

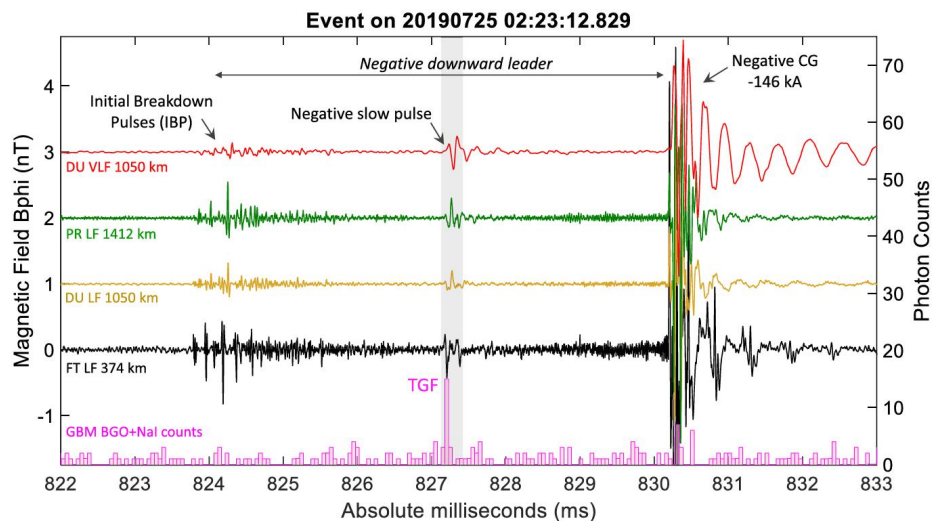
The background of the slide features a complex, abstract pattern of thin, light blue lines that form a series of overlapping, wavy shapes, resembling a stylized wave or a digital signal. The lines are more densely packed in some areas, creating a sense of depth and movement.

Probing the context of TGF events at the Pierre Auger Observatory using VLF sensors

James Sanchez, Adonis Leal, David Smith, John Ortberg, Roberta Colalillo

Lightning emits VLF signatures!

- Many processes known to emit in very low frequency (VLF)



Pu et al. 2020

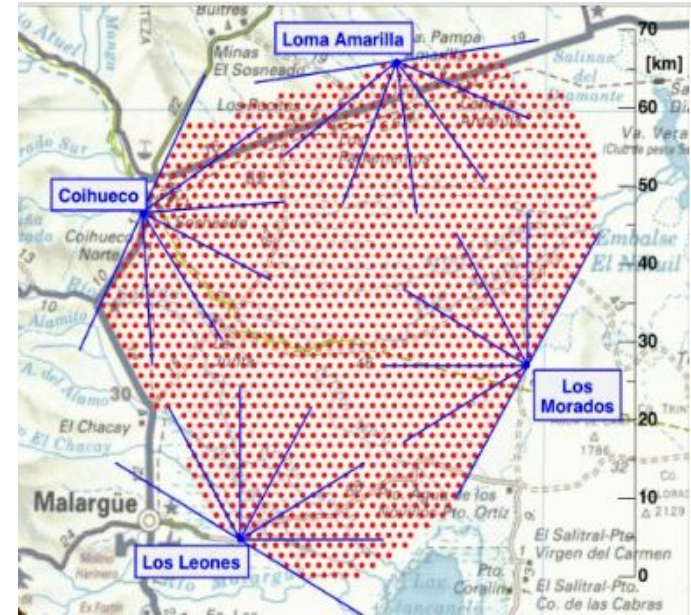
- Some processes produce TGFs

Terrestrial gamma-ray flash (TGF) production and VLF

- Not all lightning processes produce TGFs
- VLF important for getting TGF context
- Lacking consistency of what will / won't produce TGFs

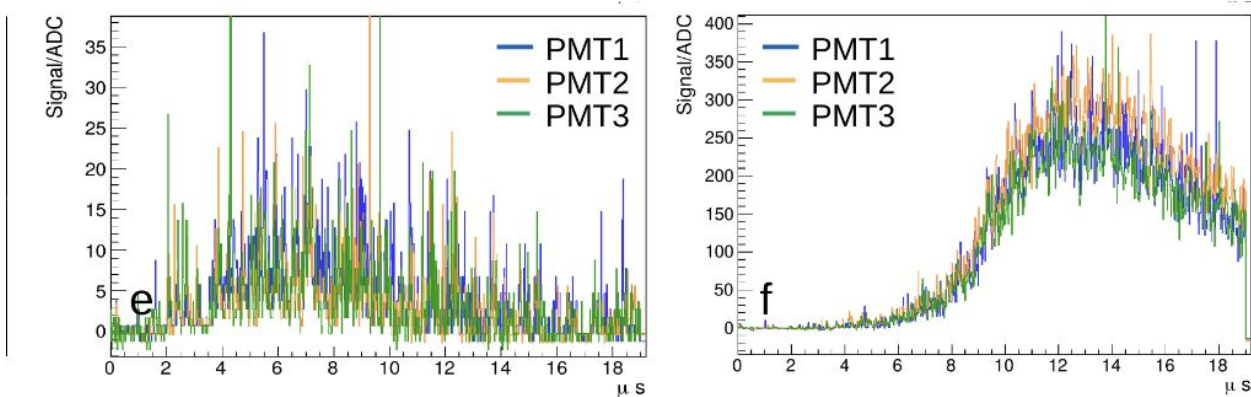
Pierre Auger Observatory

- Sophisticated cosmic-ray detection array
- Useful also for TGF studies (w/ trigger update!)



TGF detections at Auger

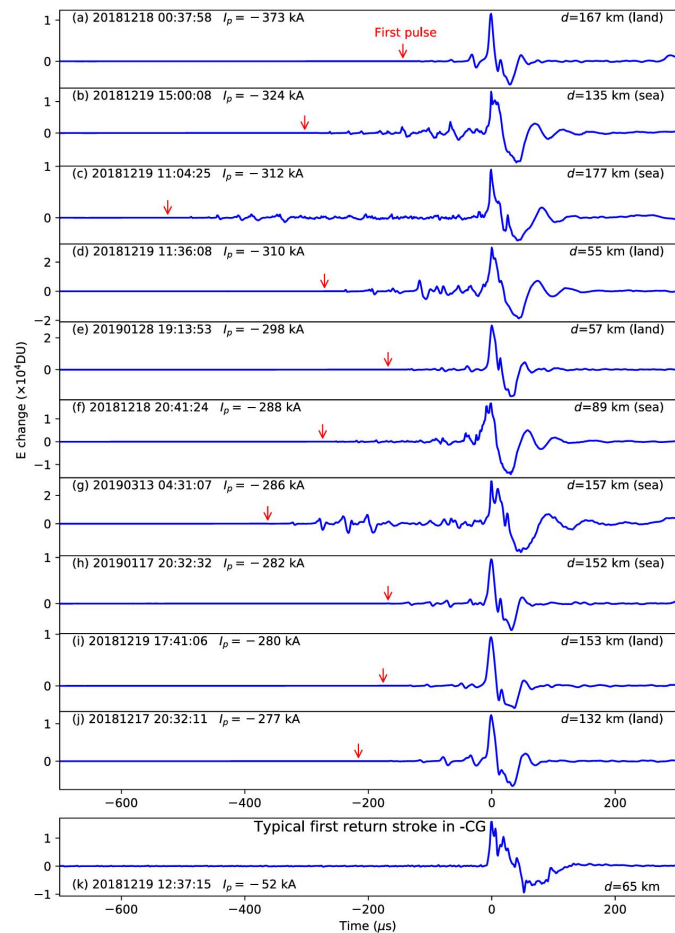
- Events far above baseline and correlated to lightning activity
- TGFs can and have happened at Auger!



Schimassek, 2022

Compact return strokes (CRSs)

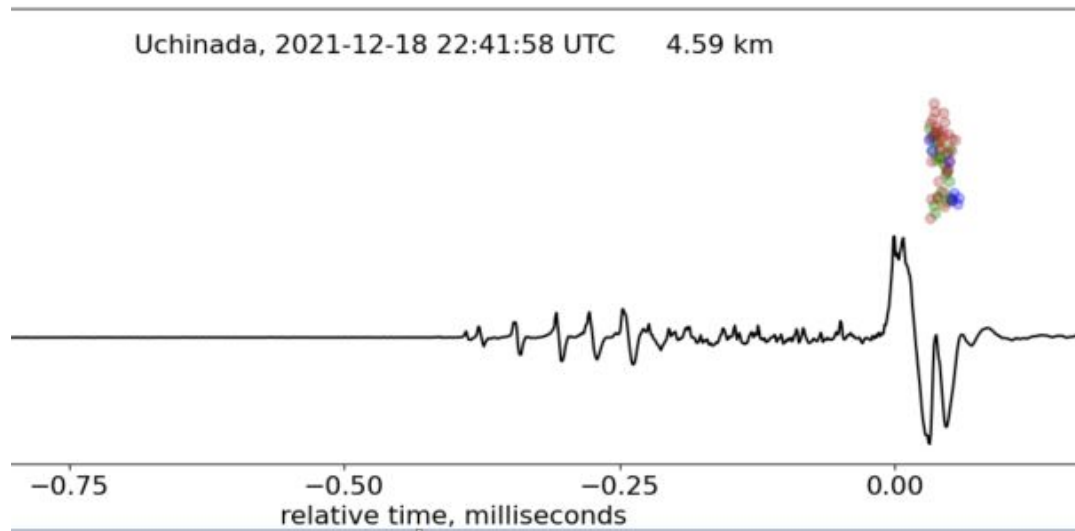
- Winter storms, western Japan
- Short preceding discharges
- Geometry and waveform characteristics
- Peak current abs >150 kA



Wu et al. 2021

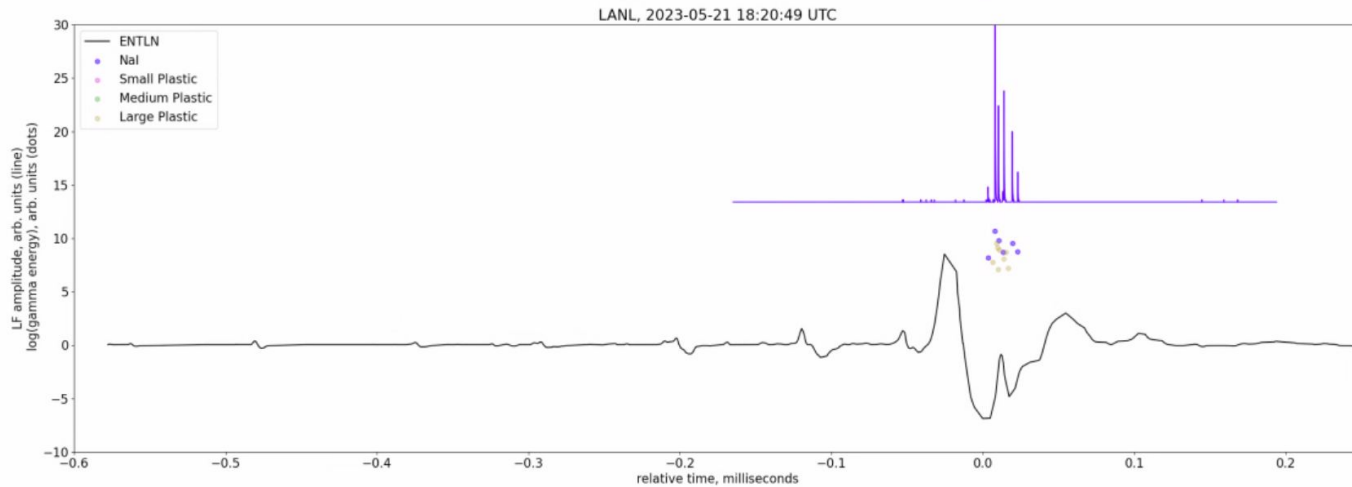
TGF from strong CRS

- (Strong) compact return stroke producing a TGF
- Shape and sequence as expected



Another CRS making a TGF

- High-altitude, mountainous terrain



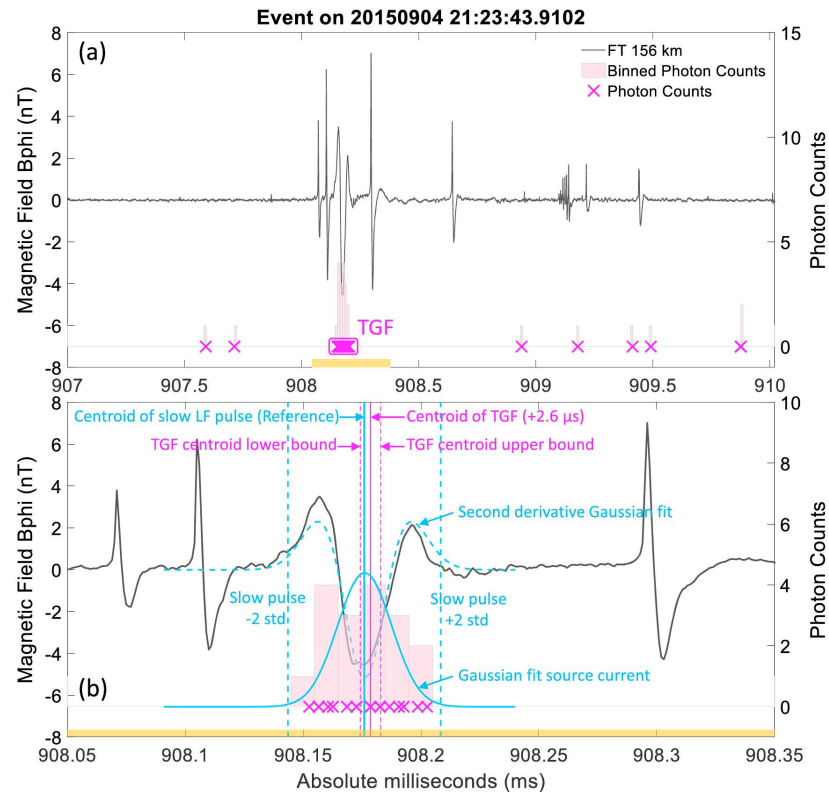
IC leader activity and TGFs

VLF pulses seen that indicate the occurrence of TGFs

- Slow pulse
- EIPs
- MEPs (maybe!)

Slow pulses

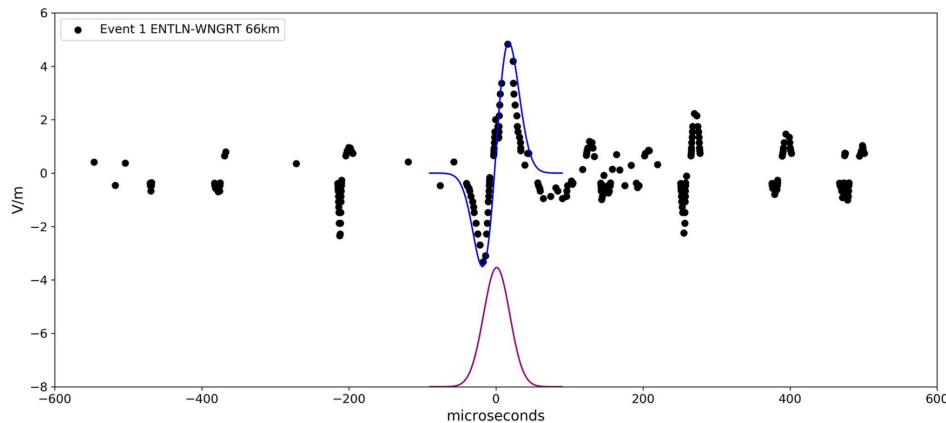
- LF pulse ~ 80 microseconds in duration
- Produced simultaneously with gamma rays
- Often in tandem with faster pulses



Pu et al. 2019

Slow pulses (cont)

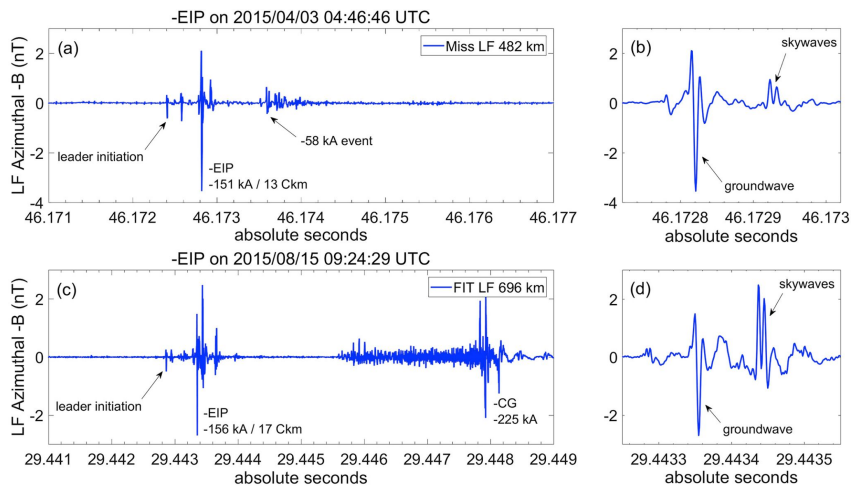
- Another example, mountaintop observation
- Between IBPs



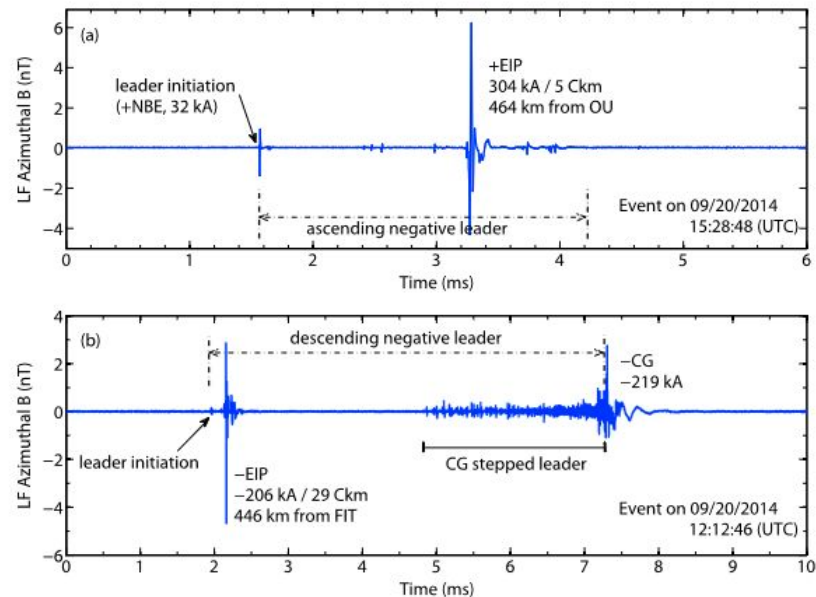
Chaffin et al. 2024

Energetic intracloud pulse (EIP)

- Generated from existing (-) leaders
- Skywave confirms elevation
- EIP categorization based on context



Lyu et al. 2018

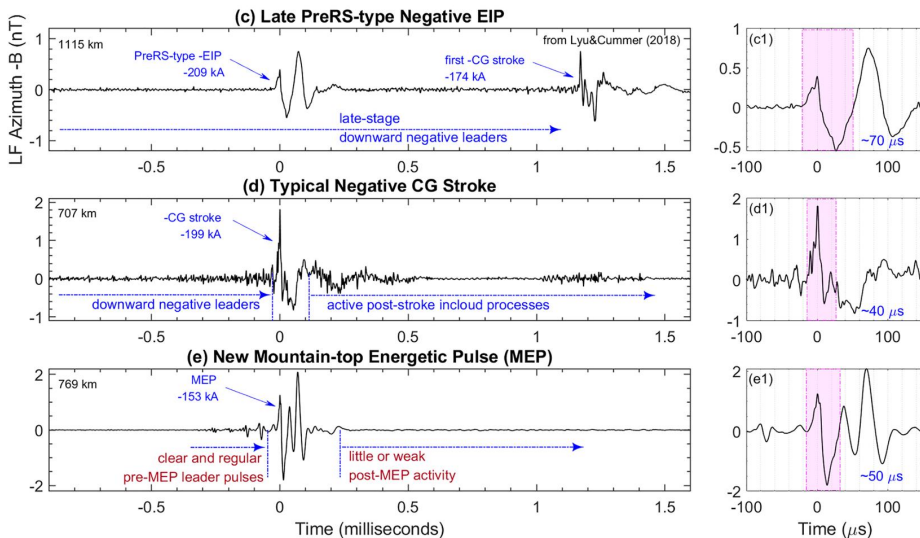


Lyu et al. 2015

Mountain-top energetic pulses (MEPs)

- Mountainous terrain, continental US
- Bipolar pulse
- Positive upward leaders and geometry

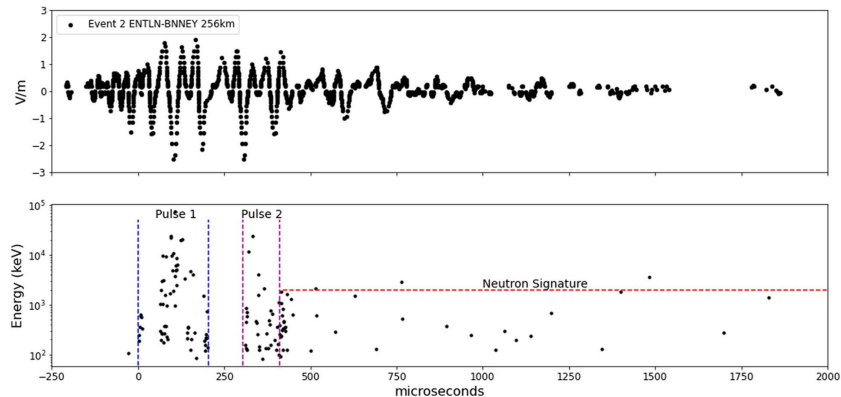
MEP →



Lyu et al. 2021

MEPs? (cont.)

- Perhaps two MEPs, or other IC activity
- Most energetic IC event of the year in this region



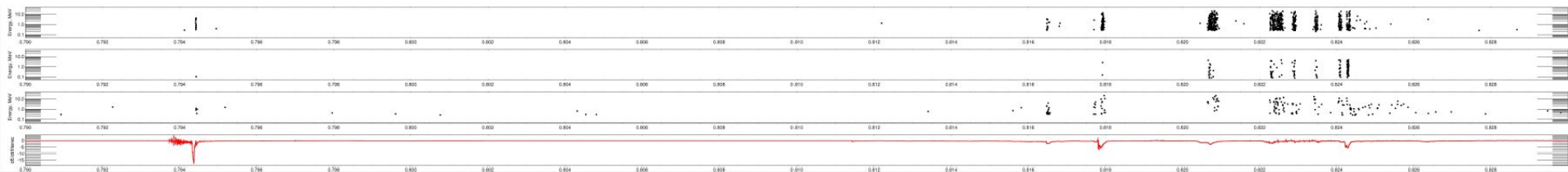
Chaffin et al. 2024

Pleiades event

- Winter, Japan coast
- Multi-pulse TGF
- Rich example of different processes

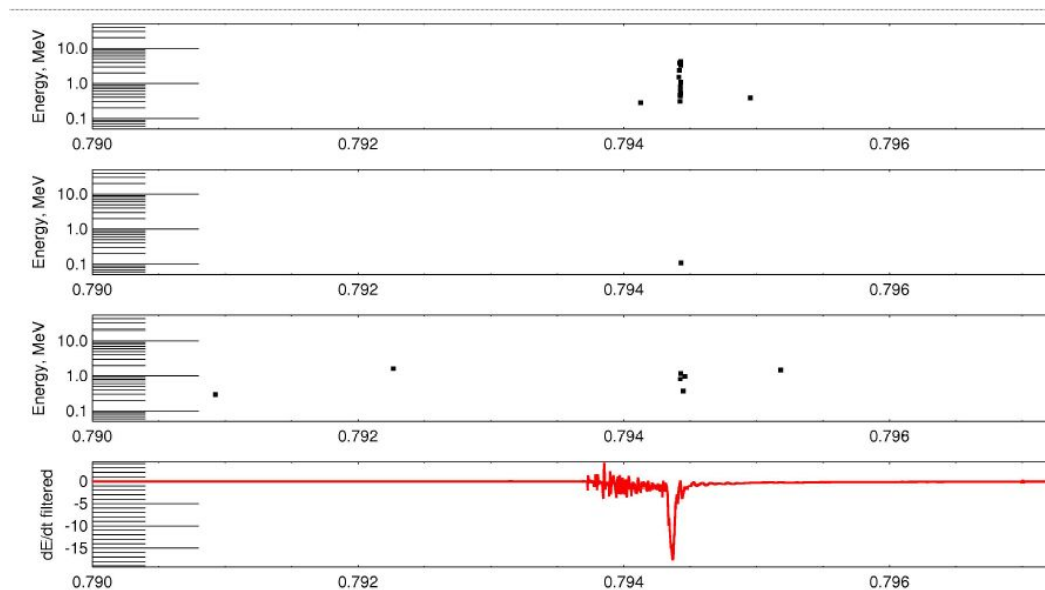
Pleiades event (cont.)

- Seven-pulse TGF
- Large separation distance between initial and subsequent pulses



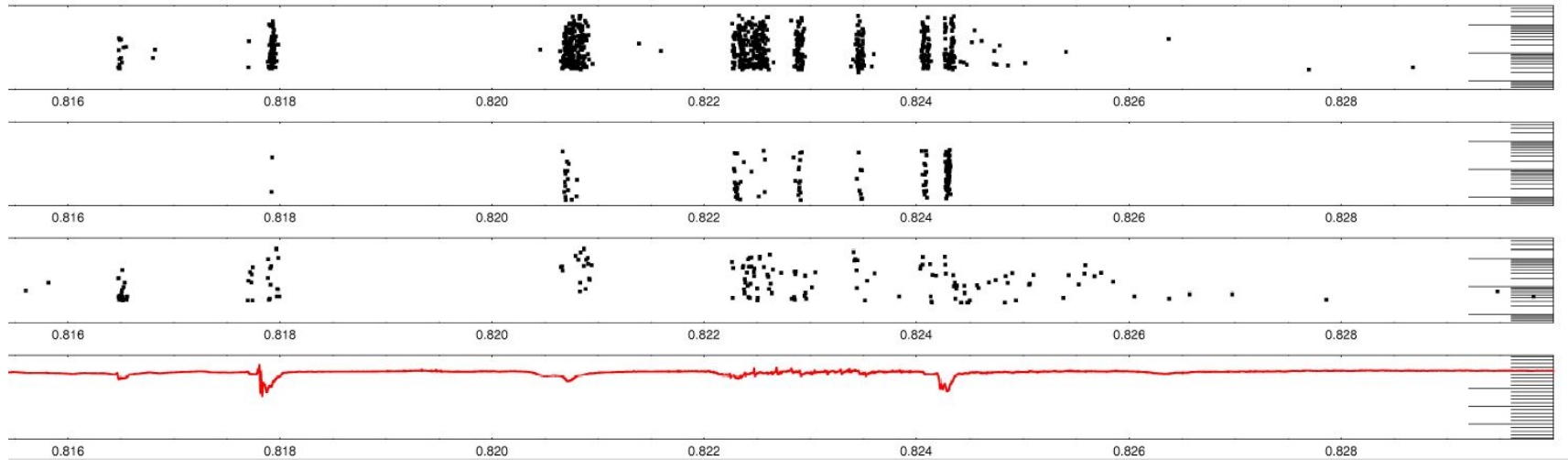
Pleiades event (cont.)

- Initial pulse likely CRS following IBP



Pleiades event (cont.)

- Subsequent pulses likely IC activity

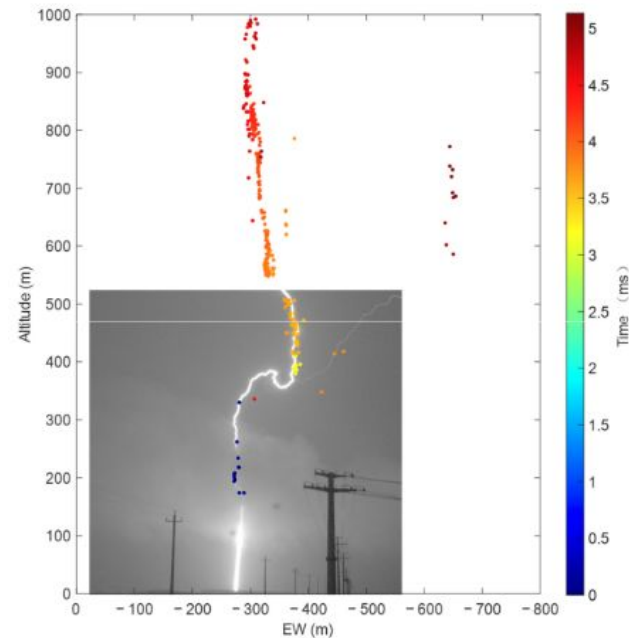


Pleiades event conclusions

- Able to align gamma emission with VLF signals
- Classification of TGF pulses with lightning processes
- Location insight possible with more VLF stations!

VLF localization capability

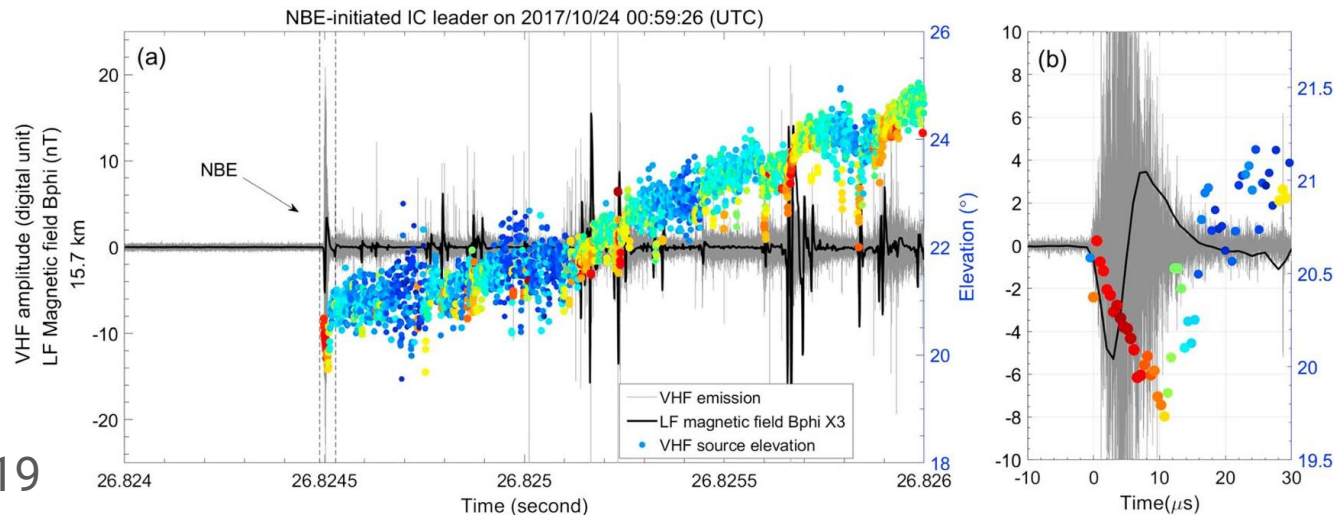
- Multiple stations and time-of-arrival
- Better insight into time evolution of lightning process



Liu et al. 2024

VLF and VHF

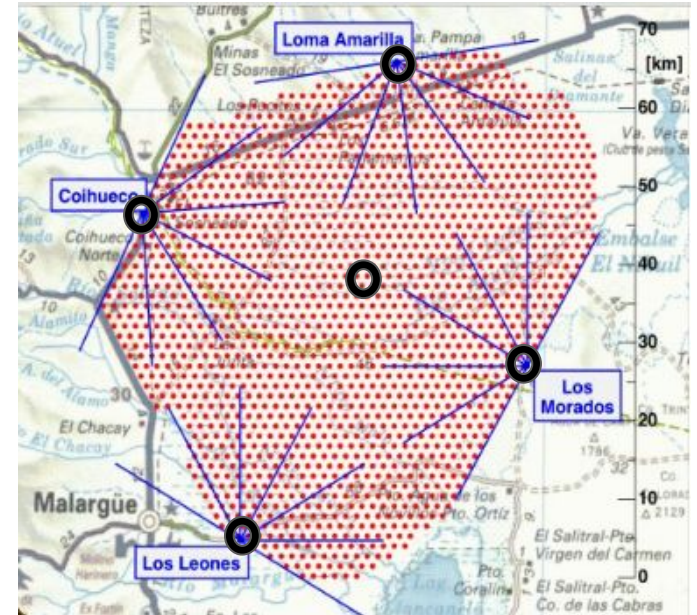
- VHF and slower processes
- Line-of-sight and distance considerations
- Fine scale localization
- Larger current movement



Lyu et al. 2019

VLF array at Auger

- Dynamic range (channel sensitivity)
- One station at each hub, one in center
- Optimal geometrical setup
- Comparison of VLF



Thank you!