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High-energy, optical and radio emissions from long streamer discharges

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The novel Streamer Parameter Model (SPM) [1] allows to quickly calculate the shape, velocity, and electric field of an electric streamer in air, without resorting to computationally-intensive hydrodynamic simulations (HDS). Various calculations, confirmed by comparisons with HDS [2], show that the streamer velocity increases as its length grows. When the streamer length exceeds several meters, the velocity may become comparable to the speed of light, which necessitates correcting the model for relativistic effects. Such long streamers may describe the fast positive and negative breakdown, experimentally observed in thunderstorms. We propose that the long streamers may produce large quantities of relativistic runaway electrons, and therefore efficiently radiate x-rays. This is facilitated by the following conditions: (1) electric fields at the streamer tip can reach values close to the so-called thermal runaway threshold (~30 MV/m), at which the low-energy (suprathermal) free electrons, produced in the ionization processes, may accelerate to relativistic energies; (2) in negative streamers, the energetic electrons are synchronized in velocity with the streamer front; (3) the streamer tip radius (calculated by SPM) may exceed tens of centimeters, providing a large volume of the high field where the thermal runaway acceleration may take place.

We apply SPM to long streamer propagation inside a thundercloud and calculate the relativistic runaway electron production, as well as radio, optical and x-ray radiation. The calculations are compared to the observations of Narrow Bipolar Events (NBE), Terrestrial Gamma Flashes (TGF), and luminous phenomena obtained during the recent ALOFT campaign.

1. N. G. Lehtinen, “Physics and Mathematics of Electric Streamers,” *Radiophys Quantum El*, **64**, June 2021, pp. 11-25, doi:10.1007/s11141-021-10108-5.

2. N. G. Lehtinen and R. Marskar, “What Determines the Parameters of a Propagating Streamer: A Comparison of Outputs of the Streamer Parameter Model and of Hydrodynamic Simulations,” *Atmosphere*, **12**, December 2021, p. 1664, doi:10.3390/atmos12121664.