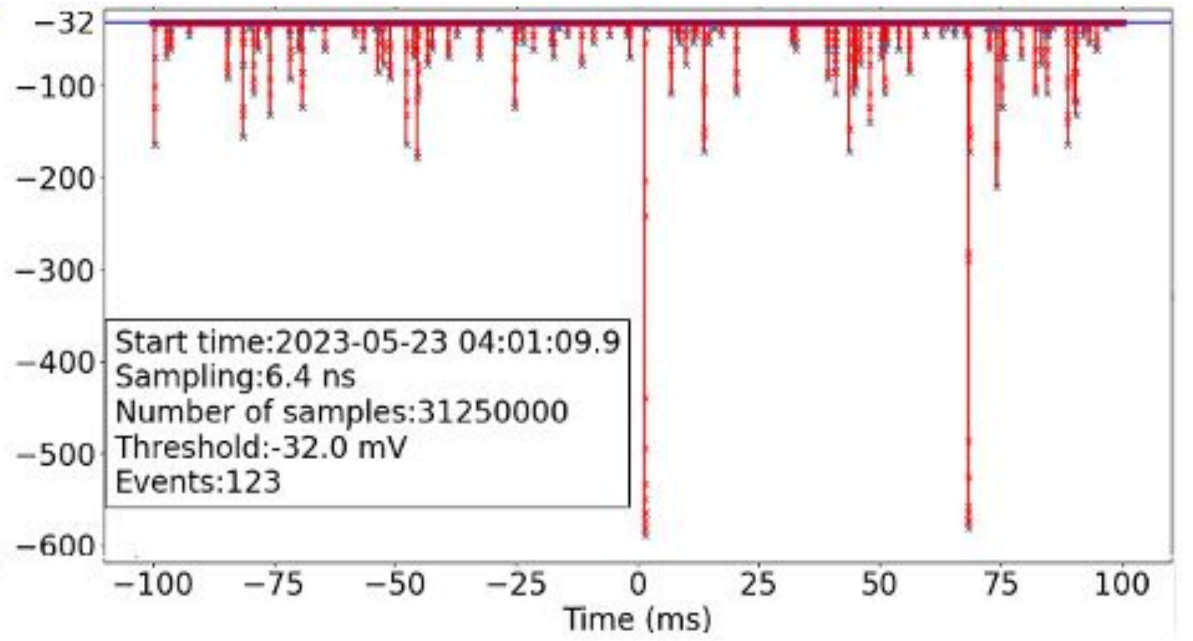
Pulses from plastic scintillators



The signals from the 3 cm thick scintillator, digitized by the oscilloscope, sampling time four ns.

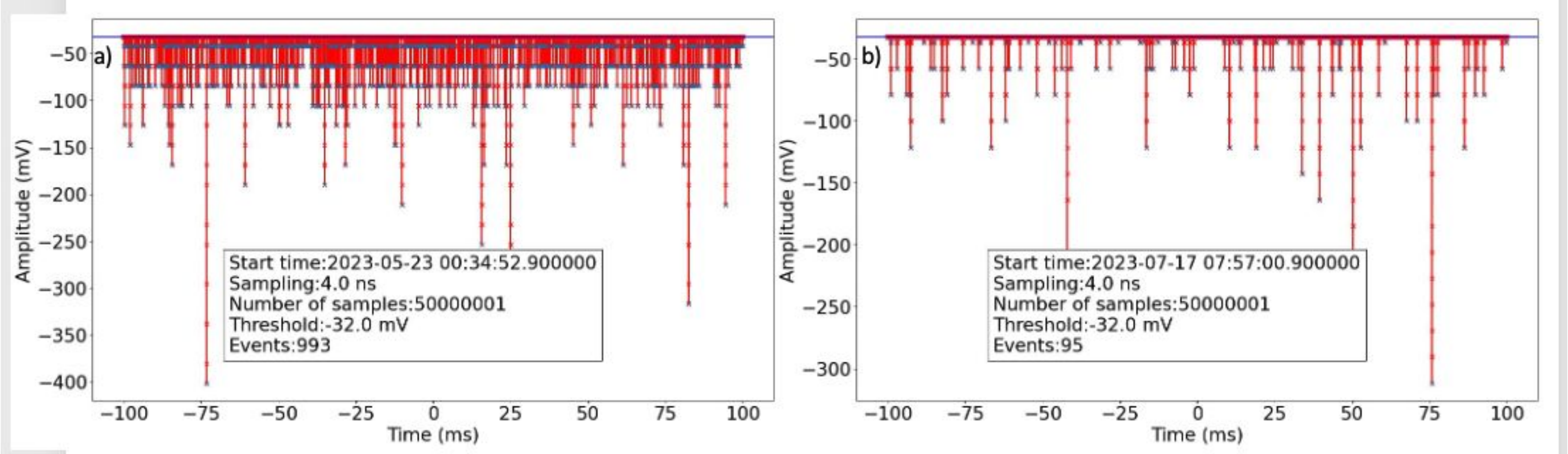
Particles arriving during TGE and at Fairweather (SKL hall)





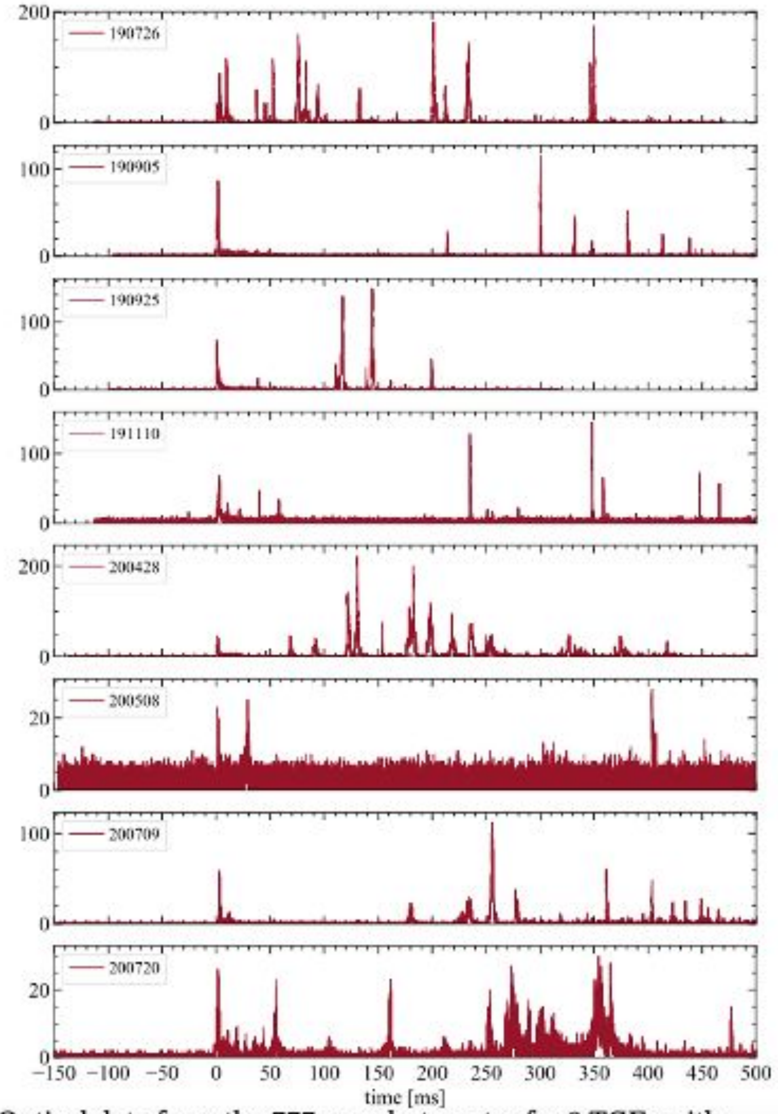
a) signals registered by the digital oscilloscope (channel A, CUBE scintillator N 2). The oscillogram contains data for 200 ms, 100 ms before trigger, and 100 ms after trigger that occurred at 00:33:53 UT on May 23, 2023, frame, and at 04:10 the same day, frame b). In the insets, we show signal sampling information and the number of selected events.

Particles arriving during TGE and at Fairweather (MAKET hall)

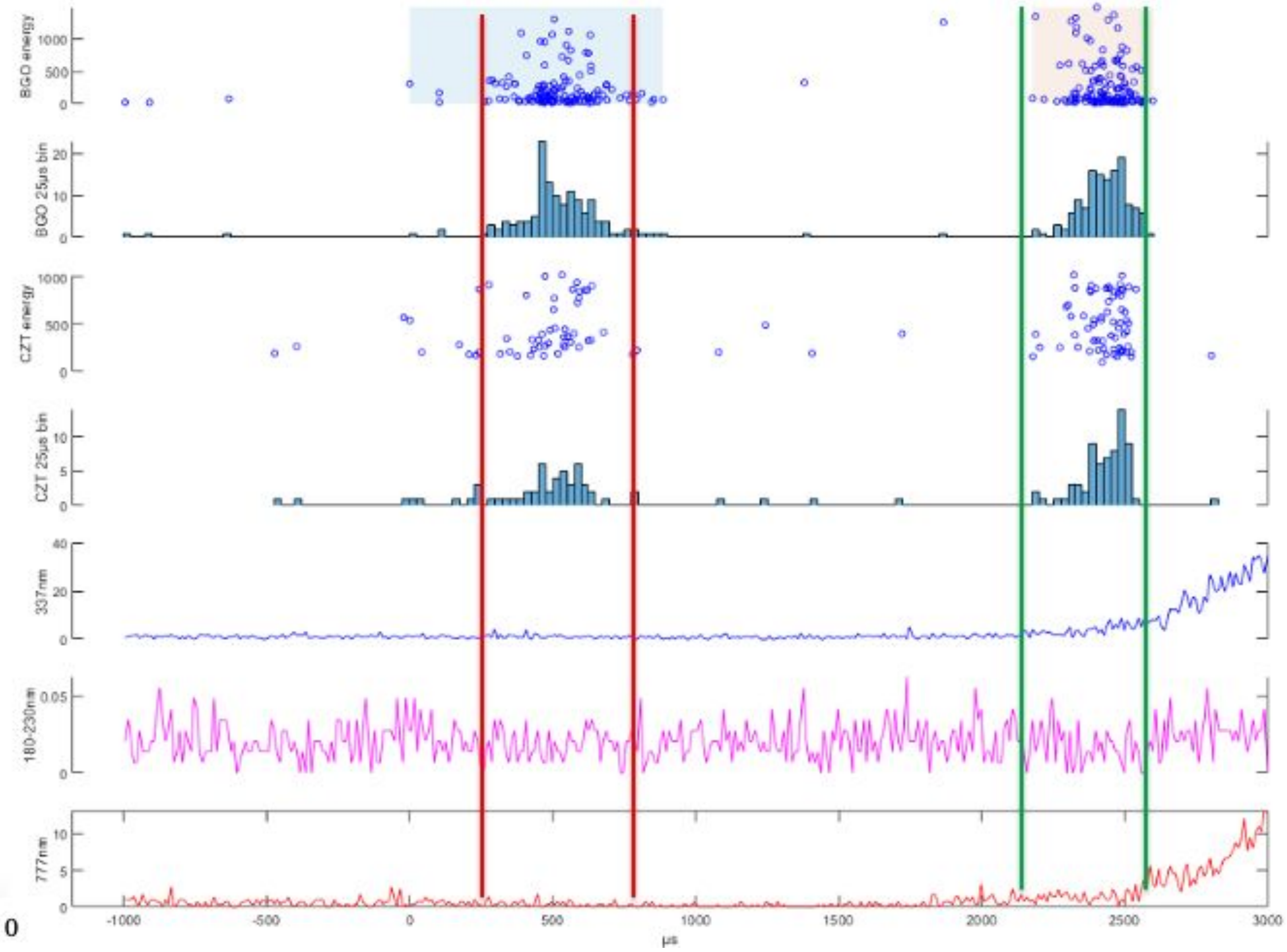


a) signals registered by the digital oscilloscope (MAKET's channel B, 3 cm thick stand-alone outdoor scintillator). The oscillogram contains data for 200 ms: 100 ms before and 100 ms after trigger that occurred at 00:34:52.9 UT on May 23, 2023; b) the same at 07:57:01 on July 17, 2023. In the insets, we show signal sampling information and the number of selected events.

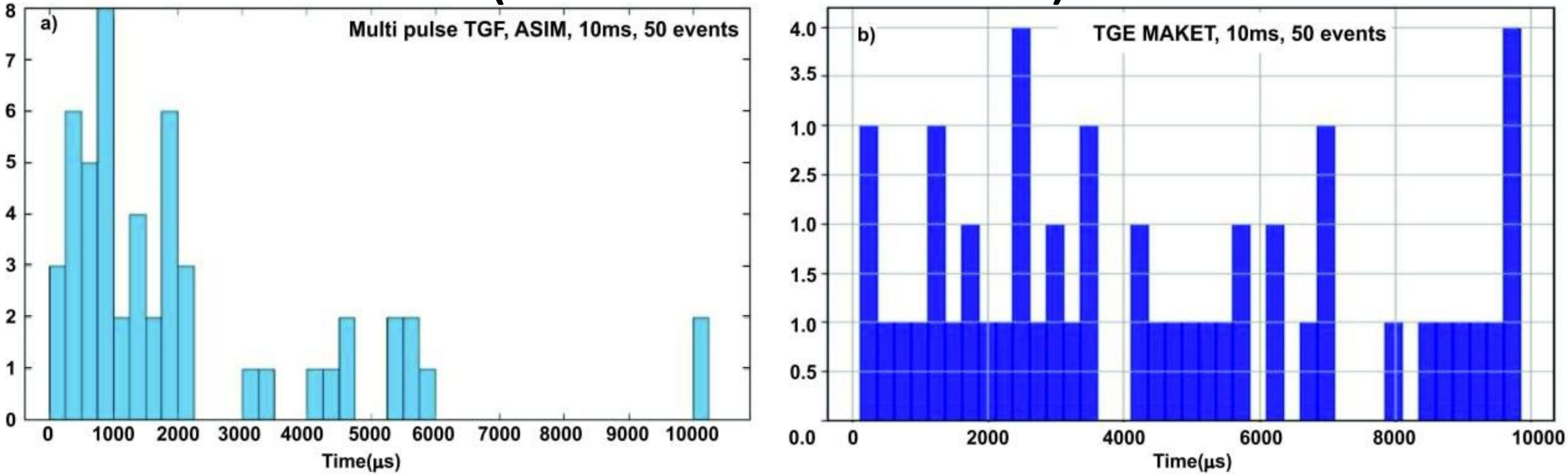
ASIM's multi-pulse TGFs was always produced before the optical associated pulse



Optical data from the 777 nm photometer for 8 TGFs with lightning activity following the TGF. The TGF time is at time = 0

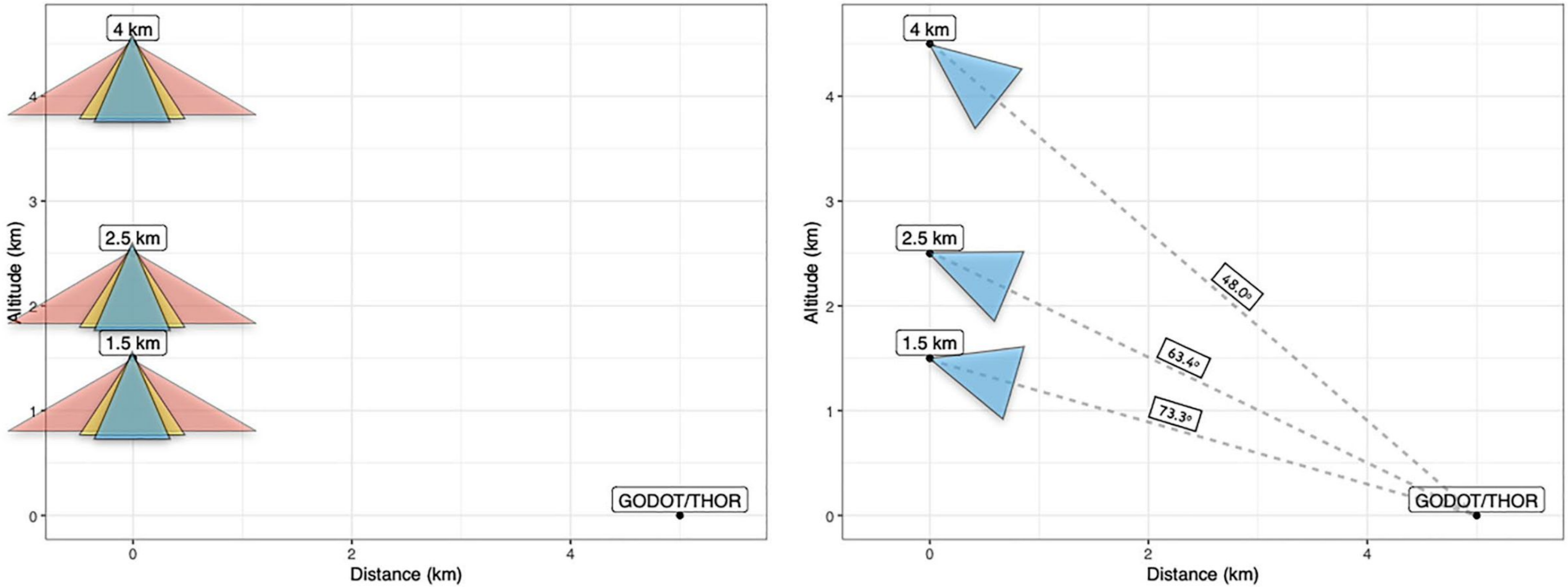


Comparison of TGF and TGE time series (ASIM and MAKET)



a) Time series of gamma-ray arrival times from the onset of the first TGF until the onset of the last TGF, registered by ASIM's high-energy detector (HED) detector; b) Time series of the TGE particle arrival times registered by STAND1 detector near MAKET experimental hall; zero time corresponds to 00:34:53.1 on May 23, 2023. The bin width of both is 250 μs.

Uchinada's downward TGFs from a lightning flash 5 km from detectors (73.3 nadir angle)



Instead of positioning the source of the particle burst just above the detector, the authors position it 5 km away at a lightning stroke, resulting in an absurd model with a point source 1.5 km above
the surface with an intrinsic brightness of 10^19 gammas or above.

1 Ortberg, J., Smith, D. M., Kamogawa, M., Dwyer, J., Bowers, G., Chaffin, J., et al. (2024). Two laterally distant TGFs from negative cloud-to-ground strokes in Uchinada, Japan. *Journal of Geophysical Research: Atmospheres*, *129*, e2023JD039020. https://doi.org/10.1029/2023JD039020

TGE and gamma glow: origin and relation to atmospheric discharges

- Particle fluxes above and below thunderclouds originate from RREA, which produce the same distribution of arriving particles coming uniformly (for large TGEs) or in patches (gamma glows several km above source and TGF several hundred km above source). The duration and intensity of observed fluxes depend on the distance of the detector from the source and share the same physical process.
- I strongly advocate for a community-wide revision of the terms we use to describe these phenomena, providing a unified platform for all sides of the physical processes. This will help avoid further confusion in future research and improper citation policies in publications.
- We need a shortage in terminology, not adding FGF and avoiding fantom: downward TGF!

New paradigm: RREA with CR seeds can explain TGfs, TGEs, and gamma glows

- Electron density at 15 km – 10^4/sec m^2
- Cloud Area 10^8 m^2
- Duration 3-4 hours appr. 10^4 sec
- RREA multiplication 10^4
- Fluence of Tropical Thundercloud ≈ 10^{20}
- Possibly, the cloud will not be uniformly bright for an hour, but
- Large tropical storms can be larger and longer!