Terrestrial Gamma-Ray Observation at

Telescope Array Surface Detector

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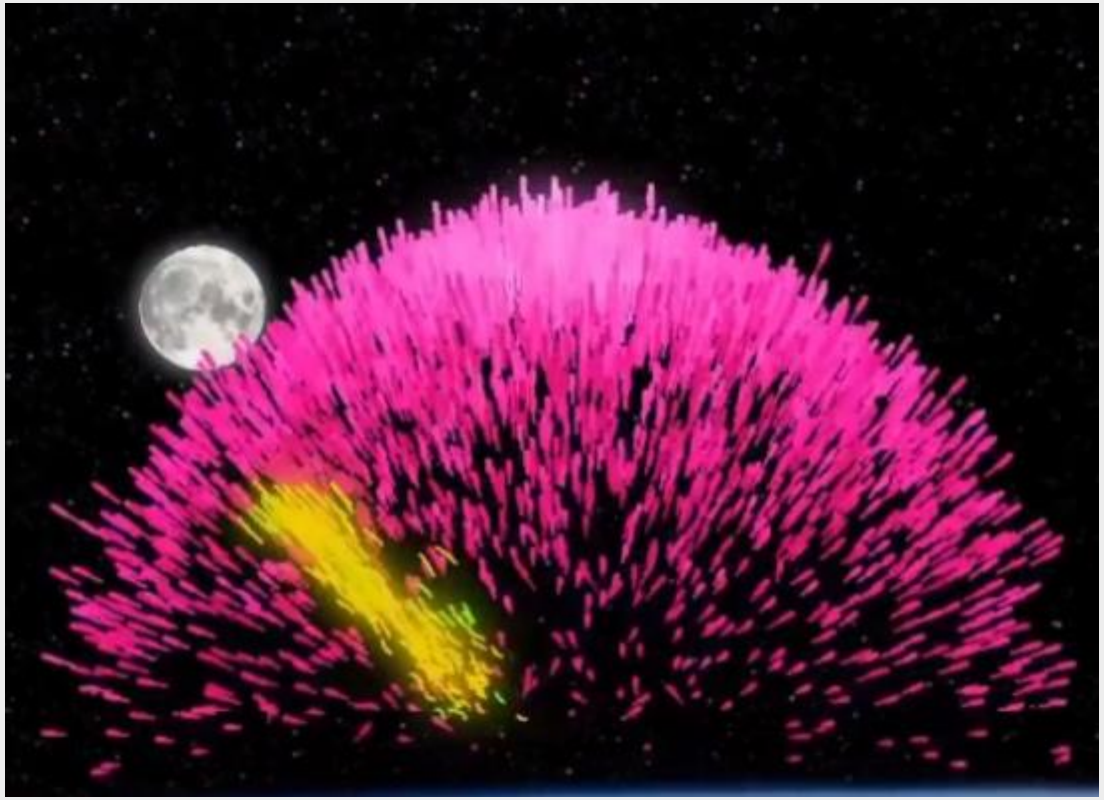
1. Terrestrial Gamma-ray Flashes - TGFs



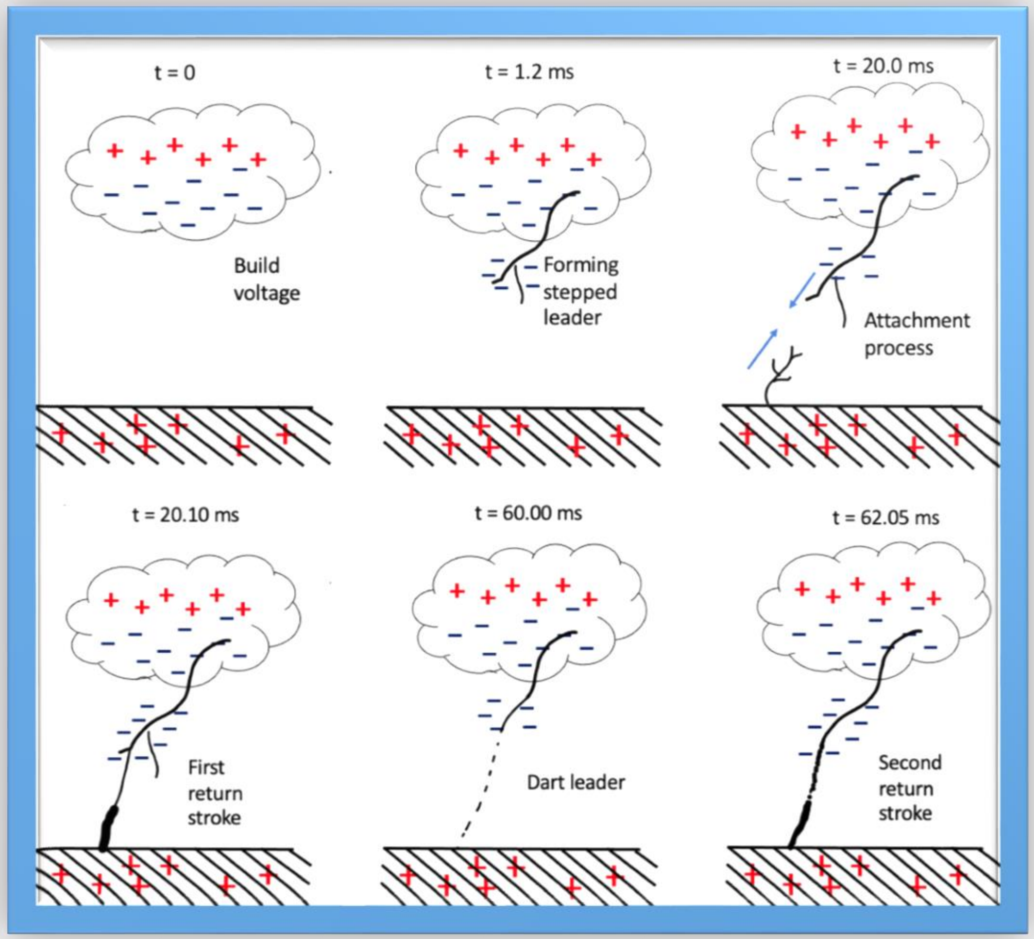
https://www.youtube.com/watch?v=lXKt7UVjd-I

TGFs are energetic Gamma bursts originated from thunderstorms.

- Energy: from 1 to 40 MeV
- Produced by around 10^{17} high-energy electrons
- Mechanism: Relativistic Runaway Electron Avalanches

2. Lightning

A lightning flash (ms) = serval strokes (µs)



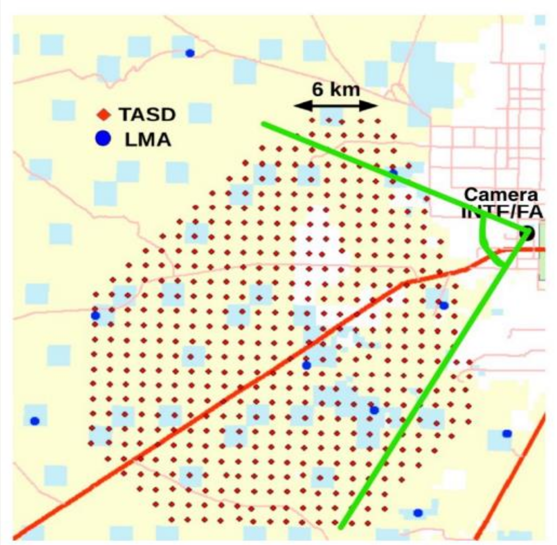
a. Lightning Leaders

b. A return stroke

A return stroke may last up to 200 µs, reaches 40 000 K and gets peak current 200 kA

3. Telescope Array Surface Detectors - TASD

a) Surface detector



b) The layout of our facilities

Designed to detect ultra-high energy cosmic rays

- 507 scintillator detectors (SDs)
- each SDs unit comprises an upper and lower scintillator 3-m^{2}planes,
- placing 1.2 km away from each other,
- covering an area of 700 km^{2,}.

From 2008, the TASD detected energetic bursts which were not arising from cosmic rays

4. Lightning Detectors

- ❖ The **National Lightning Detection Network** (NLDN) provides information of lightning flashes.
- ❖ The **Lightning Mapping Array** (LMA) produced the frequency of the radiation
- ❖ The **Fast electric field change Antenna** (FA) records the changing of the electric field
- ❖ The **interferometer** (INTF) records waveforms
- ❖ The **high-speed camera** was installed 2021

5. Accomplishment (1/3)

1. From 2008 to 2013, 10 energetic bursts were detected.

TASD + NLND: these bursts originated from lightning (***Abbasi et al., 2017***).

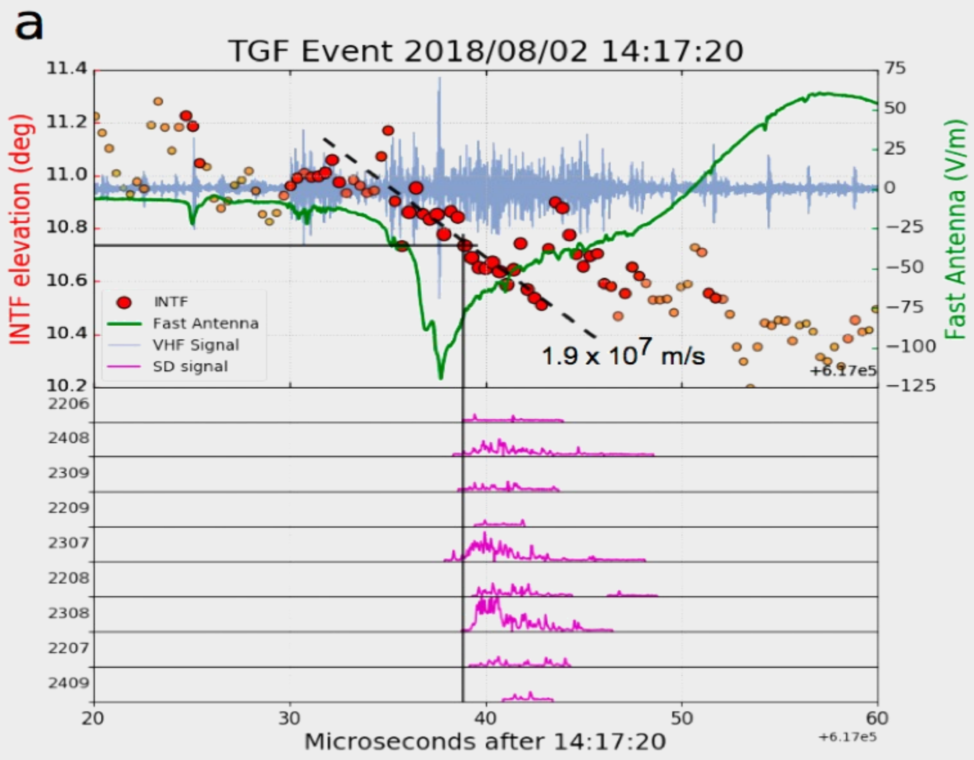
2. From 2014 and 2016, 7 additional bursts were also detected.

TASD + LMA+ FA: these TGFs showed **a short duration** (≤10 μs), originated at ≃3–5 km above ground level during the first **1–2 ms** of downward negative leader breakdown (***Abbasi et al., 2018).***

5. Accomplishment (2/3)

3. TASD + INTF + FA (J. Belz et al., 2020)

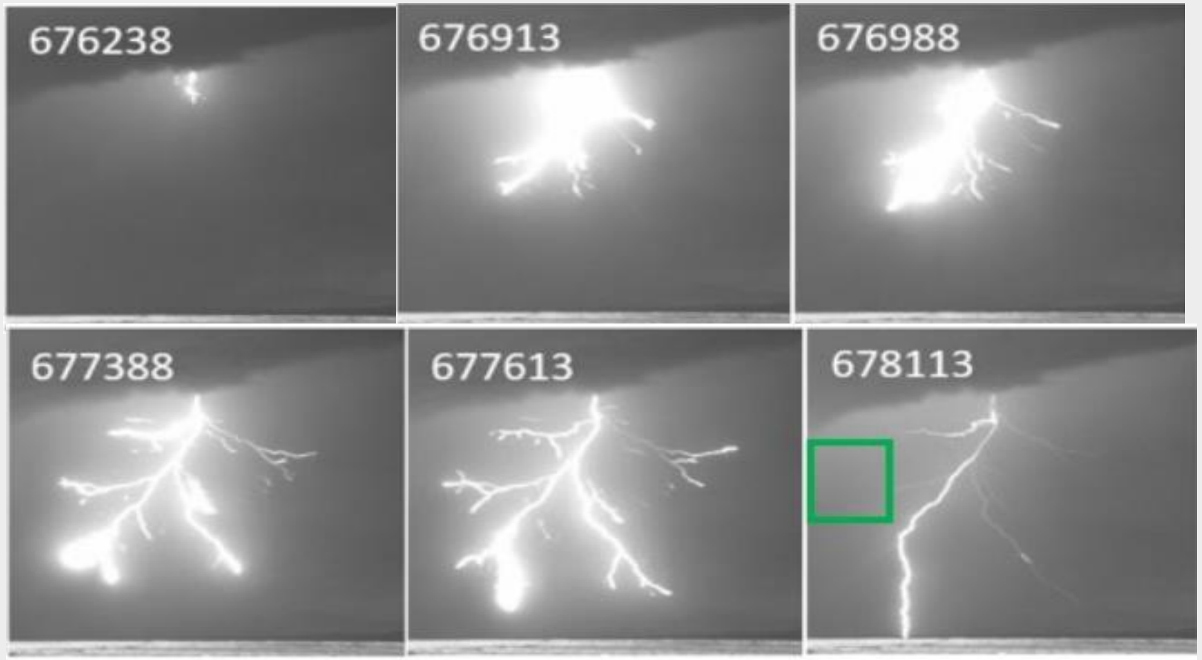
- In 2018: 4 additional TFGs bursts were obtained
- TGFs show a clear correspondence with downward negative breakdown
- The negative breakdown progresses at a fast speed ($\simeq$ 1-3x10^7m/s), indicative of a newly recognized type of discharge process called fast negative breakdown (FNB)



5. Accomplishment (3/3)

4. TASD + … + high speed camera

- On September 11th 2021, **the first optical emissions** of TGFs emission were recorded (Abbasi et al., 2021, submitted)



6. References

1. **T. Abu-Zayyad** et al., “The surface detector array of the telescope array experiment,” Nuclear Instruments and Methods in Physics Research, vol. 689, pp. 87–97, ***2012***.

2. **R. Abbasi, et al.,** “The bursts of high energy events observed by the telescope array surface detector,” Physics Letters A, vol. 381, no. 32, pp. 2565–2572, ***2017.***

3. **R. Abbasi**, et al., “Gamma ray showers observed at ground level in coincidence with downward lightning leaders. Journal of Geophysical Research: Atmospheres, 123, 6864–6879, ***2018.***

4. **J. Belz, et al.,** “Observations of the origin of downward terrestrial gamma-ray flashes,” Journal of Geophysical Research: Atmospheres, vol. 125, no. 23, p. e2019JD031940, ***2020.***