Cosmic-Ray-Induced Air Showers in Thunderstorms: A probe of the local electric field and a trigger of lightning activity

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Energetic cosmic particles generate extended air showers when penetrating our atmosphere. We recently have found (1) that these air showers can be used to probe the local electric field in thunderstorms, and (2) that they provide thermal free electrons to start lightning activity in an electrified cloud, if also ice particles of sufficient size and shape are present.

1. Cosmic ray induced air showers

Cosmic particles from outside our solar system can have energies of up to 10^{20} eV or possibly more; these particles are traces of supernovae or other astro/cosmological processes.

If the particles have sufficient energy, they create extended air showers when penetrating our atmosphere. The radio-emission of these air showers can be measured on ground, and distributed radiotelescopes like LOFAR (www.lofar.org) provide sufficient shower data to reconstruct type (atomic nuclei from hydrogen to iron, as well as electrons and photons), energy and direction of the incident particle. This is currently a hot topic in astroparticle physics.

I will present two results of our collaboration with astroparticle physicists on the interaction of extended air showers with thunderstorms that were recently published in Physical Review Letters [1,2].

2. Energetic cosmic particles as a probe of electric fields in thunderstorms

Cosmic particles can be used as a probe and a radiotelescope like LOFAR as a detector to determine electric fields in a thunderstorm along the trajectory of the cosmic particle. As the shower and the radio emission propagates (essentially) with the speed of light, the field is distorted by the created ionization only after the measurement. The method forms an alternative to the only other meaningful measurements done by weather balloons.

In [1], we provide a proof of principle for the method. The abstract of the article is as follows:

"We present measurements of radio emission from cosmic ray air showers that took place during thunderstorms. The intensity and polarization patterns of these air showers are radically different from those measured during fair-weather conditions. With the use of a simple two-layer model for the atmospheric electric field, these patterns can be well reproduced by state-of-the-art simulation codes. This in turn provides a novel way to study atmospheric electric fields."

3. How air showers and ice particles trigger lightning activity

Electric fields in thunderstorms measured by weather balloons are below the classical breakdown value. (Will our new method give different numbers?) A current suggestion is that lightning could be started nevertheless as the critical field for relativistic runaway electron avalanches (RREA) is only 1/10 of the breakdown field. However, RREAs do not create an electron density sufficient to start a classical discharge. A different suggestion is that ice particles play a role as they can enhance the electric field locally to values above the breakdown field. An open problem is that free electrons are not easily available in a cloud due to the high humidity.

In [2], we investigate these features quantitatively and show that the inception of the first streamer is likely due to the field enhancement near ice particles of appropriate shape and size, and that the lightning activity can start when an extended air shower provides free electrons. The abstract of the article is as follows:

"We derive that lightning can start if the electric field is 15% of the breakdown field, and if elongated ice particles of 6 cm length and 100 free electrons per cm^3 are present. This is one particular example set from a parameter range that we discuss as well. Our simulations include the permittivity $\epsilon(\omega)$ of ice. 100 free electrons per cm^3 exist at 5.5 km altitude in air showers created by cosmic particles of at least 5×10^{15} eV. If the electric field zone is 3 m high and 0.2 km^2 in the horizontal direction, at least one discharge per minute can be triggered. The size distribution of the ice particles is crucial for our argument; more detailed measurements would be desirable."

4. References

[1] P. Schellart, T.N.G. Trinh, S. Buitink, A. Corstanje, J.E. Enriquez, H. Falcke, J.R. Hörandel, A. Nelles, J.P. Rachen, L. Rossetto, O. Scholten, S. ter Veen, S. Thoudam, U. Ebert, C. Koehn, C. Rutjes, and the LOFAR collaboration, *Probing Atmospheric Electric Fields in Thunderstorms through Radio Emission from Cosmic-Ray-Induced Air Showers*, Phys. Rev. Lett. **114** (2015) 165001.

[2] A. Dubinova, C. Rutjes, U. Ebert, S. Buitink, O. Scholten, G.T.N. Trinh, *Prediction of Lightning Inception by Large Ice Particles and Extensive Air Showers,* Phys. Rev. Lett. **115** (2015) 015002.