Thunderstroms as electron accelerators and the discharge zoo above the clouds

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With the discovery of Transient Luminous Events above thunderclouds in 1990 and of Terrestrial Gamma-ray Flashes from thunderstorms in 1994, lightning physics has got a new impetus. Sprite discharges shooting downwards from the ionosphere are the first lightning phenomenon that can be quantitatively explained by the underlying discharge physics. Here precise observations, lab experiments and theory have jointly succeeded in explaining the observations. Furthermore, thunderstorms also emit gamma-ray flashes, electron bursts, and even substantial positron bursts that can be measured from satellites. I will review these observations, and I will sketch elements of physical understanding of this energetic radiation: electron run-away and local field enhancement.

The field of lightning physics has long been dominated by lightning protection. Understanding all the multiscale highly dynamic discharge processes in a thundercloud in detail seemed beyond the scope of reasonable research projects, while electroengineers had to deal with the practical issue of lightning protection, frequently based on phenomenological models. However, this situation has changed with the discovery of Transient Luminous Events (TLE's) above active thunderstorms, and with the observation of very energetic radiation associated with thunderstorms, so-called Terrestrial Gamma-ray Flashes (TGF's) as well as electron and positron flashes (TEF's and TPF's). Lightning physics has gained a new link with discharge physics.

1. TLE's, in particular, sprite discharges

Solar radiation drives water evaporation, cloud formation and strongly turbulent convection within the clouds. Below freezing temperature, collisions of water and ice particles in this turbulent flow can separate electric charges on a large scale. The generated electric-potential differences within the thundercloud drive lightning strokes, as we all know − but they also drive a zoo of discharges above the cloud: elves, halo's, sprites, jets, gigantic jets etc. Basic ingredients of modeling and understanding these Transient Luminous Events are gas discharge physics together with the geometry of the problem: the cloud separates electric charges while being located between two conducting layers, the earth and the ionosphere. And the air density decreases exponentially with altitude.

Sprite discharges shooting down from the ionosphere in response to a lightning stroke have been observed with large spatial and temporal resolution in the past years. They have been triangulated, and the electromagnetic signature of parent lightning stroke and sprite have been measured. Sprites are actually the upscaled versions of streamer discharges, and they are the first lightning phenomenon that is being understood quantitatively, based on discharge physics with its cross-sections etc. [1-3]. I will review observations, analogous lab experiments and theory.

2. Terrestrial Gamma-ray Flashes, electron and positron beams

In 1994 the BATSE satellite found strong gamma-ray flashes coming from earth, and it was soon understood that they originate in thunderstorms. According to the most recent measurements of the AGILE satellite [4], quantum energies in these flashes can exceed 100 MeV. Possibly there are different types of flashes with differing duration and spectrum [5]. Electron bursts occur as well, and recent measurements with the GBM satellite [6] even showed a strong positron content in these bursts. The underlying extreme physical conditions in the thundercloud are presently under international investigation.

Two different mechanisms are invoked for explaining this phenomenon. The first mechanism is based on the relativistic run-away of electrons: electrons with energies around 1 MeV can maintain velocity and create ionization avalanches at lower electric fields than electrons with eV energies. This is the case because inelastic and ionizing cross-sections strongly decrease with electron energy above ~200 eV in air [7-11]. Highly energetic cosmic particles therefore could create such avalanches, but electrons runnig away from a conventional discharge could do that as well [12-13]. This suggestion takes the second mechanism into account, namely the strong field enhancement at the tips of streamers and leaders that could accelerate the electrons up to relativistic energies as well.

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