Towards coarse-grained models for extensive streamer coronas in thunderclouds

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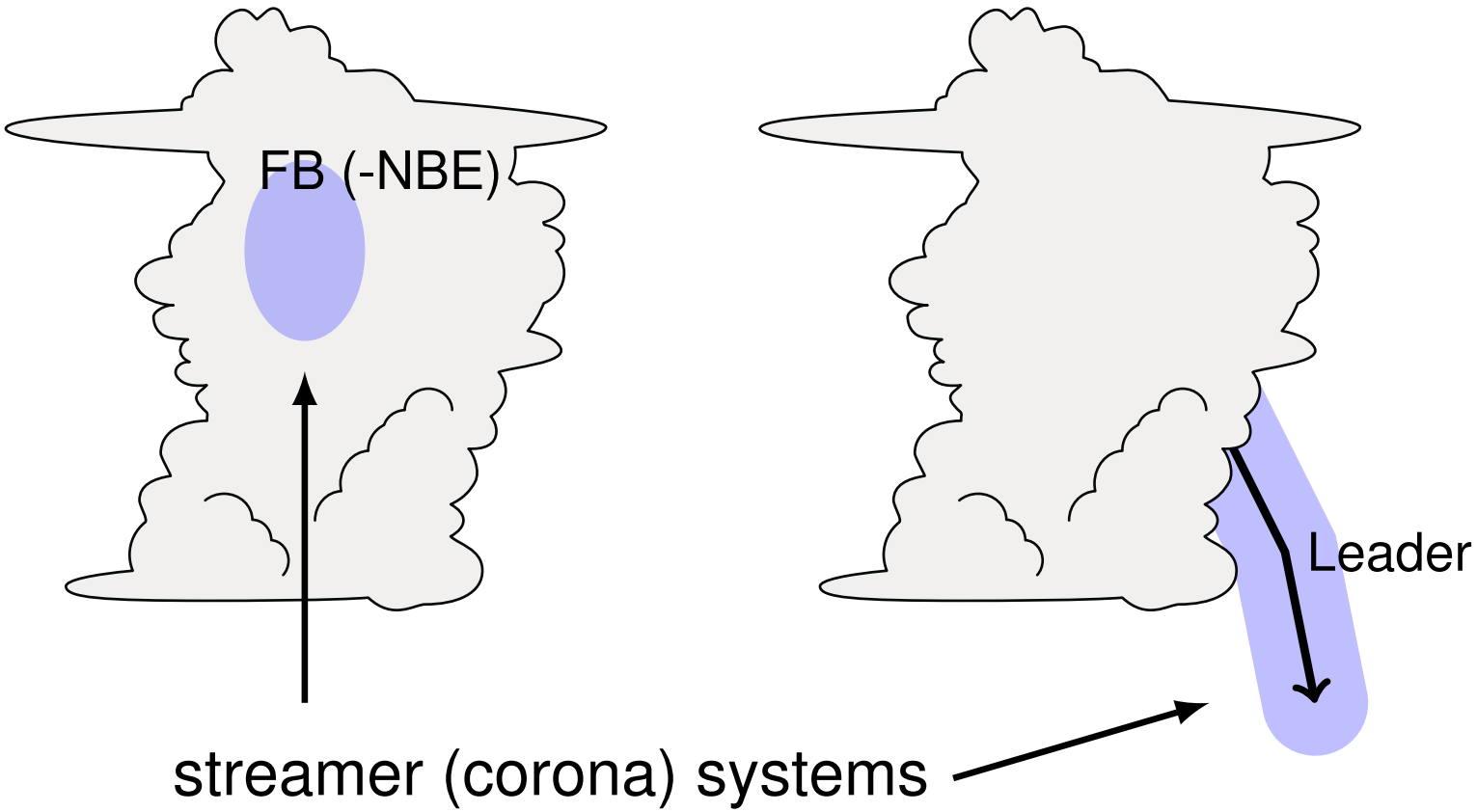
Streamer coronas in thunderclouds

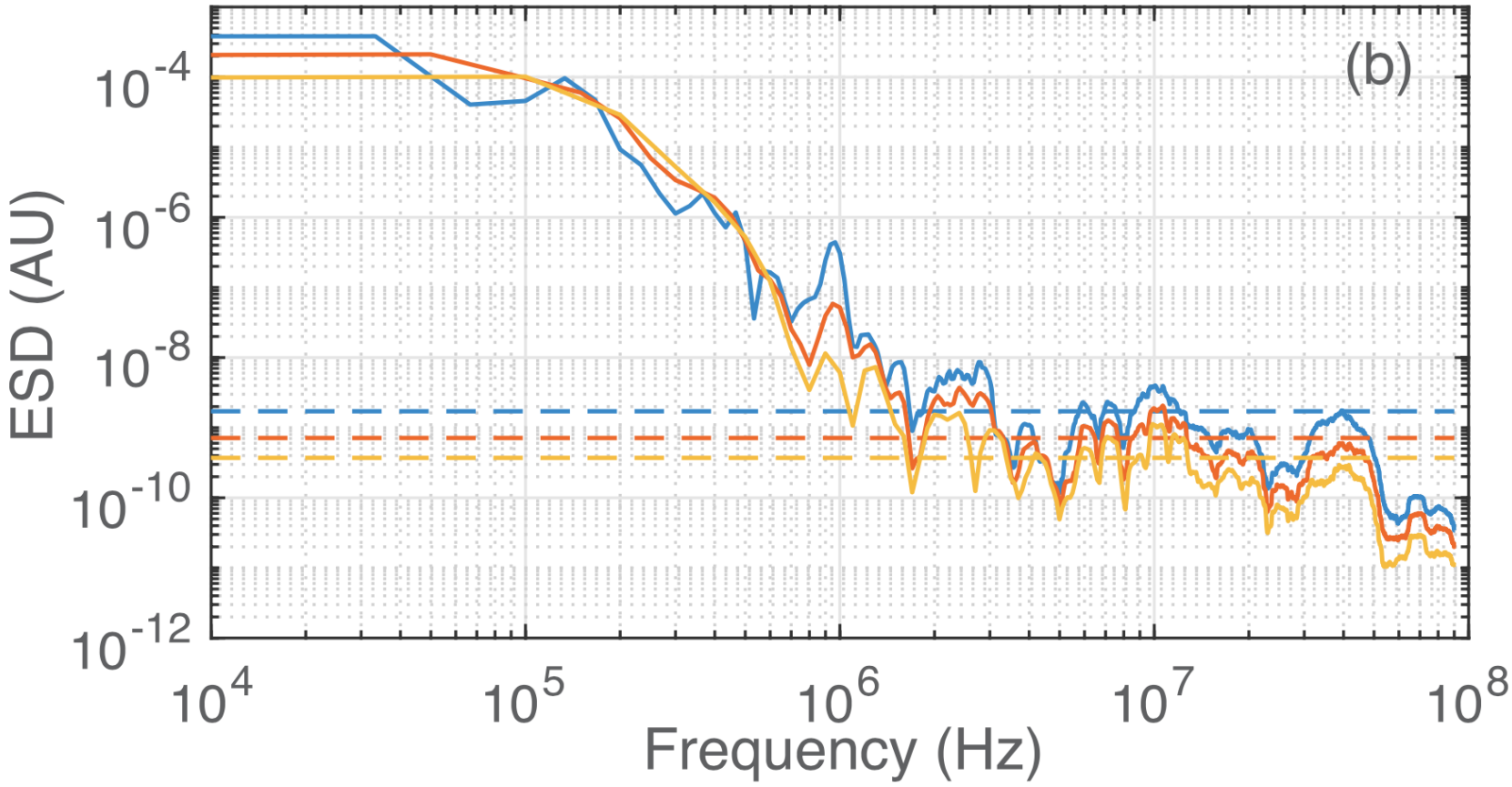


Streamer coronas in lightning models

- Likely key to lightning initiation.
- Pre-conditioners of leader propagation.
- Maybe related to TGFs.

How many streamers in FB?

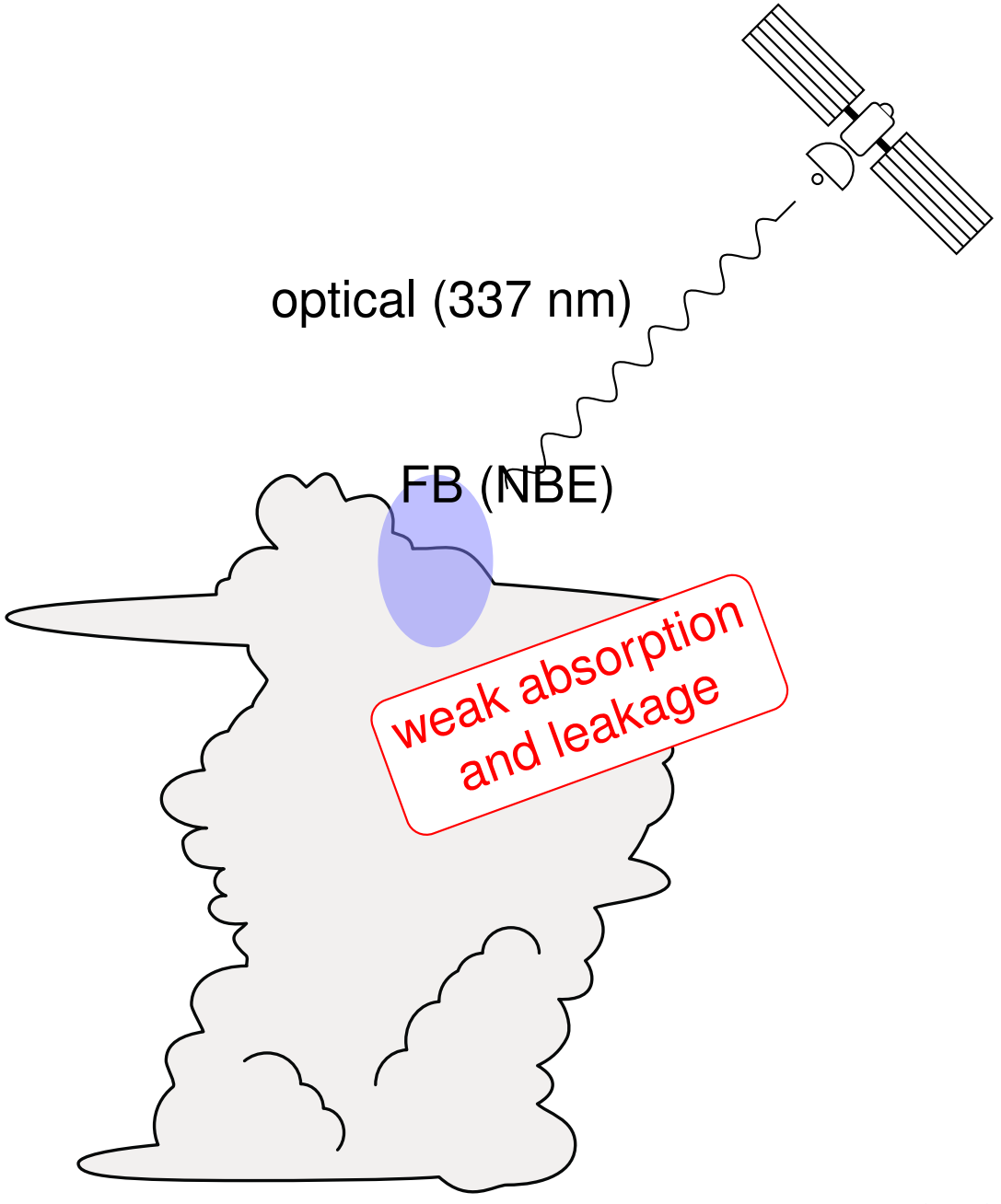
From radio observations:



$\rightarrow$ streamers $\approx 10^7 - 10^8$.

Liu *et al.*, JGR 2019

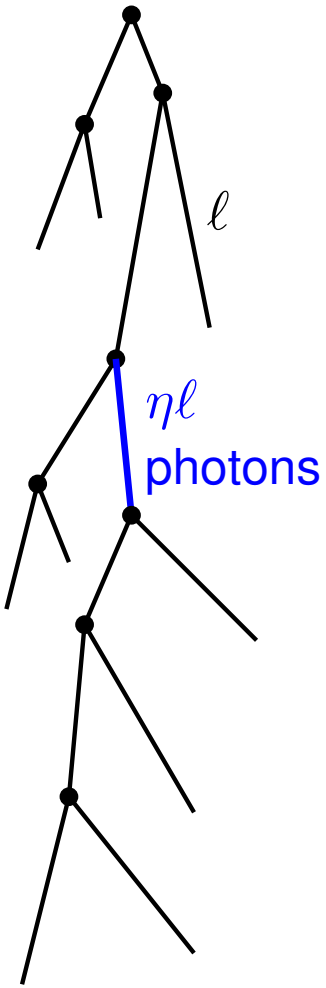
How many streamers in FB?



Optical energy at 337 nm (J)
1.8×10^4
1.9×10^4
1.2×10^4
1.3×10^4
2.4×10^4
1.8×10^4
1.6×10^4
4.6×10^3

Li, D., *et al.* JGR (2021)

How many streamers in FB?

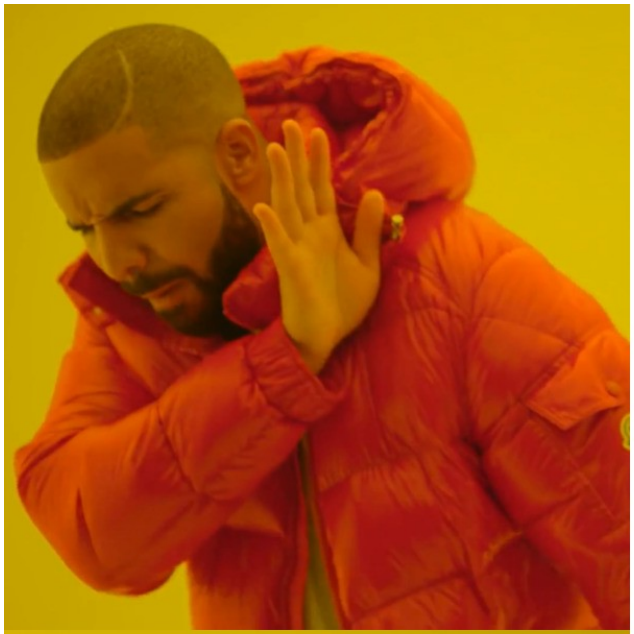


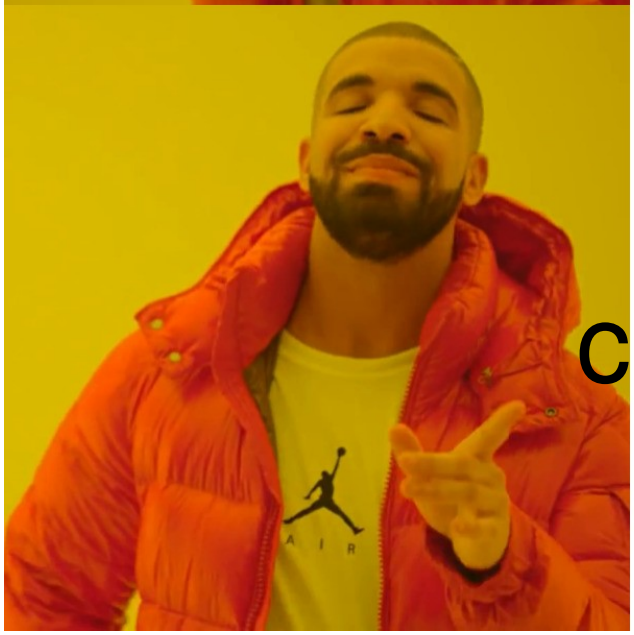
- streamers $= 2 \times$ branchings.
- emissions/streamer $= \eta\ell$.
- total emissions $= 2\eta\ell \times$ branchings.
- scaling atm pressure:
  - $\eta \approx 5 \times 10^{13}\,\mathrm{m}^{-1}$.
  - $\ell \approx 20\,\mathrm{cm}$.
- optical energy at 337 nm $\approx 10^4$ J.
- $\rightarrow$ branchings $\approx 10^9$

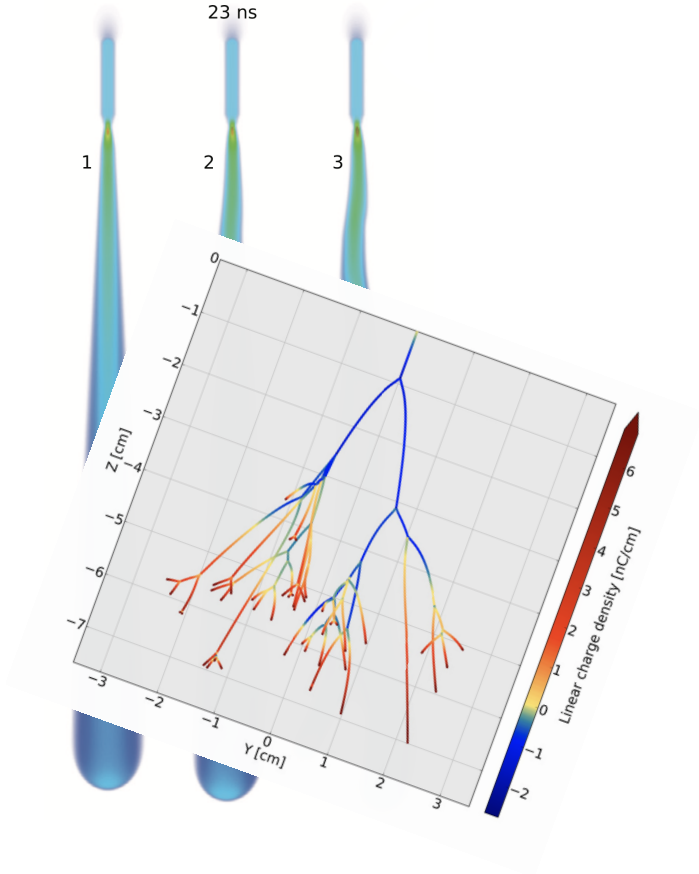
Li, D., *et al.* JGR (2021)

10^7-10^9

streamers







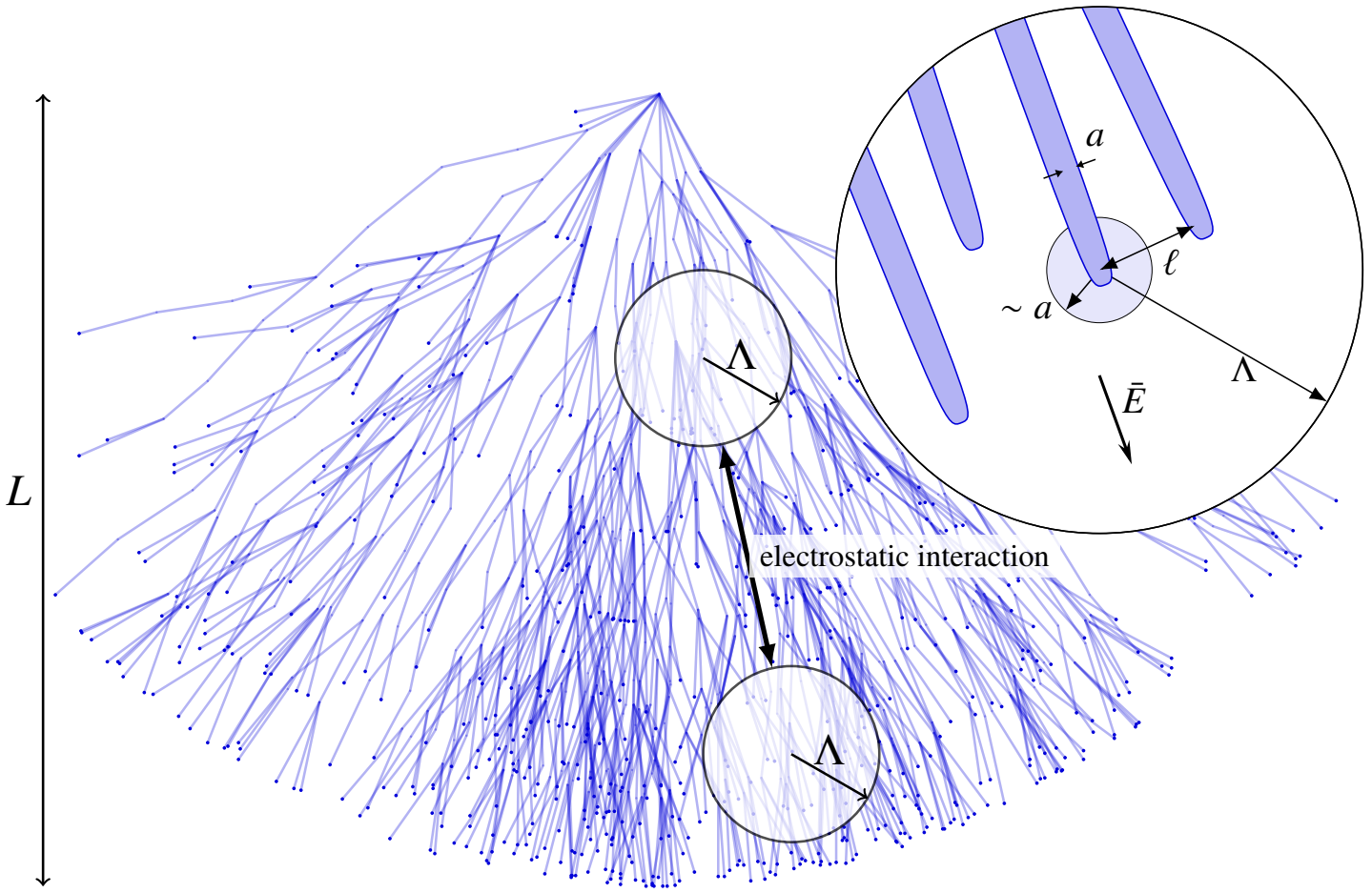
coarse-grained models

observed / modeled streamer features:

- Velocity distribution.
- Branching rate.
- Internal conductivity.

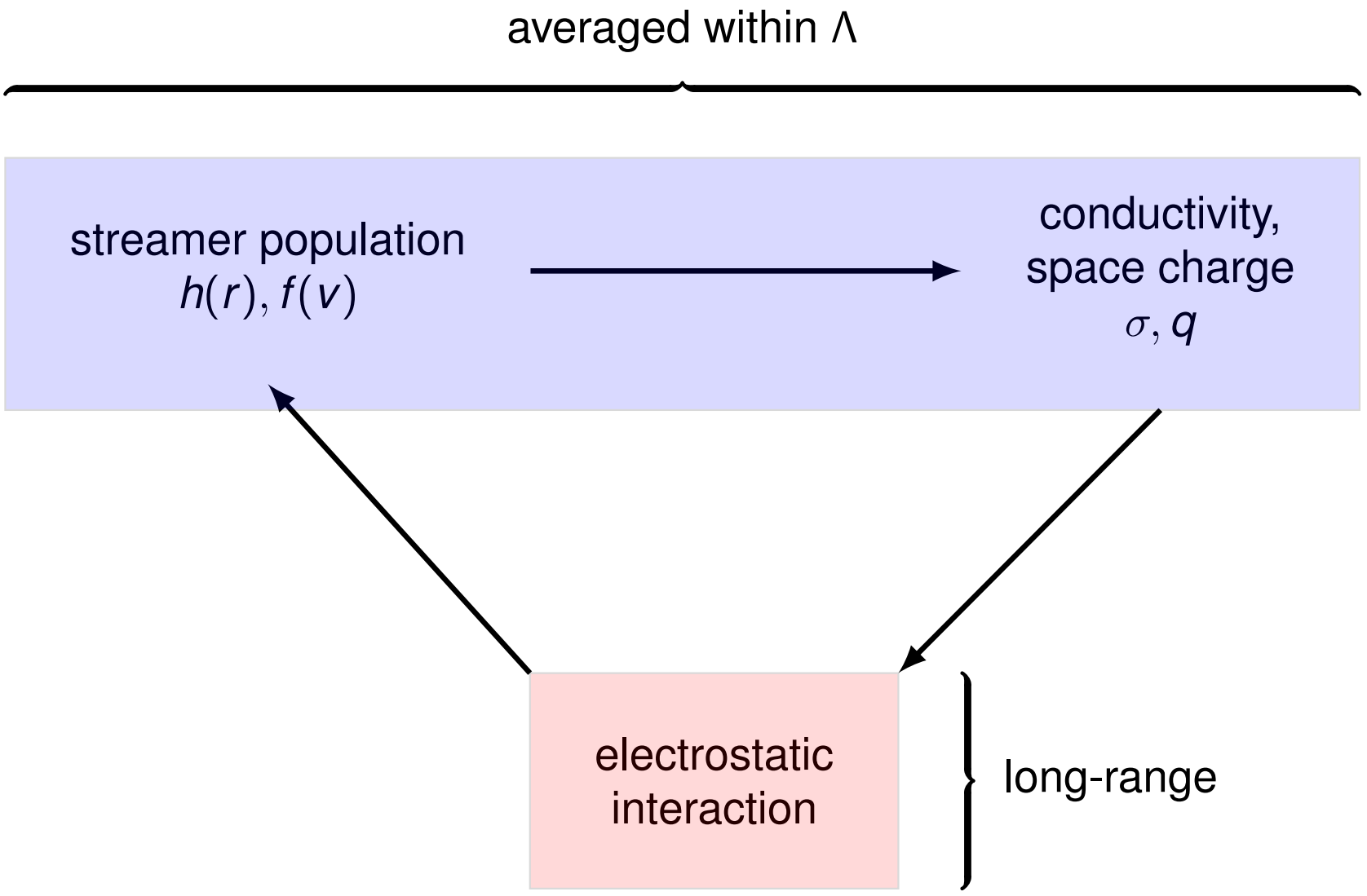
realistic model for thunderstorms

Length scales



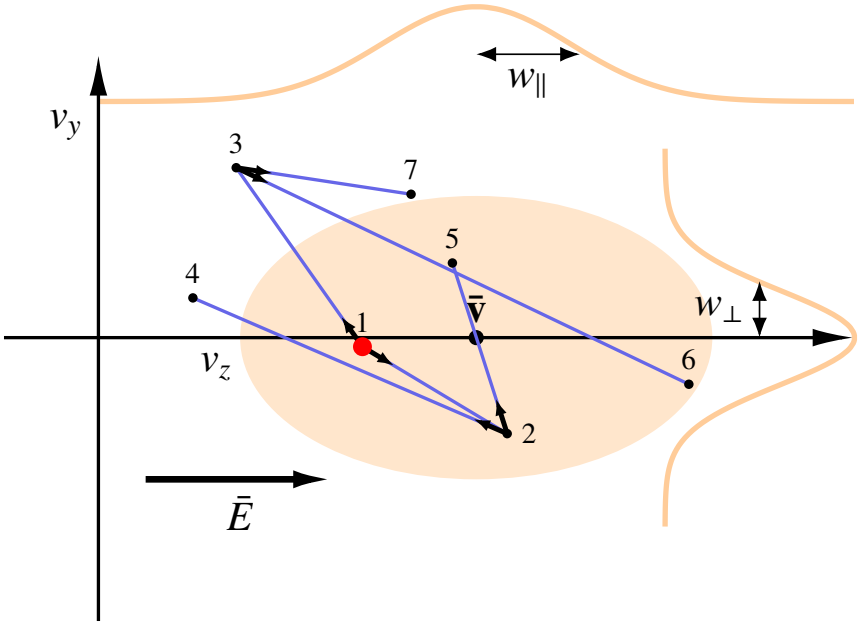
$$a < \ell \ll \Lambda \ll L.$$

Program

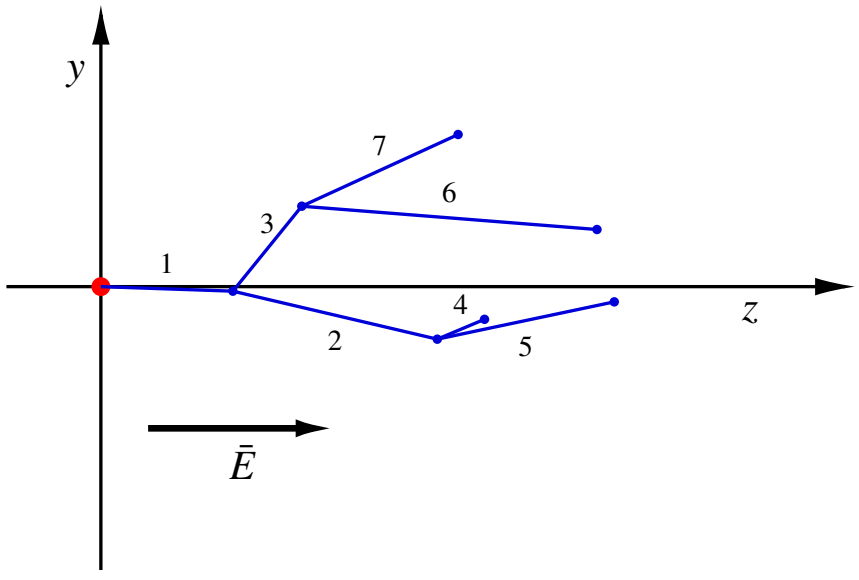

averaged within Λ
streamer population
$h(r), f(v)$
conductivity,
space charge
σ, q
electrostatic
interaction
long-range

Bifurcated random walk

velocity space

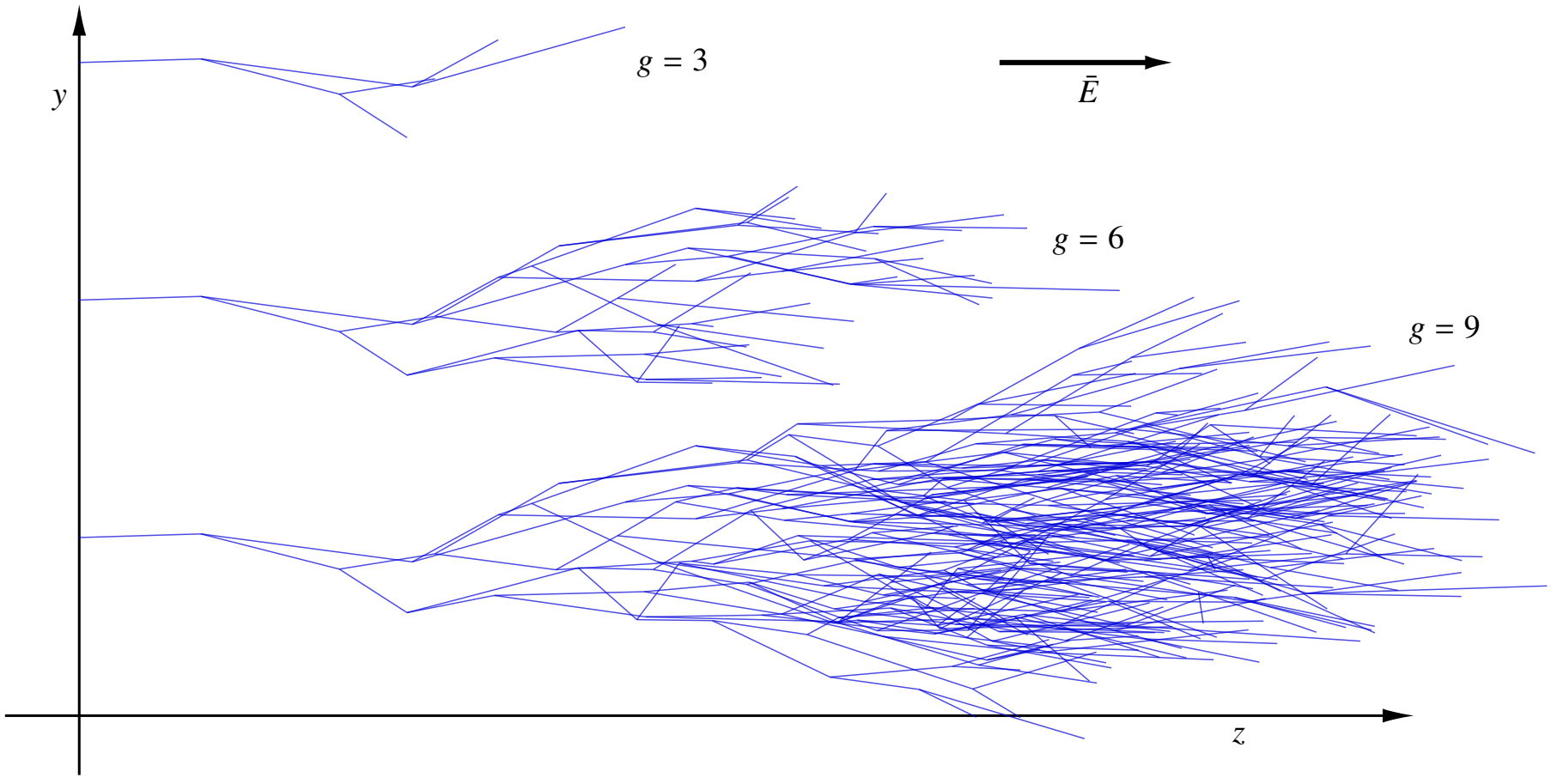


position space



- Field-dependent vel. dist.: $f_{\mathbf{E}}(\mathbf{v})$.
- Prob. branching per unit time: $1/\tau_B$.
- Branching $\rightarrow$ sample 2x from $f_{\mathbf{E}}(\mathbf{v})$.

Bifurcated random walk



Macroscopic model

From $f_{\mathbf{E}}(\mathbf{E})$, we can derive a full macroscopic model:

- Evolution of the density of streamer heads, $h(\mathbf{r}, t)$:

$$\frac{\partial h}{\partial t} + \nabla \cdot (h\bar{\mathbf{v}} - \mathbf{D}\nabla h) = \frac{h}{\tau_B}.$$

$$D_{\parallel,\perp} = \frac{1}{2} w_{\parallel,\perp}^2 \tau_B.$$

- Evolution of the space conductivity

$$\left(\frac{\partial \boldsymbol{\sigma}}{\partial t}\right)_p = \eta h(\mathbf{r}) \int \frac{d^3\mathbf{v}\, f(\mathbf{v}) \mathbf{v} \otimes \mathbf{v}}{|\mathbf{v}|}.$$

- Electric current

$$\mathbf{j} = \sigma \bar{\mathbf{E}} + h Q_h \bar{\mathbf{v}} - Q_h \mathbf{D} \nabla h.$$

$$Q_h = \text{Charge per streamer head}$$

What is the velocity distribution

$$f_{\mathbf{E}}(\mathbf{v})\ ?$$

1. Homogeneous scaling

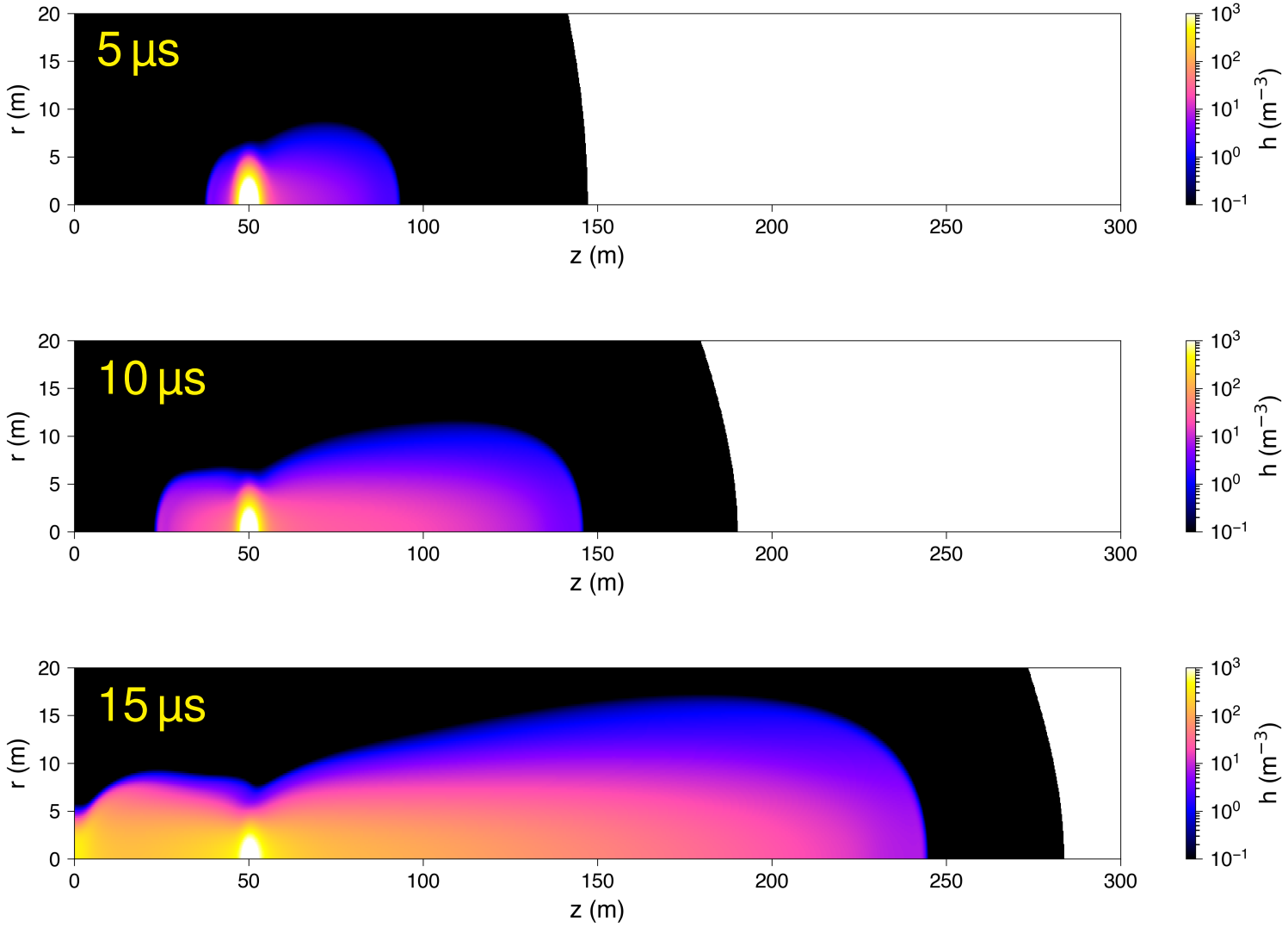
$$f(\mathbf{v}, E) = f(c(E)\mathbf{v}),$$

$$w_{\parallel,\perp} = \kappa_{\parallel,\perp}|\bar{\mathbf{v}}|$$

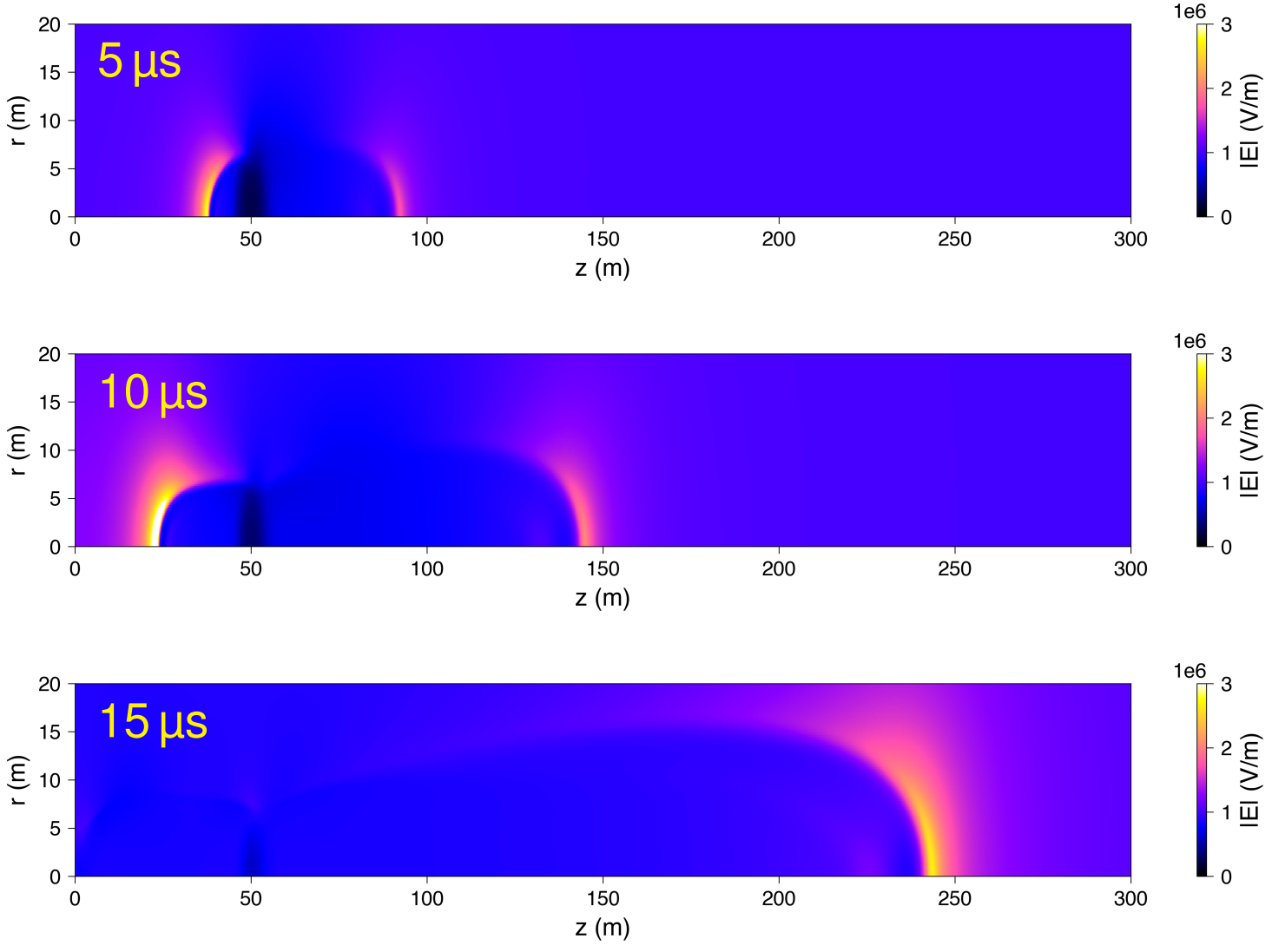
$$\bar{v}(E) = 10^6\,\mathrm{m/s} \times \left(\frac{E}{1\,\mathrm{MV/m}}\right)^3.$$

Allen & Mikropoulos, JPD 1999

Some results: density of heads



Some results: electric field



Outlook

- **Preliminary results**
- Calibration and testing with real data (VHF, optical) needed.
- Coupling to leader and cloud charging models.

Some codes for lightning modeling

Purpose	Repository	Documentation?
Optical scattering	`github.com/aluque/CloudScat.jl`	Somewhat
FDTD	`github.com/aluque/DipoleRadiators.jl`	Terrible
Radiation from transmission-line models	`github.com/aluque/LFDTD.jl`	No good
Chemical models	`github.com/aluque/Chemise.jl`	Nonexistent.
Adaptive Mesh Refinement (AMR) for streamers	`github.com/aluque/Steamroller.jl`	My dog ate it.
High/Low Energy Monte Carlo	`github.com/aluque/Particulator.jl`	`/dev/null`