Branching of Sprite Streamers Propagating at an Angle From the Vertical Direction

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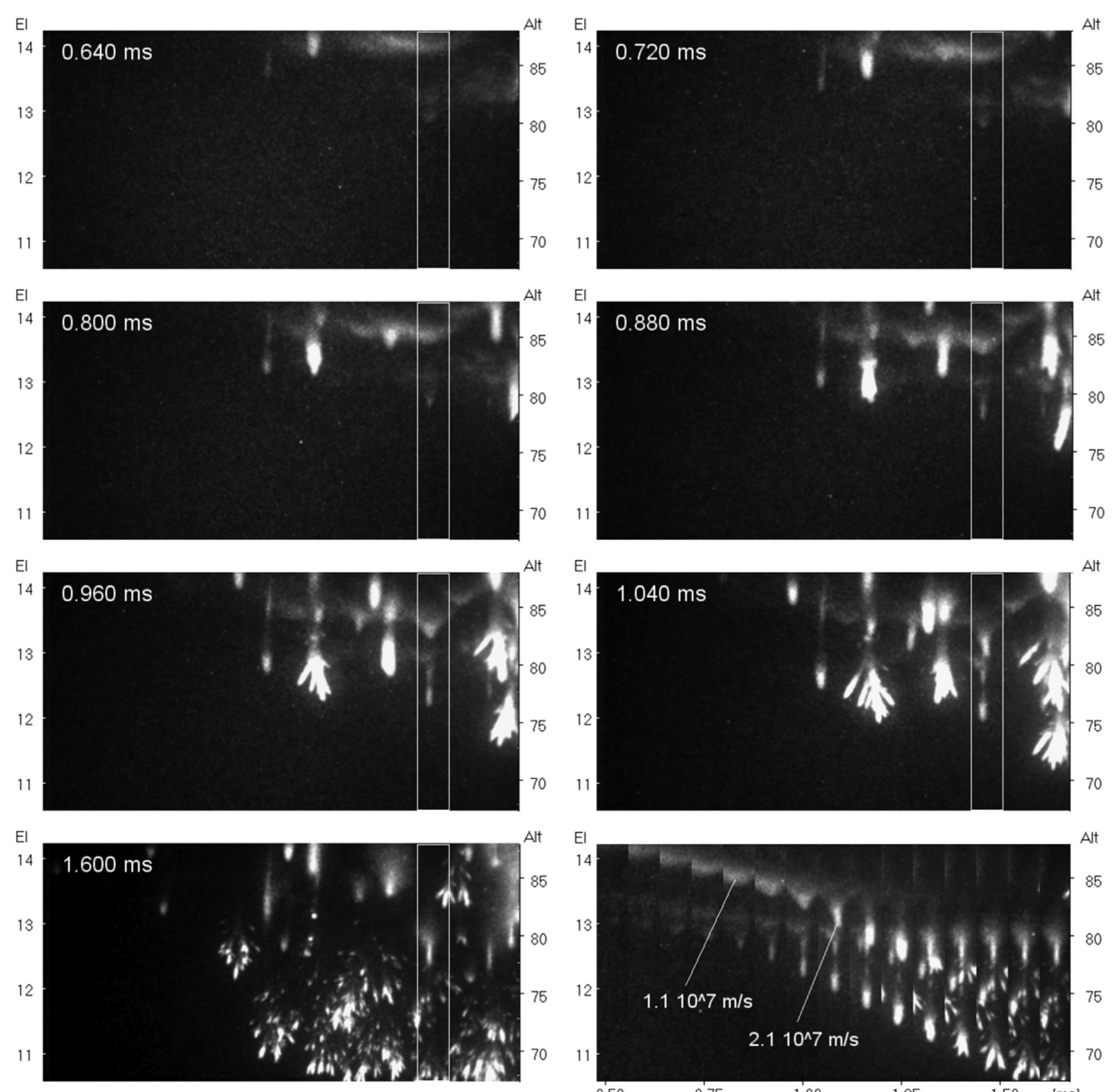
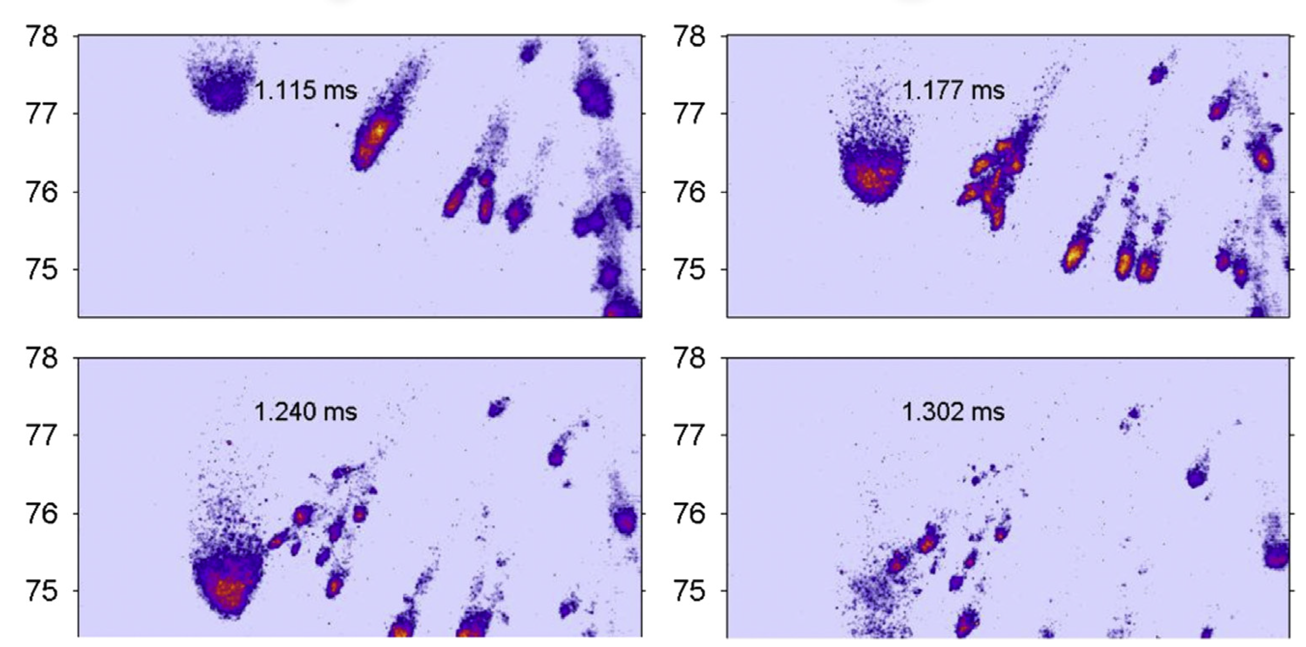
Abstract

Streamer branching is one of prominent features in the high-speed images of sprites [e.g., McHarg et al., JGR, 115, A00E53, 2010; Liu et al., JASTP, 136, 98, 2015]. It is, however, poorly understood at present. The current theory of streamer branching suggests that as a streamer expands and accelerates, it will approach an unstable state [Liu and Pasko, JGR, 109, A04301, 2004]. Laplacian instability will then occur in the streamer head and lead to streamer branching [e.g., Arrayas et al., PRL, 88, 174502, 2002; Rocco et al., PRE, 66, 035102, 2002]. High-speed images show that an unstable streamer head typically splits into two pieces, but streamer splitting into as many as ten pieces has also been observed during one high-speed image exposure of twenty microseconds [Liu et al., 2015]. Furthermore, streamers propagating at an angle from the vertical direction tend to branch more often than those propagating in the vertical direction [McHarg et al., 2010; Liu et al., 2015].

In this talk, we investigate why a streamer may branch more often when it propagates in a slanted direction. Streamer simulation results will be presented to show that a streamer propagating along a slanted direction approaches the unstable state and branches earlier than those in the vertical direction.



Sprite Streamer Branching



These two figures show a sprite event captured by two high-speed cameras on 15 July 2010. The images on the left were recorded at a frame rate of 12,500 fps, and the camera's field of view is 7.3 x 3.7 degrees. The images above were recorded at a frame rate of 16,000 fps, and the camera's field of view is 1.3 x 0.6 degrees [Liu et al., 2015]. The figures show that as sprite streamers move downward, they branch and those propagating in a slanted direction of the vertical branch more often.

Streamer Model

The dynamics of a streamer is described by electron and ion drift-diffusion equations coupled with Poisson's equation:

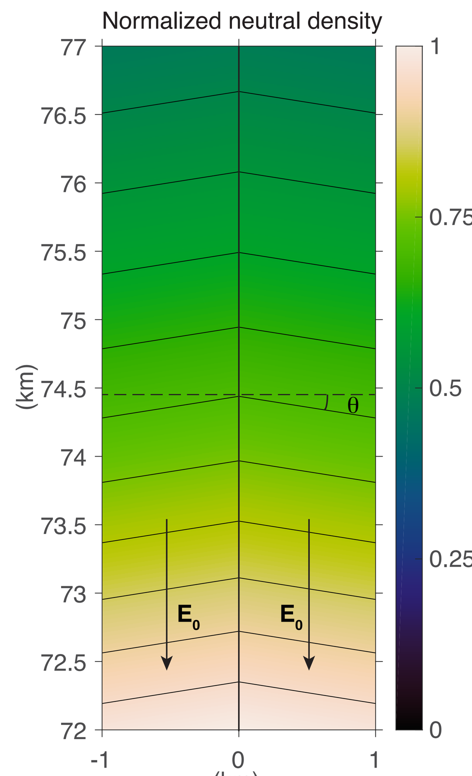
$$\begin{aligned}
\frac{\partial n_e}{\partial t} + \nabla\cdot(n_e\vec{v}_e) - D_e\nabla^2 n_e &= (\nu_i - \nu_{a2} - \nu_{a3})n_e - \beta_{ep}n_e n_p + \nu_d n_n + S_{ph},\\
\frac{\partial n_p}{\partial t} &= \nu_i n_e - \beta_{ep}n_e n_p - \beta_{np}n_n n_p + S_{ph},\\
\frac{\partial n_n}{\partial t} &= (\nu_{a2} + \nu_{a3})n_e - \nu_d n_n - \beta_{np}n_n n_p,\\
\nabla^2\phi &= -\frac{e}{\varepsilon_0}(n_p - n_e - n_n),
\end{aligned}$$

where

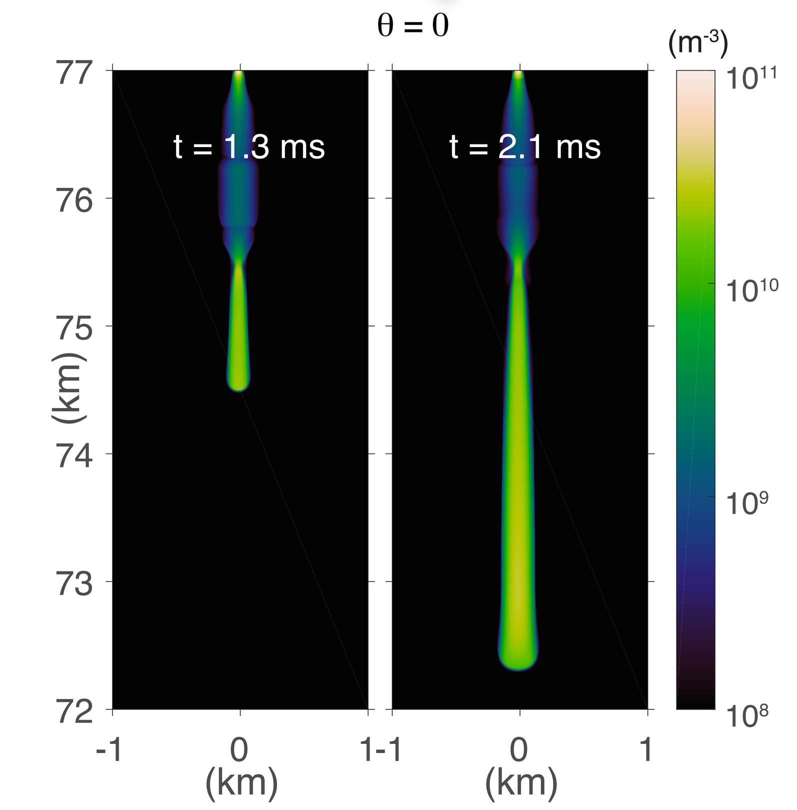
n_e, n_p, n_n – the density of electrons and ions,
v_e – drift velocity,
D_e – diffusion coefficient,
ν_i – electron impact ionization frequency,
ν_{a2}, ν_{a3} – two- and three-body attachment frequencies,
β_{ep}, β_{np} – recombination coefficients,
ν_d – electron detachment frequency,
S_{ph} – photoionization rate,
ϕ – electrostatic potential.

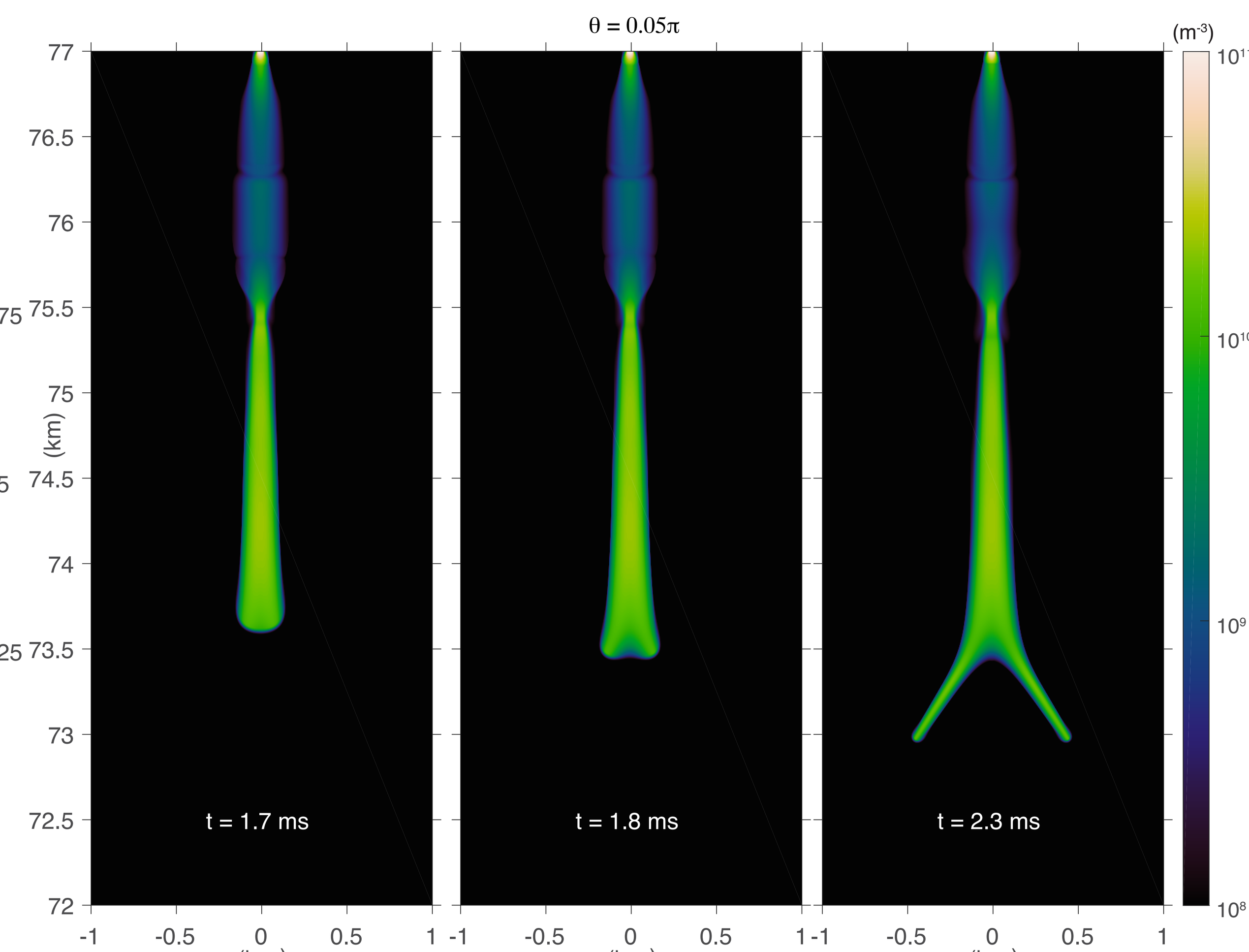
Simulation Setup

In order to study the branching of a slanted streamer by using a cylindrically symmetric code, the direction of streamer propagation is set to be the z axis, while the gradient of the neutral density subtends a small angle with the z axis.

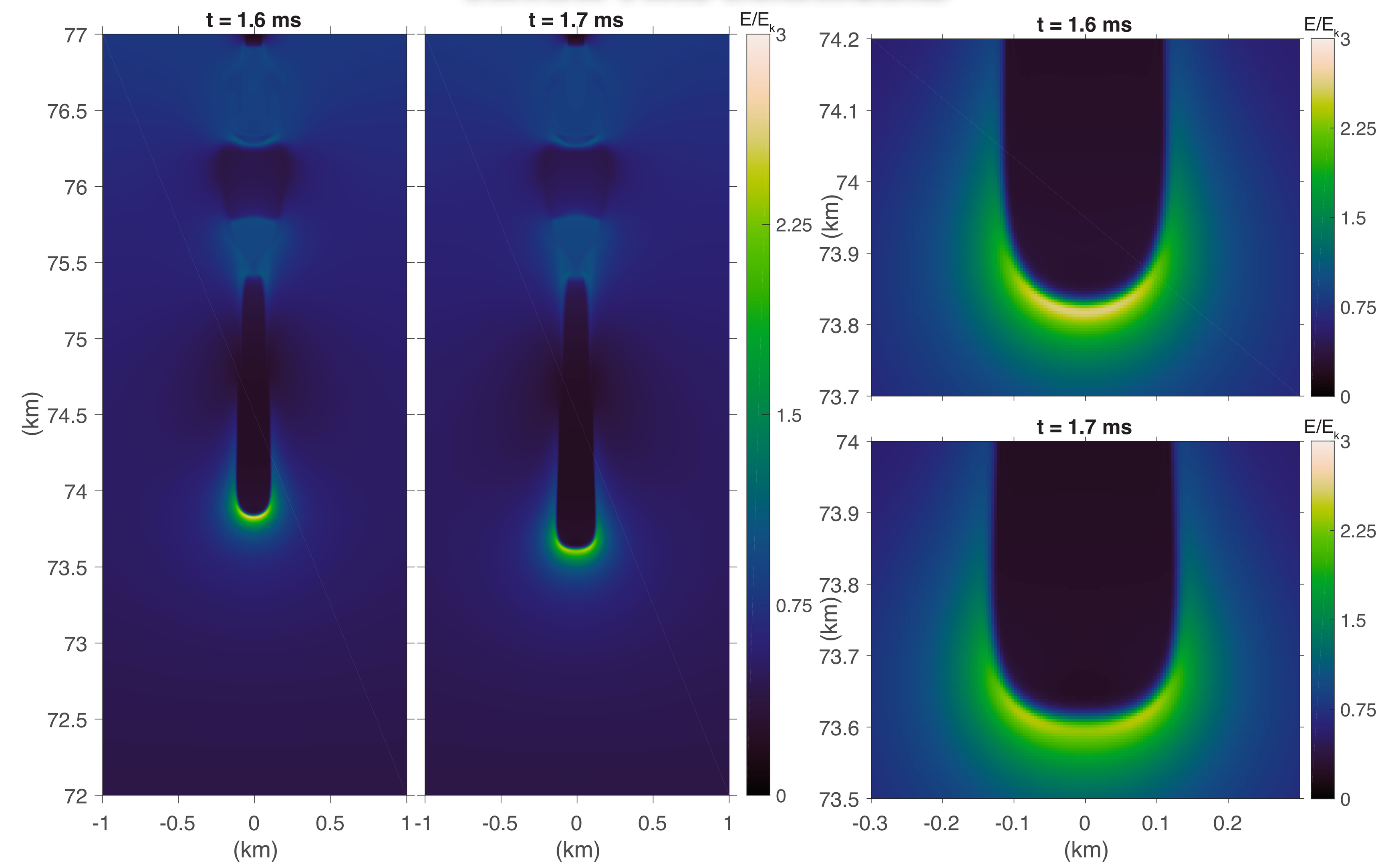


Electron Density Distribution

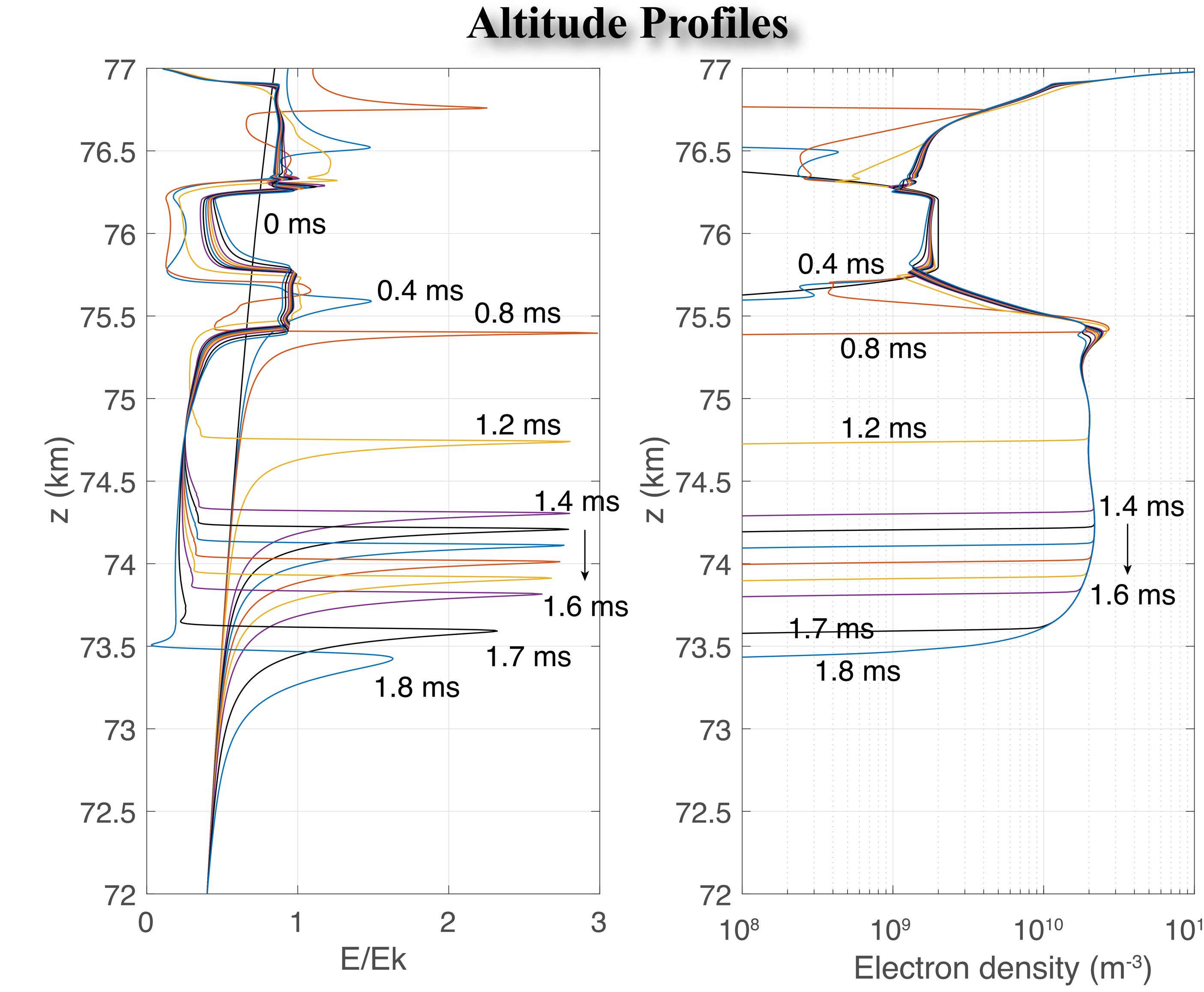




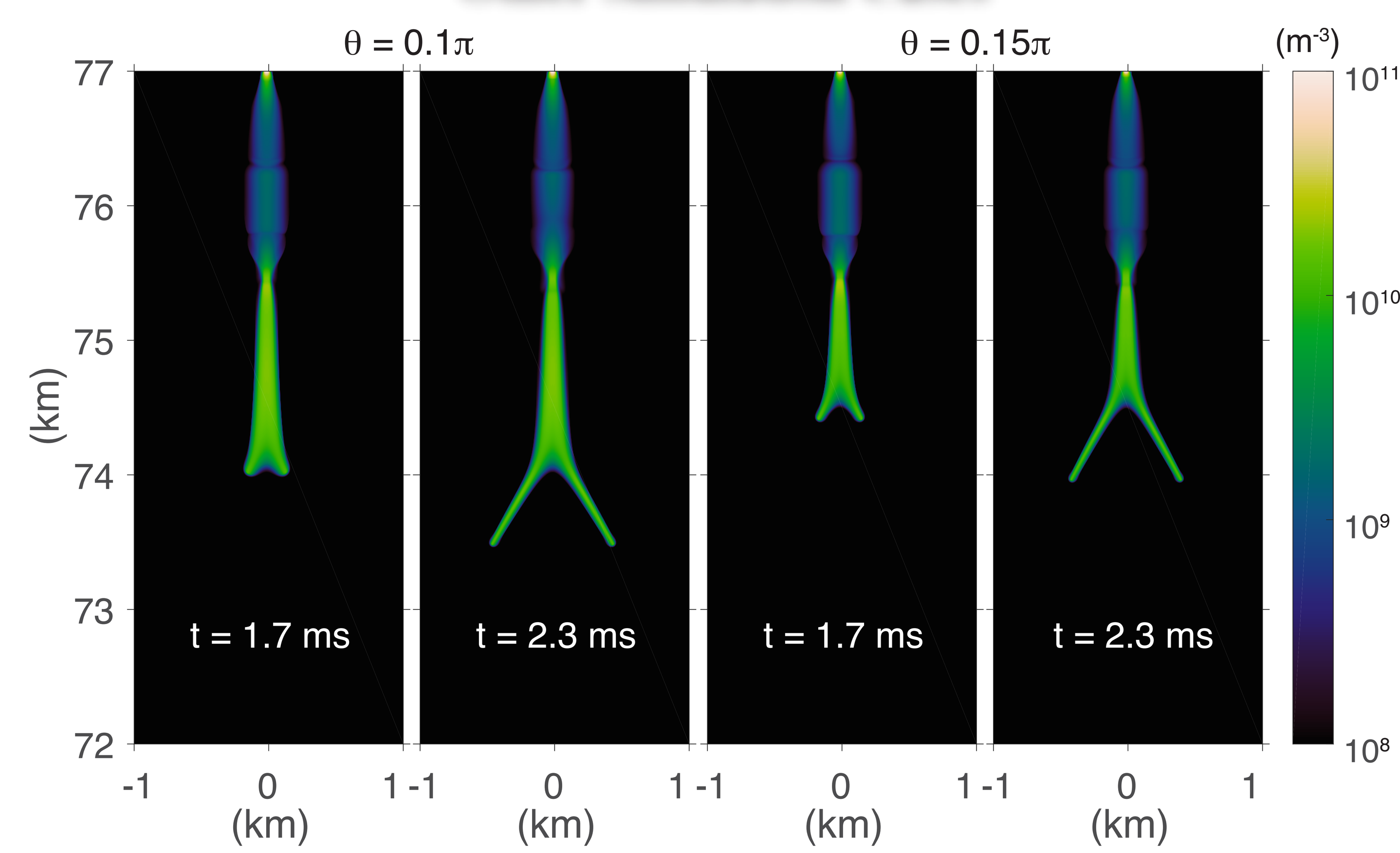
Electric Field Distribution



Altitude Profiles



Other Simulation Cases



Summary and Conclusion

1. This study investigates why a slanted streamer branches more often than a streamer propagating in the vertical direction.

2. A slanted streamer propagates in a direction different from the direction of neutral density gradient. This leads to a flattening streamer head. During this process, the location of the maximum field in the streamer head gradually moves away from the streamer axis as well as the maximum ionization rate. This eventually leads to streamer branching.

3. If the angle between the propagation direction and the neutral density gradient is increased, a streamer branches earlier.

4. Prior to branching, there are no significant changes to the streamer head field and electron density.

Acknowledgements

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References

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Rocco, A., U. Ebert, and W. Hundsdorfer (2002), Branching of negative streamers in free flight, *Phys. Rev. E*, *66*, 035102(R), doi:10.1103/PhysRevE.66.035102.