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Particle versus density models in spark formation: X-rays from pulled fronts?

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Streamer discharges govern the early stages of sparks and lightning, of spark-like phenomena in water, oil, and semiconductors, in industrial corona reactors, or in gigantic sprite discharges above thunderclouds [1,2]. Thunderstorms recently have been found to emit terrestrial gamma-ray flashes or X-rays towards satellites and towards the ground. These emissions might be explained by particle models of "pulled" streamer ionization fronts. In general, the growing discharge channel has an inner structure with multiple scales [1-3]. While the largest part of this channel can be treated in a density approximation for the electrons and ions, the dynamics of the ionization front is that of a pulled front; it is determined in the leading edge where the density approach eventually breaks down. We therefore investigate a realistic MC particle model for the motion of single electrons in a discharge in pure nitrogen. The particle model not only incorporates particle fluctuations, but also shows that the electron energies are systematically larger in the leading edge of the front than in the corresponding density model, and that the ionization level behind the front is higher as well, while the front velocity hardly changes [3]. These effects increase with increasing applied electric field and might actually cause the recently observed X-ray emission from lightning through rare very energetic runaway electrons in the tail of the distribution. Comparing the leading edge of the particle front with a linear particle avalanche, the avalanche shows the same mean density gradient and energy overshoot in its leading edge as the nonlinear front; hence the pulled front concept in this sense applies to discrete particle models as well [3]. This gives a key to understanding the above effects through analytical approximations and to develop efficient numerical methods coupling particle and density models in space.

[1] U. Ebert *et al.*, Plasma Sources Sci. Techn. **15**, S118 (2006) (arXiv:physics/0604023).
[2] *Streamers, sprites, leaders, lightning: From micro- to macroscales*, workshop in Oct. 2007:
`http://www.lorentzcenter.nl/lc/web/2007/265/info.php3?wsid=265`; and cluster issue in J. Phys. D in fall 2008; organizers/editors: U. Ebert and D.D. Sentman.
[3] C. Li *et al.*, J. Appl. Phys. **101**, 123305 (2007) (arXiv:physics/0702129).