Streamer Formation in Sub-Breakdown Conditions

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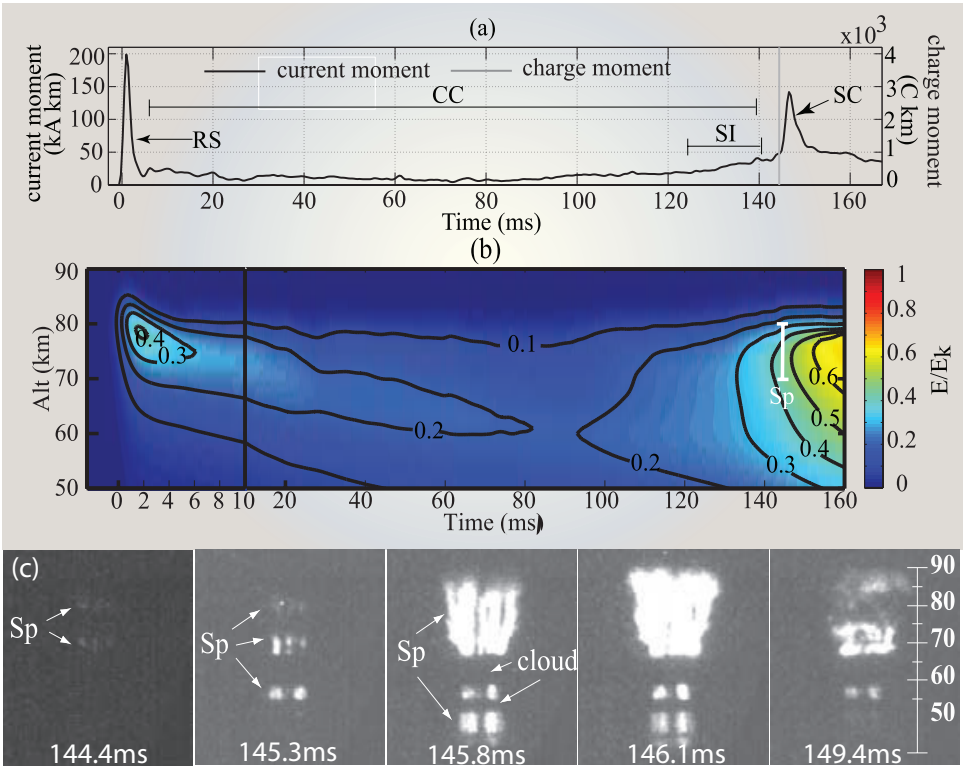
Measurement-Inferred Mesospheric Lightning Fields at Sprite Initiation

- For the event presented below, measurement-inferred mesospheric lightning field is E = $0.45E_k$ at the time of sprite initiation at 72 km altitude [*Li et al.*, 2008]. It is currently unknown how sprites can start in such low fields.



Sprite Streamer Model Formulation

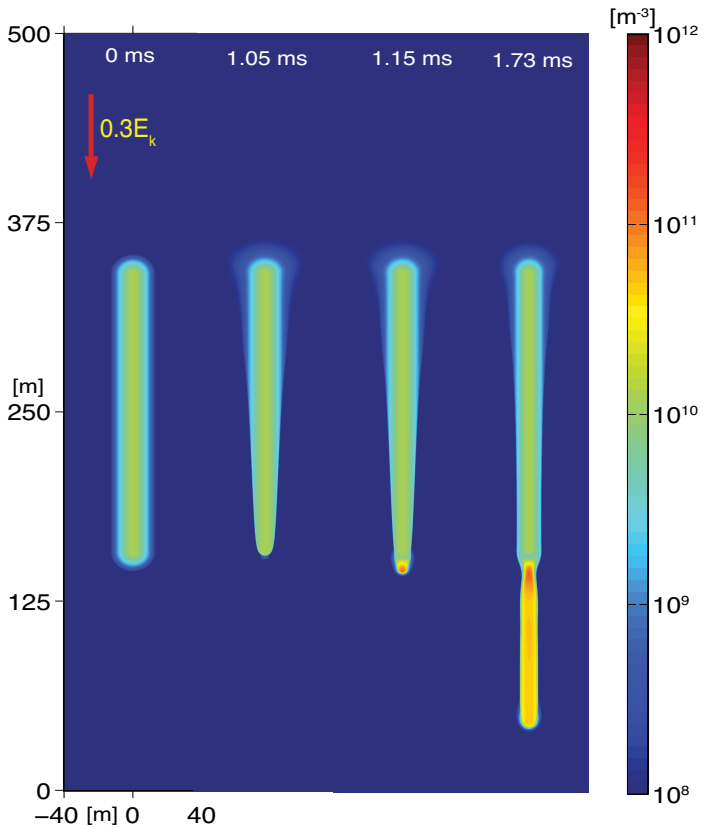
- The dynamics of a streamer are described by the electron and ion drift-diffusion equations coupled with Poisson's equation in a cylindrical coordinate system [*Liu and Pasko*, 2004; *Bourdon et al.*, Plasma Sources Sci. Technol., 16, 656, 2007].

$$\begin{aligned}
\frac{\partial n_e}{\partial t} + \nabla \cdot n_e \vec{v}_e - D_e \nabla^2 n_e &= (\nu_i - \nu_{a2} - \nu_{a3}) n_e - \beta_{ep} n_e n_p + S_{ph} \\
\frac{\partial n_p}{\partial t} &= \nu_i n_e - \beta_{ep} n_e n_p - \beta_{np} n_n n_p + S_{ph} \\
\frac{\partial n_n}{\partial t} &= (\nu_{a2} + \nu_{a3}) n_e - \beta_{np} n_n n_p \\
\nabla^2 \phi &= -\frac{e}{\epsilon_0}(n_p - n_e - n_n)
\end{aligned}$$

- The coefficients of the model are assumed to be functions of the local electric field and obtained from the solutions of the Boltzmann equation [*Moss et al.*, JGR, 111, A02307, 2006].
- The current model uses SP_3 method [*Bourdon et al.*, 2007; *Liu et al.*, Appl. Phys. Lett., 91, 211501, 2007] to calculate the production rate of electron-ion pair by photoionization.

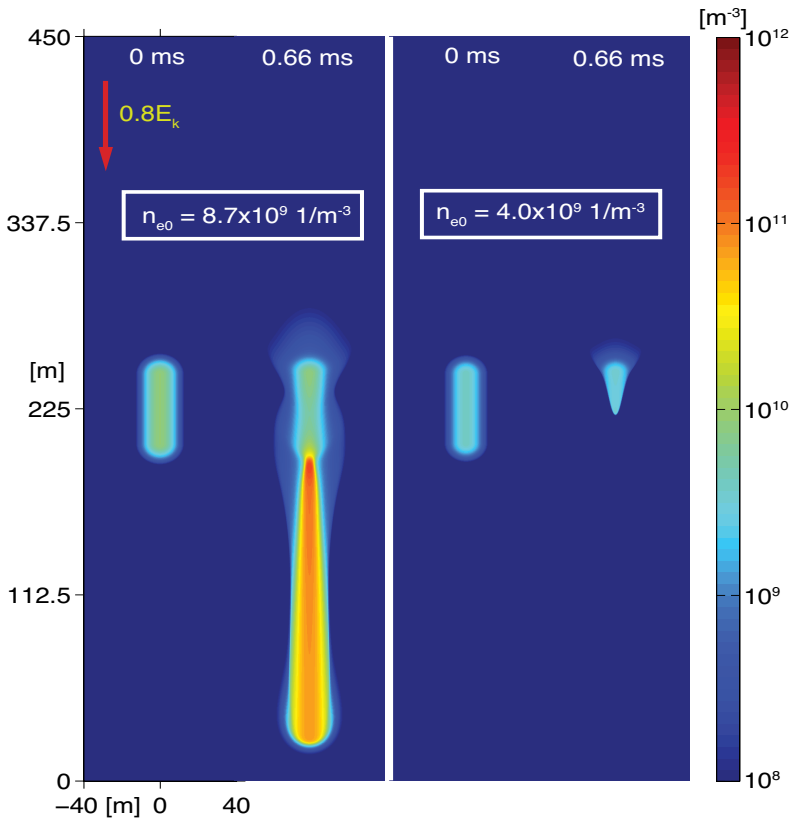
Streamer Formation from an Ionization Patch at Sub-Breakdown Conditions

- In sprite literature, it has been speculated that sprite streamers can be initiated from ionospheric ionization patches such as meteor trails or disturbances created by thunderstorm and/or lightning.



Influence of the Column Density on Streamer Initiation

- Whether a streamer is able to form from an ionospheric ionization patch depends upon the density of the ionization column and its size [Liu et al., PRL submitted].



Choosing a = 6 m, $E_m \sim 5E_k$ and $E_0 = 0.8E_k$

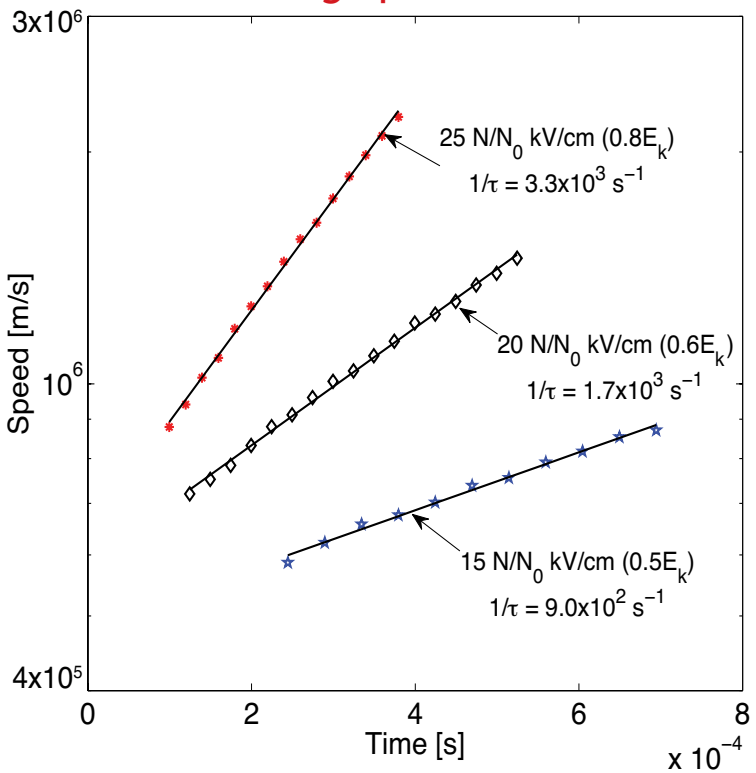
$$E_m = [3 + 0.56(l/a)^{1/0.92}]E_0$$

$$n_{e0} = \frac{2\varepsilon_0(3a + l)E_0}{e\pi^{0.5}a^2}$$

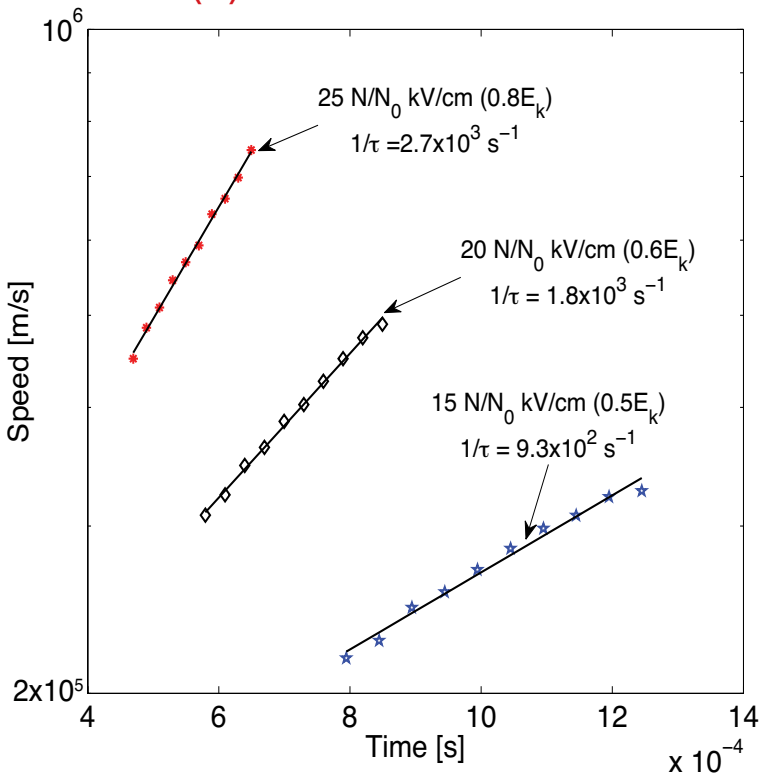
We estimate:
$l = 42$ m and $n_{e0} = 8.7\text{x}10^9$ m^{-3}

Growth Rates Associated with Streamers Forming at Sub-Breakdown Conditions

(a) Conducting Sphere [Kosar, 2010]



(b) Ionization Column



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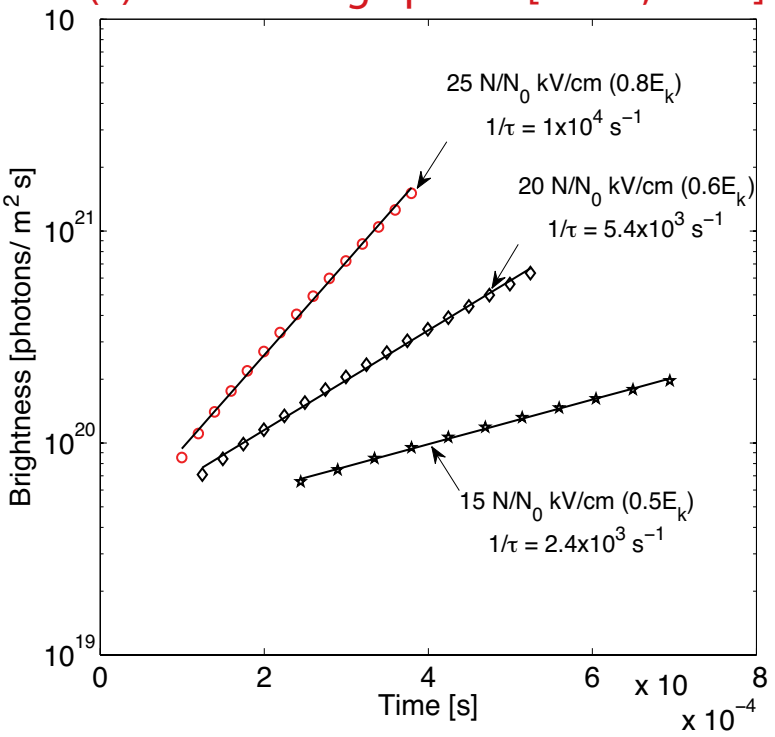
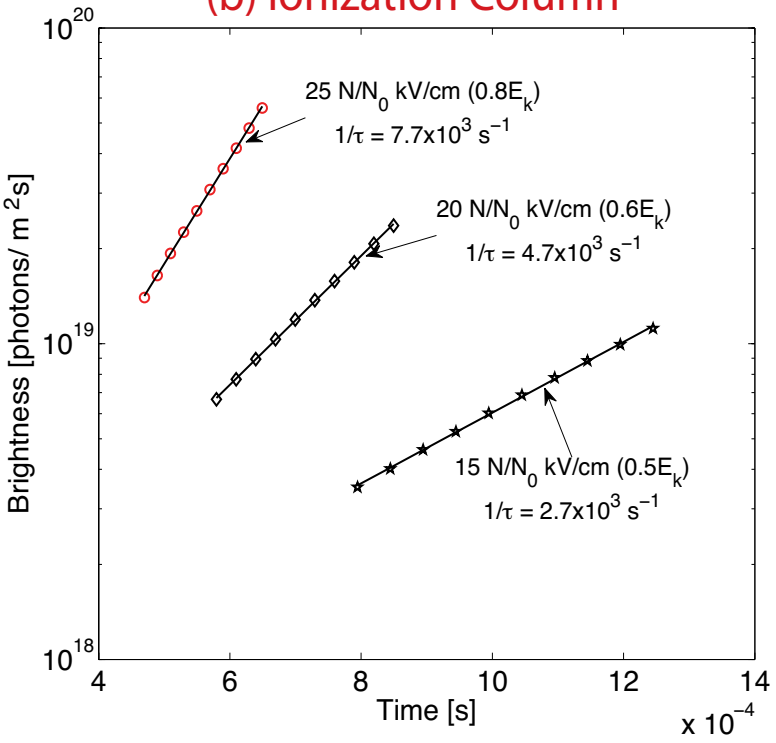
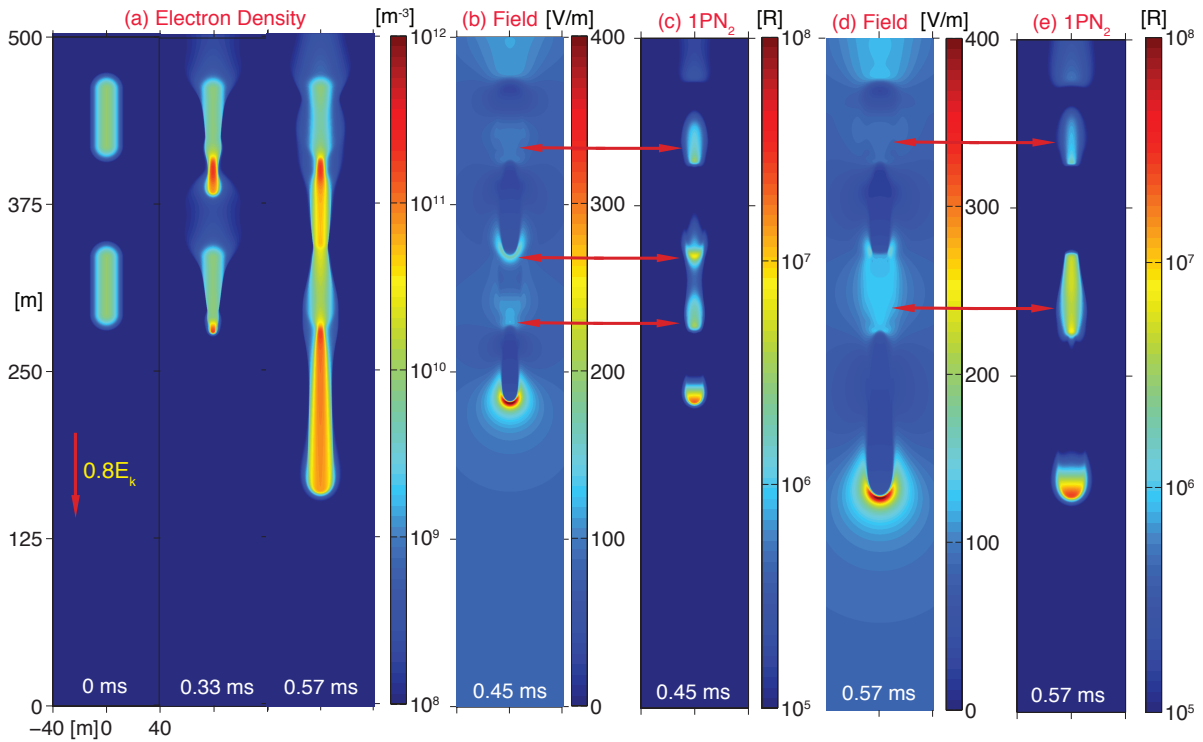


(b) Ionization Column



Persisting Luminosities from Sprite Streamers

- The bright region corresponding to the junction of the upper streamer and the lower column may represent sprite beads observed at collision of streamers [*Cummer et al.*, 2006]. Another interesting feature is that the initial column becomes luminous following the streamer formation and persists during the course of streamer propagation.



Summary and Conclusions

- We investigate the possibility of sprite streamer initiation at sub-breakdown conditions. Successful formation of positive streamer from column ionization patch is observed at measurement-inferred lightning electric field reported by *Li et al.* [2008]. Size and density of the column are critical parameters determining whether the streamer is able to form.
- Positive streamers are much easier than negative streamers to form from ionization patch. Even at the field stronger than the minimum field required for propagation of negative streamers, they fail to start after positive streamers have propagated a long distance.
- The growth rates of the streamer from ionization patch are very close to those of the streamer forming about a conducting sphere.
- The initial column becomes very bright after the streamer formation, and the brightness persists as the streamer propagates. The column becomes even brighter, if another streamer runs into it. This may explain the bead formation due to the collision of streamers as reported by *Cummer et al.* [2006].

THANK YOU!