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Streamer Discharges From Isolated Hydrometeors in Thunderclouds

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Overview

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- Streamer Model Formulation
- Streamer Simulation from Model Hydrometeors Results
- Dimension of the Model Hydrometeor
- Formation of Branching Structures
- Streamer Simulation from Other Geometries
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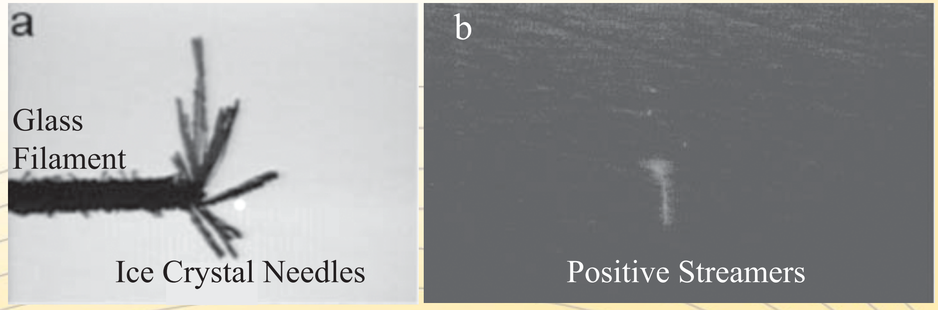
Theory of Lightning Initiation from Hydrometeors

- One theory of air breakdown that has been applied to explaining the initiation of lightning discharges is the conventional breakdown theory [e.g., MacGorman and Rust, 1998; Rakov and Uman, 2003].
- A critical component of this theory is to demonstrate that streamers are able to originate in thundercloud electric fields.
- The observed maximum value of this field varies from 0.13 - $0.3E_k$ [Stolzenburg et al., 2007], where E_k is the conventional breakdown threshold field.
- The initiation of streamers from hydrometeors with an applied electric field less than the breakdown threshold field has been observed in laboratory experiments [e.g., Dawson,1969; Griffiths and Latham, 1974; Griffiths and Phelps, 1976, Peterson et al., 2006].



Positive streamers forming from an ice crystal cluster [Modified from Petersen et al., 2006].

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Streamer Model Formulation

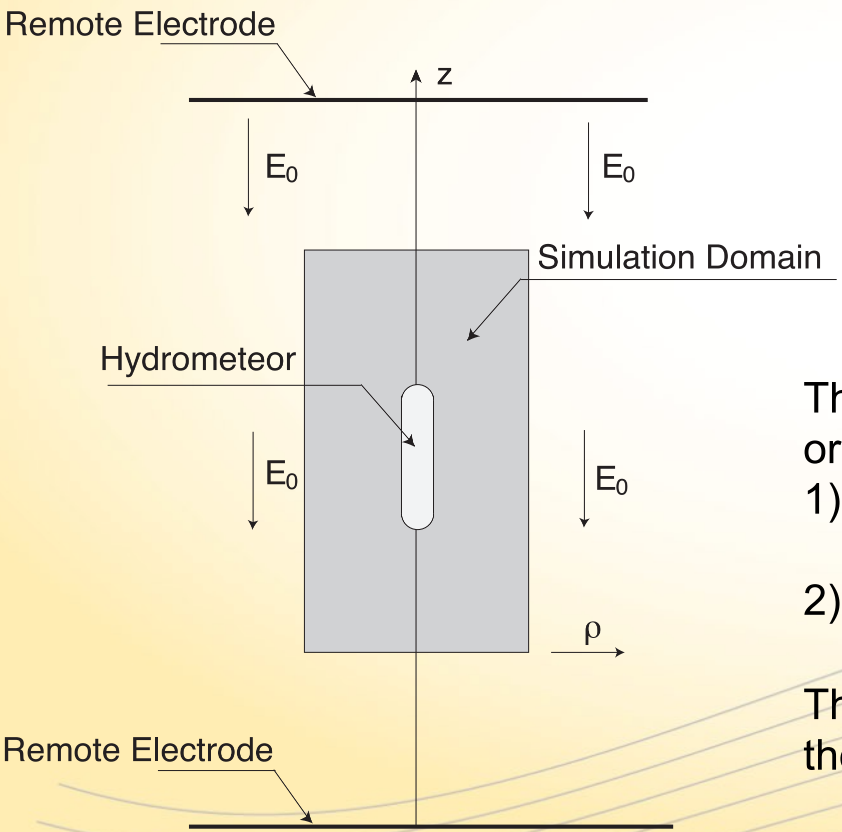
$$\frac{\partial n_e}{\partial t} + \nabla \cdot n_e \vec{v_e} - D_e \nabla^2 n_e = (\nu_i - \nu_{a2} - \nu_{a3}) n_e - \beta_{ep} n_e n_p + S_{ph}$$

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

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

$$\nabla^2 \phi = -\frac{e}{\varepsilon_0}(n_p - n_e - n_n)$$

Liu and Pasko [2004]



The most favorable configurations for streamers to originate from hydrometeors in thunderclouds are:

1) glancing collisions of two water drops [Crabb and Latham, 1974]
2) individual ice crystals [Griffiths and Latham, 1974].

This simulation domain can be used to model both of these cases.

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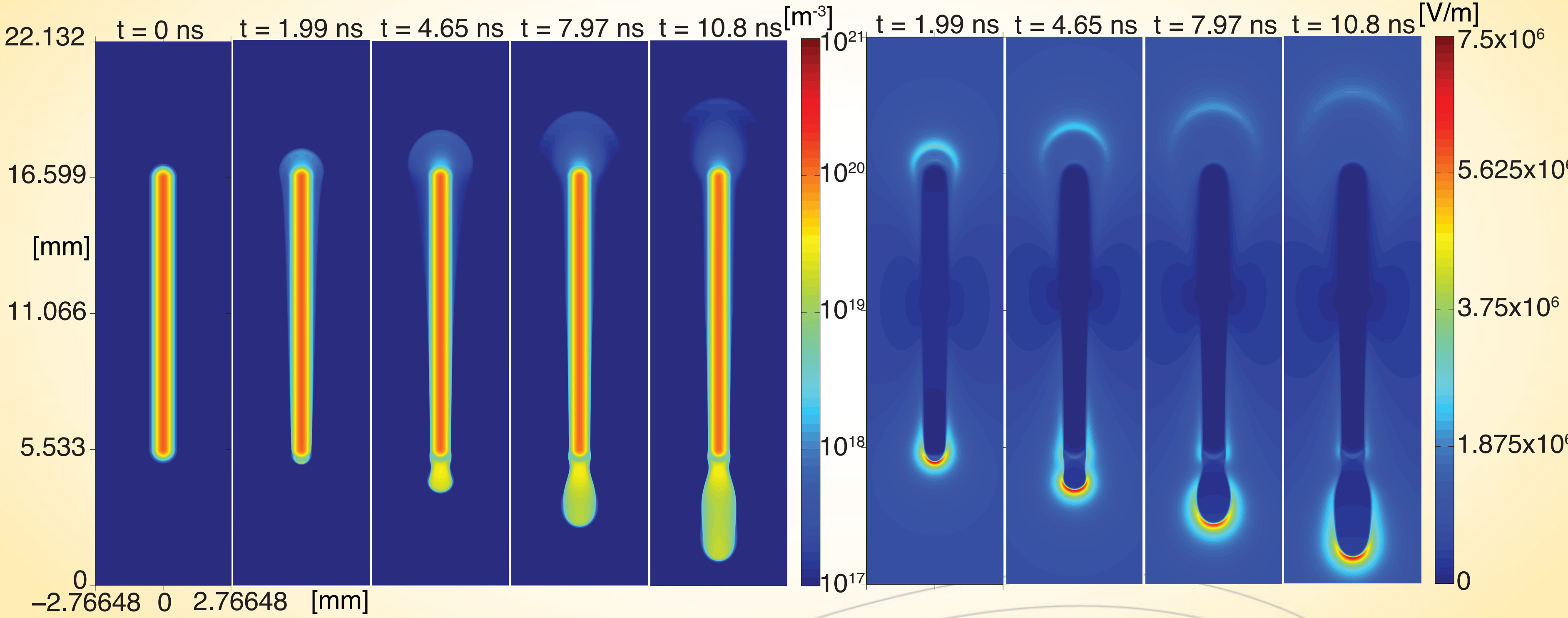
Streamer Simulation from Model Hydrometeor Results



Cross-sectional views of distributions of electron density and electric field of a streamer at 7km.
E_0 = 0.5E_k, l = 11.07 mm, a = 0.22 mm, peak density = 1.23×10^{20} m^{-3}.

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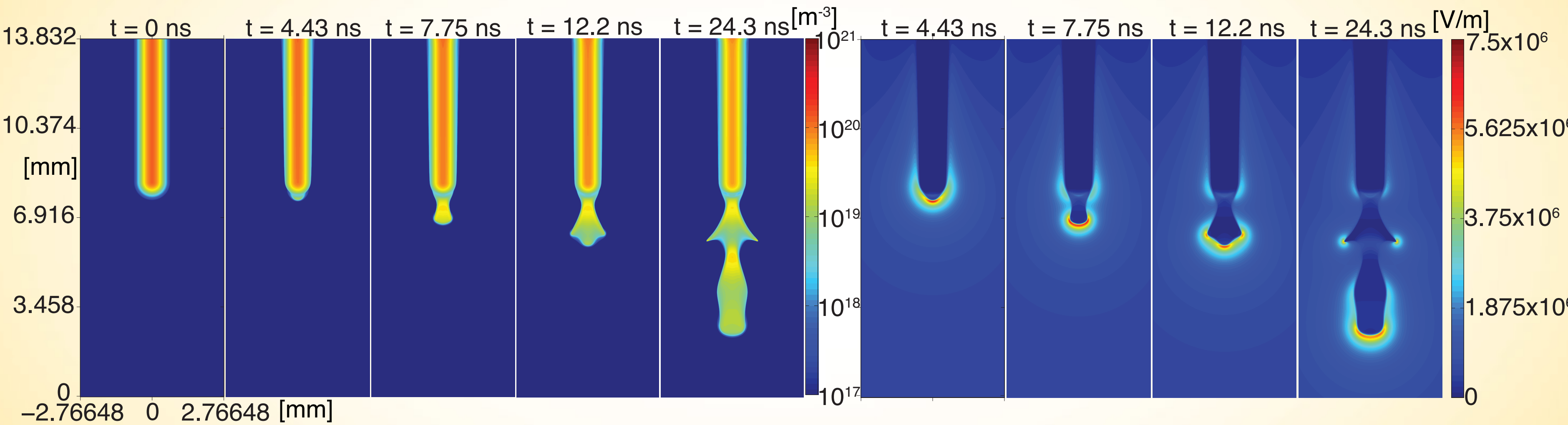
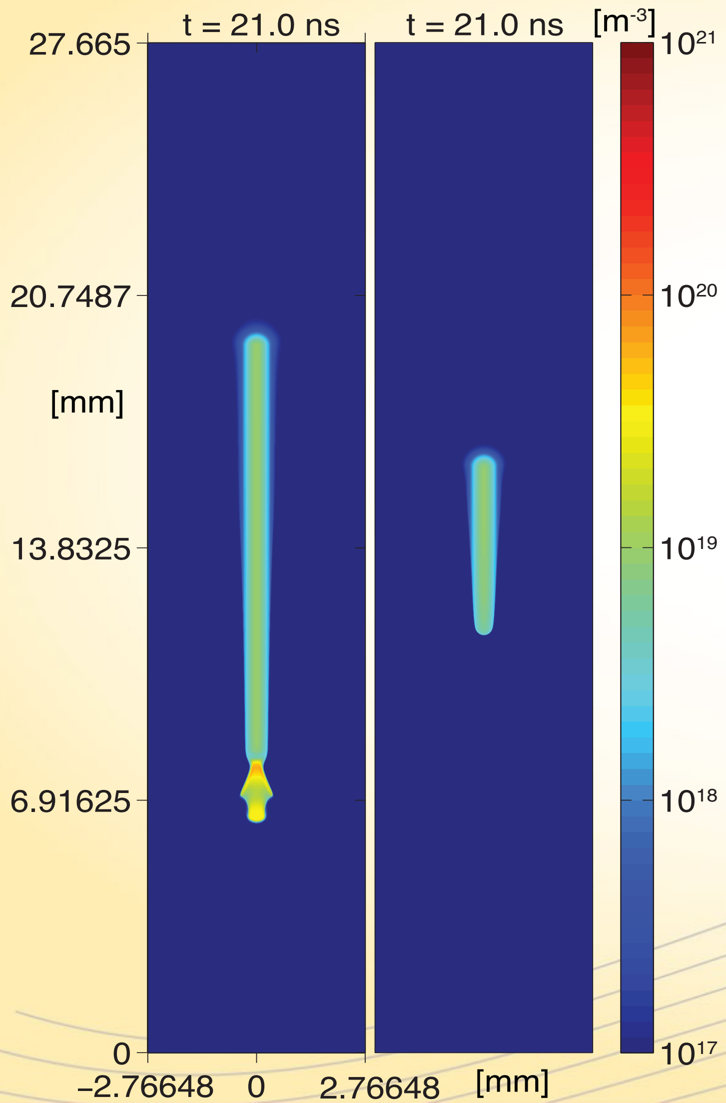
Streamer Simulation from Model Hydrometeor Results



Cross-sectional views of distributions of electron density and electric field of a streamer at 7km.
E_0 = 0.3E_k, l = 11.07 mm, a = 0.22 mm, peak density = $1.23x10^{20}$ m^{-3}.

Dimension of the Model Hydrometeor



The streamer initiation is sensitive to the dimension of the initial ionization column. To estimate the requirements for streamer initiation from the model hydrometeor, we treat the initial ionization column as a perfect conductor [Liu et al., PRL, submitted].

$$E_m = [3 + 0.56(l/a)^{0.92}]E_0$$

[Bazelyan and Raizer, Spark Discharge, 1998]

For the streamer to be able to form, the maximum field at the tip of the cylinder should be around the streamer head field 3-5E_k, if ***a*** has a value of typical streamer radii. Then ***l*** can be calculated as:

$$l = a[\frac{1}{0.56}(E_m/E_0 - 3)]^{1/0.92}$$

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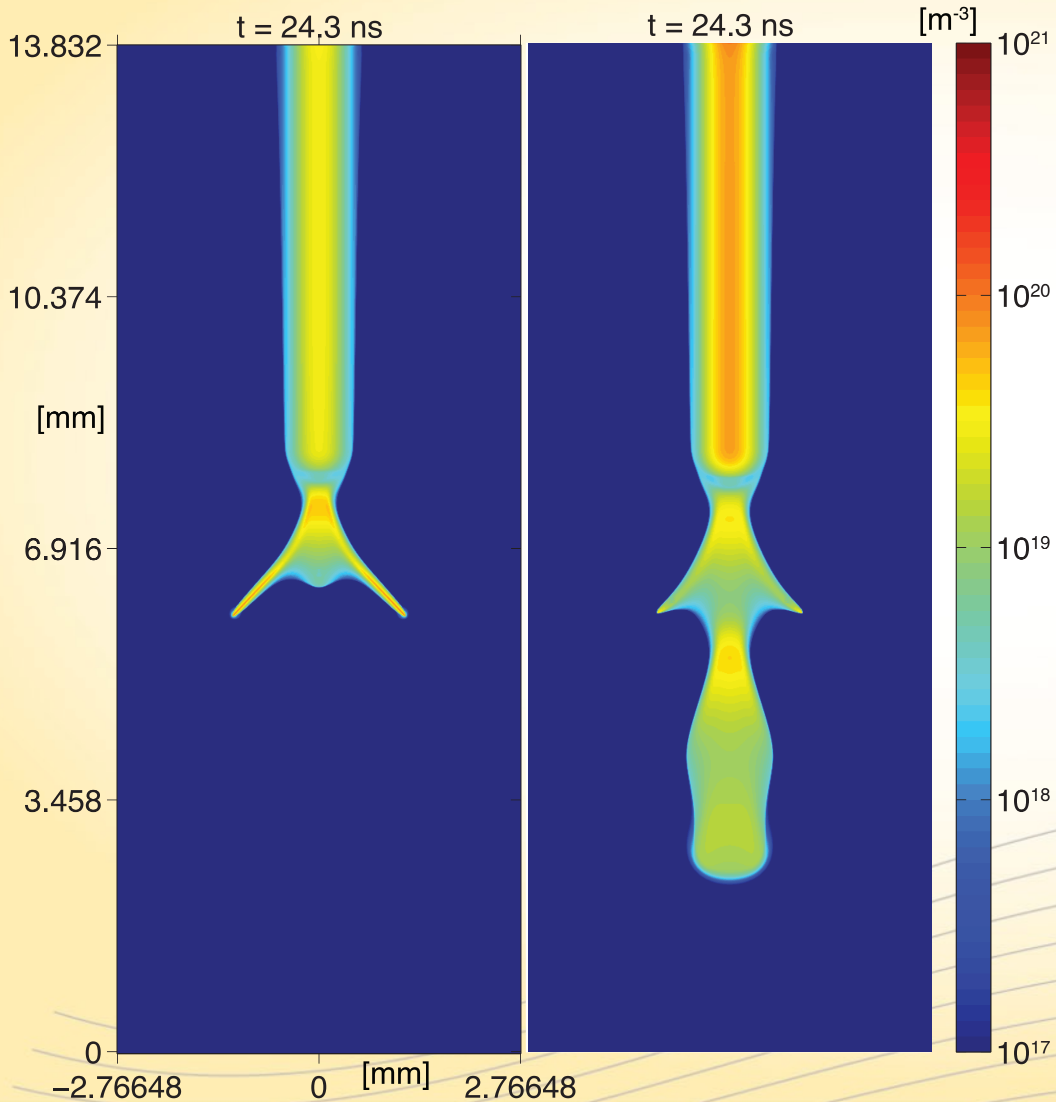
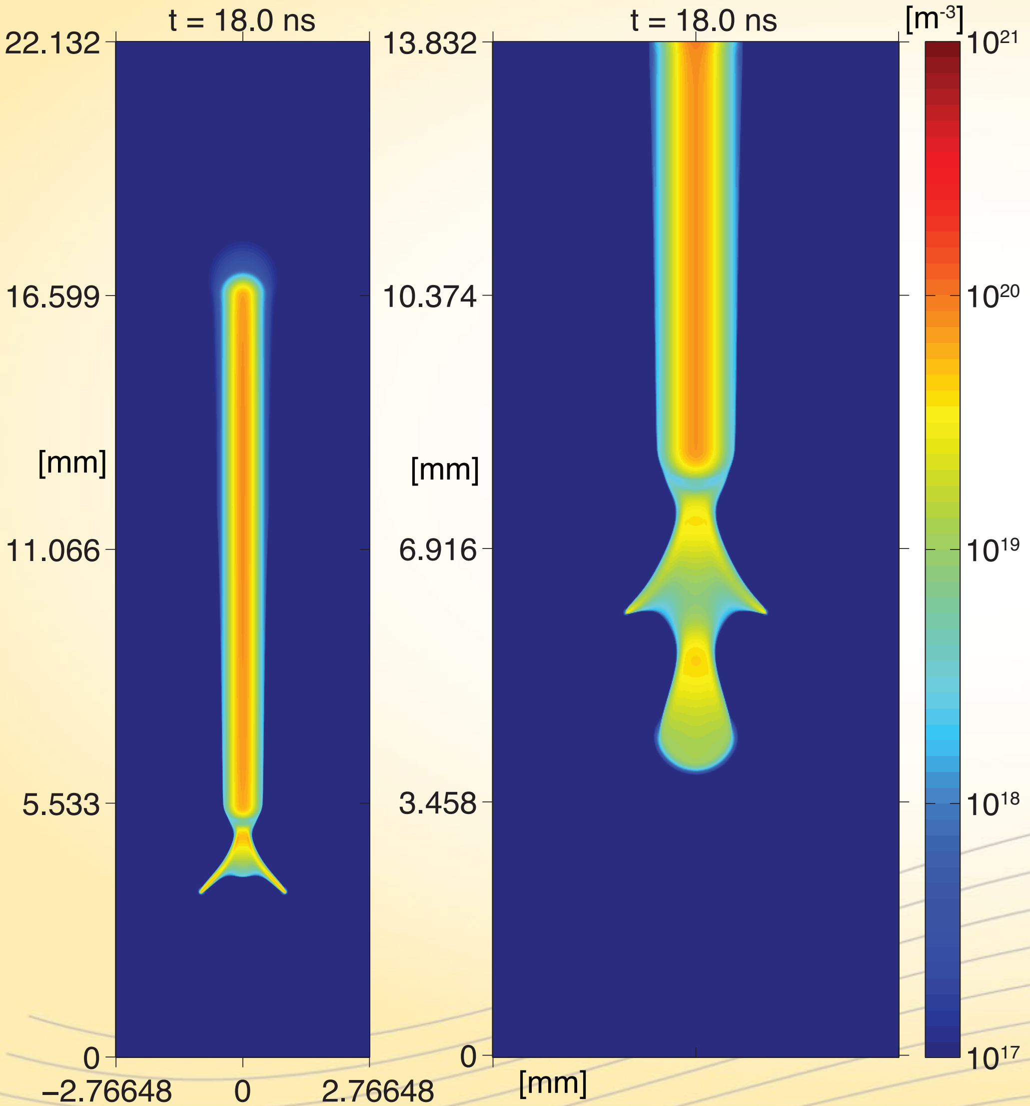
Formation of Branching Structures



- Effects of density
- Formation of branching structure:
  $E_0 = 0.3E_k$, altitude = 7 km,
  l = 11.07 mm, a = 0.27 mm,
  peak density = 0.41×10^{20} m^{-3}.
- Streamer formation:
  E0 = 0.3Ek, altitude = 7 km,
  l = 11.07 mm, a = 0.27 mm,
  peak density = 1.23×10^{20} m^{-3}.

Formation of Branching Structures



- Effects of radius

- Formation of branching structure:
  $E_0 = 0.3E_k$, altitude = 7 km,
  l = 11.07 mm, a = 0.22 mm,
  peak density =$1.23\text{x}10^{20}$ m^{-3}.

- Streamer formation:
  $E_0 = 0.3E_k$, altitude = 7 km,
  l = 11.07 mm, a = 0.27 mm,
  peak density = $1.23\text{x}10^{20}$ m^{-3}.

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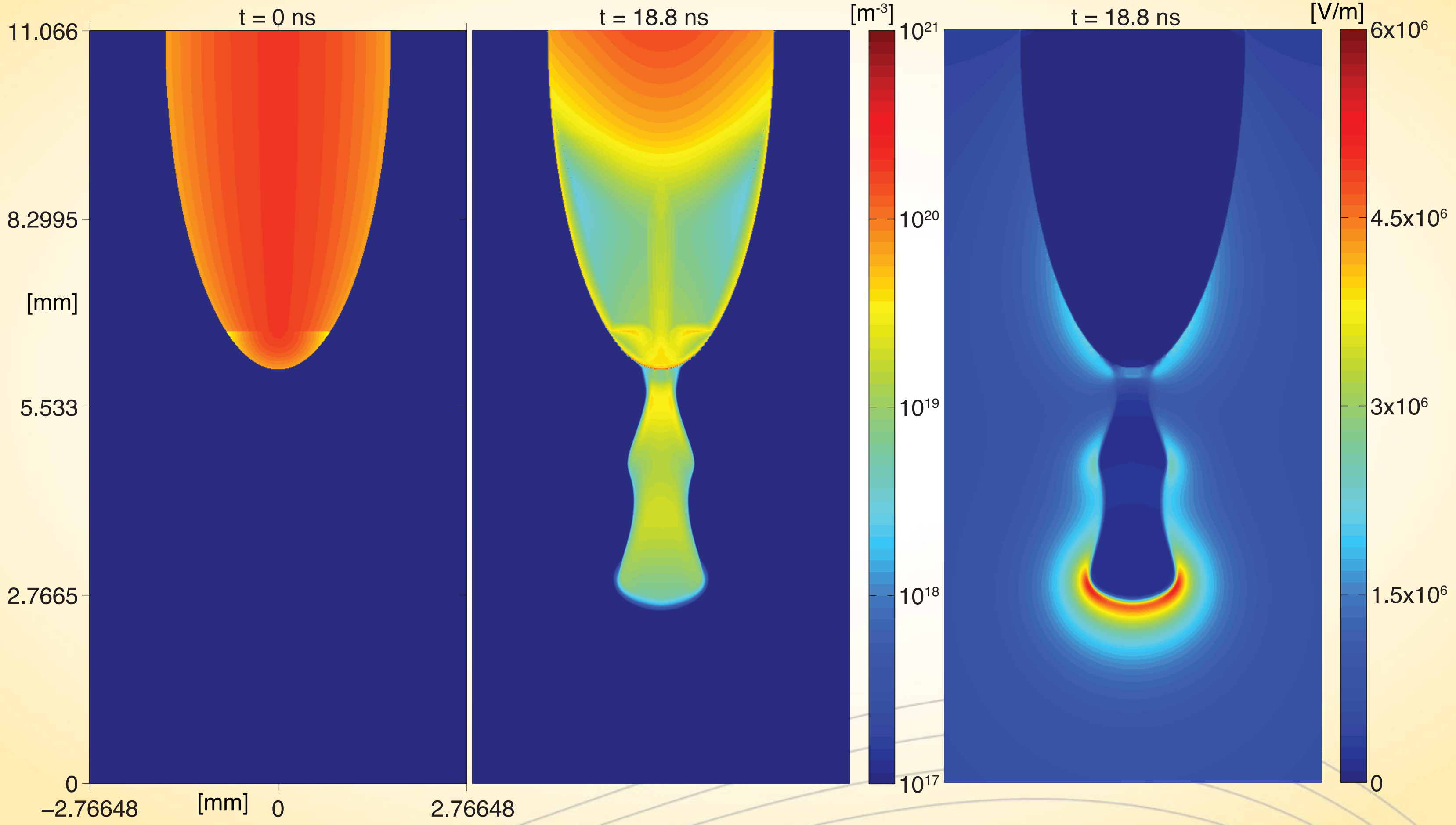
Streamer Simulation from Other Geometries



$E_0 = 0.3E_k$, 7 km, peak plasma density is 1.84×10^{20} m^{-3}, major and minor diameters: 9.96 mm and 3.32mm.

Summary and Conclusions

Results from this study are summarized as below:

1. It has been demonstrated in this study that streamers can be initiated from hydrometeors in fields lower than the air breakdown field. We observed streamer formation for fields as low as $0.3E_k$. Future work will be conducted to investigate the possibility of streamer initiation in even lower field values.

2. Dimensions, i.e., length and radius of the initial ionization column, have a critical effect on the initiation of streamers in fields lower than the air breakdown field. If the dimension of the column does not follow the required value, the streamer may not form. We have estimated the length and size requirement for column hydrometeors in this study.

3. Our modeling results show that higher initial peak plasma density reduce the effects of branching. Also, the results show that a characteristic spatial scale contributes to stable streamer initiation.

4. Preliminary results show that changing the geometry of the ionization column to an ellipsoid prevent or delay the formation of branching structures.

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