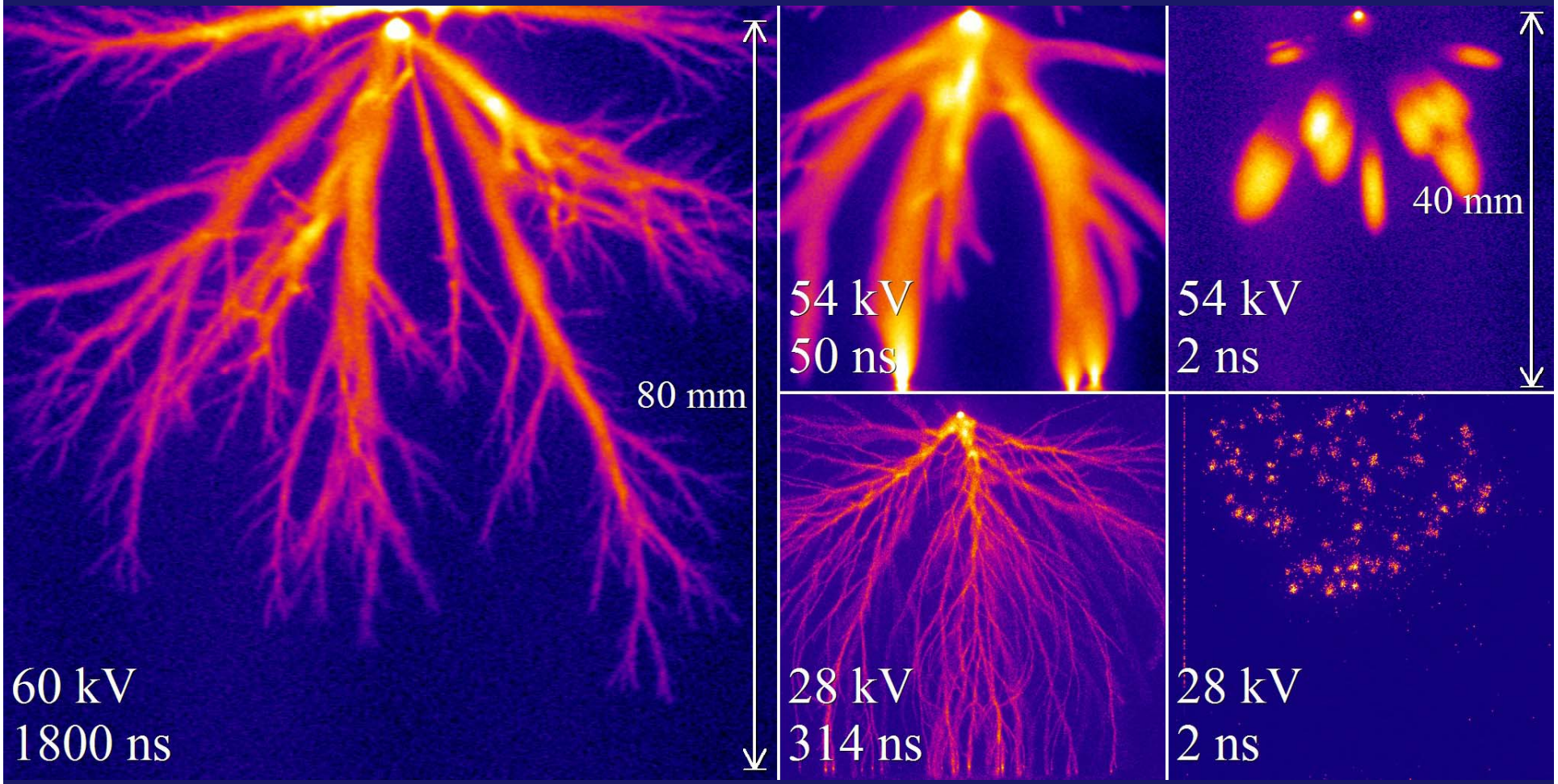
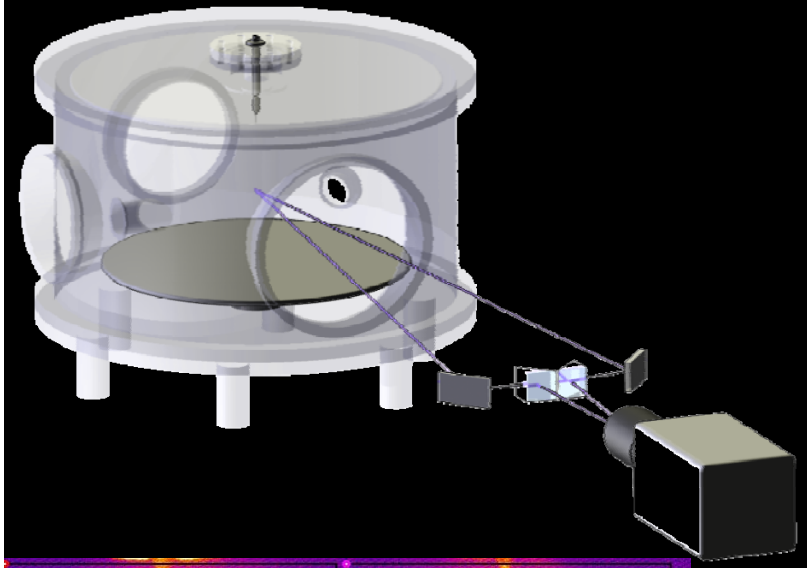
Electromagnetic characterization of streamers and streamer trees:

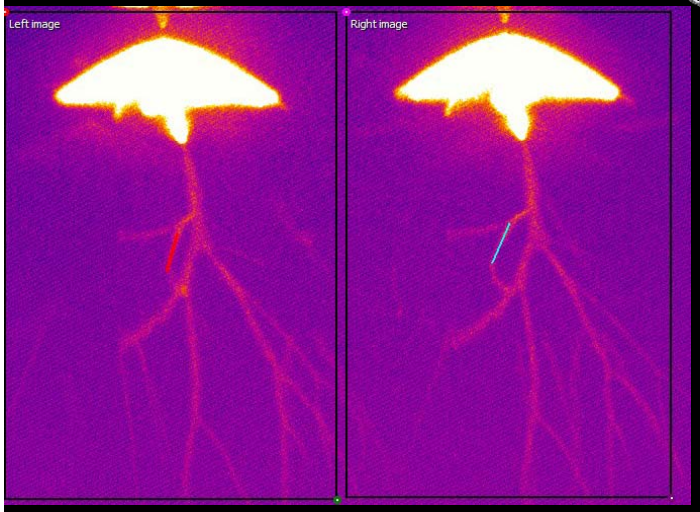
Head and channel dynamics

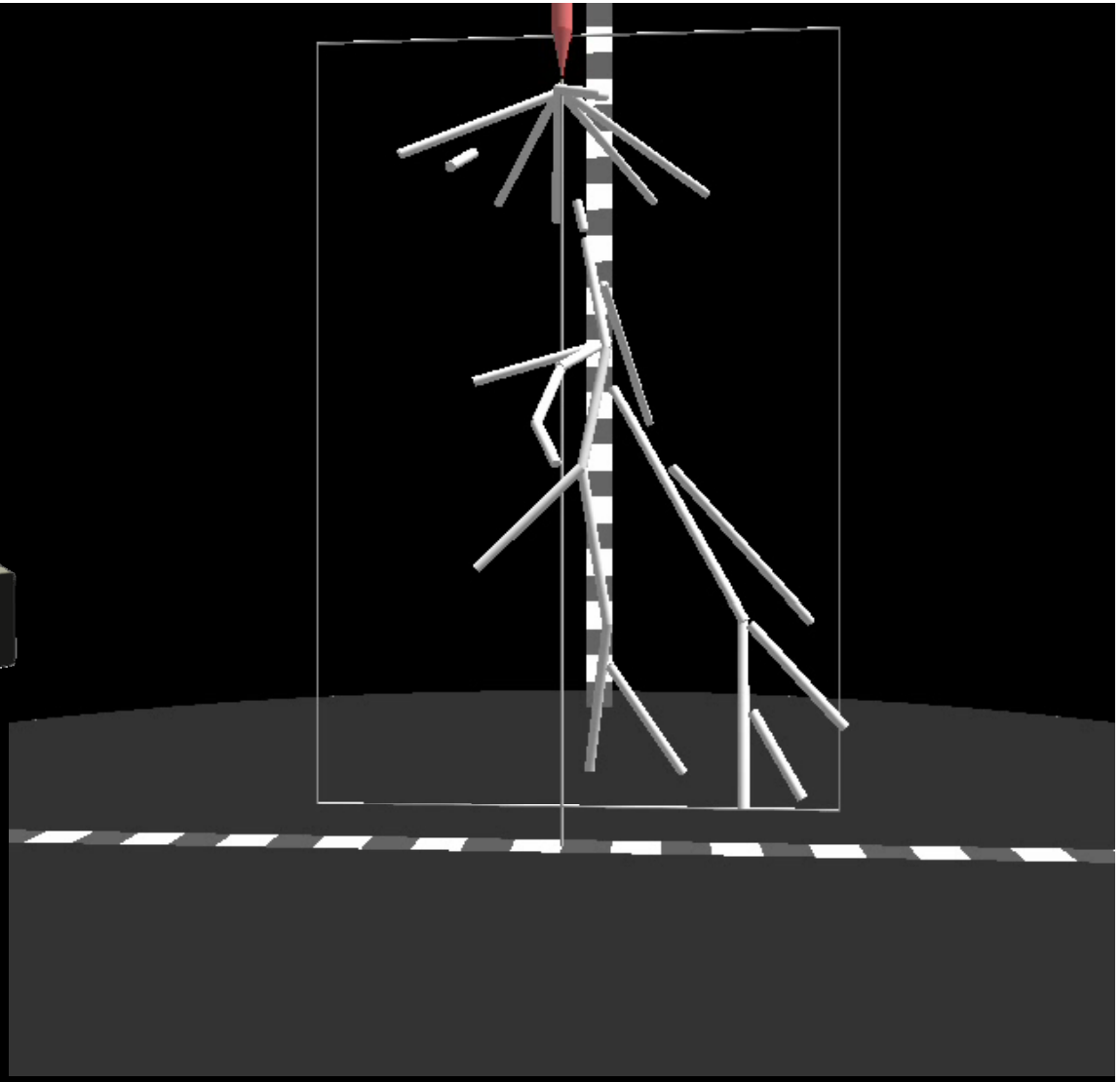


Thick and thin streamers [Ebert et al., JGR 2010]

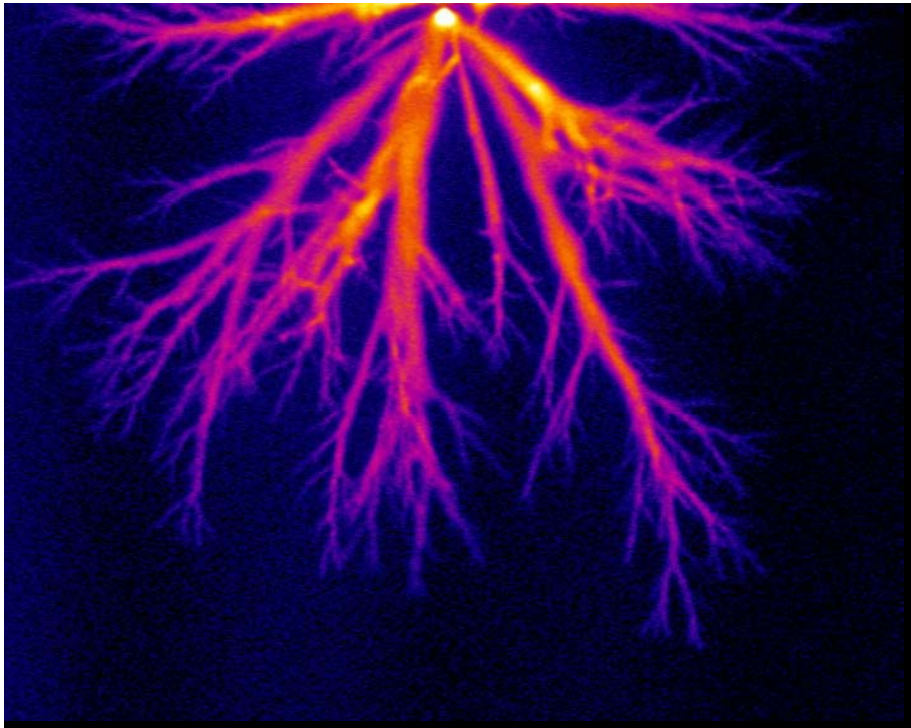
Stereography:

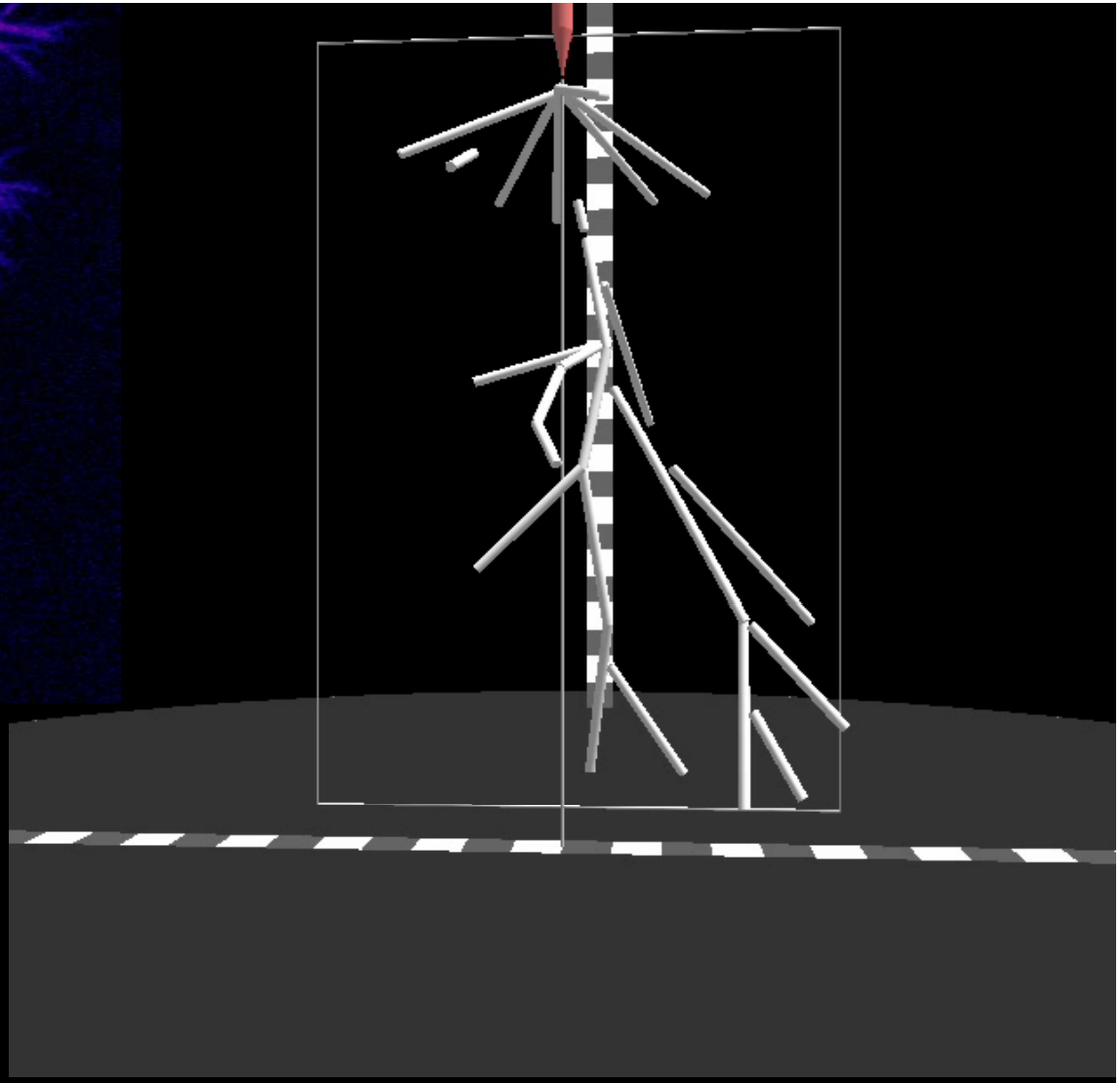






- **Branching angles** [Nijdam et al., Appl. Phys. Lett. 2008]
- **Reconnections** [Nijdam et al., J. Phys. D 2009]



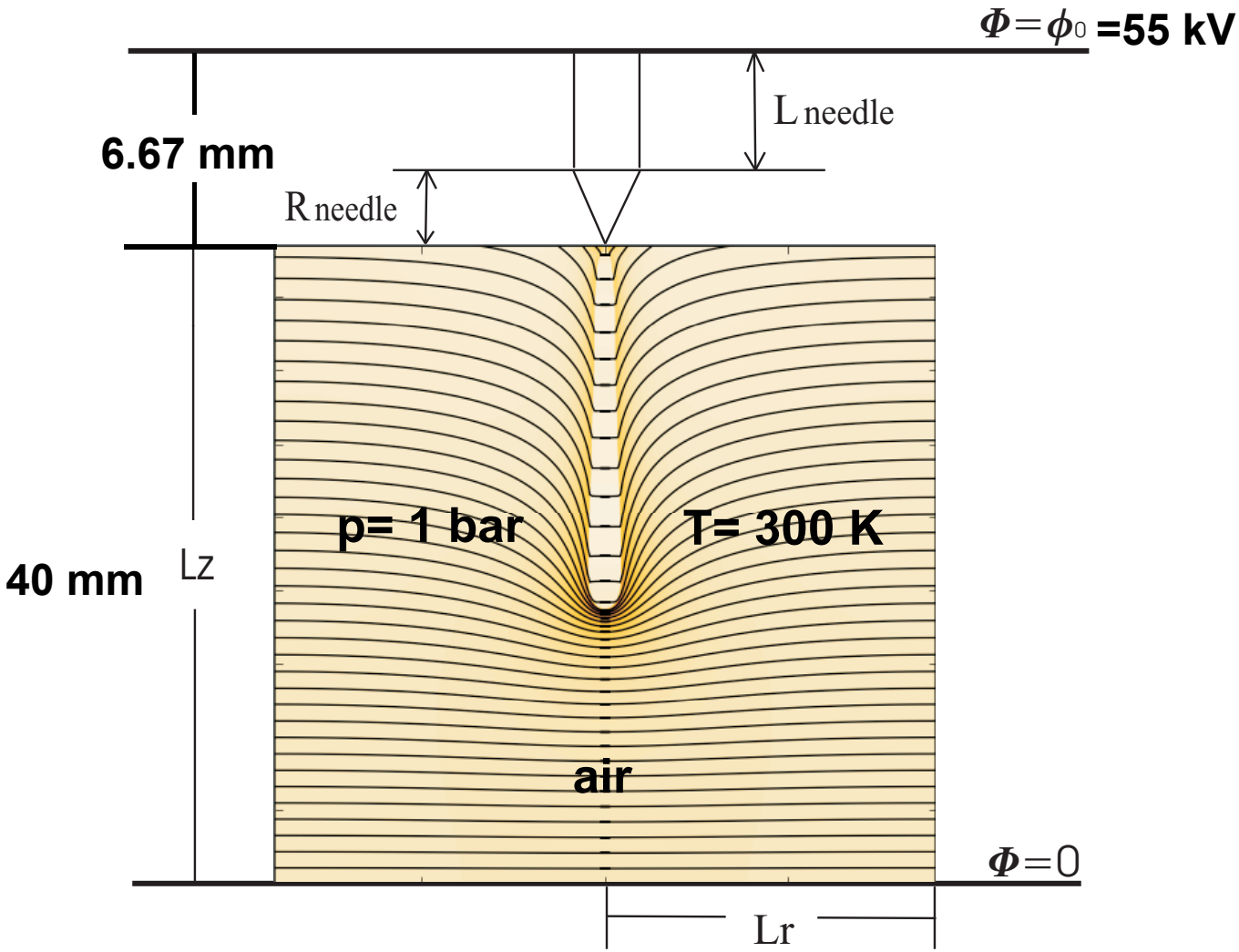


Can we model

the complete tree?

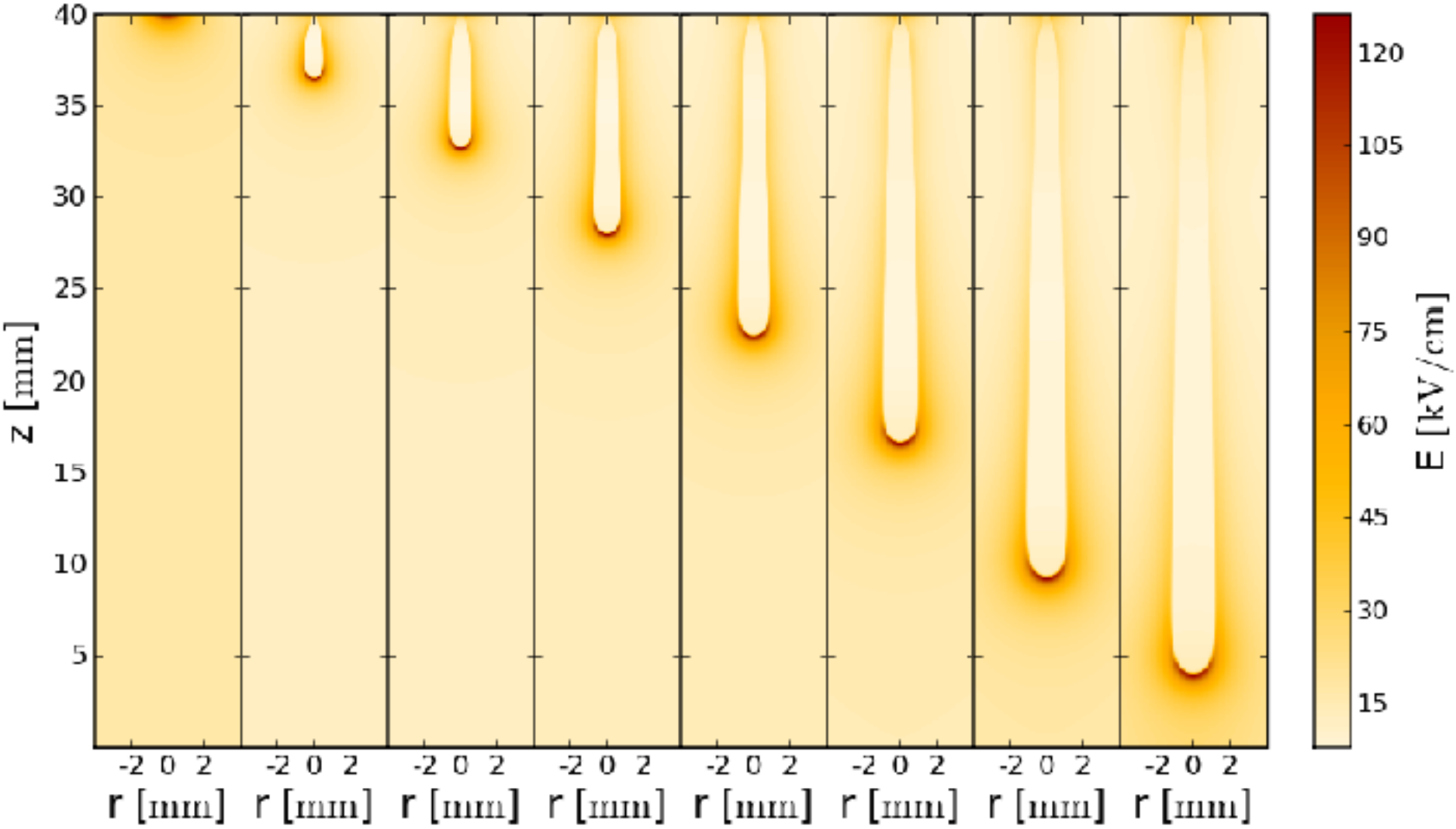
Work in progress. Observations along the road ...

A long positive streamer in protrusion-plane geometry



[V. Ratushnaya, A. Luque and U. Ebert, submitted]

Electric field strength of the streamer in time steps of 10 ns

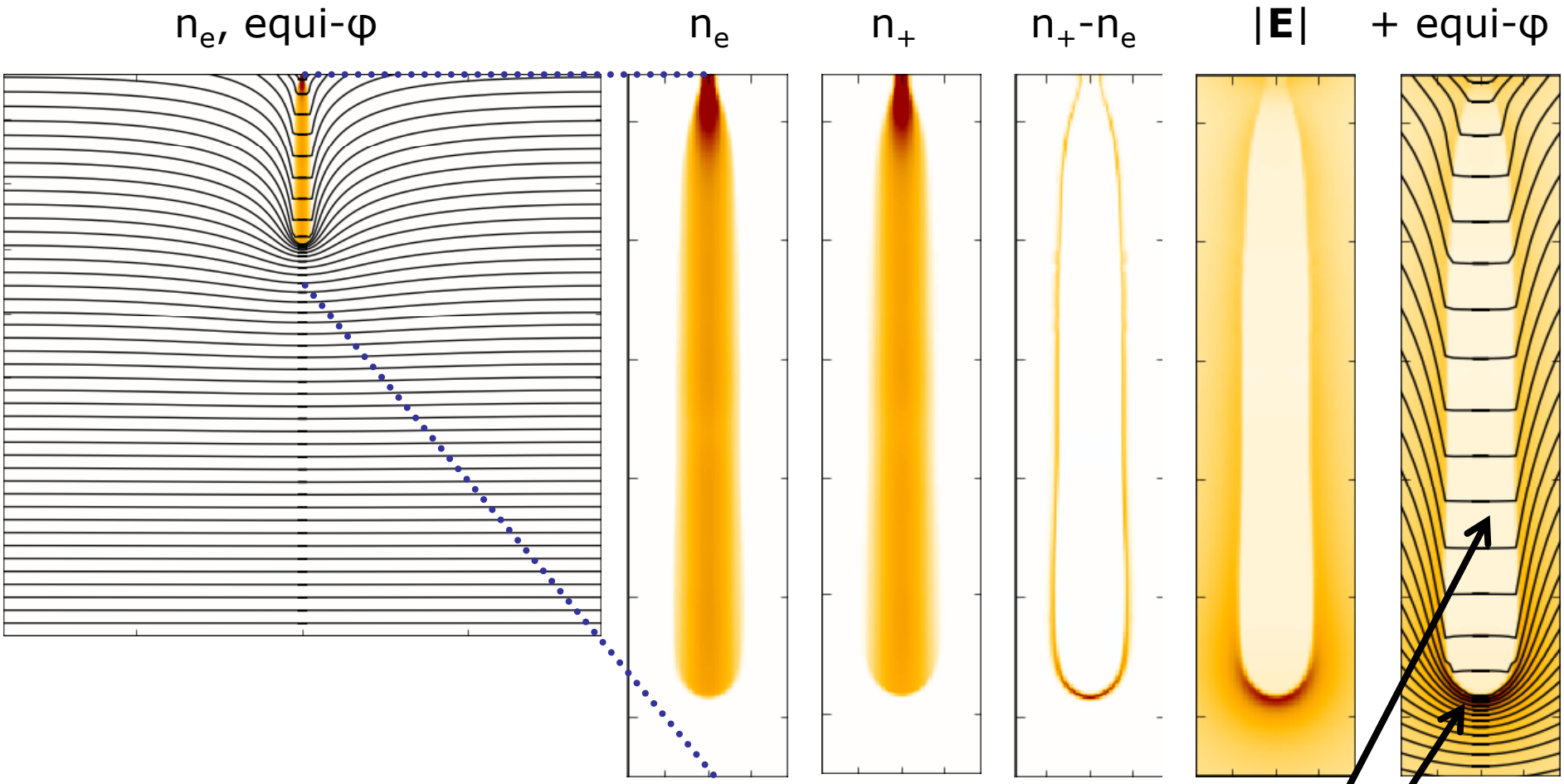


Acceleration and slightly expansion

A single streamer

Complete system:

Zoom:

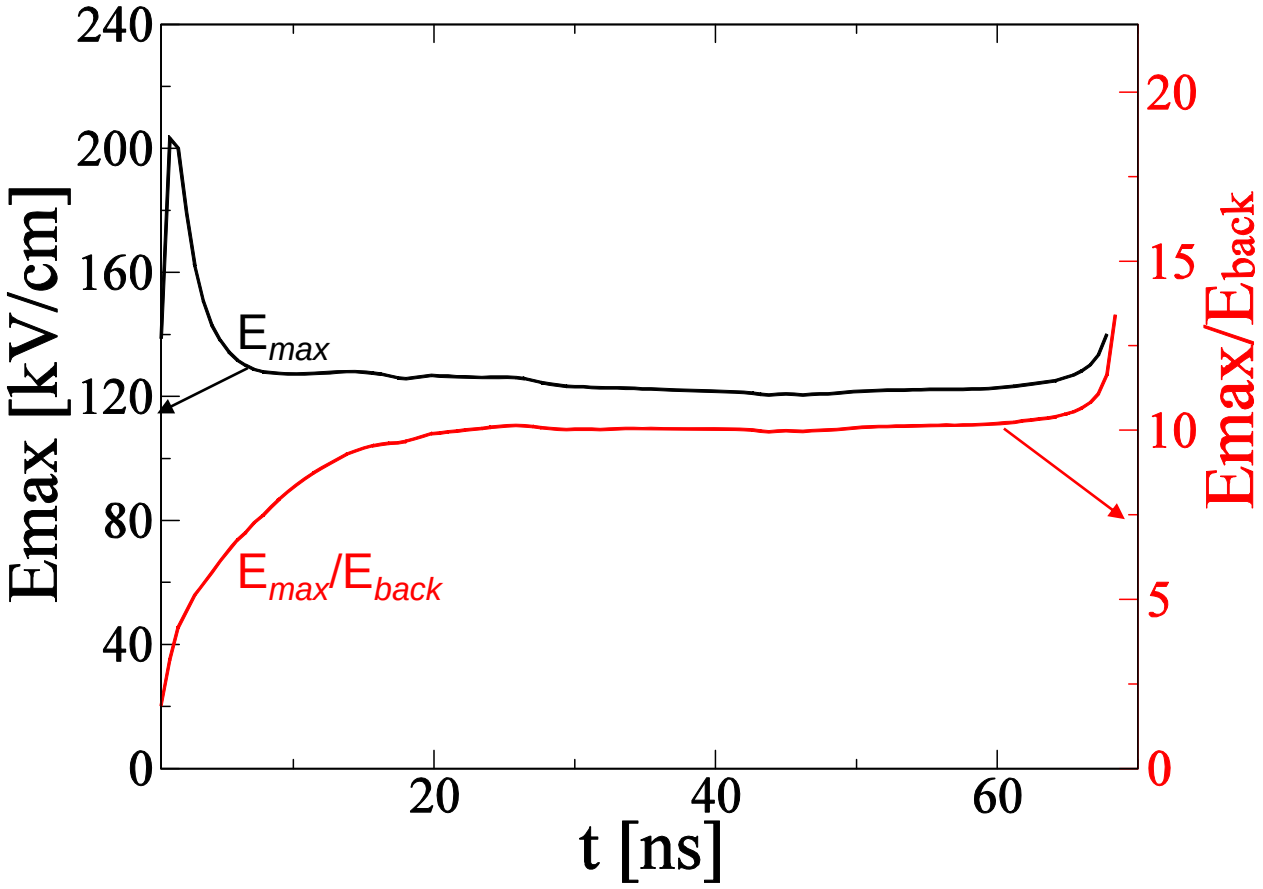


$\mathbf{E_{back} \approx E_{crit}/3}$

$\mathbf{E_{interior} \approx constant}$

$\mathbf{E_{max} \approx 10\ E_{back}}$

Maximal and reduced electric fields



E_{max}:
maximal electric field

E_{back}:
background field at the place of E_{max}

E_{max} ≈ const

E_{max}/E_{back} ≈ 10

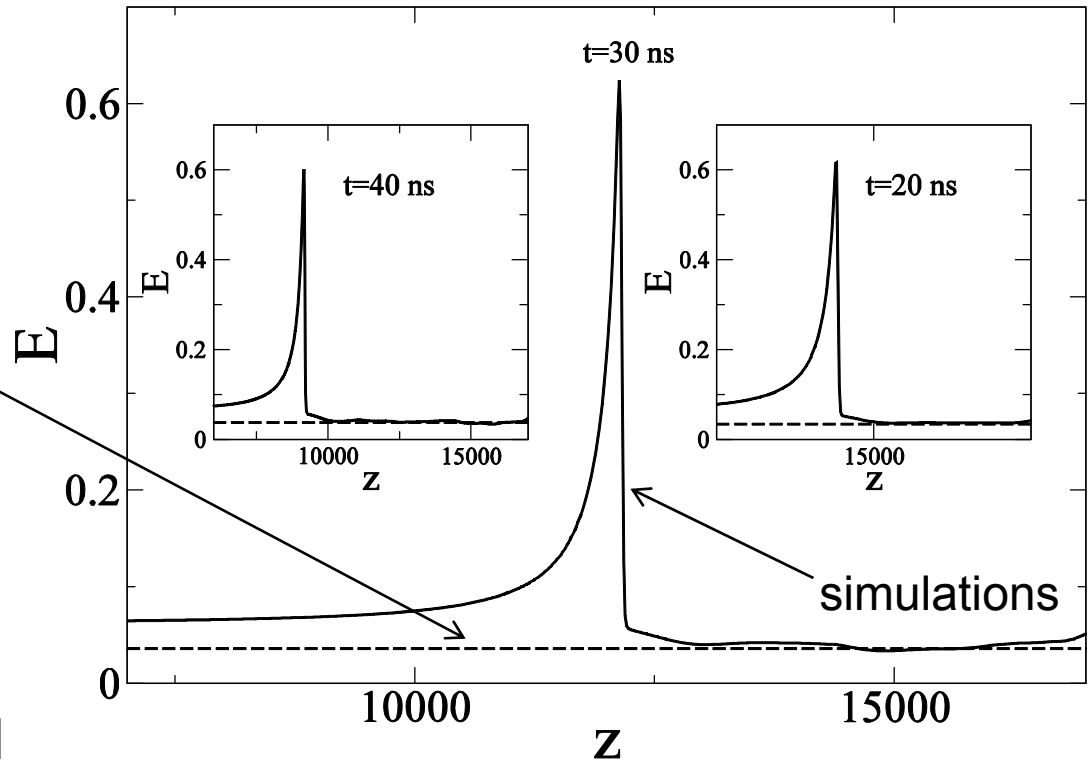
Electric field in streamer head

Assumptions:
- Uniform translation
- Weakly curved front

Conservation of the total current:

$$\nabla \cdot \boldsymbol{J} = 0, \ \boldsymbol{J} = \frac{\partial \boldsymbol{E}}{\partial t} + \sigma \boldsymbol{E}.$$

$$E_{interior} = \frac{2v}{R\sigma_{interior}} E_{max}$$



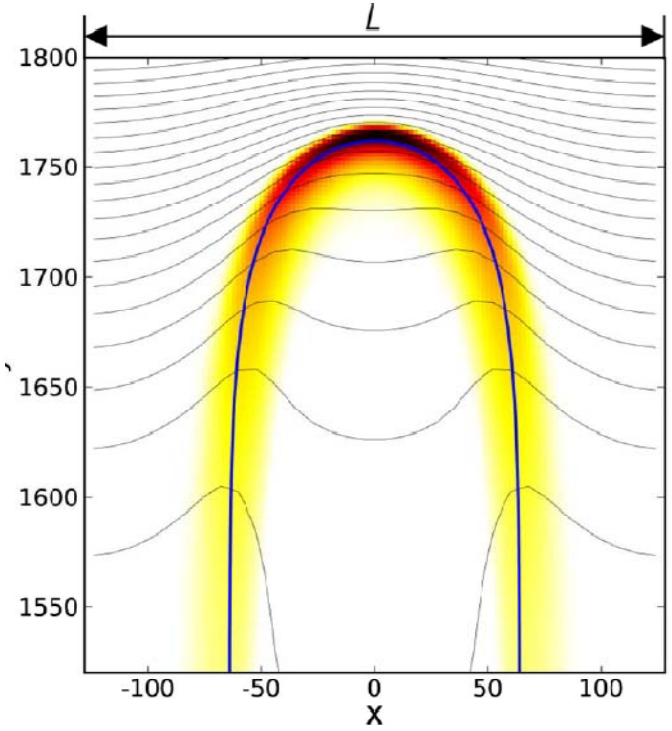
[Ratushnaya et al., submitted]
Find a different derivation in 2D in [Brau *et al.*, PRE 2008].

Electrodynamic characterization of streamer head:

$$\sigma^- E^- = j^- \approx \frac{2vE_{max}}{R}$$ [Brau *et al.*, PRE 2008, Ratushnaya *et al.*, subm.]

$$\sigma^- \approx \sigma^-(E_{max})$$ [Li *et al.*, JAP 2007 and earlier]

$$v = v(R, E_{max})$$ [Naidis, PRE 2009 + …]



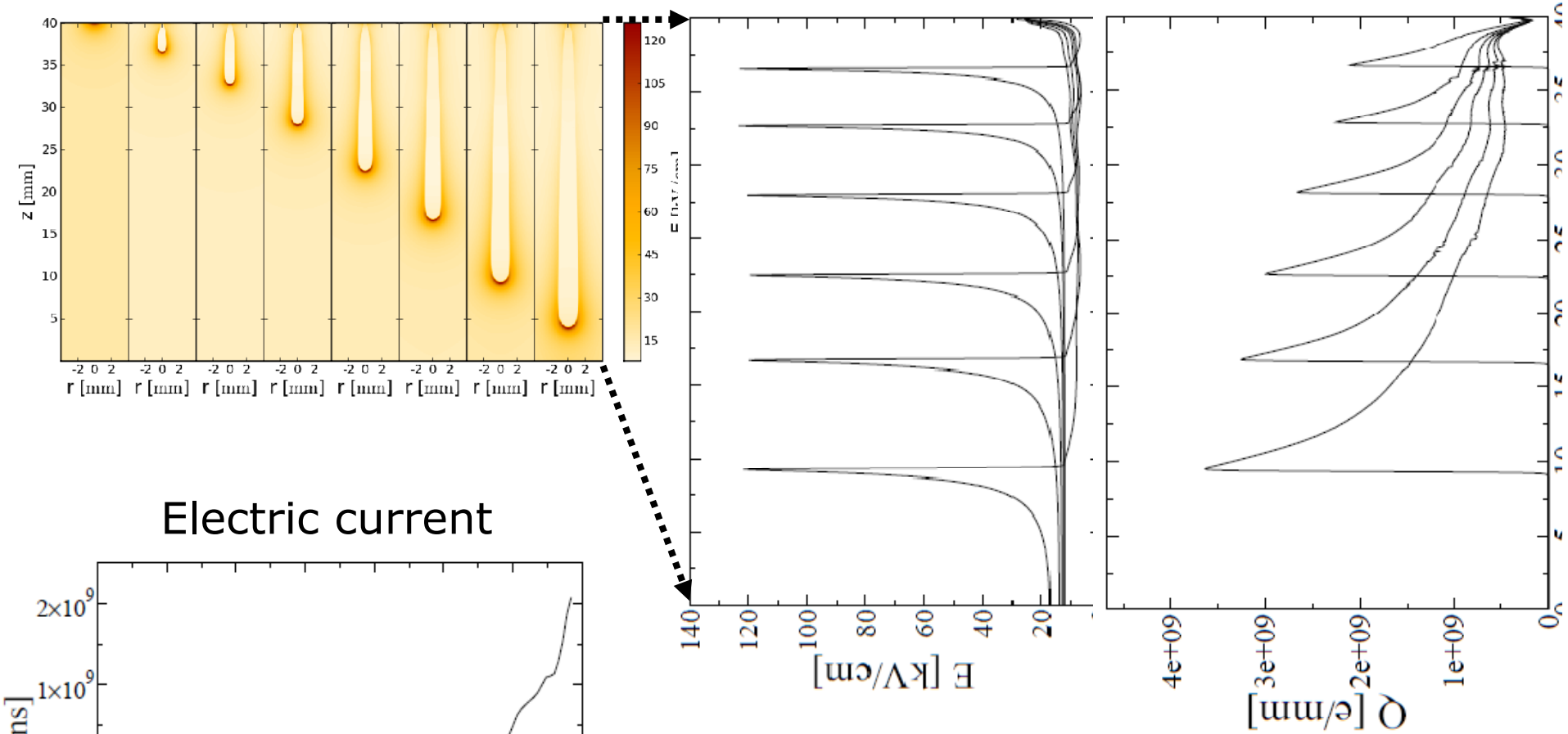
-> Streamer head (v, n_e, $E_{interior}$) should be fully characterized by R and $E_{max,}$ in arbitrary gas and polarity.

What about the channel? Is it dull?

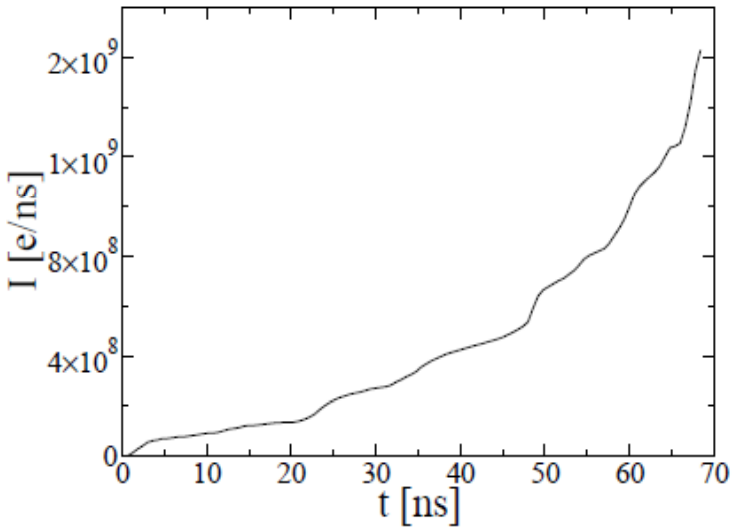
Channel of single streamer

Electric field

Charge per length

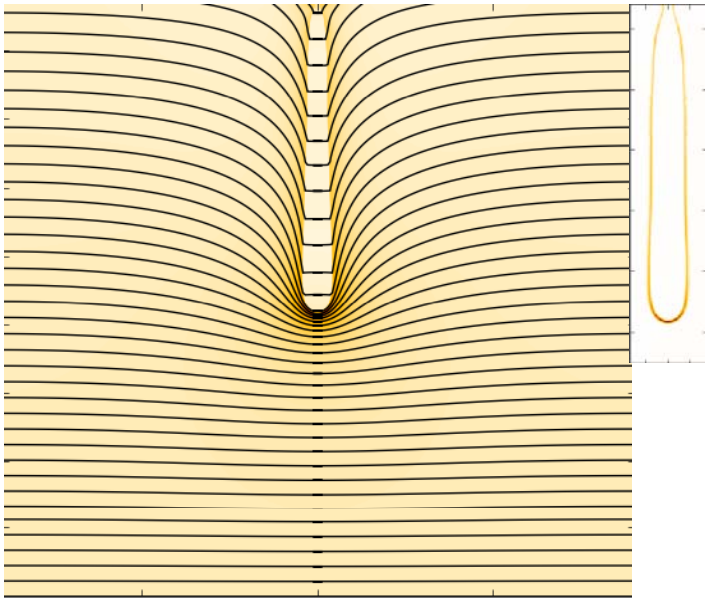


Electric current

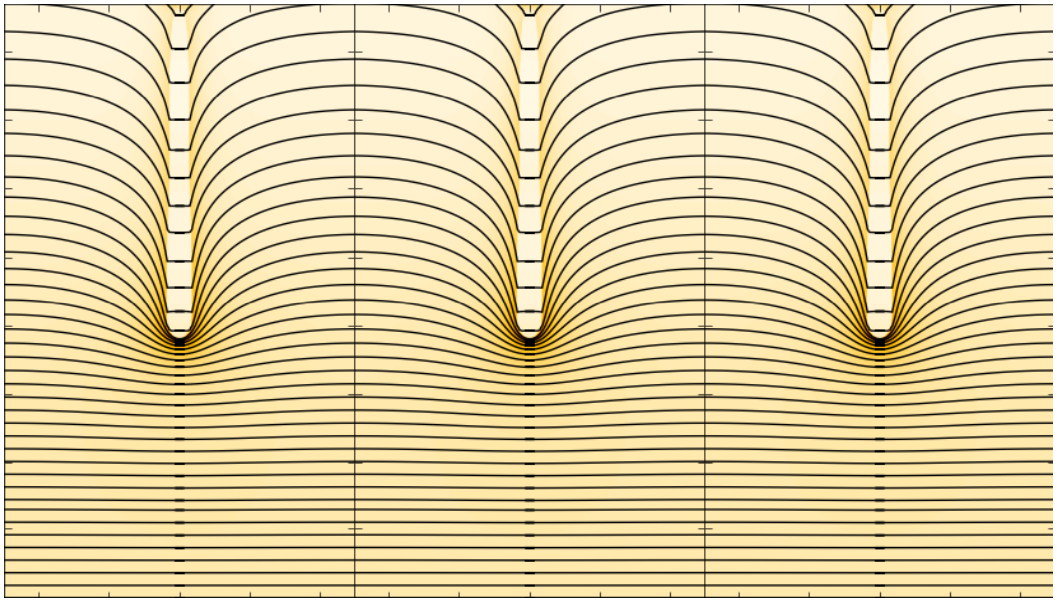


Generic?

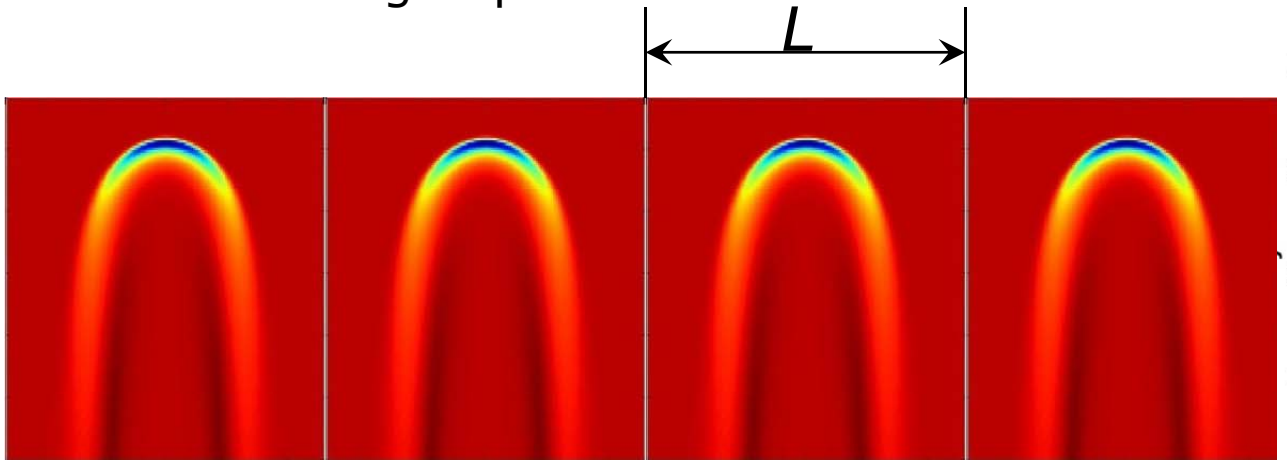
Single streamer

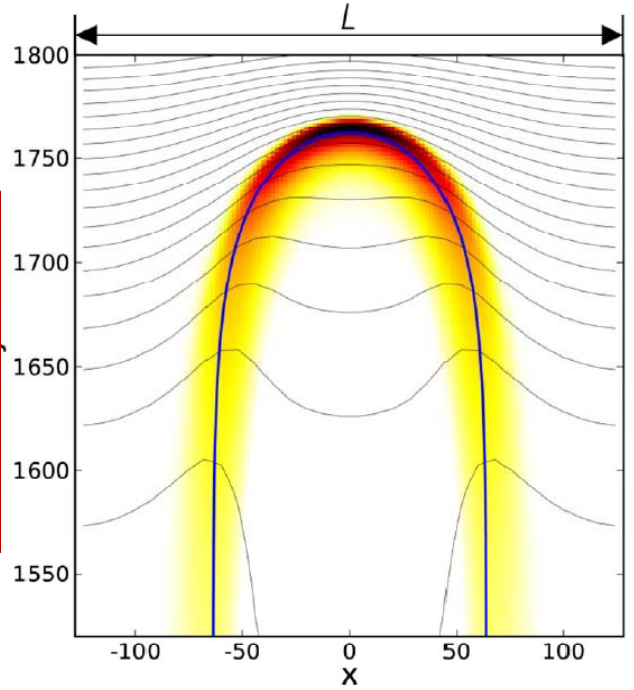


Streamers with electrostatic interaction



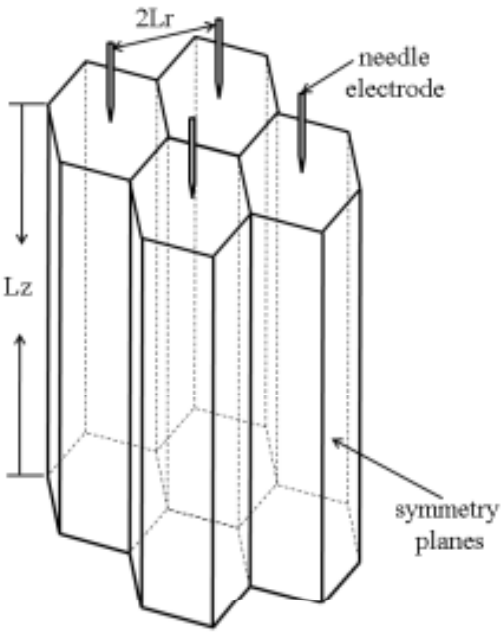
Extreme case: complete screening behind the group of heads

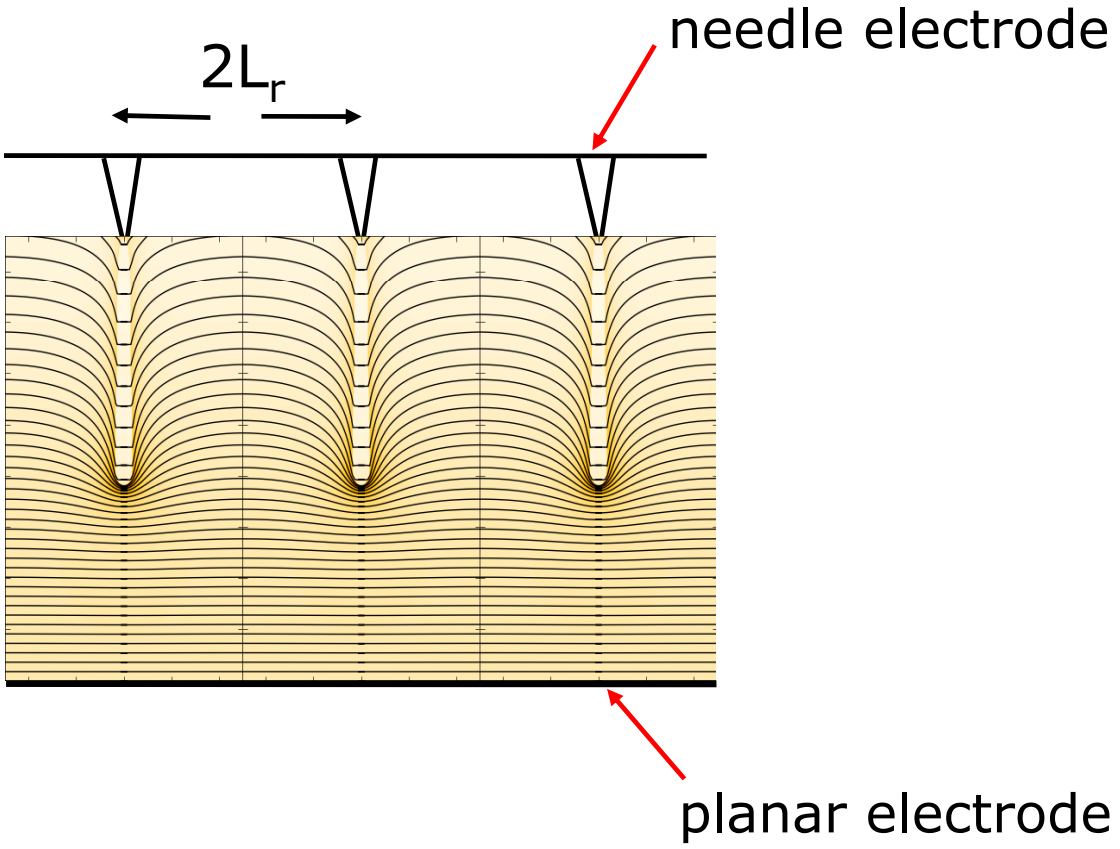


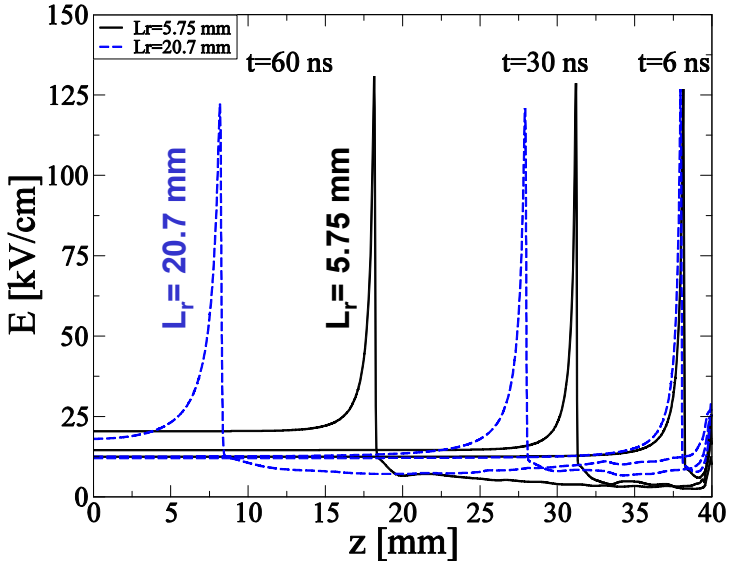


2D negative streamers [Luque et al., PRE 2008]

Interacting streamers







Electric field on the axis

Streamer groups are slower and thinner than single streamers.

The interior field is not constant.

Re-illumination of sprite trail

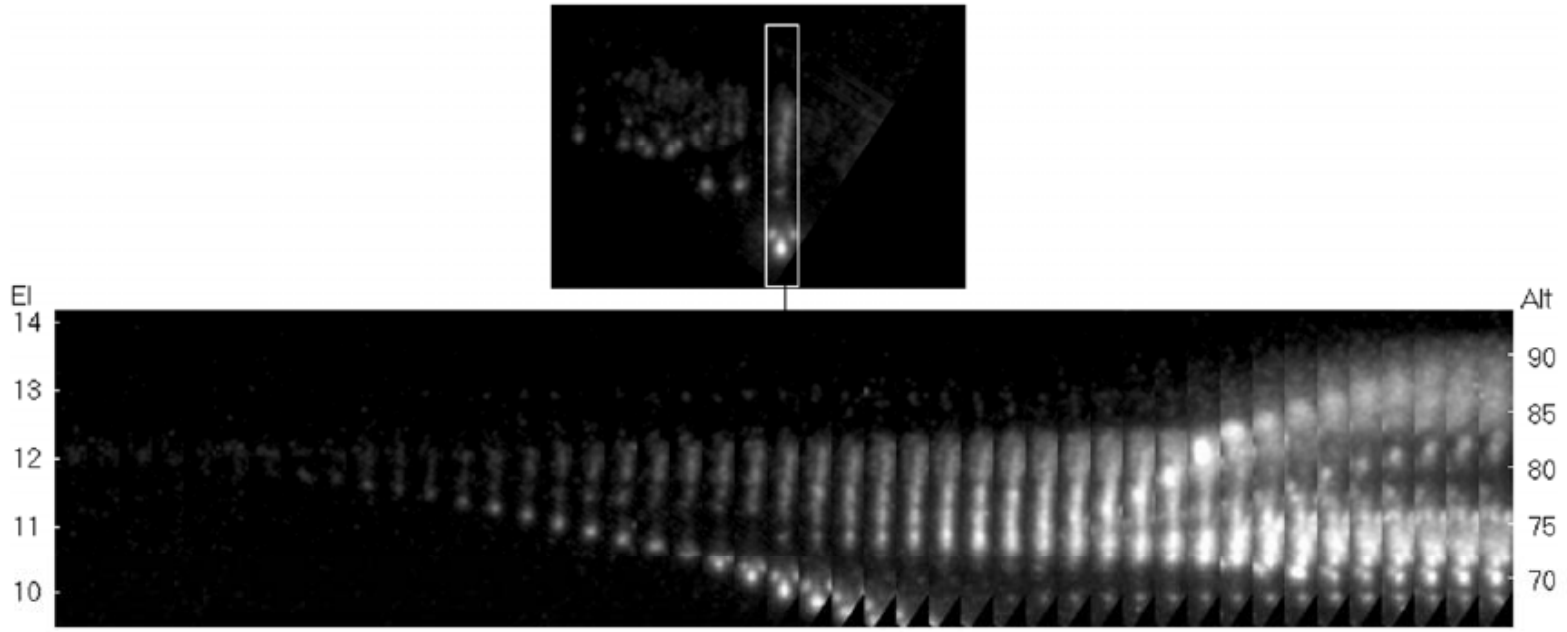
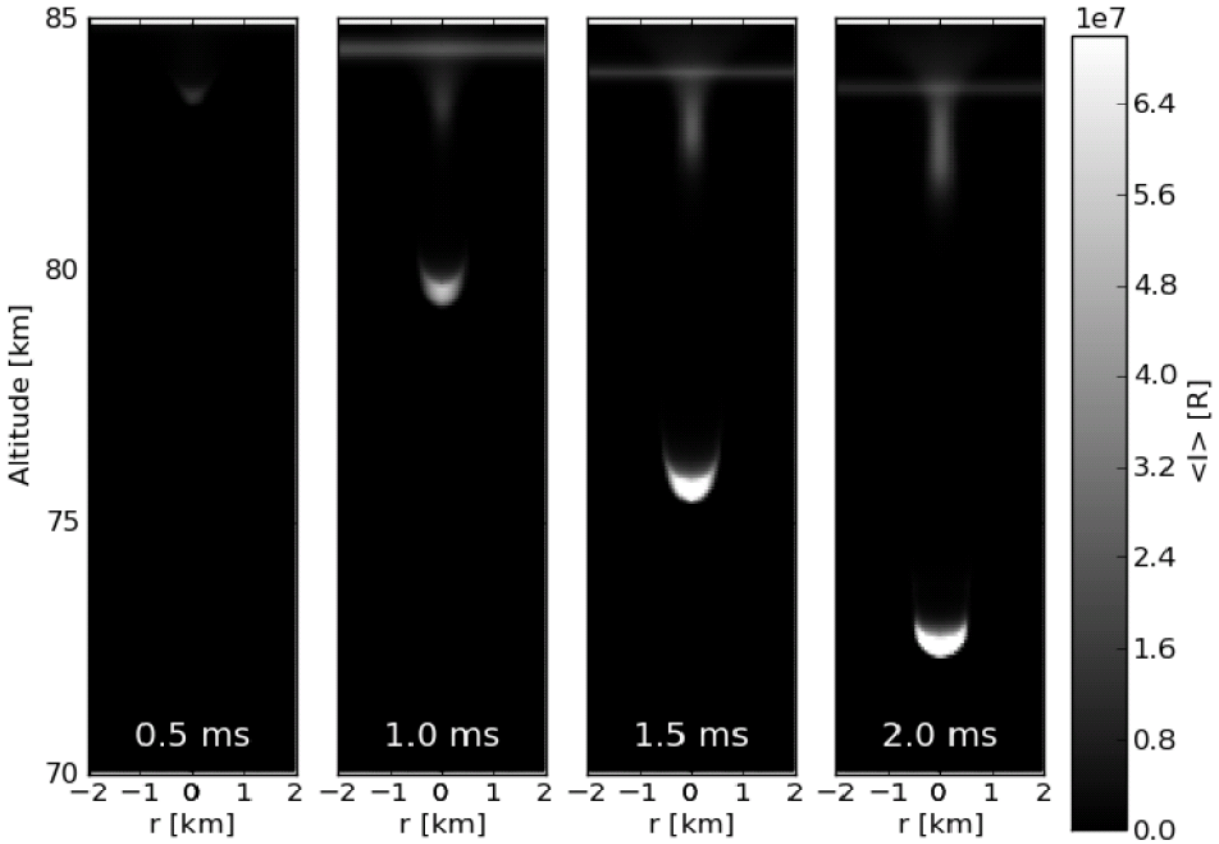


Figure 5. Image time series from the initial phase of a bright sprite (09 July 2005 04:15:17 UT). Each strip is a cut from successive images recorded at 10 000 fps. The total time covered is 4.5 ms. The elevation angle of the observation is shown on the left and altitude on the right. The altitude was derived assuming the sprite over the causal lightning strike as recorded by NLDN. For scene context a section of the full image is shown above with the strip forming the image time series indicated. The sprite starts with a downward streamer head. The upward streamer head starts later and from a lower altitude; it also starts from existing sprite structure, and it terminates with a 'puff' leaving a diffuse glow at the top of the sprite. The maximum downward and upward streamer head velocities are 1.3×10^7 m s^{-1} and 2.3×10^7 m s^{-1}, respectively.

Light emission from long sprite in changing air density



[Luque, Ebert, GRL 37, L06806 (2010)]

Air density N changes by factor 6 from 85 to 72 km.

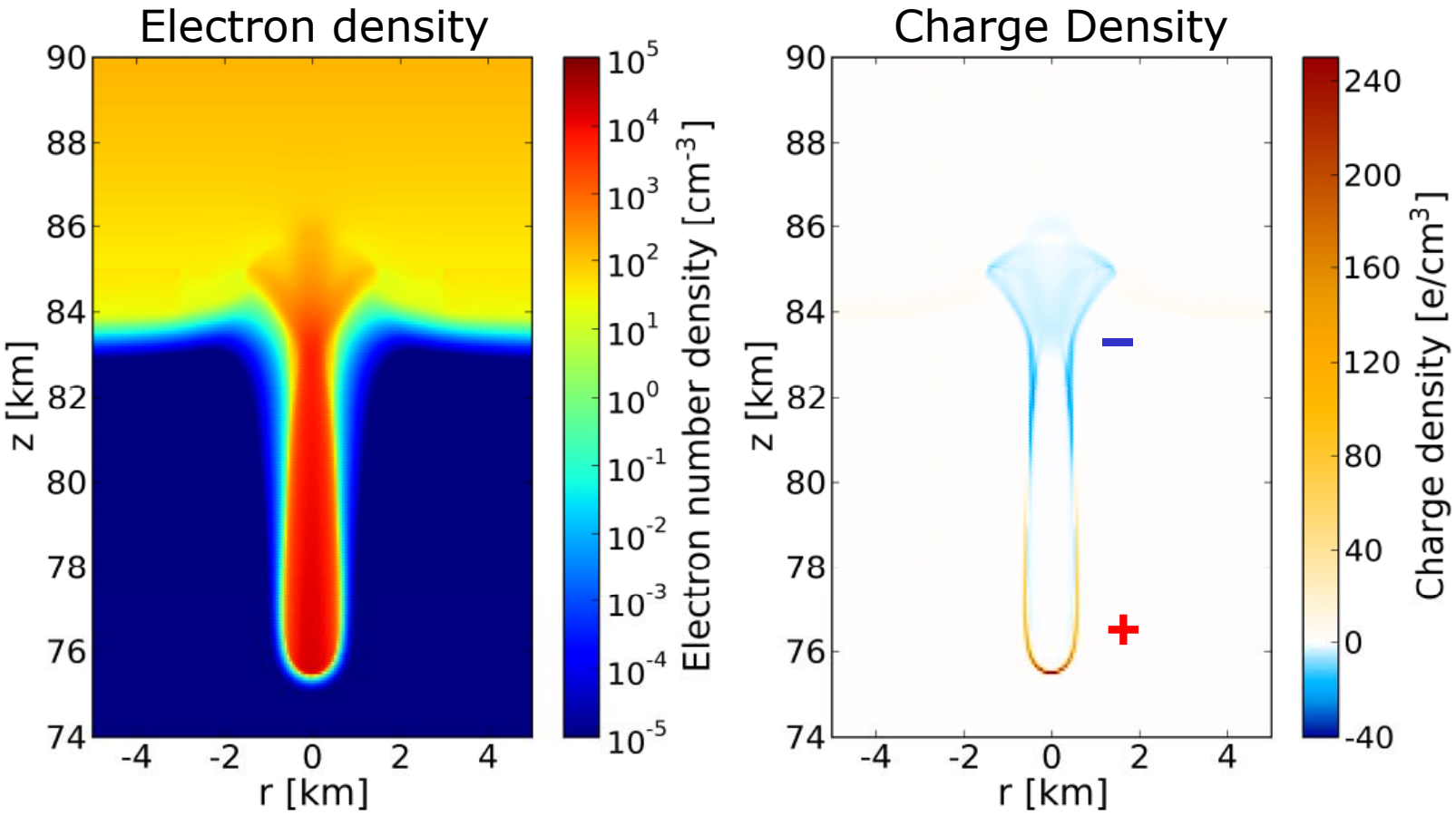
Diameter ≈ constant

Light intensity ~ N

Velocity increases and then decreases as observed.

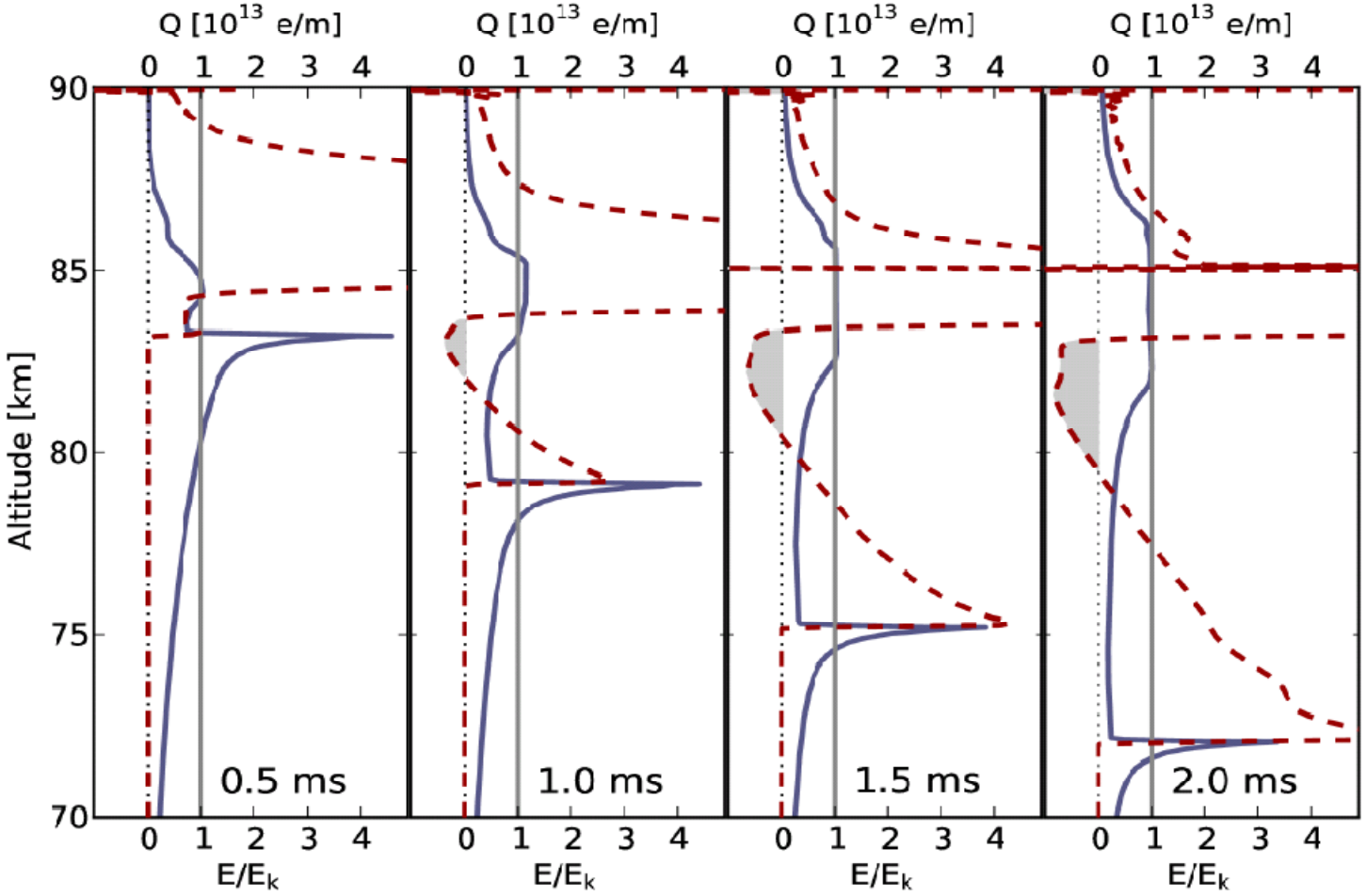
Glowing trail ….

Sprite streamer in changing air density



Charge separation -> secondary ionization wave
-> glowing trail, attraction

[Luque, Ebert, GRL 37, L06806 (2010)]


Q [10^13 e/m]
0 1 2 3 4
90
85
80
75
70
Altitude [km]
0.5 ms
1.0 ms
1.5 ms
2.0 ms
E/E_k

Primary and secondary streamers

+ 74 kV **- 72 kV**

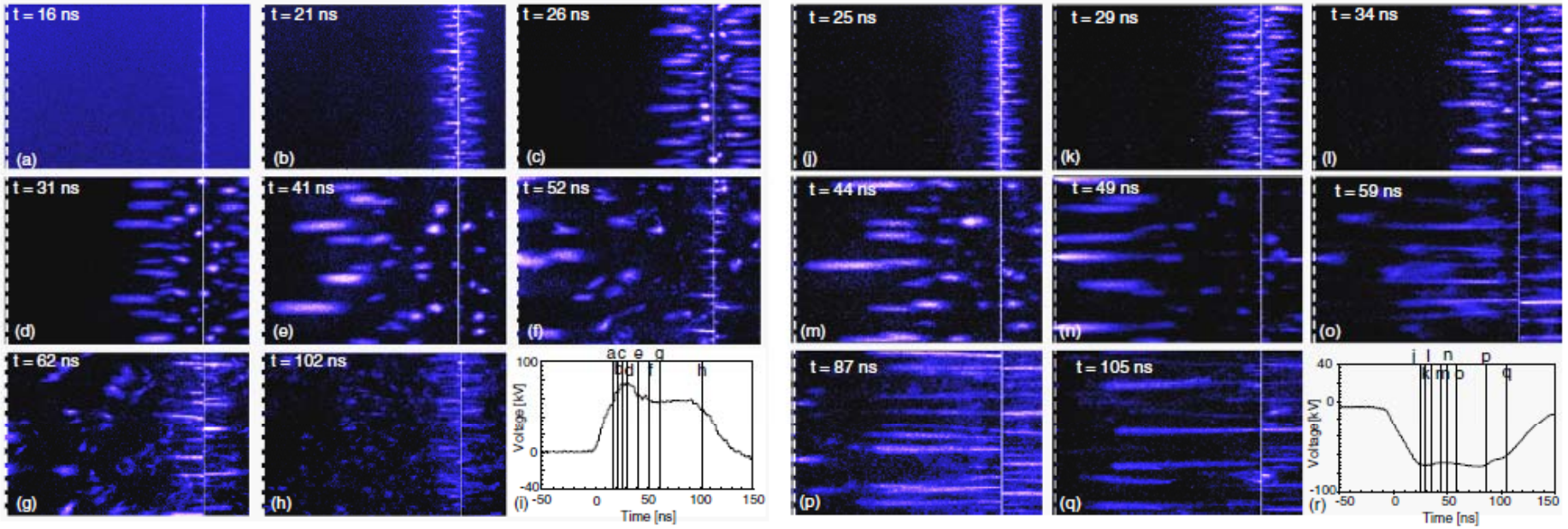


Figure 2. Time resolved 5 ns gate time ICCD pictures. White line: reactor wire. Dotted line: reactor wall. Pulse width: 110 ns. The time the picture is taken, relative to the moment the voltage on the reactor begins to increase, is shown in the top-left corner of the pictures and also in (*i*) and (*r*). Left, (*a*)–(*i*) Picture size: $\sim 7 \times 5\,\mathrm{cm}^2$. Positive polarity. Pulse voltage 74 kV, rise rate $2.7\,\mathrm{kV\,ns}^{-1}$. Right, (*j*)–(*r*) Picture size: $\sim 5.5 \times 4\,\mathrm{cm}^2$. Negative polarity. Pulse voltage −72 kV, rise rate $2.7\,\mathrm{kV\,ns}^{-1}$.

The residual streamer channel: Return strokes and secondary streamers

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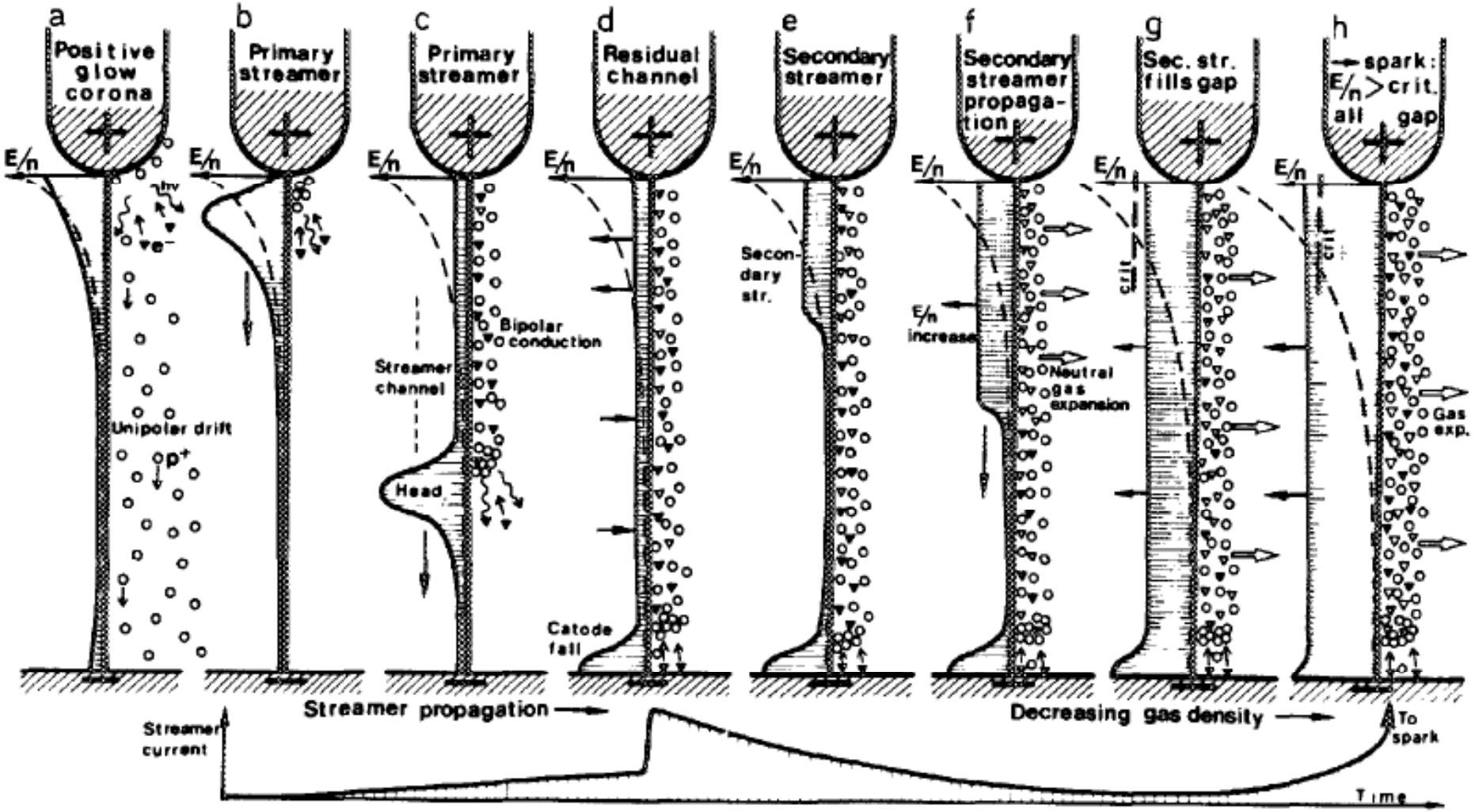
(Received 27 May 1983; accepted for publication 30 November 1983)

J Appl Phys **56**, 1355 (1984)



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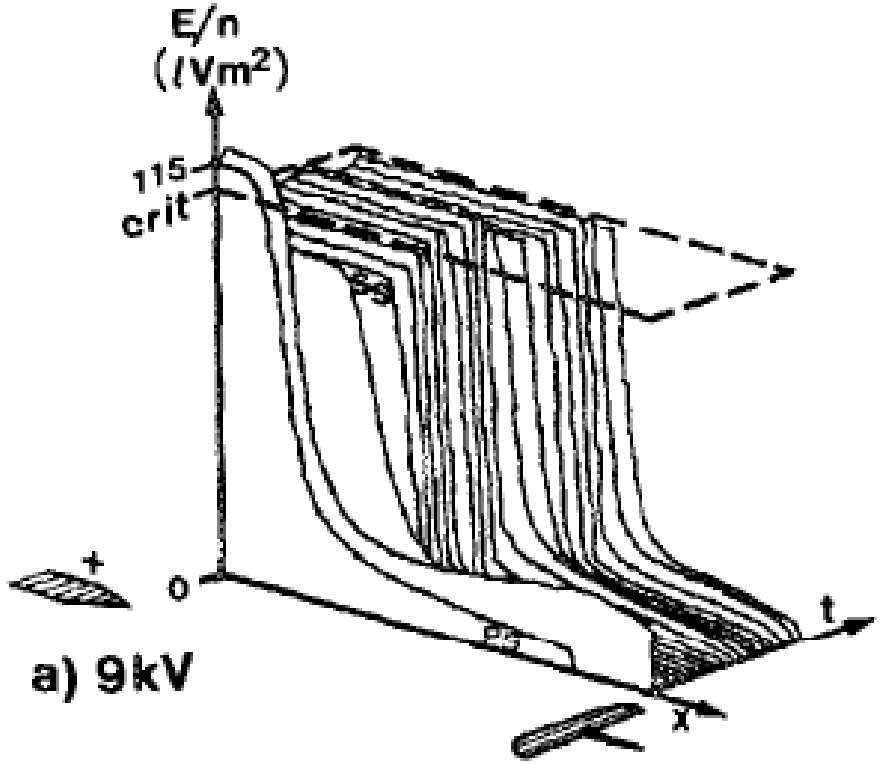
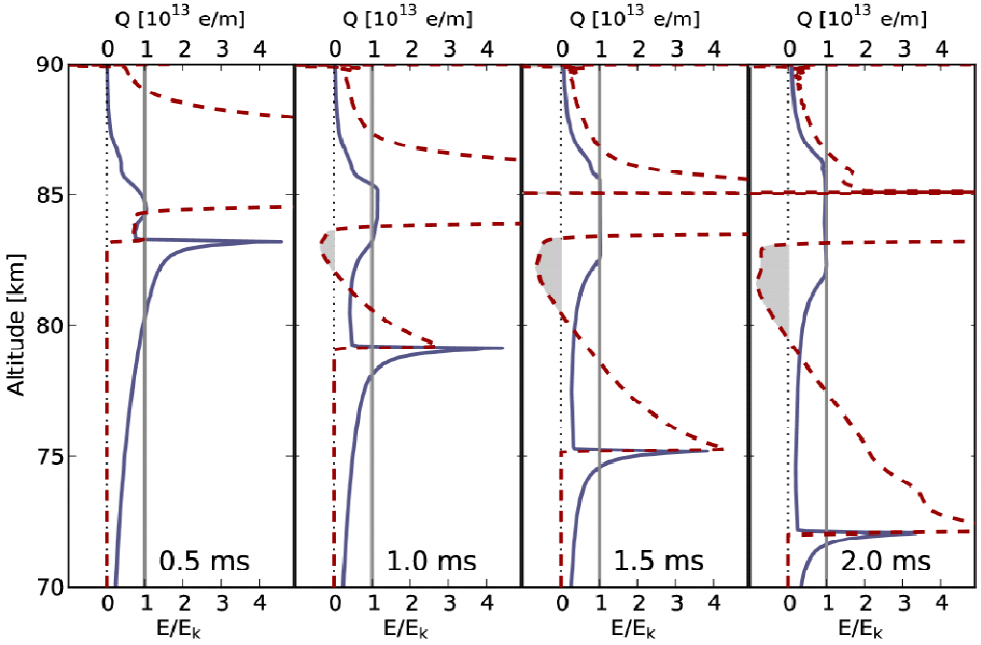
J Appl Phys **56**, 1355 (1984)

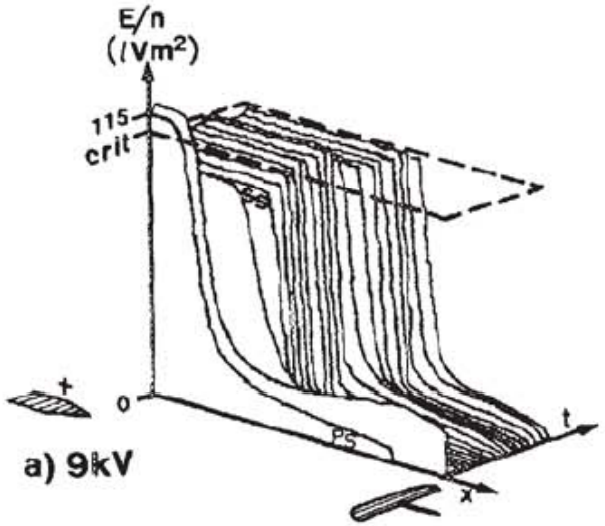
[Bastien & Marode 1982]:



Sprite “afterglow”



Secondary streamer



Nonlinear analysis:

A discharge
with constant electric current
and E = E_{crit} and *[additional criteria]*
is dynamically stable.

[Luque, Schäfer, Ebert, in preparation]

Towards streamer trees and the streamer corona of lightning leaders:

Streamer head (v, n_e, $E_{interior}$)
to be characterized by R and E_{max},
in arbitrary gas and polarity.

$\boldsymbol{E_{max} \geq 10\, E_{back}}$

Streamer channel:
Field in fairly uniformly translating single streamer quite constant.
But not in a group of streamers!
Different charge content and electric currents.

Sprite current can generate secondary ionization wave
= "afterglow"
?=? secondary streamer?

with $\boldsymbol{E = E_{breakdown}}$!

Find papers and preprints on
http://homepages.cwi.nl/~ebert