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Stochastic Electron Acceleration in Lightning Flashes

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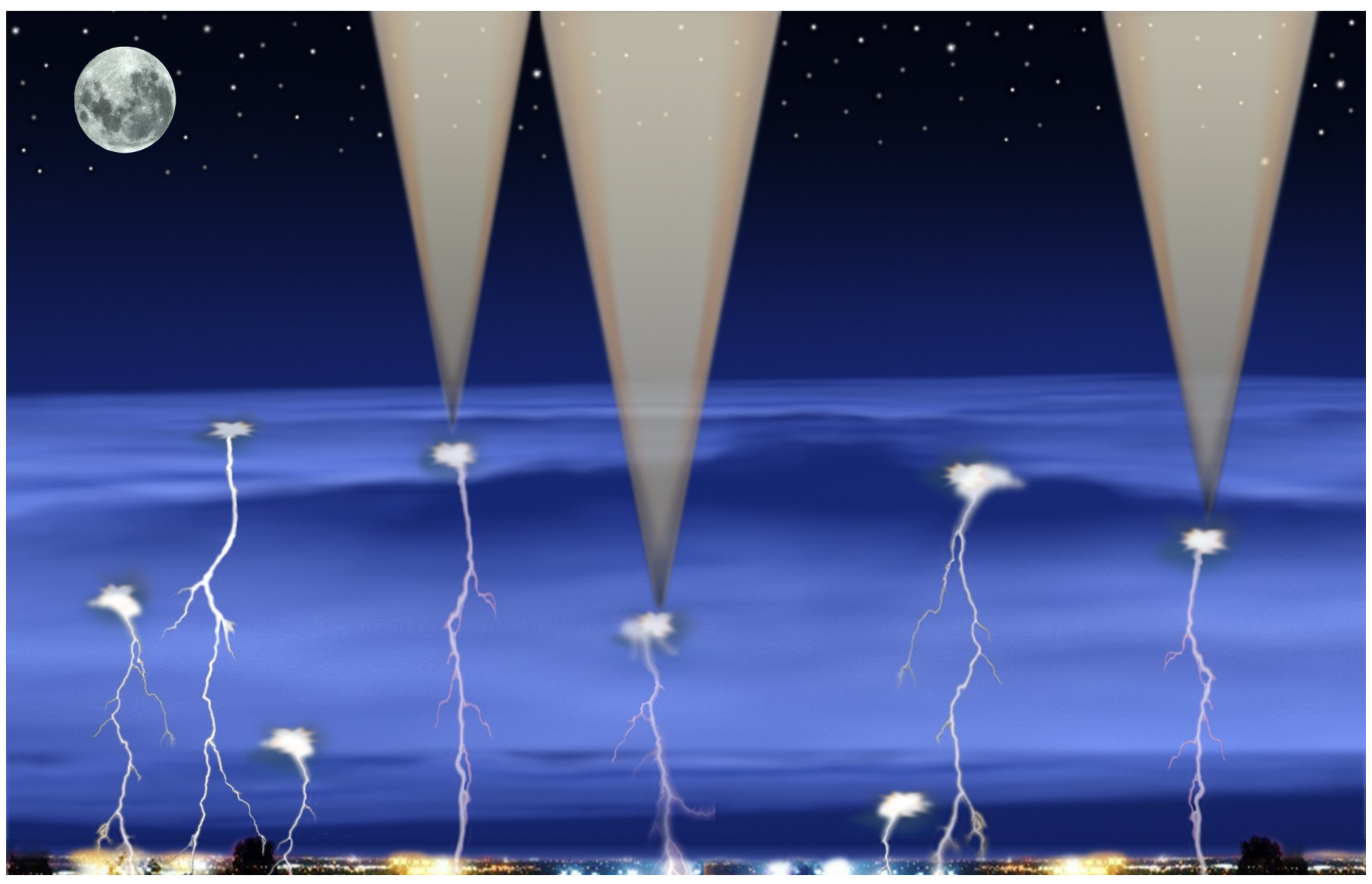

Figure 1: Illustration of lightning flashes and TGFs. Image Credits: NASA/Robert Kilgore.

Overview

Terrestrial Gamma-ray Flashes (TGFs) are energetic pulses of photons, which are intense and short in duration, originating in the atmosphere during thunderstorm activity. Since their discovery 1994 scientist have been investigating the mystery of this gamma-ray emission by trying to determine their production mechanisms. TGF energy spectra indicate that they should be produced by Bremsstrahlung process of MeV electrons.

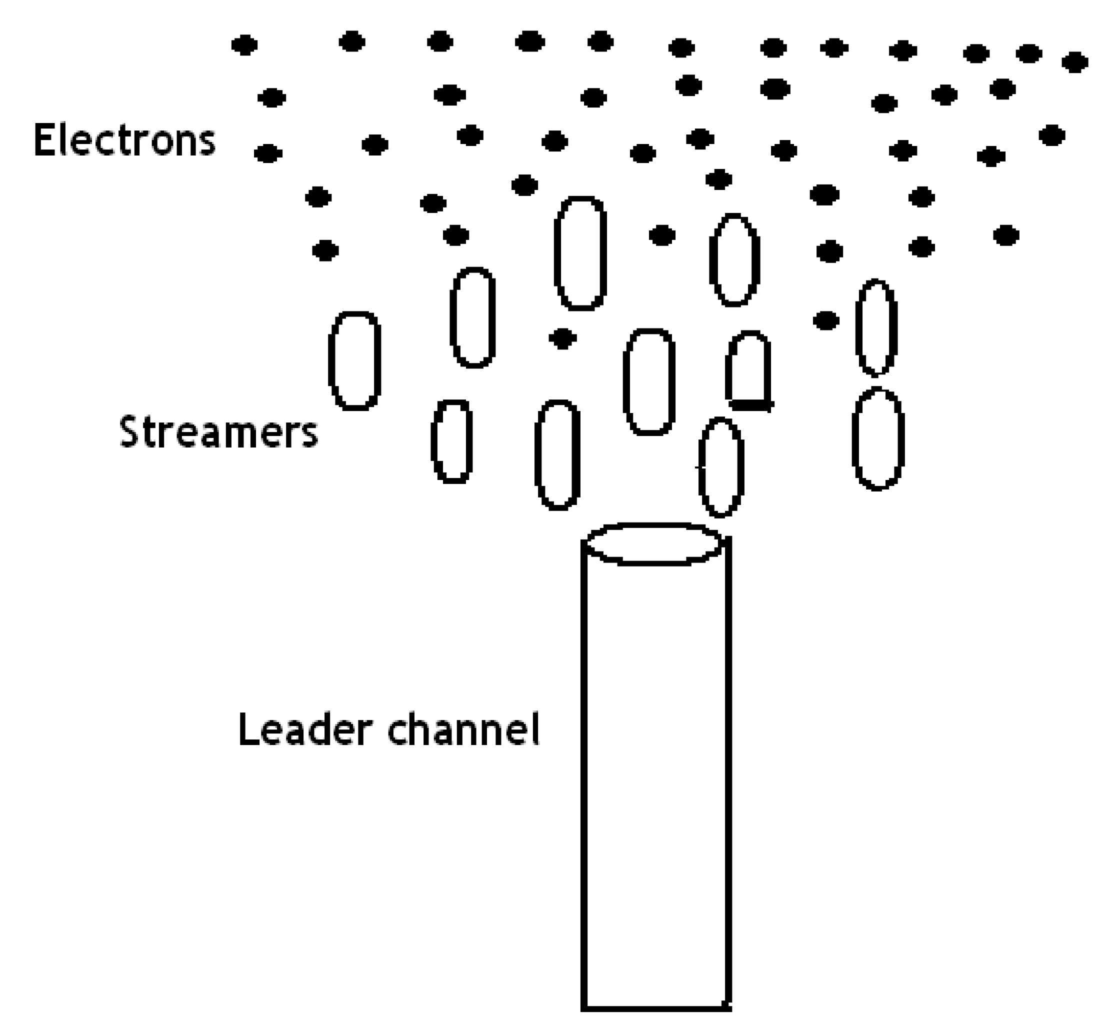

Figure 2: Illustration of a lightning flash and streamers.

Model

To model a streamers electric field, we consider a one-dimensional electric field that is stochastic in time and space. Each streamer is represented by a Gaussian pulse in space and time,

$$E(x,t) = A\sum_{n=1}^{N} e^{-b_1(t-t_n)^2} e^{-b_2(x-x_n)^2},$$

where $\mathrm{A} = 10^4\ \mathrm{Vcm}^{-1}$, $\mathrm{b}_1 = 0.0005\ \mathrm{s}^{-2}$, $\mathrm{b}_2 = 0.0005\ \mathrm{m}^{-2}$, and t_n and x_n are random numbers

The diffusion coefficient is given by

$$D(v) = \frac{1}{2}\left(\frac{q}{m}\right)^2 \int_{-\infty}^{\infty} d\tau\ C(v\tau,\tau)$$

Where $C(v\tau,\tau)$ is the electric field autocorrelation function.

Fokker-Planck Equation

$$\frac{\partial u(v,t)}{\partial t} = -\frac{\partial}{\partial v}\Big[A(v)\ u(v,t)\Big] + \frac{1}{2}\frac{\partial}{\partial v}\Big[\big(D_c(v)+D(v)\big)\ \frac{\partial}{\partial v}u(v,t)\Big] - \frac{\partial}{\partial v}\Big[F(v)\ u(v,t)\Big]$$

Where $A(v)$ and $D_c(v)$ are Coulomb collisions drift and diffusion coefficients, and $F(v)$ is the velocity loss due to atomic excitations and ionizations.

Results

We solve the FPE numerically and normalize the velocity to the electron thermal velocity. Figure 3 shows the evolution of the velocity distribution function in time.

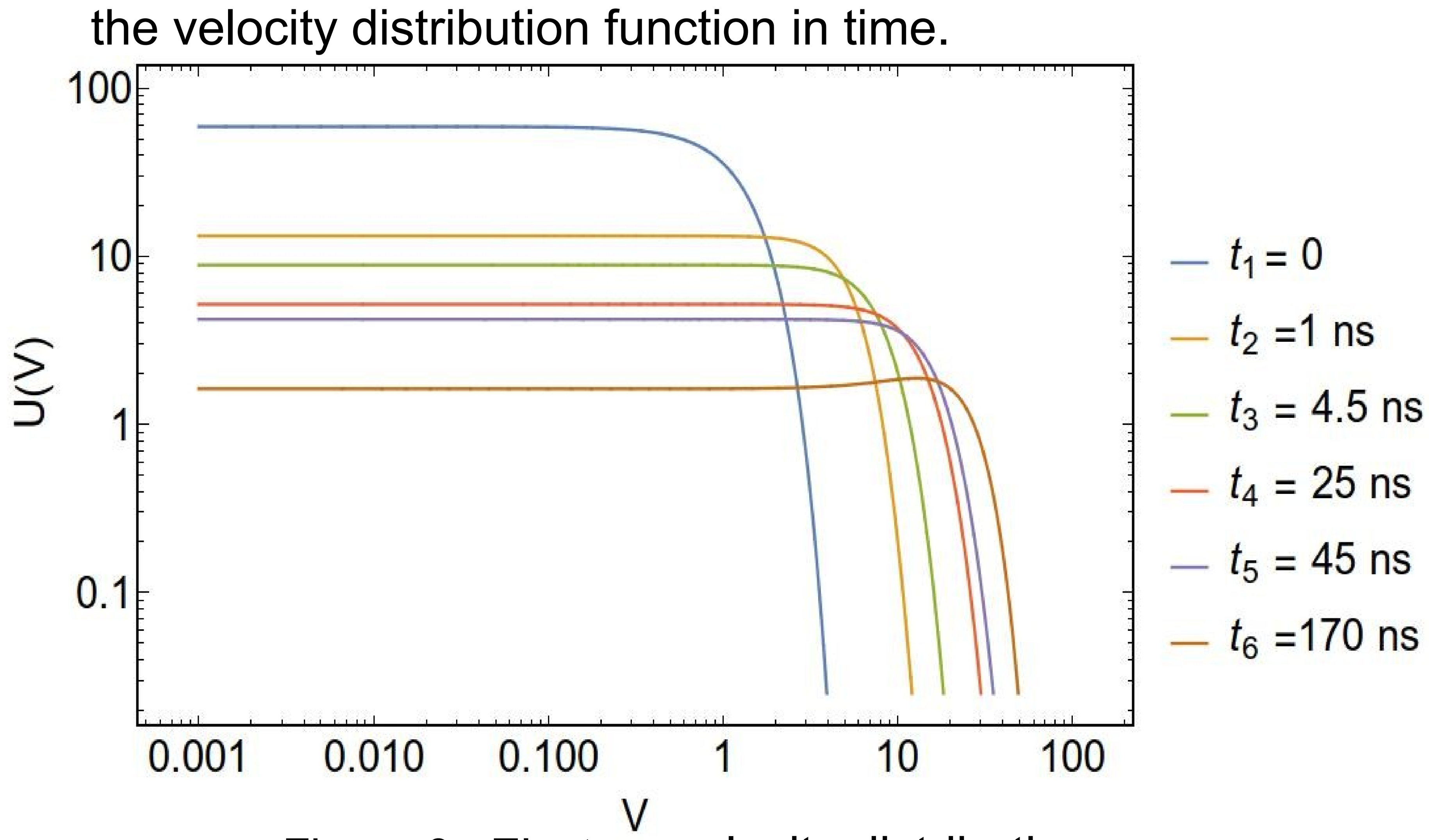

Figure 3: Electron velocity distribution function in time.

Acknowledgments

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