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Streamer formation in electric fields above and below the breakdown threshold

Anbang Sun (1), Jannis Teunissen (1), Cristoph Koehn (1), Ute Ebert (1,2)

(1) Center for Mathematics and Computer Science (CWI), Science Park 123, 1098 XG, Amsterdam, The Netherlands, (2) Department of Applied Physics, Eindhoven University of Technology, The Netherlands

Streamers are rapidly growing plasma filaments that can penetrate into non-ionized regions due to the electric field enhancement at their tips. They play a key role in the early stages of many atmospheric discharges, for example in lightning inception, in the streamer coronas of lightning leaders and of jets, and in sprite discharges. There are positive and negative streamers. Positive streamers propagate along the direction of the electric field, while negative streamers propagate in the opposite direction.

With fully three-dimensional particle simulations, we study the combined effect of natural background ionization, electron detachment and photoionization on the formation of streamers in atmospheric air. We use adaptive grid refinement and adaptive particle management, and we have parallelized our particle code.

We show that in electric fields below the breakdown threshold, positive streamers can only form if there is a strong initial seed present. Negative streamers fail to originate, at least on the time scales we have considered. In electric fields above the breakdown threshold, the situation is very different. New avalanches continuously form all over the domain. They originate from free electrons, which can be created by photoionization or by detachment from negative ions. Instead of the “double-headed“ streamers that show up in most fluid models, we observe a more uniform discharge. We conclude that single elongated streamers exist only if the overall background electric field is below the breakdown value. The local field at the streamer head, of course, has to exceed the breakdown field.