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# Thunderstorms and particle physics

Egor Stadnichuk  
MIPT, INR RAS





# Contents

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- Mysteries of thunderstorm physics
- Experimental observations
- Particle physics in thunderstorm

# Lightning

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Conducting channel is produced step-by-step between a thundercloud and the Earth surface.

To start the process breakdown electric field within the thundercloud is needed.





# Direct electric field measurements

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Straight thundercloud electric field measurements show that **the electric field is lower than 200 kV per m**. This is in order less than conventional breakdown electric field.





# The great mystery of lightning

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What initiates lightning?





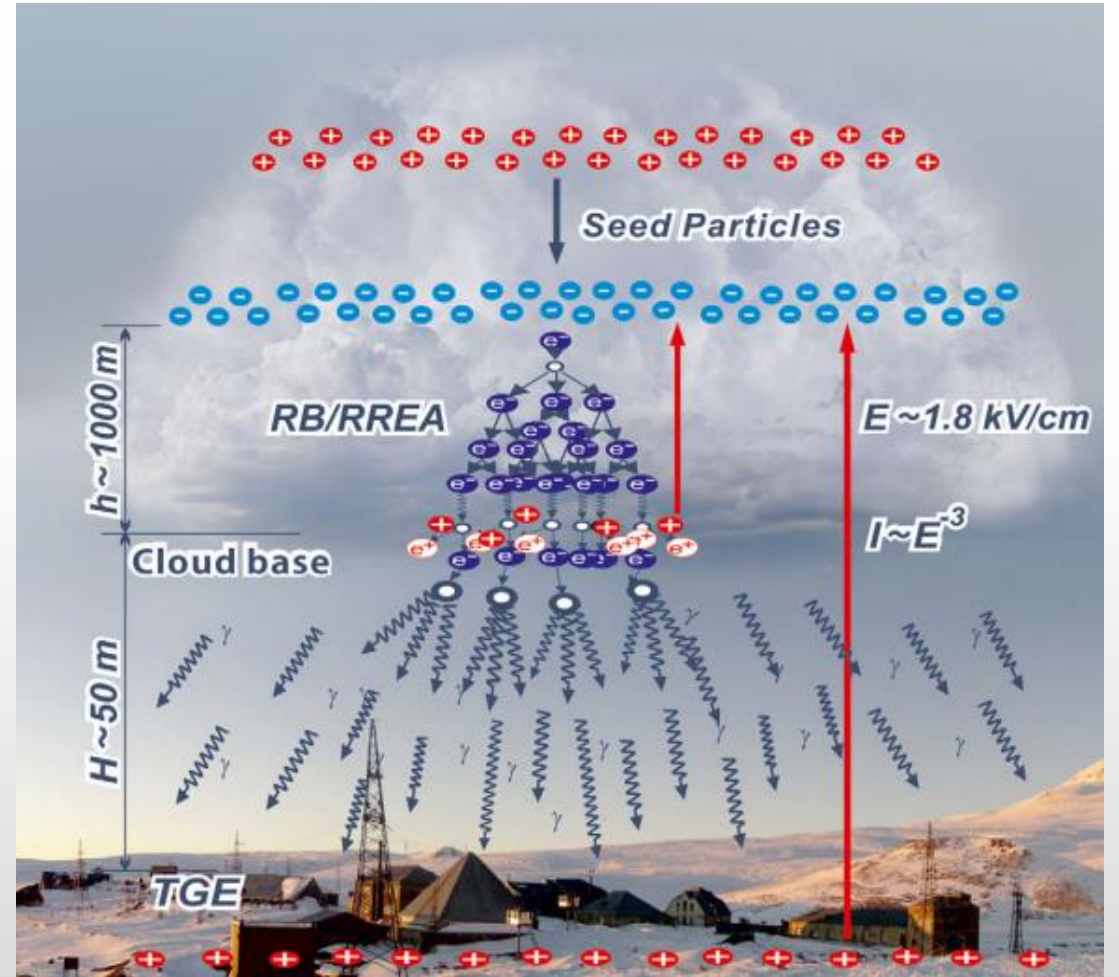


# Thundercloud electric field structure

The most admitted model of electric field is **tri-pole model**.

It was **not confirmed** by straight measurements and remains questionable.

Another mystery of thunderstorm science is electric field structure.





# Thunderstorm gamma enhancement

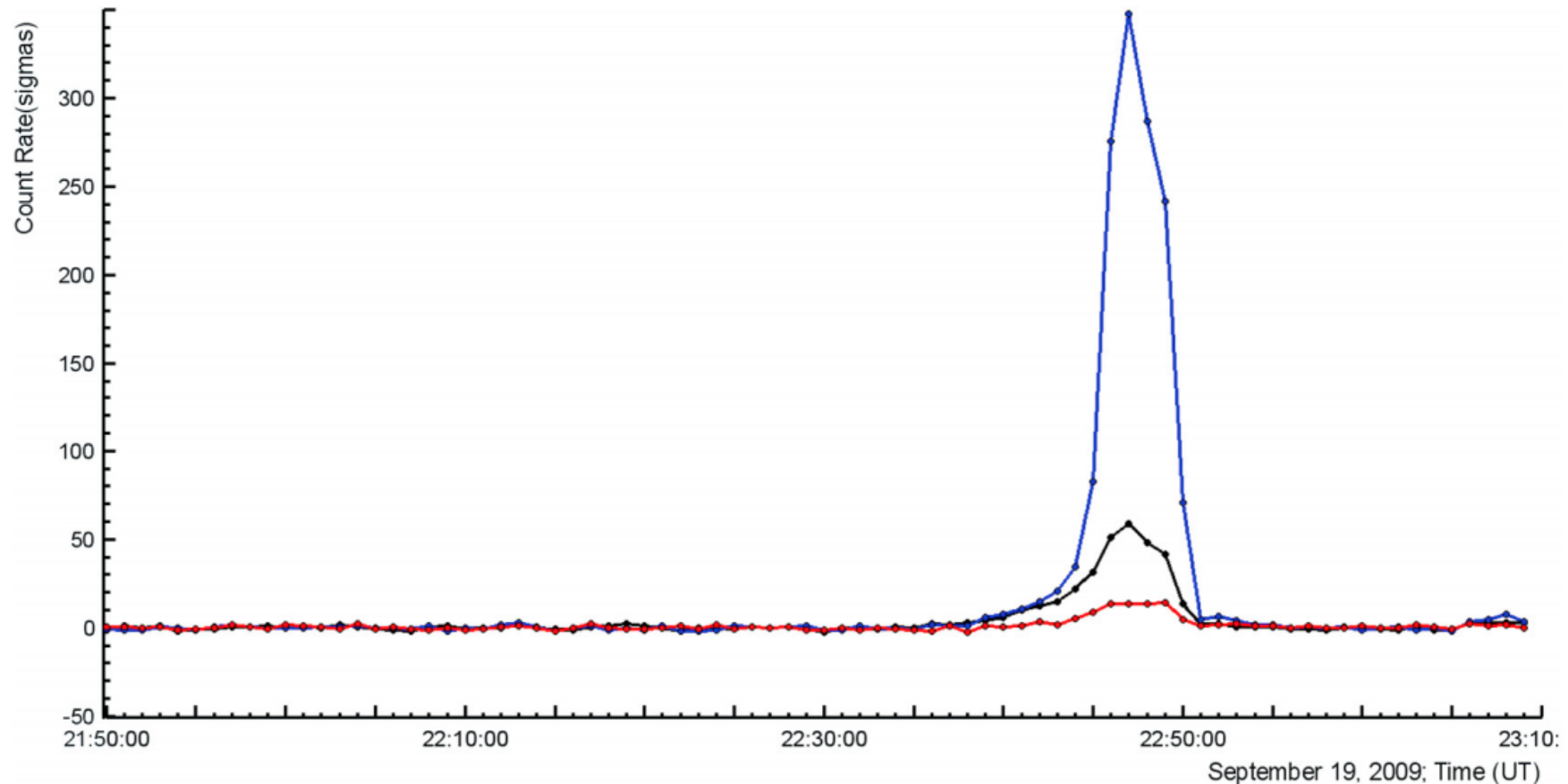
Aragats station (Armenia) observes gamma rays during thunderstorms.

Gamma energy during **thunderstorm gamma enhancement (TGE)** is up to 50 MeV.





# TGE on Aragats



A. Chilingarian et. al. (2017), In situ measurements of the Runaway Breakdown (RB) on Aragats mountain





# Looks like a job for particle physicists

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This is where the fun begins.

# Space observations

Space gamma telescopes observe intensive gamma ray flashes from the Earth.

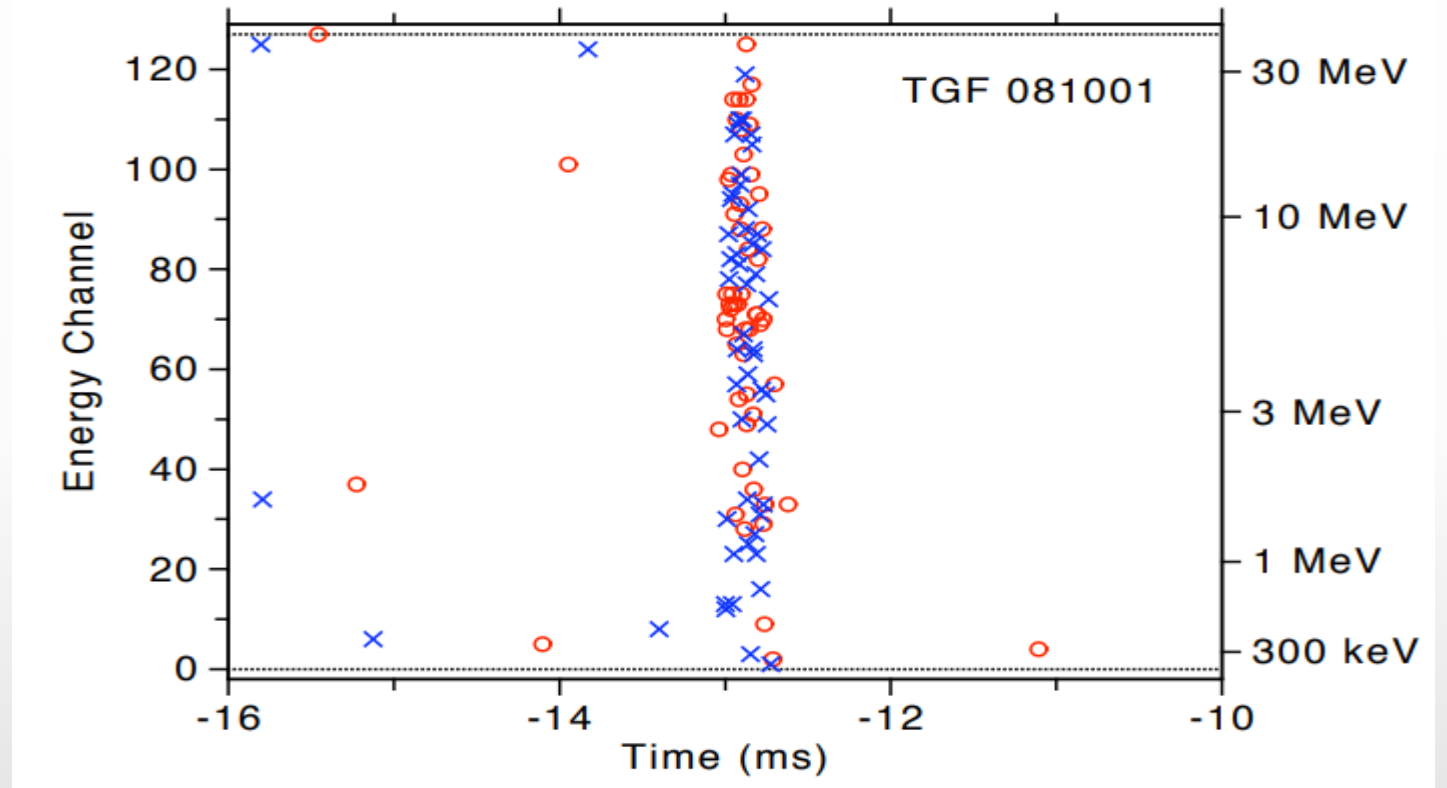




# Terrestrial gamma-ray flashes (TGF)

**TGF** – intensive and short bursts of gamma rays radiating from the Earth into space.

The source of TGFs are **thunderstorms**, mostly on equatorial latitudes.



TGF event registered by Fermi telescope

[Briggs - 2013 - Fermi GBM Observations of Terrestrial Gamma-ray Flashes \( TGFs \)](#)



## What is going on?

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- What is the difference between a thunderstorm and a good weather?

✓ Electric field

- Why is there a breakdown in a low electric field?

✓ Possibly, the air is ionized (not a fact)

- What is the source of ionization?

✓ Cosmic rays (but cosmic ray ionization is not enough for breakdown)

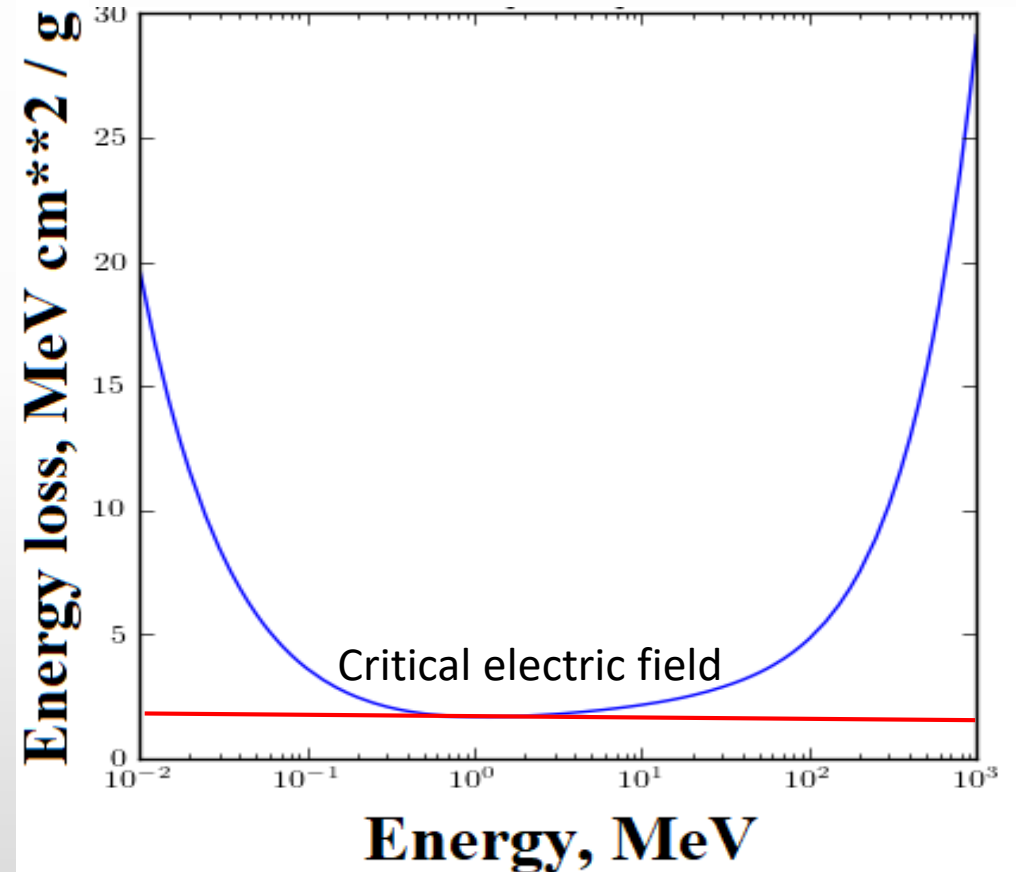
=> the electric field stimulates ionization and high energy particle production



# Runaway breakdown (Gurevich 1992)

Electric field might give to relativistic electron more energy than it wastes on interaction with air.

Such electric field is called **critical electric field**, accelerated electrons are called **runaway electrons**.







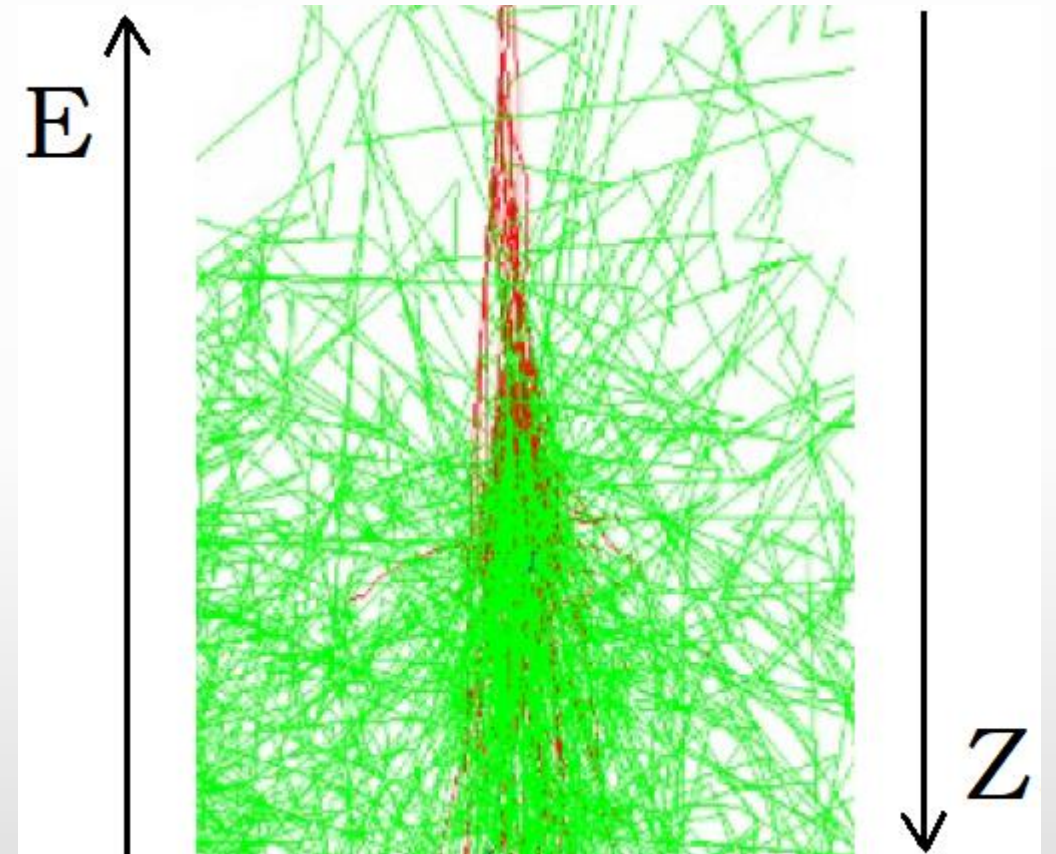
# Relativistic runaway electron avalanche

Runaway electrons produce new runaway electrons by collision with air molecules' electrons.

The law of the **RREA** growth:

$$N(\mathbf{z}) = N_0 \cdot e^{\frac{\mathbf{z}}{l_a}}$$

$$l_a \sim 50 \text{ m}$$



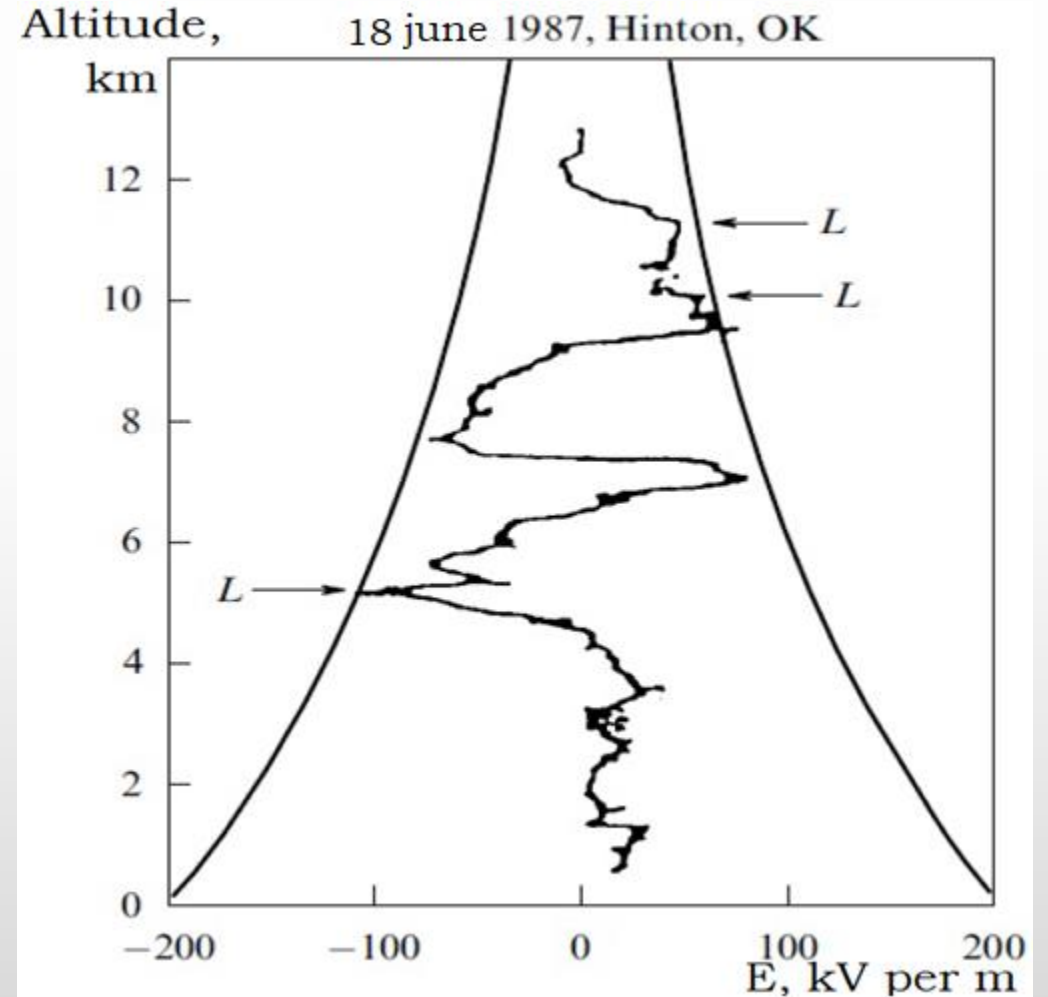
Geant4 simulation of RREA. **Green** – gammas, **red** – electrons.



# Supporting experiment

A balloon was sent into thunderstorm and measured the electric field on its way.

Lightning stroke when the electric field was close to critical.





# Problems of runaway breakdown model

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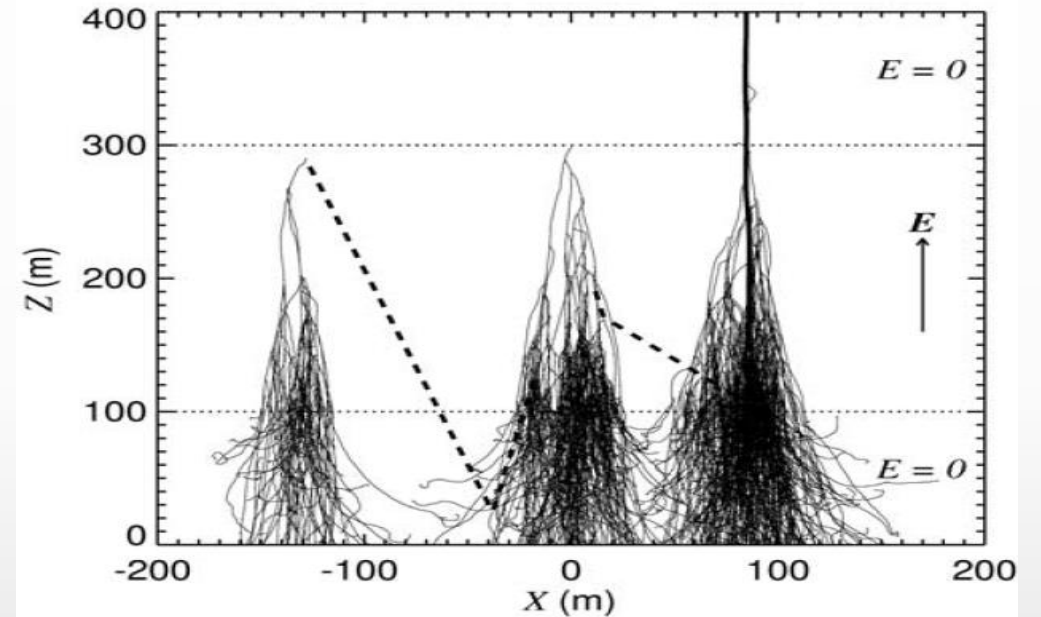
- Not enough ionization considering cosmic ray flux.
- TGF cannot be explained because of durability.

# Dwyer RFDM

RREA reproduce themselves by positron and gamma feedback mechanisms.

Positrons are created by RREA bremsstrahlung and propagate in direction opposite to RREA propagation. Consequently, positrons create secondary avalanches at the beginning of the cell.

**Does not work in observable conditions.**



R. Dwyer J. A fundamental limit on electric fields in air // Geophysical Research Letters. — Vol. 30, no. 20. — URL: <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2003GL017781>.



# Conclusions

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- There are a lot of problems in thunderstorm physics to be solved
- High energy processes may be the solution





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