Modeling Terrestrial Gamma-ray Flashes and related phenomena

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Terrestrial Gamma-ray Flashes (TGFs)

Terrestrial Gamma-ray Flashes (TGFs) are sub-millisecond bursts of high energy photons originating in thunderstorms.

They have been routinely detected from space since the 1990s [Fishman et al., Science, 264, 5163, 1994].

The TGFs detected from space are typically produced at altitudes between 10 and 14 km [e.g., Xu et al., GRL, 39, L08801, 2012; Cummer et al., GRL, 41, 8586, 2014].

TGFs are associated with initial stages of intra-cloud (IC) lightning [e.g., Cummer et al., GRL, 42, 7792, 2015].

TGFs are produced by bremsstrahlung from high energy electrons "running away" as the force they gain from an electric field exceeds the friction they experience from the surrounding air.

The exact mechanism creating the conditions for this to occur remains unknown.

Models

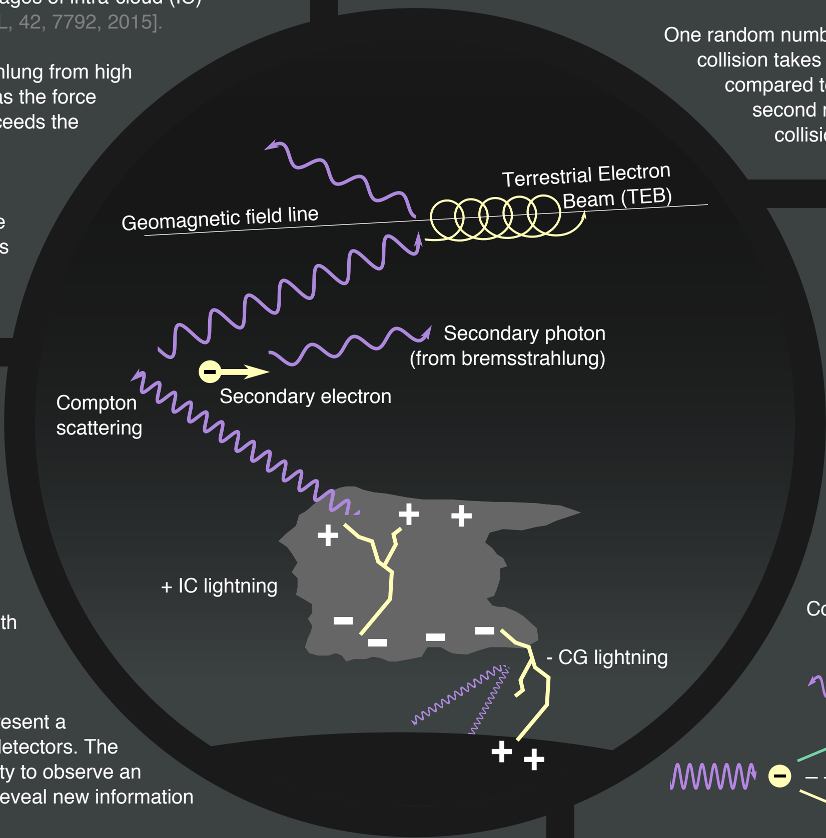
Monte Carlo method: uses random sampling to draw from probability distributions.

Photon transport: calculates a free path based each step on probability of particle interactions. Decides change in energy and direction from cross sections.

Free parameters include initial geometry, energy spectrum, and source altitude.

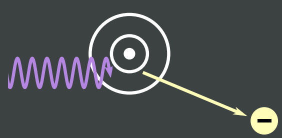
Electron transport: uses a set time step based on the maximum collision frequency possible.

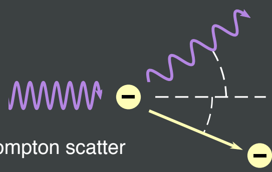
One random number is used to decide whether any collision takes place (based on the time step size compared to the frequency of collision), a second random number decides whether collision is "real".



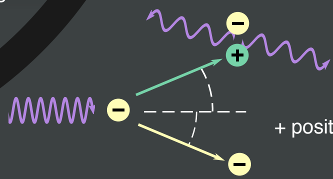
Particle interactions

Photoelectric effect





Compton scatter



Pair production
+ positron annihilation

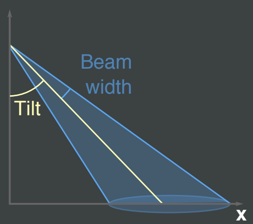
Downward directed TGFs

Until recently, ground-based observations of TGFs were few and far between. Since the Telescope Array in Utah, USA, started reporting detections of high-energy particles correlated with lightning, their number has greatly increased.

Ground observations of TGFs represent a valuable addition to space-borne detectors. The proximity to the event and the ability to observe an event with several detectors may reveal new information about the production of TGFs.

Through simulating downward TGFs we find that:

- Using ground-based detectors, most TGF beaming geometries can be uniquely identified by the mean and standard deviation of the detections' position along the tilt axis (Figure 1 and 2).
- Pulses of < 10 μs duration with tens of μs separation that have been observed on ground, should be observable from space, given sufficient detector time resolution.
- The number of photons arriving to the ground is heavily dependent on the photons' initial energy spectrum. Photon populations with a softer spectrum will not only be smaller initially, but a lower percentage of them will make it to ground.



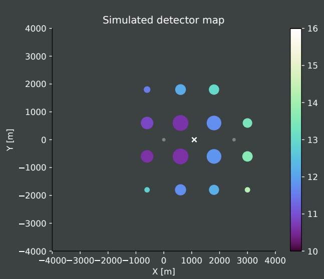


Figure 1: Simulation of downward TGF detected by network of detectors.

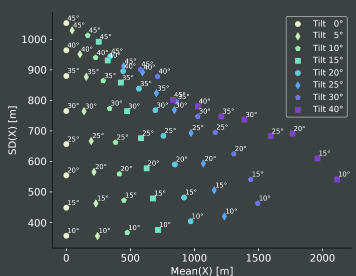


Figure 2: Parameter space of the mean and standard deviation along the tilt axis for different initial TGF geometries.

Present and future work

Secondary photons

As TGFs propagate, secondary electrons are created through interaction with the atmosphere. These electrons then create a secondary population of photons through bremsstrahlung.

Up to 17 % of photons observed at satellite altitude may be secondary photons, representing a signature of the energy deposited in the atmosphere by TGF generated free electrons.

Radio emissions from TGF sources

The electron and ion densities left behind runaway electrons will affect the timescale of the field collapse in the acceleration region, and the amplitude of the current moment.

Through modeling, we want to investigate how the observation of radio emissions produced by these currents may help constrain the geometry of the TGF-producing electron beam.

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