Overview of Lightning Research at University of New Hampshire

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Northeast Radio Observatory Corporation (NEROC) Symposium: Radio Science And Related Topics
MIT Haystack Observatory, 4 November 2016

Outline

- **Optical Observations of Lightning and Transient Luminous Events**
- **Modeling Ionospheric Impact of Thunderstorms and Lightning**
- **Energetic Radiation from Thunderstorms and Lightning**

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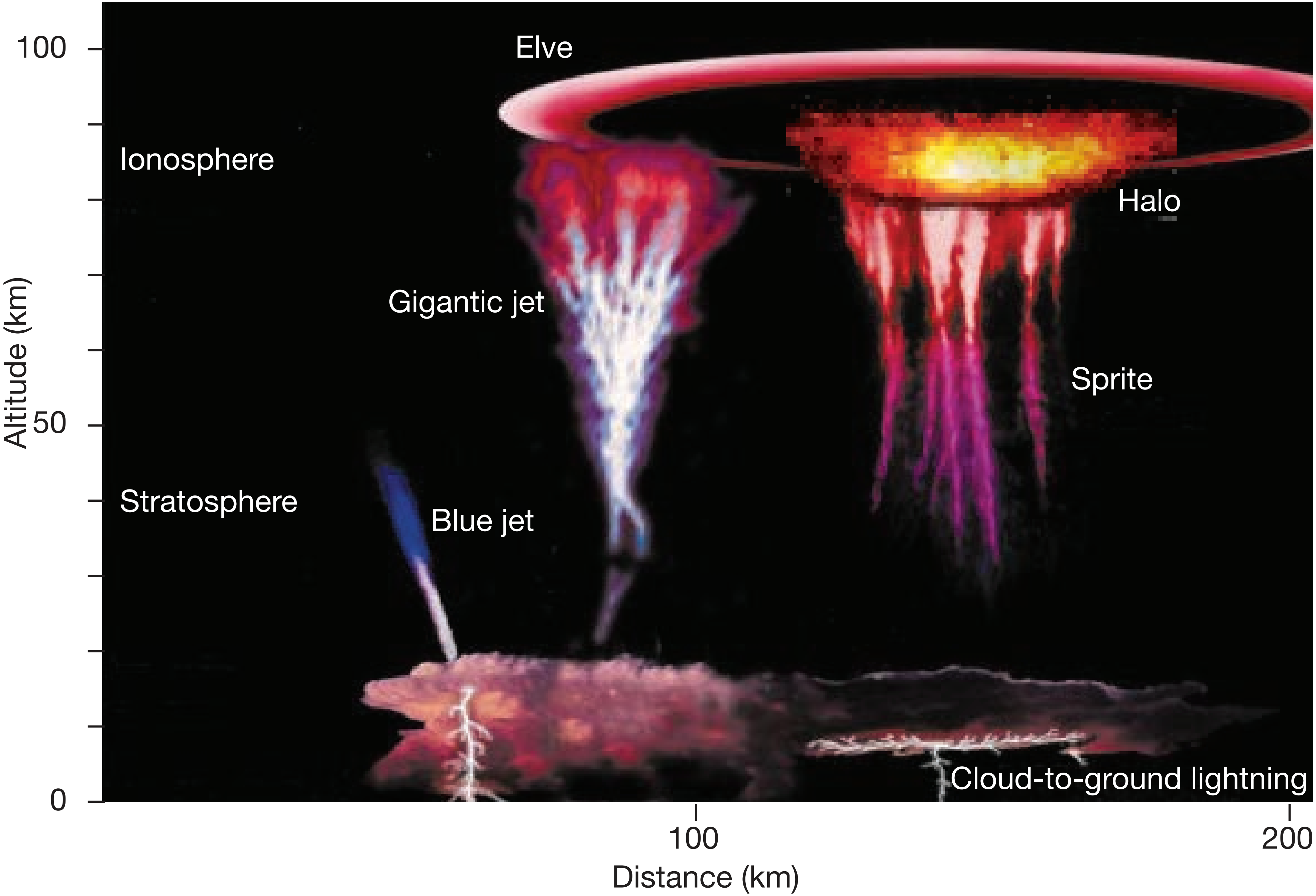
Lightning and Transient Luminous Events

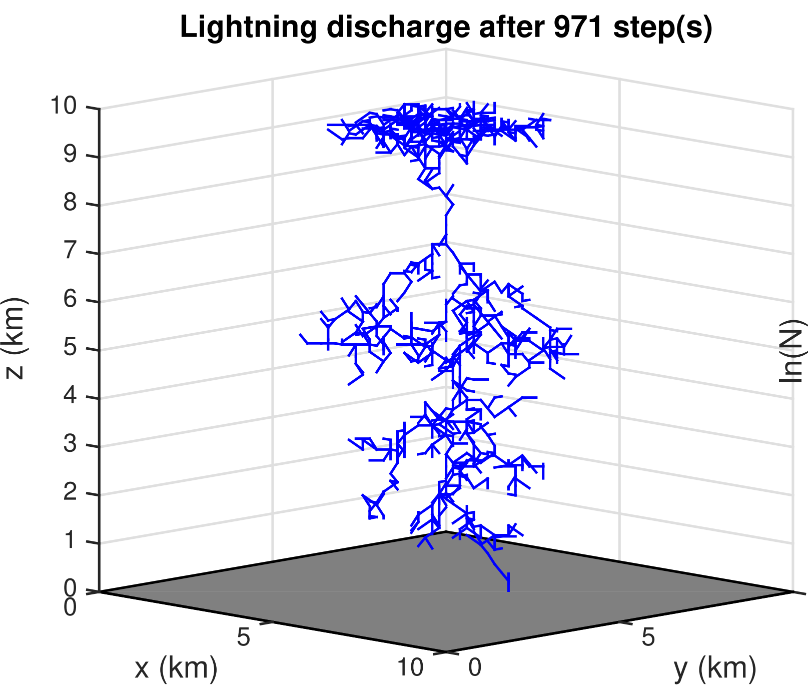


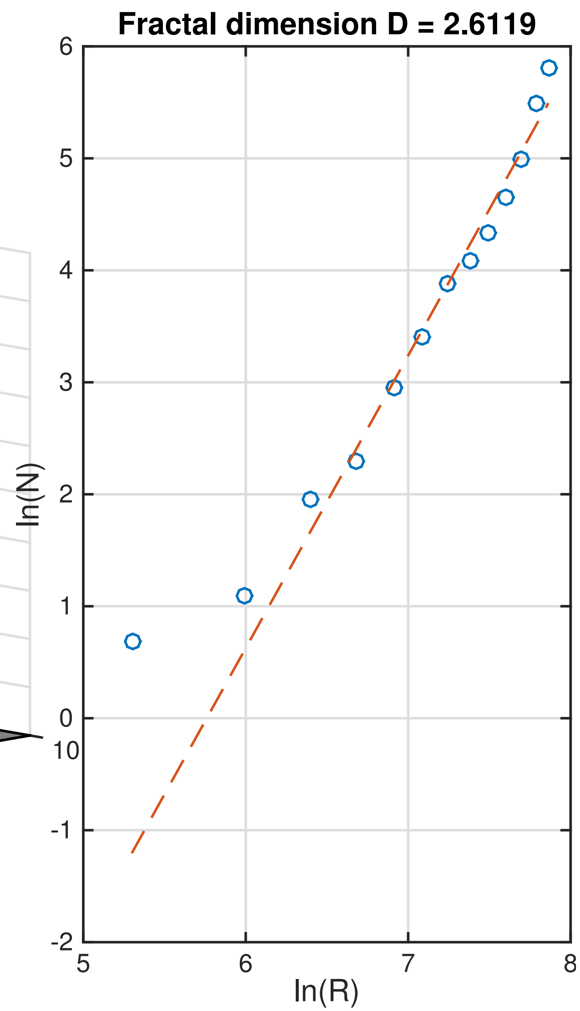
Pasko (2003), Electric jets, **Nature,** 423, 927–929.

Lightning Propagation: Complex Dynamics and Spatial Structures

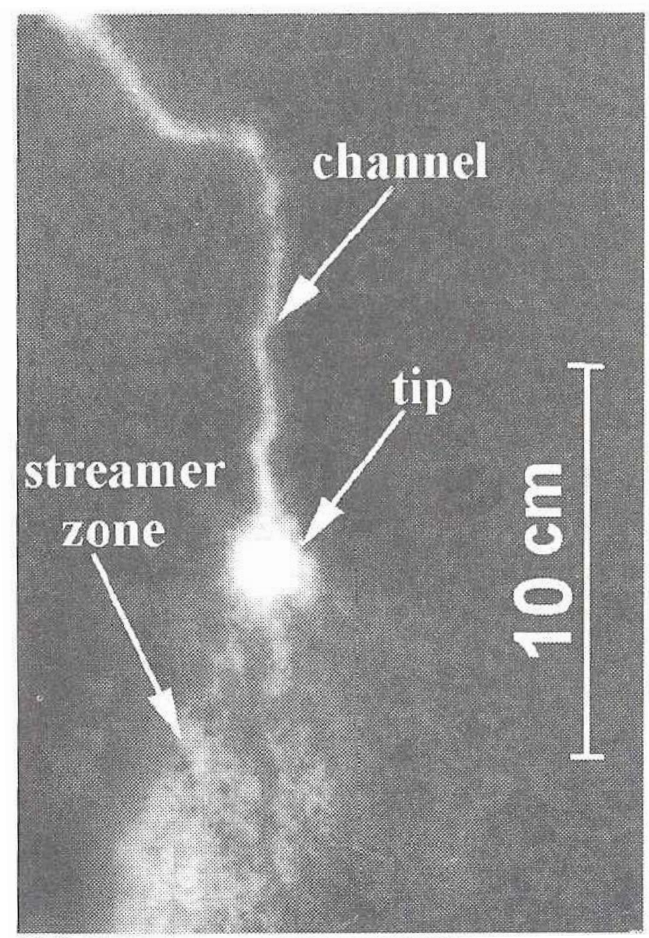
Two lightning flashes observed on May 20th, 2016

Fractal Modeling and Detailed Lightning Channel Structure



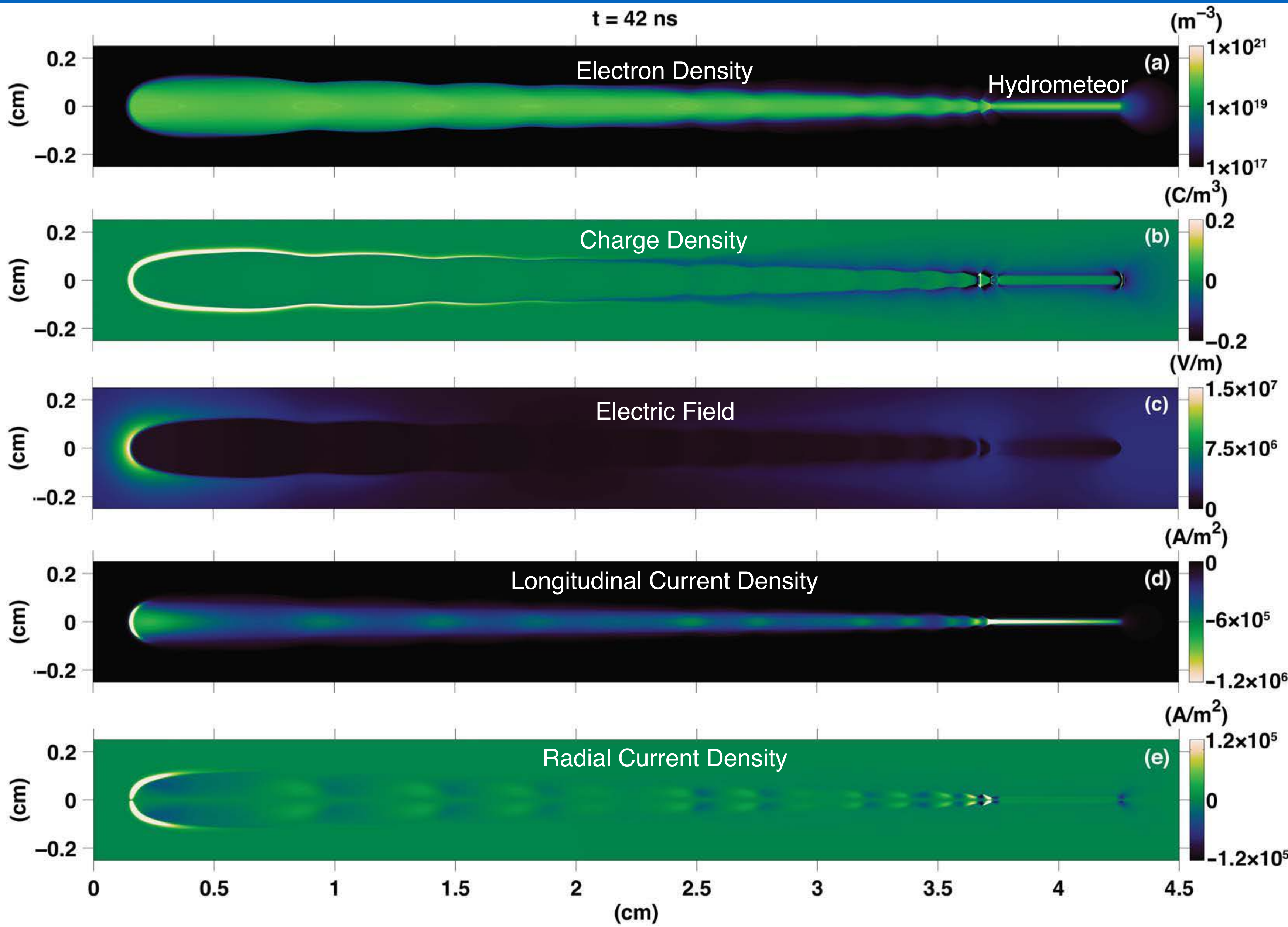


Fractal modeling results obtained by Prof. Jeremy Riousset at ERAU



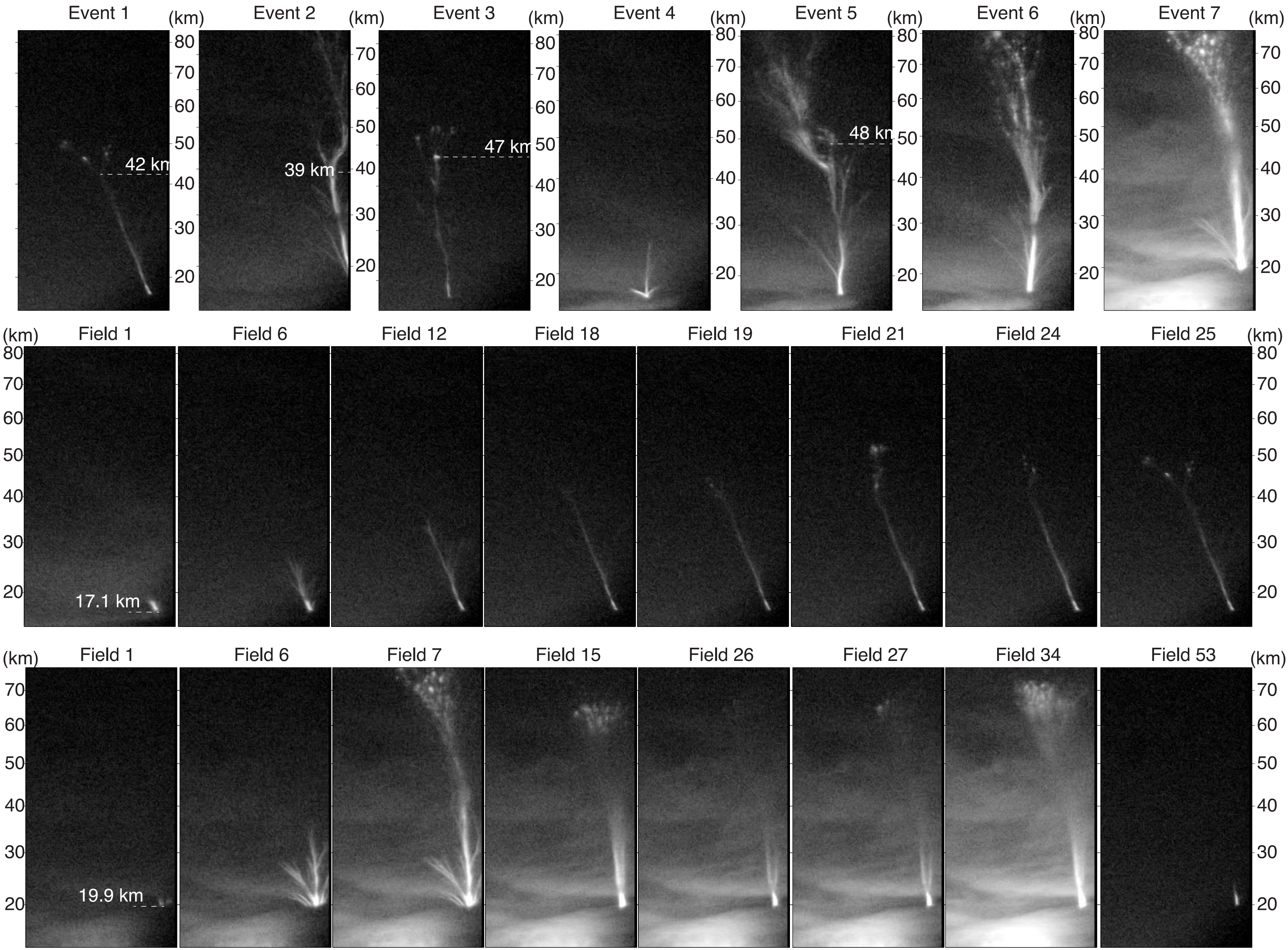
High-resolution Image of lightning channel [Bazelyan and Raizer, 2000].

Simulating Streamer Initiation and Propagation to Study Lightning Initiation



- The current carried by the streamer exponentially increases with a timescale of a few nanoseconds, which can lead to strong HF/VHF radiation [Shi et al., 2016].
- Recent RF measurements suggest that the most powerful VHF source in nature, known as Narrow Bipolar Events or Compact Intracloud Discharges, consists of many streamers [Rison et al., 2016].

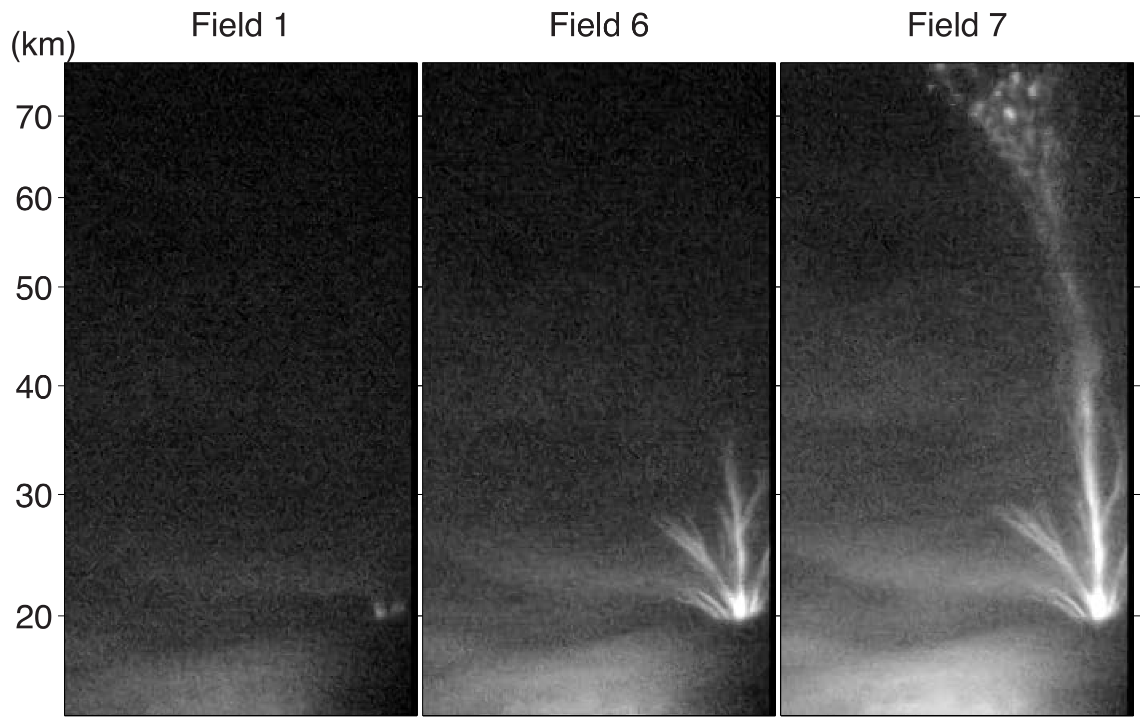
Videos of Jets and Gigantic Jets (Standard Rate)

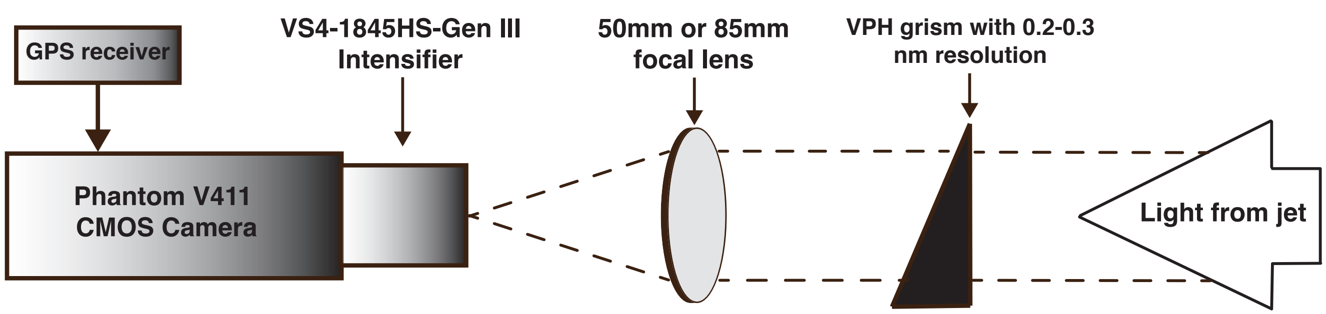


Liu et al. (2015a), Upward electrical discharges observed above Tropical Depression Dorian, **Nat. Commun.**, 6, 5995, doi:10.1038/ncomms6995.

High-Speed Imaging of Jets and Gigantic Jets

- Neither high-speed images nor spatially-resolved spectra have been reported.
- For gigantic jets, does the upward discharge propagate all the way up to the ionosphere? Or are electrical discharges triggered in the lower ionosphere, which then propagate downward?
- Are they as hot as lightning channels?





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Steady State Lower Ionosphere Conductivity Model

- Thunderstorms can establish an electrostatic field and steady current in the upper atmosphere.
- The electric field is sufficient to modify electron mobility and electron attachment coefficient [Salem et al., 2015, 2016].

$$E = \frac{J}{\sigma},$$

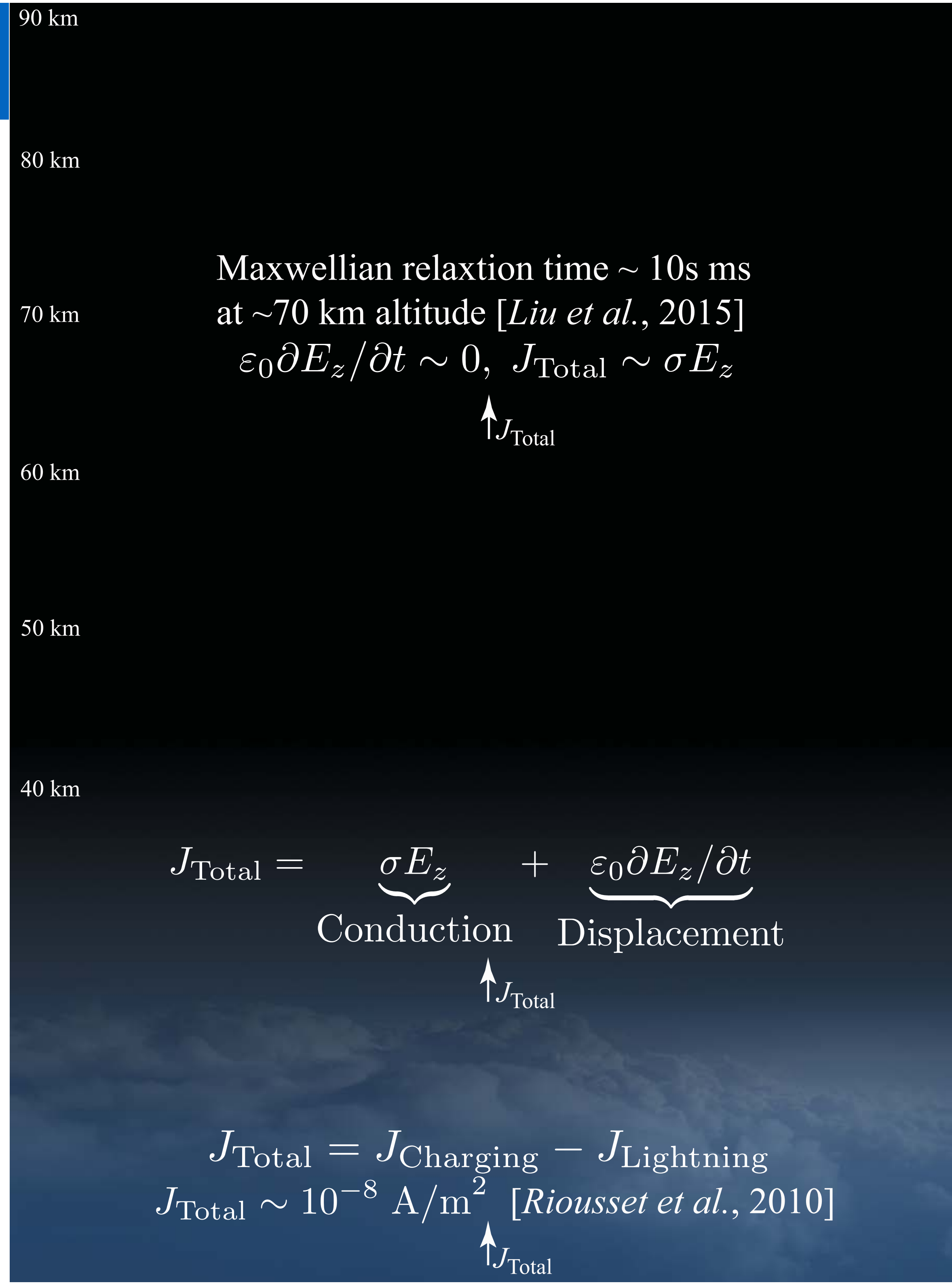
$$\frac{dn_i}{dt} = 0 = S_i - L_i,$$

$$\sum_i n_i^+ = \sum_i n_i^-,$$

$$\sigma = \sum_i e n_i \mu_i$$

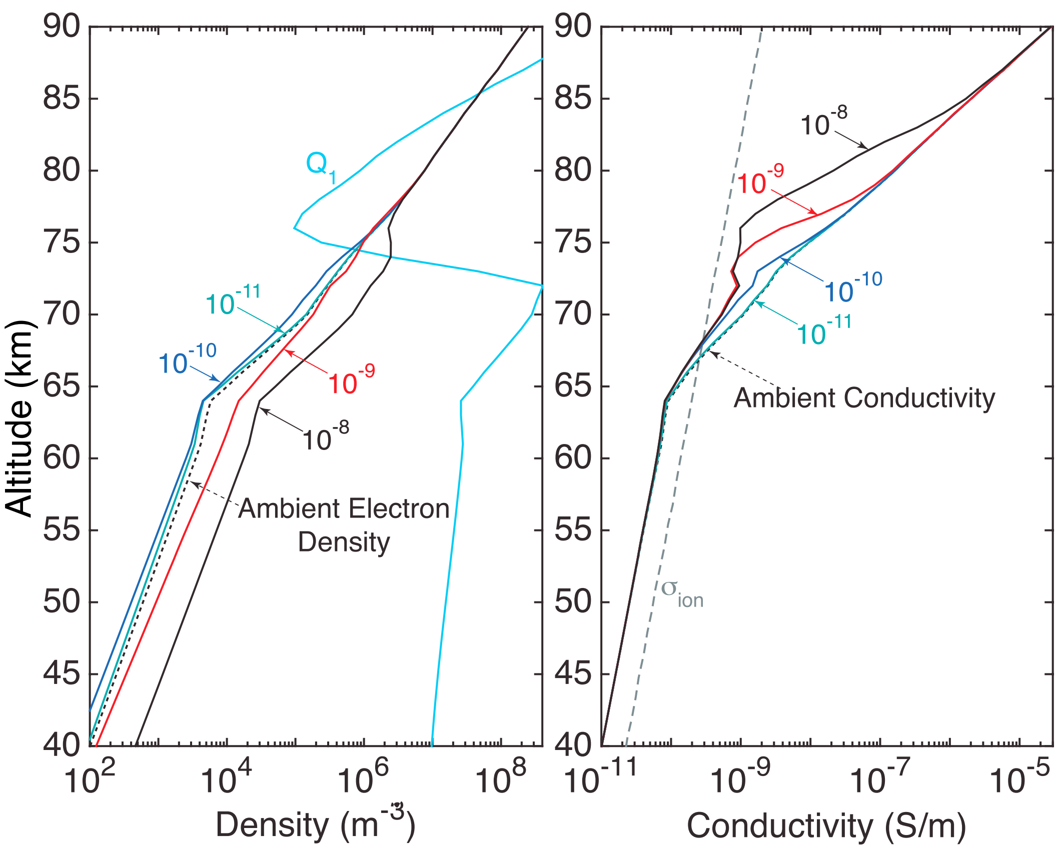
Salem, M. A., N. Liu, and H. K. Rassoul (2015), Geophys. Res. Lett., 42, doi:10.1002/2015GL063268.

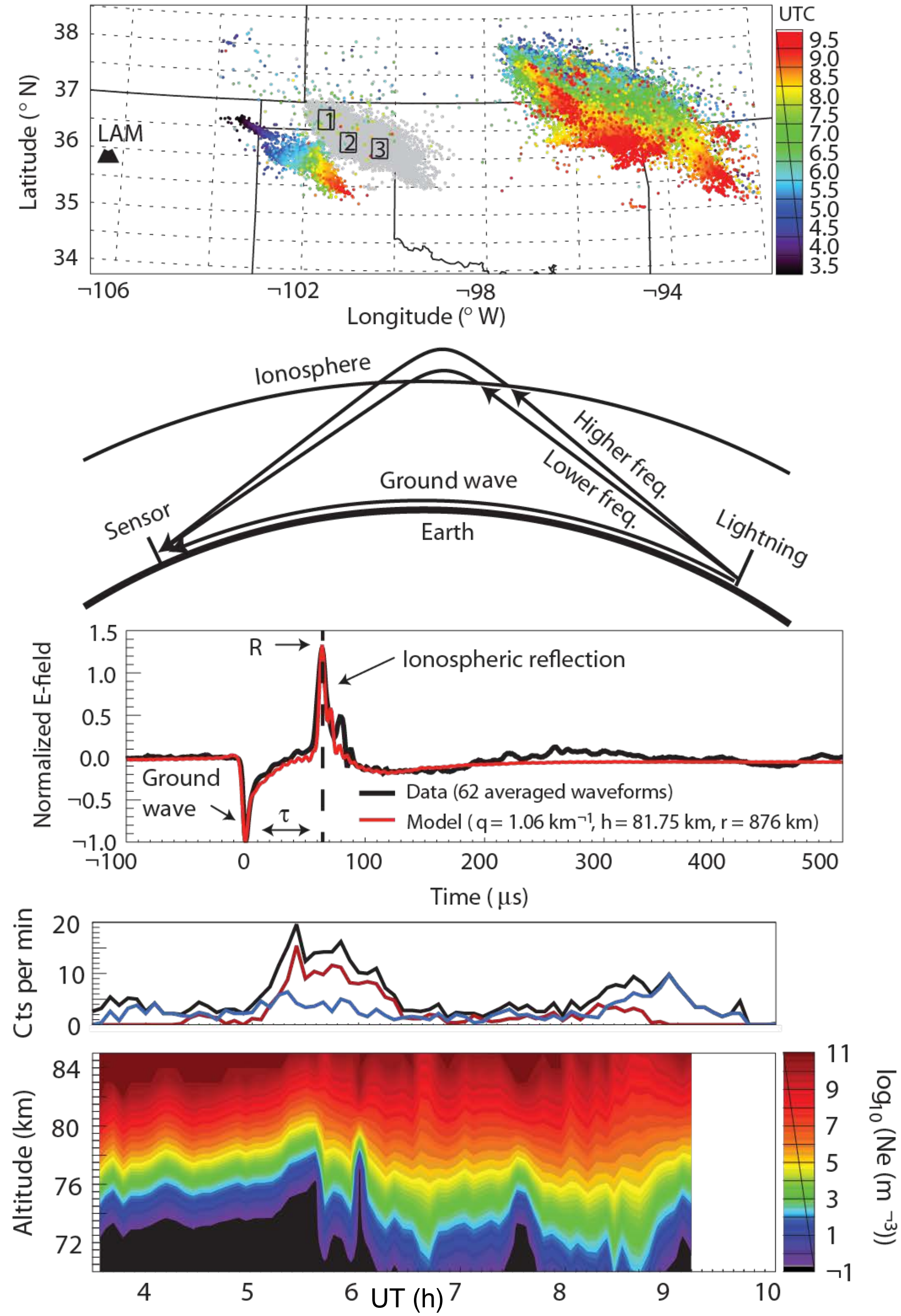
Salem, M. A., N. Liu, and H. K. Rassoul (2016), Geophys. Res. Lett., 43, doi:10.1002/2015GL066933.



Hourly Variation of Ionospheric Density Above Thunderstorms

- The hourly variation of the lower ionospheric density correlates with underlying lightning activity [e.g., Shao et al., Nat. Geosci., 2013].
- Modeling investigation of the effects of thunderstorms [Salem et al.., Geophys. Res. Lett., 2015, 2016].

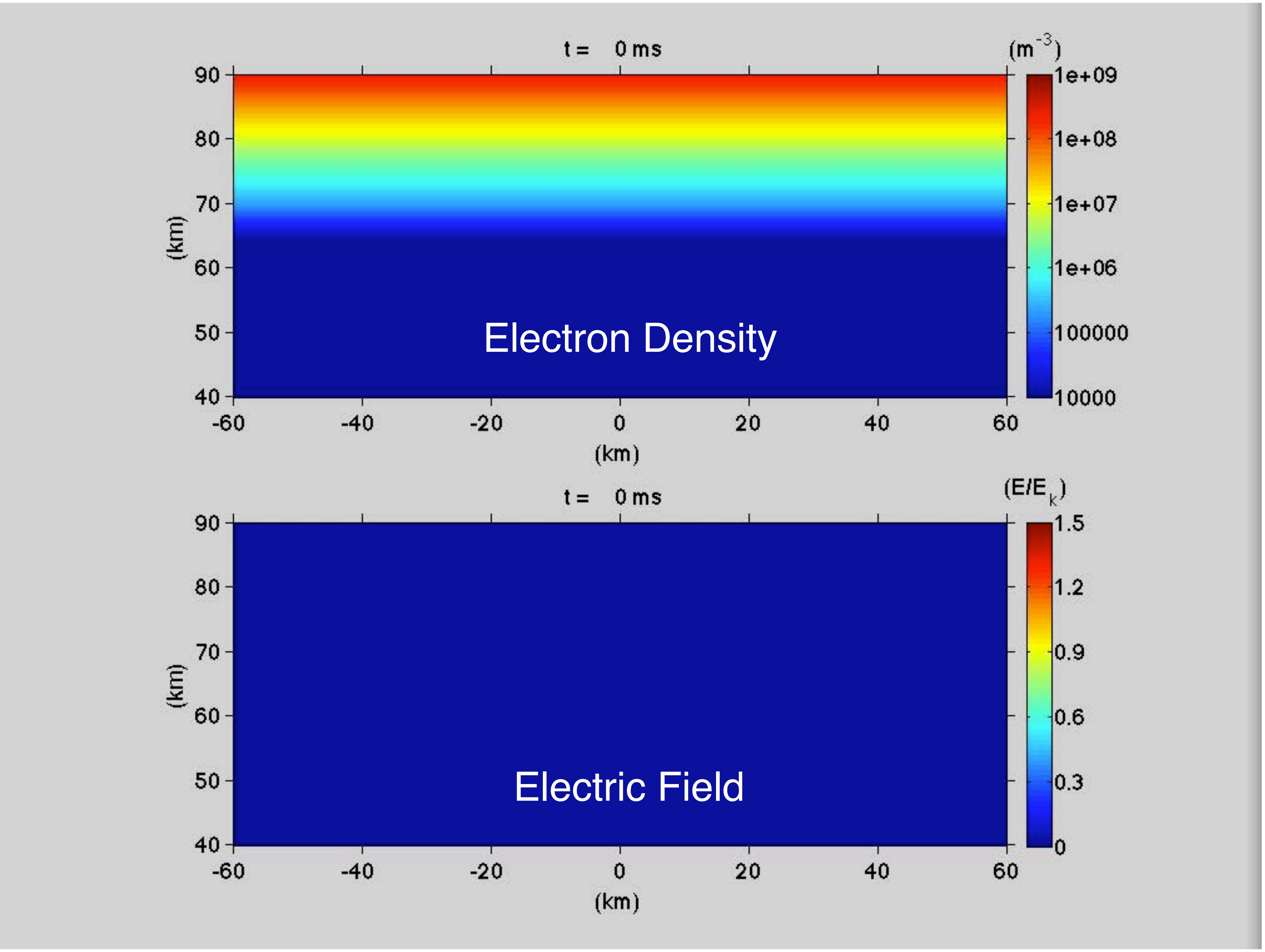




Shao et al. (2013), Reduction of electron density in the night-time lower ionosphere in response to a thunderstorm, **Nat. Geosci.**, 6, 29-33, doi:10.1038/ngeo1668.

Ionospheric Impact of Lightning: Halos and Sprites

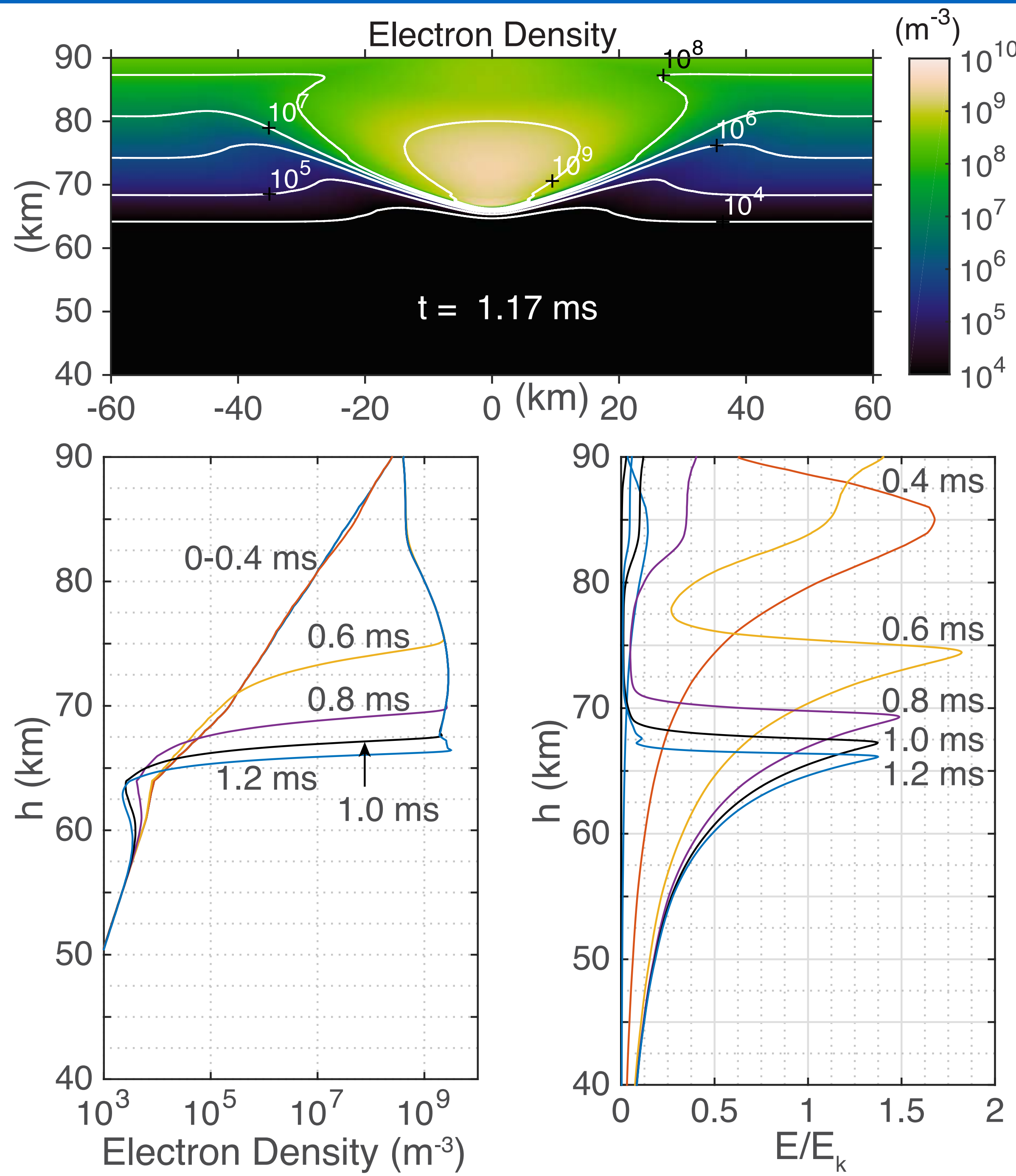
- A plasma fluid discharge model is typically used — Poisson's equation and transport equations of electrons and ions.
- The model accounts for ionization, attachment, detachment, electron drift, electron diffusion, etc.



Liu, N. Y. (2012), Multiple ion species fluid modeling of sprite halos and the role of electron detachment of O⁻ in their dynamics, **J. Geophys. Res.**, 117, A03308, doi:10.1029/2011JA017062.

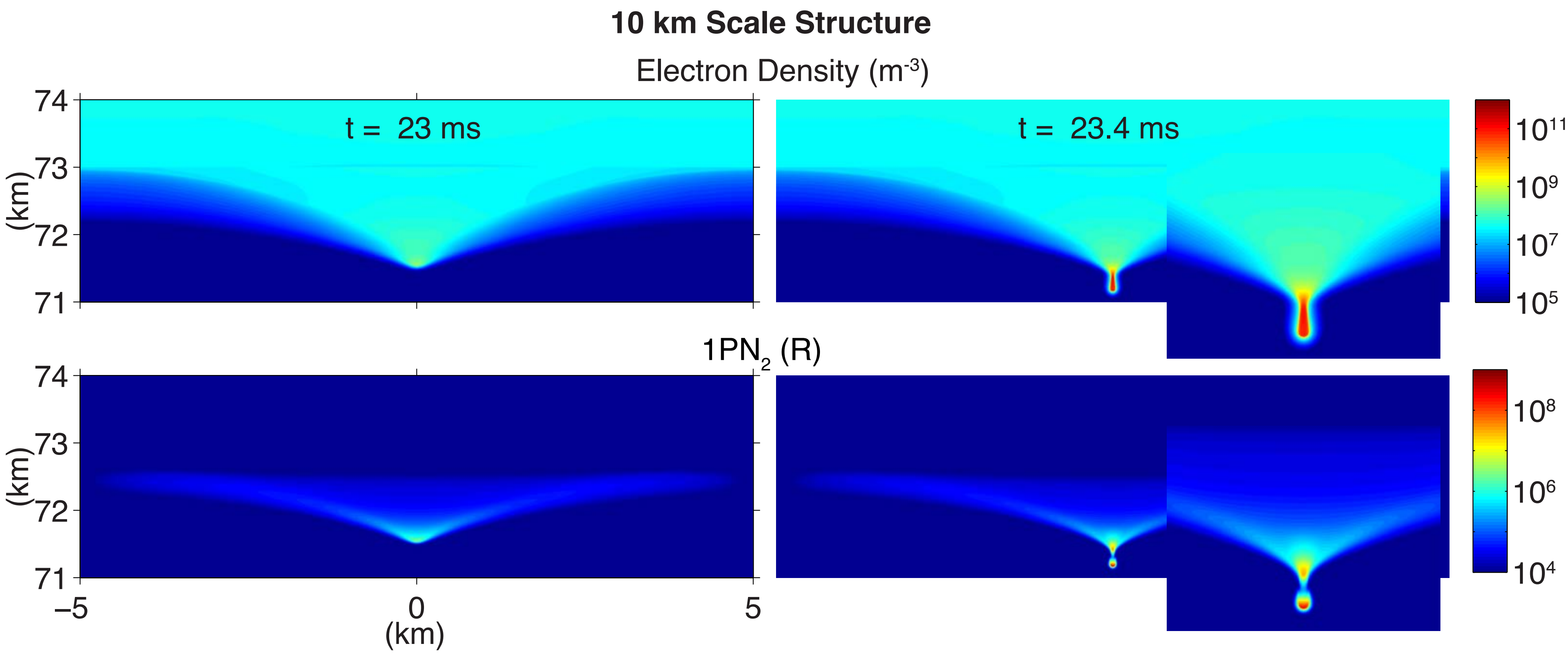
Significant Ionospheric Impact of Impulsive Lightning

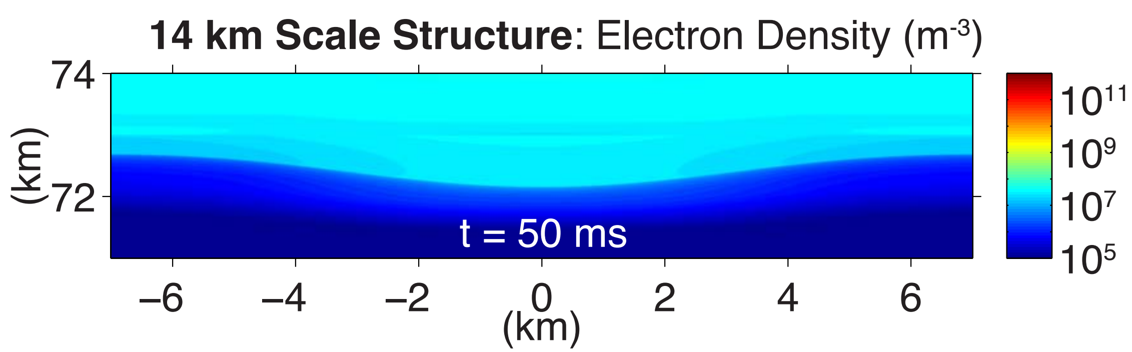
- Conducted for an impulsive lightning stroke detected in Florida in 2014.
- Electron density is increased in a significant volume of the lower ionosphere.
- Peak electron density reaches 3×10^9 m^{-3}, more than 4 orders of magnitude higher than the ambient.



Liu, N., L. D. Boggs, and S. A. Cummer (2016), Observation-constrained modeling of the ionospheric impact of negative sprites, **Geophys. Res. Lett.**, 43, doi:10.1002/2016GL068256.

Streamer Initiation from Mesospheric Structures





Liu et al. (2015b), Sprite streamer initiation from natural mesospheric structures, **Nat. Commun.**, 6, 7540, doi:10.1038/ncomms8540.

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Energetic Radiation Produced by Thunderstorms

How thunderstorms launch particle beams into space

1. Electric fields near the top of the storm create an upward-moving avalanche of electrons. When their paths are deflected by molecules in the air, these electrons emit gamma rays, the highest-energy form of light.

These images are based on a TGF simulation by Joseph Dwyer at the Florida Institute of Technology. This frame tracks the gamma rays and particles from a 0.2-millisecond-old TGF that began at an altitude of 9.3 miles (15 km).

2. When gamma-ray energy collides with electrons, they accelerate to near the speed of light. Some gamma rays pass near the nuclei of atoms. When this happens, the gamma ray transforms into an electron and its antiparticle, a positron.

These high-energy electrons and positrons escape into space by spiraling along Earth's magnetic field. In this frame, the TGF is 1.4 milliseconds old.

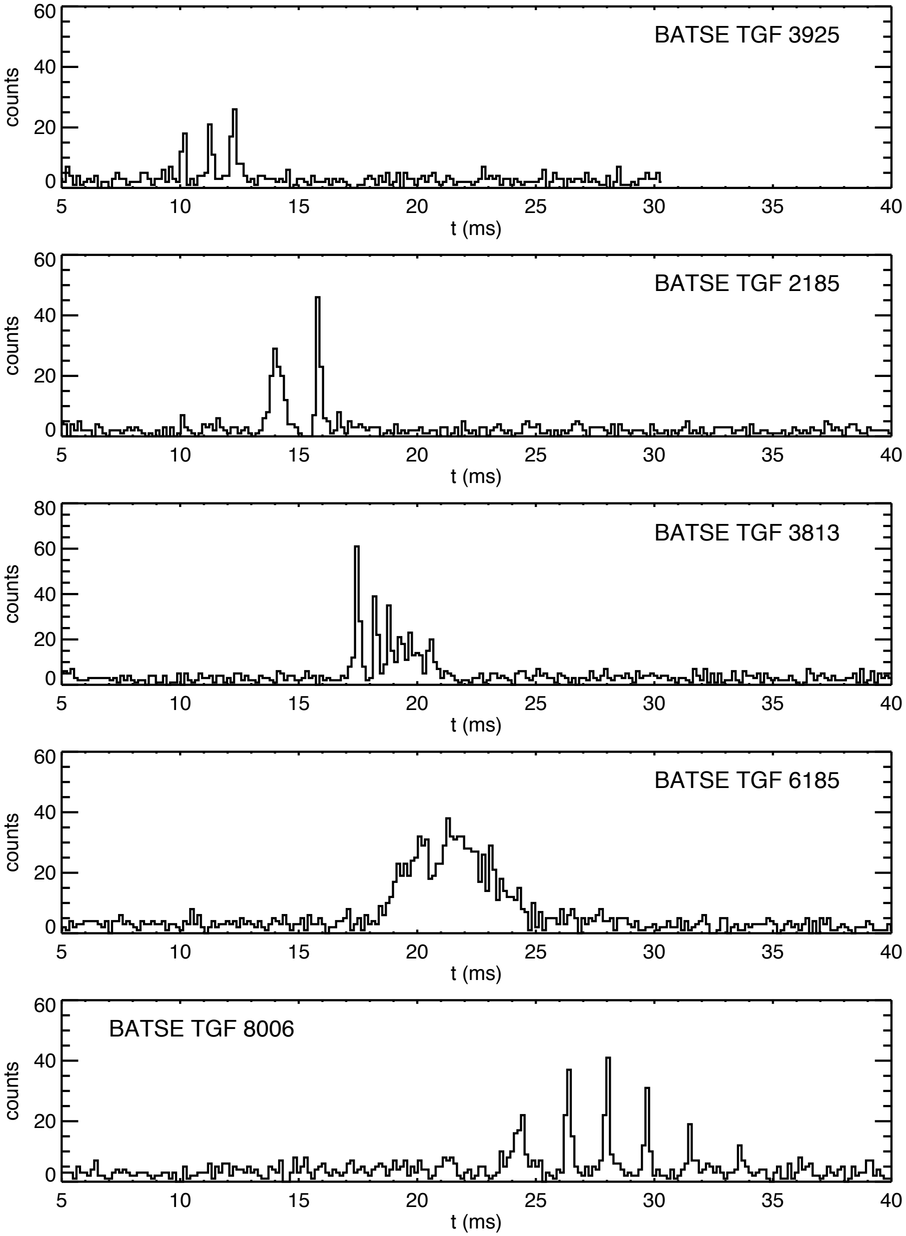
3. Here the TGF is 1.98 milliseconds old, and its electron/positron beam is reaching altitudes where it may intercept spacecraft, such as NASA's Fermi Gamma-ray Space Telescope.

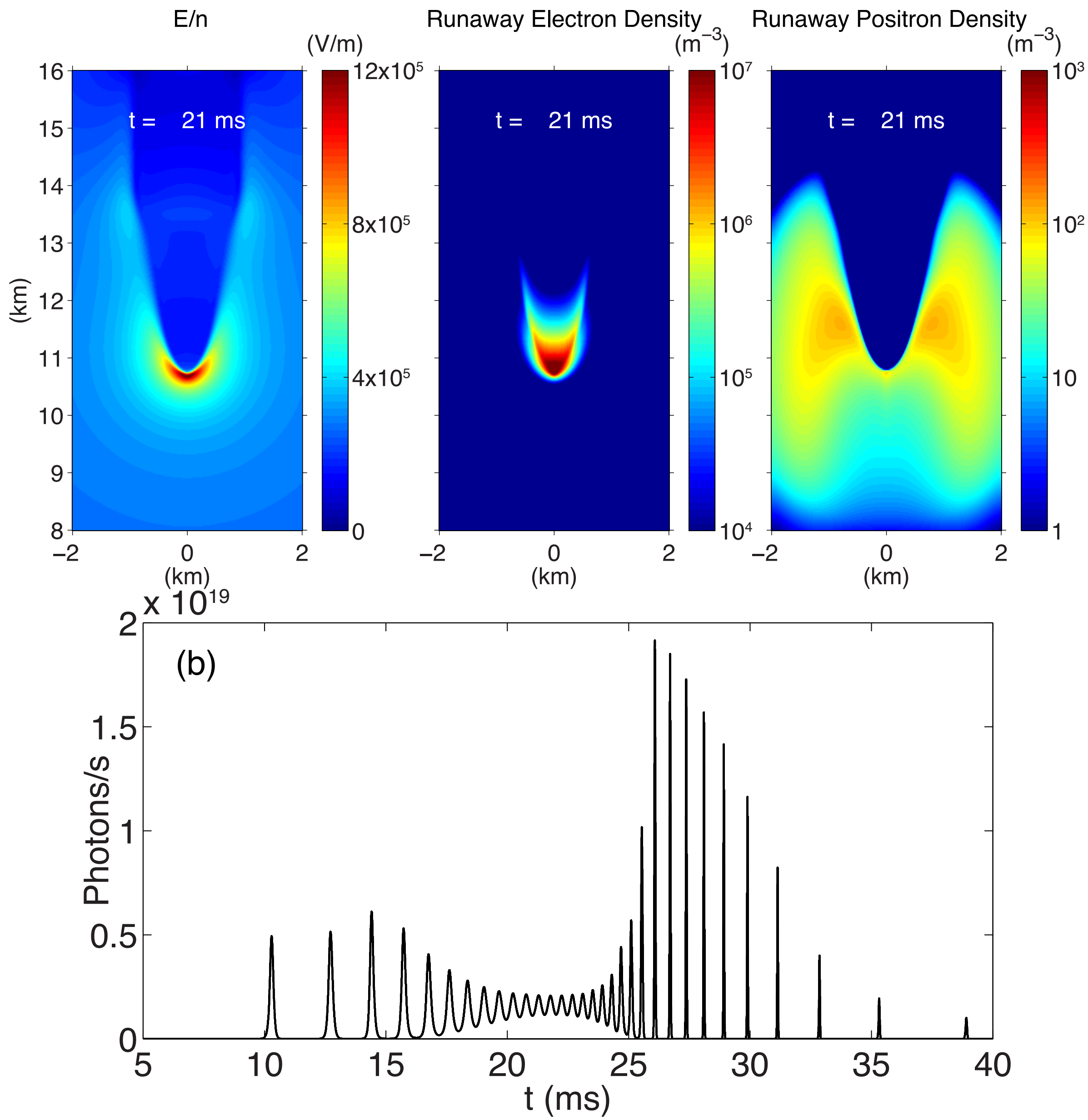
Fermi's Gamma-ray Burst Monitor detected a signal charateristic of positron annihilation. When a positron collided with an electron on the spacecraft, the two particles transformed into gamma rays.

Credit: NASA/Goddard Space Flight Center/J. Dwyer, Florida Inst. of Technology

http://www.nasa.gov/mission_pages/GLAST/news/fermi-thunderstorms.html

Physical Mechanism of Terrestrial Gamma Ray Flashes





Liu, N. Y., and J. R. Dwyer (2013), Modeling terrestrial gamma ray flashes produced by relativistic feedback discharges, J. Geophys. Res., doi:10.1002/jgra.50232.

Summary

- The UNH lightning team works on nearly all aspects of lightning-related research. We conduct observational, modeling, and theoretical research to understand various forms of electrical discharges in earth's atmosphere and their impact.
- We welcome collaborative projects.

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