Initiation of Negative Streamers from Hydrometeors at Subbreakdown Field Conditions

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Introduction

- ❑Recent high-speed interferometer observations have indicated that the initiation of lightning may begin as compact intracloud discharges (CIDs), caused by fast positive/negative breakdown that consists of positive/ negative streamers [Rison et al., Nat. Commun., 7, 10721, 2016; Tilles et al., AE12A-03, AGU Fall Meeting, 2016].
- ❑Initiation of negative streamers from isolated hydrometeors in lightning fields (subbreakdown conditions) has never been reproduced by modeling studies [Liu et al., Phys. Rev. Lett., 109, 025002, 2012; Sadighi et al., J. Geophys. Res. Atmos., 120, 3660, 2015; Shi et al., J. Geophys. Res. Atmos., 121, 7284, 2016].
- ❑In this poster, it will be shown that the negative streamer can be initiated from the tip of a cone-shaped hydrometeor in an electric field well below the conventional breakdown threshold field (E_k), suggesting that the shape of hydrometeors plays an important role in streamer initiation.

Model

- Takes into account:
  - electron impact ionization
  - two-body and three-body electron attachments
  - electron-positive ion and negative-positive ion recombinations
  - drift and diffusion of electrons
  - photoionization

$$\partial n_e/\partial t + \nabla \bullet (n_e \mathbf{v}_e - D_e \nabla n_e) = (\nu_i - \nu_{a2} - \nu_{a3}) n_e - \beta_{ep} n_e n_p + S_{ph}$$

$$\partial n_p/\partial t = \nu_i n_e - \beta_{ep} n_e n_p + S_{ph}$$

$$\partial n_n/\partial t = (\nu_{a2} + \nu_{a3}) n_e - \beta_{pn} n_p n_e$$

$$\nabla^2 \varphi = -(n_p - n_e - n_n)/\varepsilon_0$$

- A cone-shaped hydrometeor is used:
  - length: 6 mm
  - peak density: 2×10^{20} m^{-3}
  - base radius: 0.2-1.2 mm
  - Gaussian distribution characteristic radius: cone radius at the corresponding height

Results

Case Number	Ambient Field	Base Radius
Case 1	$-0.65E_k$	0.6mm
Case 2	$-0.65E_k$	0.2mm
Case 3	$-0.5E_k$	1.2mm

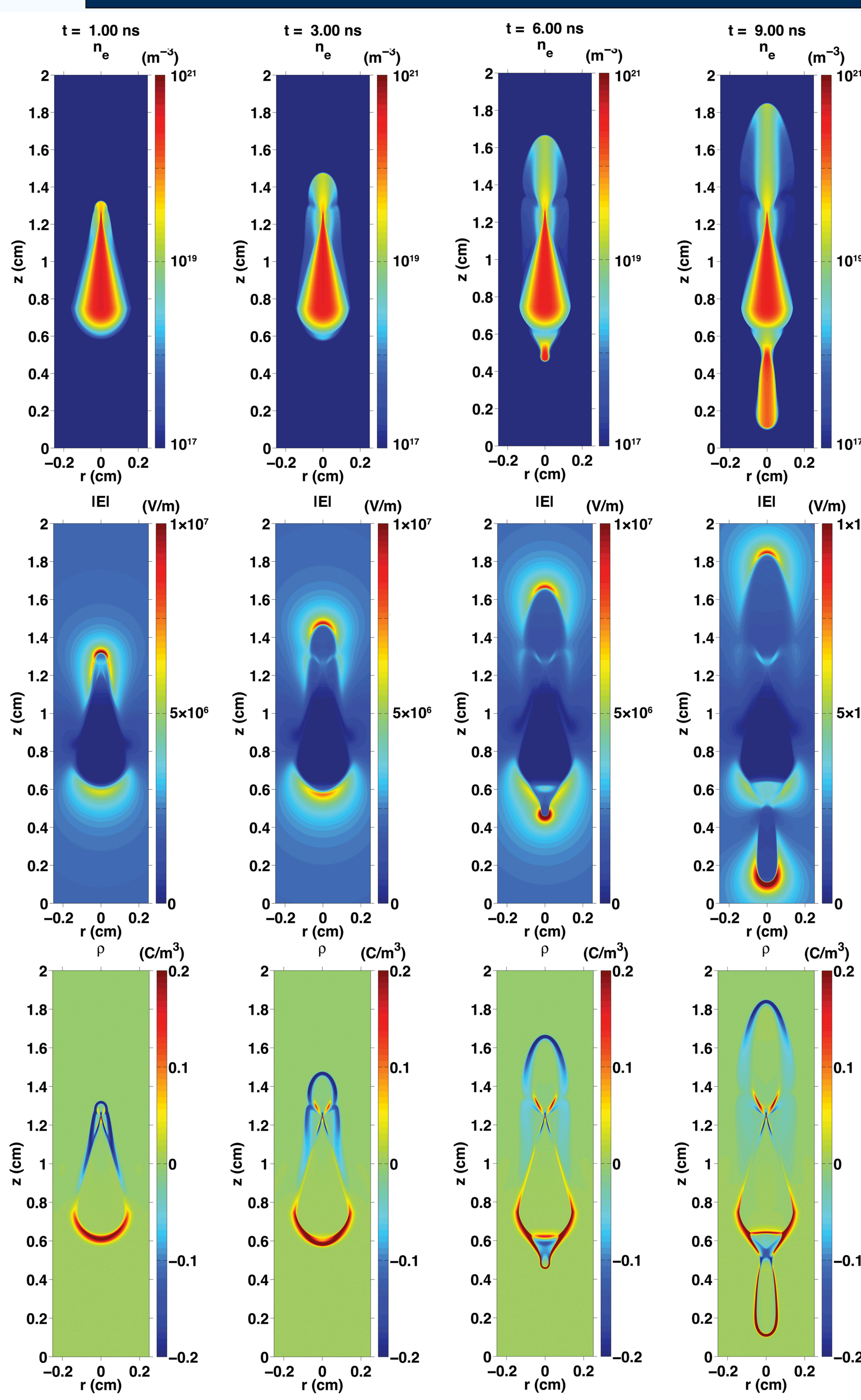

Figure 1 (Case 1): Cross sectional views of electron density, electric field and space charge density at t=1ns, 3ns, 6ns and 9ns, respectively.

- ❖ Column 1: Strong electric field (~$4E_k$) has been established around the negative tip, and begins to move upward, indicating the initiation of the negative streamer. Positive space charge also forms at the bottom end, but the field (~$1.5E_k$) is not strong enough to initiate positive streamer yet.
- ❖ Column 2: The negative streamer has been successfully initiated, while strong electric field (~$5E_k$) at the positive end has been established.
- ❖ Column 3: Both the negative and positive streamers have been initiated.
- ❖ Column 4: The appearances of both propagating streamers are different.

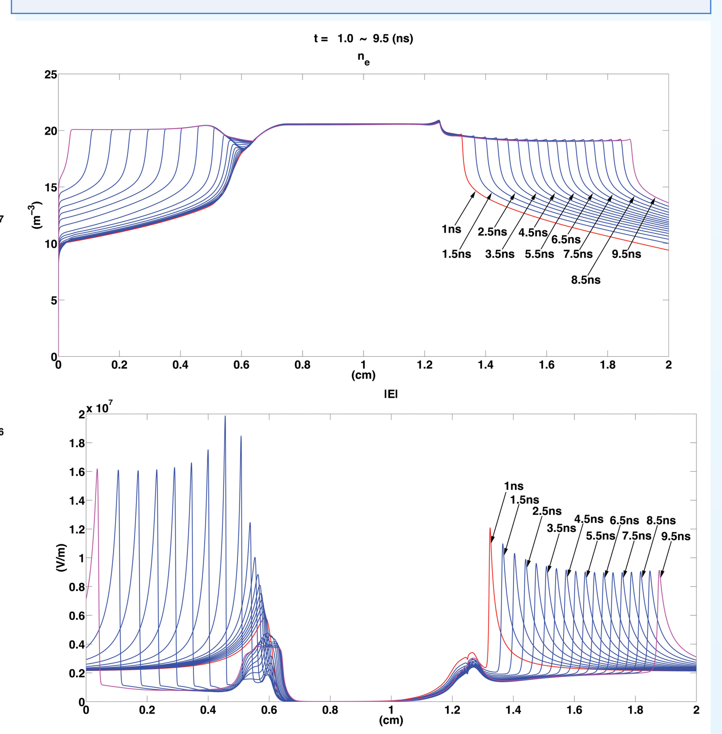

Figure 2 (Case 1): The axial profiles of electron density (top) and electric field (bottom) at different moments of time, with constant time intervals of 0.5ns. The red and pink lines show the profiles at t=1ns and t=9.5ns, respectively. It can be seen that negative and positive streamers are fully formed at t~4ns and t~7ns, respectively.

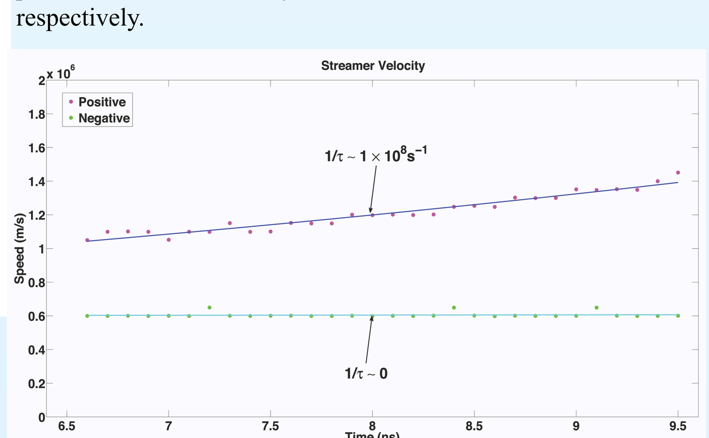

Figure 3 (Case 1): The speeds of both streamers show quite different behaviors while propagating. The dots are obtained from simulation data, which are fitted by exponential curves. The positive streamer shows similar properties as previous modeling studies so it is expected to grow exponentially, while the negative streamer propagates with constant speed.

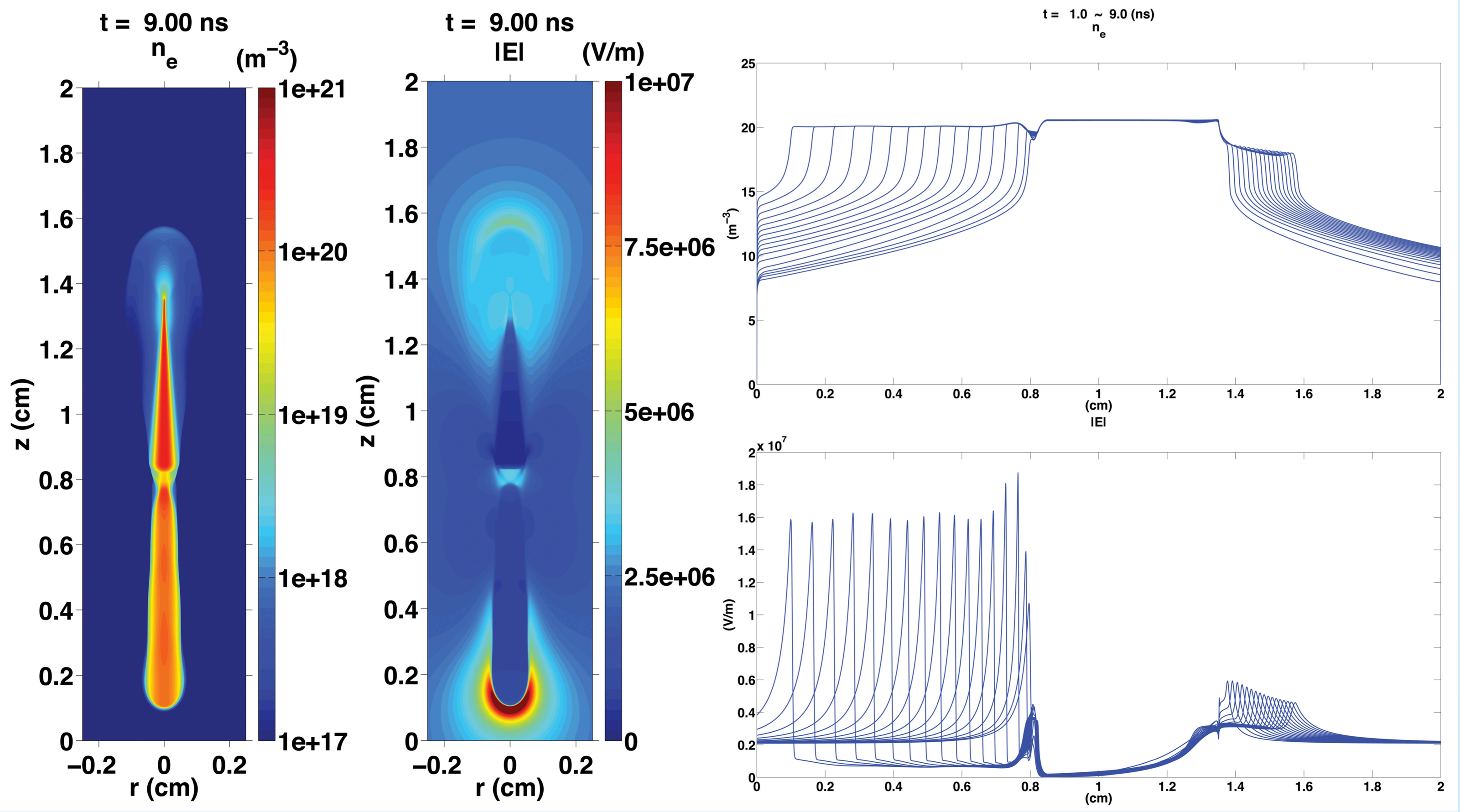

Figure 4 (Case 2): Cross sectional views of electron density (left) and electric field (middle) at t=9ns, and evolution of axial profiles of electron density (right top) and electric filed (right bottom) from t=1ns to t=9ns with constant time intervals of 0.5ns, respectively. It shows that with a very small cone base radius at $0.65E_k$, the positive streamer is initiated but the negative streamer is not able to be initiated. The positive streamer shows similar properties as in [Shi et al., J. Geophys. Res. Atmos., 121, 7284, 2016].

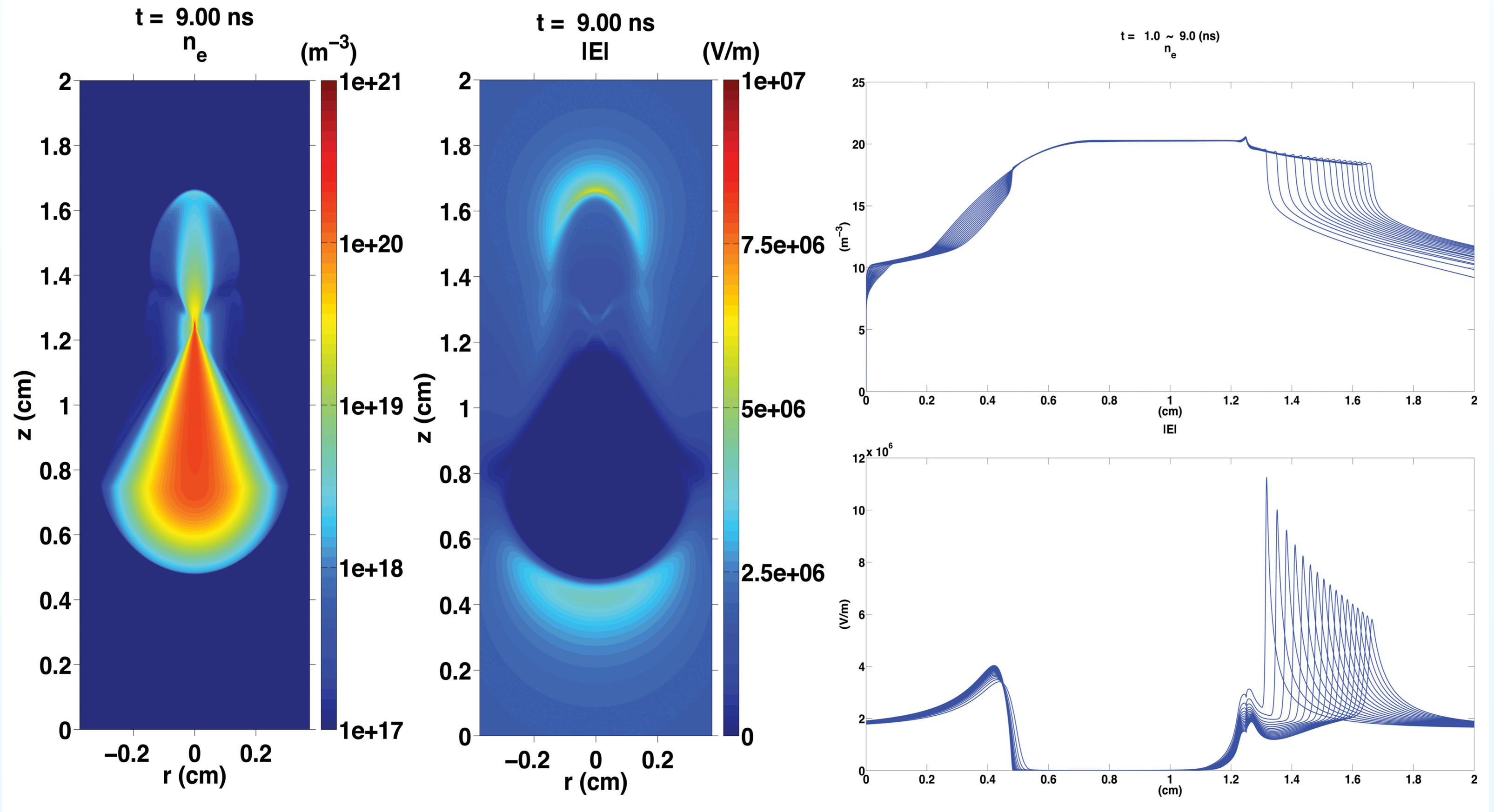

Figure 5 (Case 3): Cross sectional views of electron density (left) and electric field (middle) at t=9ns, and evolution of axial profiles of electron density (right top) and electric filed (right bottom) from t=1ns to t=9ns with constant time intervals of 0.5ns, respectively. It shows that an ionization wave is formed at the negative tip, but negative streamer is not initiated. Meanwhile, the positive streamer is not formed yet .

Summary

- ❑Negative streamers can be initiated from isolated cone-shaped hydrometeors under subbreakdown field conditions. The dimensions and the shape of the hydrometeor, as well as the ambient field, play important roles during this process.
- ❑The characteristics of positive and negative streamers developing in the same ambient subbreakdown field can be quite different.
- ❑The initiation of negative streamers can occur earlier than that of positive streamers.
- ❑From our modeling results, it appears that the initiation of negative streamers is always accompanied by the formation of positive streamers.

Acknowledgements

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