# Monte Carlo Simulation of Terrestrial Gamma-ray Flashes

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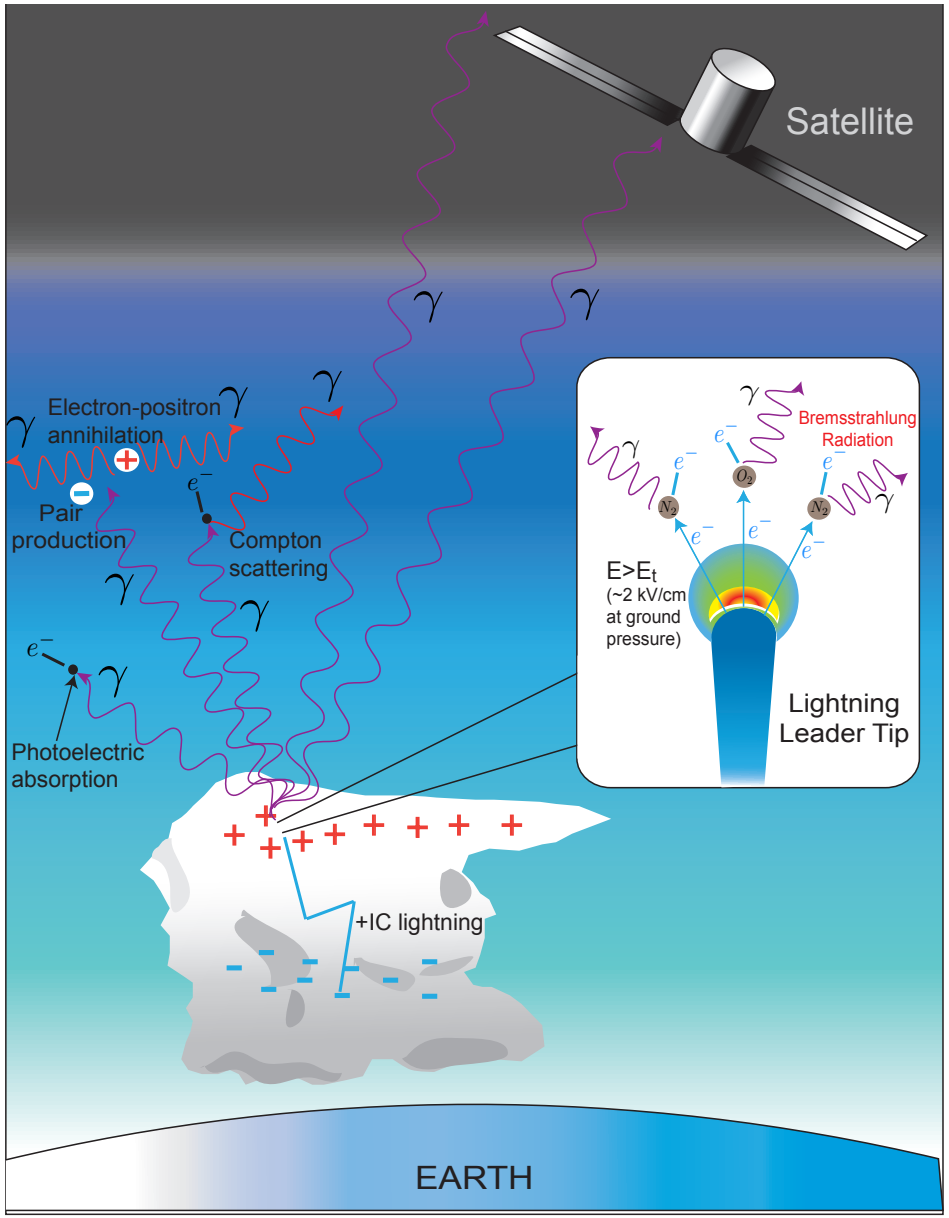
# Introduction



- Terrestrial Gamma-ray Flashes (TGFs) are high-energy photon bursts originating from the Earth's atmosphere. TGFs were first discovered in 1994 by the Burst and Transient Source Experiment (BATSE) detector aboard the Compton Gamma-Ray Observatory (CGRO) [*Fishman et al.*, Science, 264, 1313, 1994].

- This phenomenon has been further observed by the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), the Fermi Gamma-ray Space Telescope and the Astrorivelatore Gamma a Immagini Leggero (AGILE) satellite.

- In theory, potential and fluence of energetic electrons produced during negative corona flashes of +IC lightning leaders are high enough to produce TGFs [*Celestin and Pasko*, JGR, 116, A03315, 2011].

Is the photon spectrum produced by energetic electrons accelerated in lightning leader tip fields consistent with satellite measurement of TGFs?

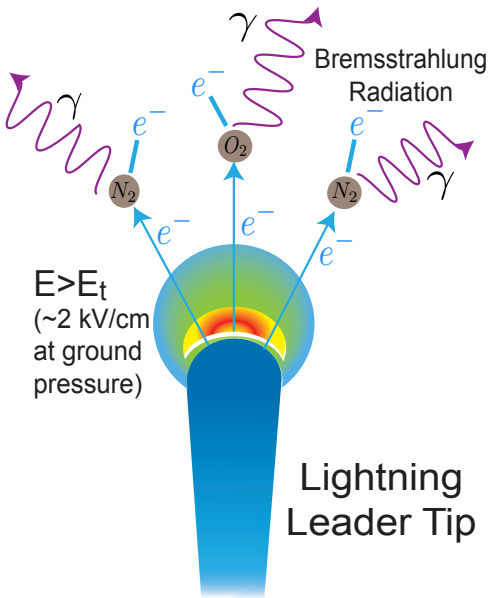
# Monte Carlo Model

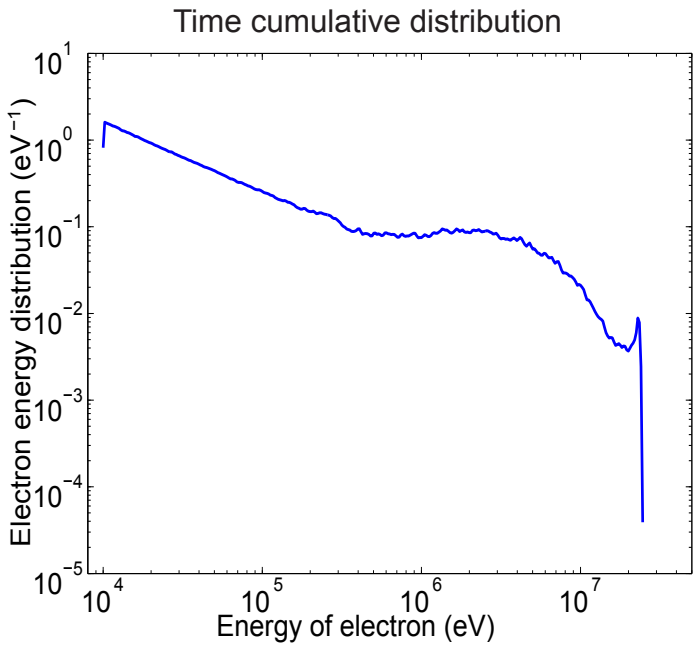
The Monte Carlo code we developed is based on the model described in [*Østgaard et al.*, JGR, 113, A02307, 2008]. It simulates bremsstrahlung radiation and photon transport.

- Bremsstrahlung radiation (or "braking radiation") is produced by the acceleration of charged particles. Braking of energetic electrons in the high-field of atomic nuclei produces a copious amount of X-rays. The bremsstrahlung differential cross section formula is taken from [*Lehtinen.*, PhD thesis, Stanford Univ., 2000, Section 3.2.1].
- As for the photon transport, three different photon collision types are considered.

# Acceleration of energetic electrons

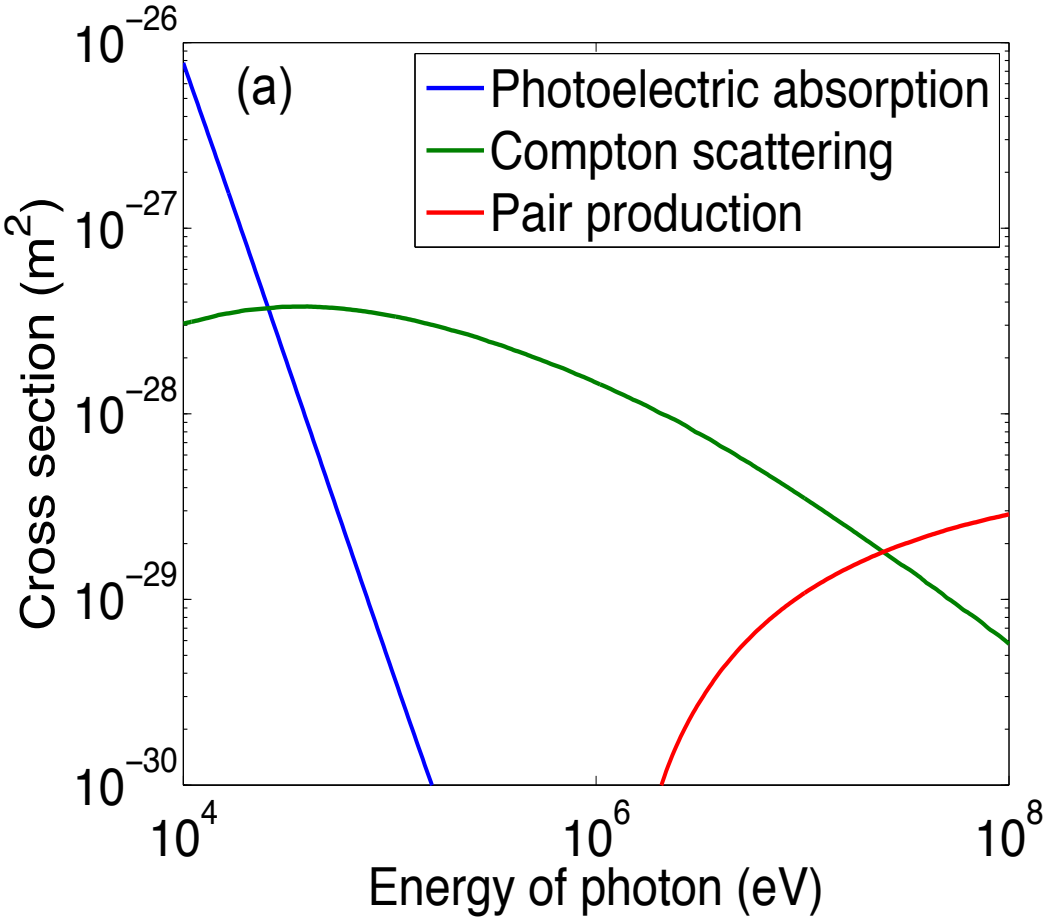
- We studied the production and transport of energetic electrons by lightning leader with given electrical properties [*Celestin and Pasko*, 2011].
- We use a long unbranched intracloud lightning discharge in our model transporting negative charges upward (+IC): length 4 km, radius 1 cm, propagating under an ambient large-scale electric field of 0.5 kV/cm.



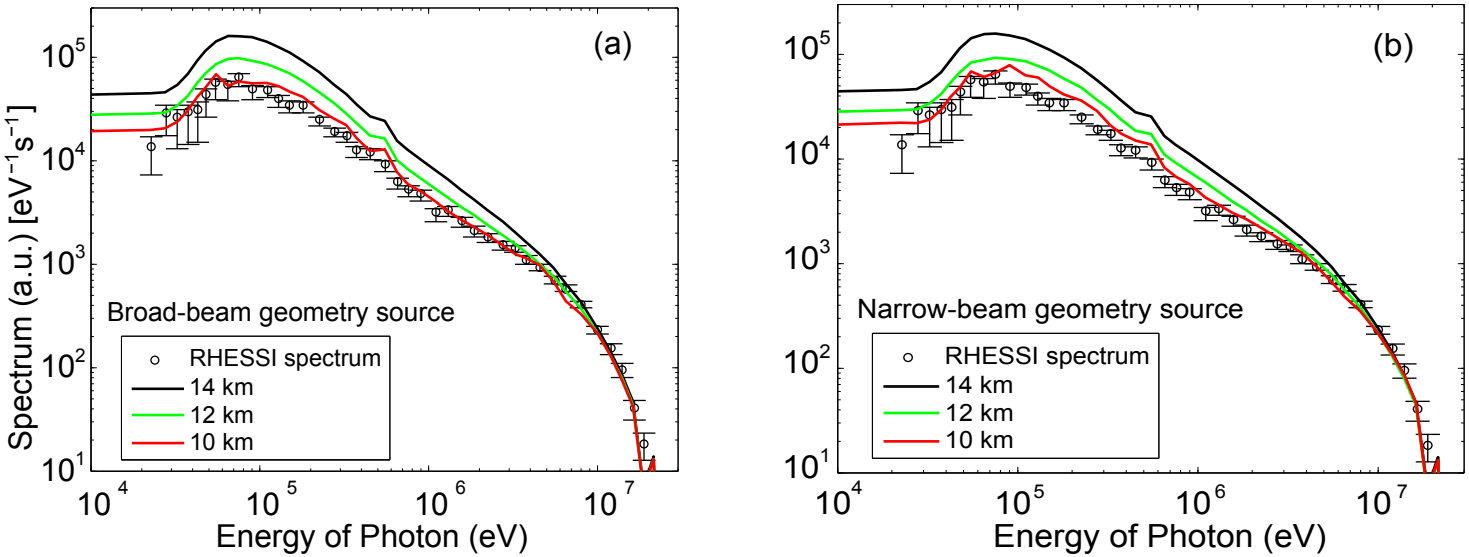



# Photon transport

- We consider three collision types: photoelectric absorption (main process for energies $<$30 keV), Compton scattering (main process from 30 keV to 30 MeV) and electron-positron pair production (main process for energies $>$30MeV).



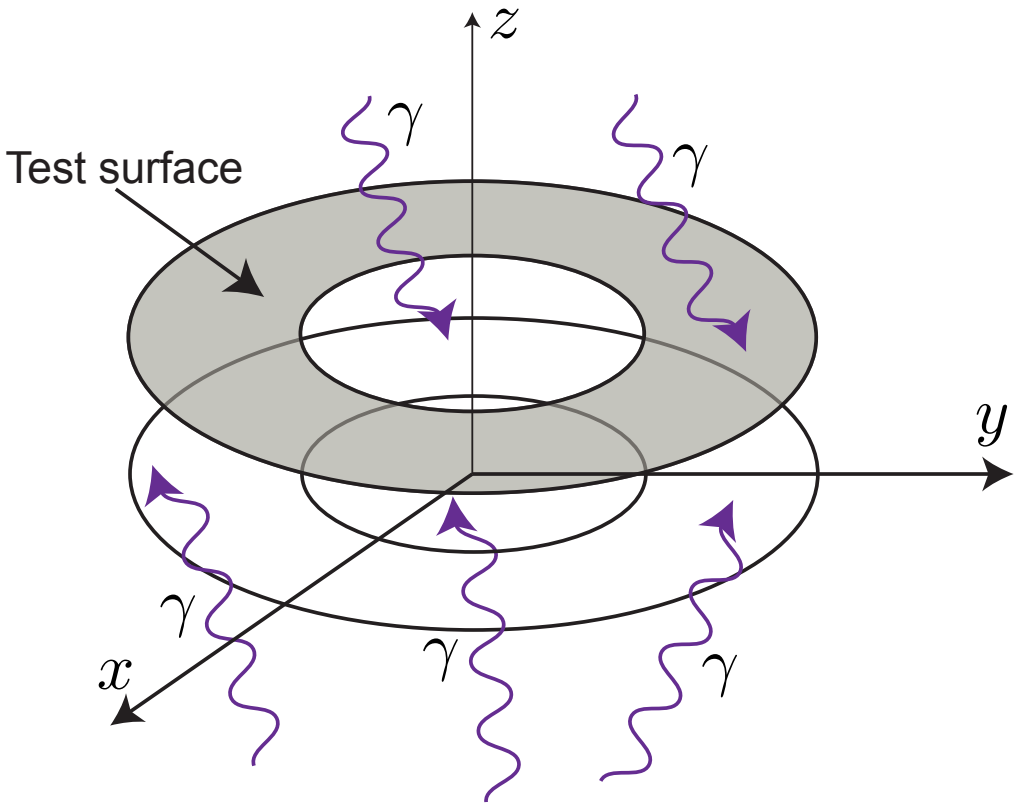
# Results




(a) The solid curves are simulated TGFs spectra at 500 km corresponding to sources with the same broad-beam geometry (isotropic within a 45° angle) positioned at different altitudes. (b) The solid curves are simulated TGF spectra at 500 km corresponding to narrow-beam geometry sources positioned at different altitudes. The RHESSI data are taken from [*Dwyer and Smith*, 2005] and the detector response matrix is taken from `http://scipp.ucsc.edu/~dsmith/tgflib_public/data/`.

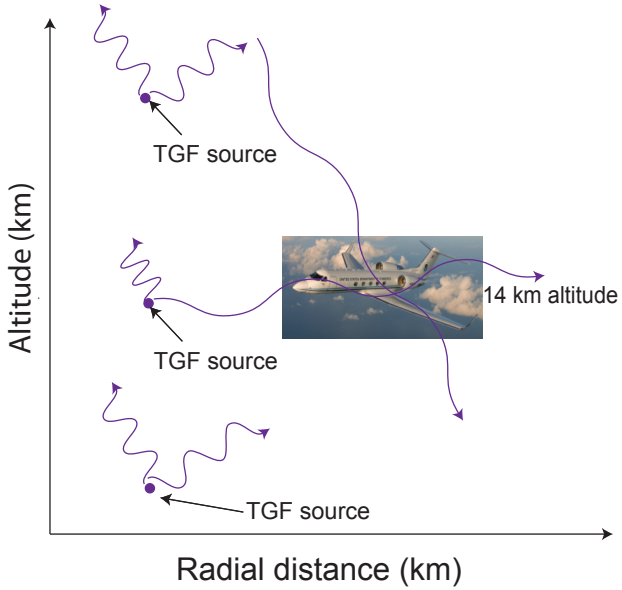
- The photon spectrum produced by acceleration of electrons during negative corona flashes matches the TGF spectrum measured!
- We found that a TGF source located at around 10 km best fits the RHESSI spectrum.

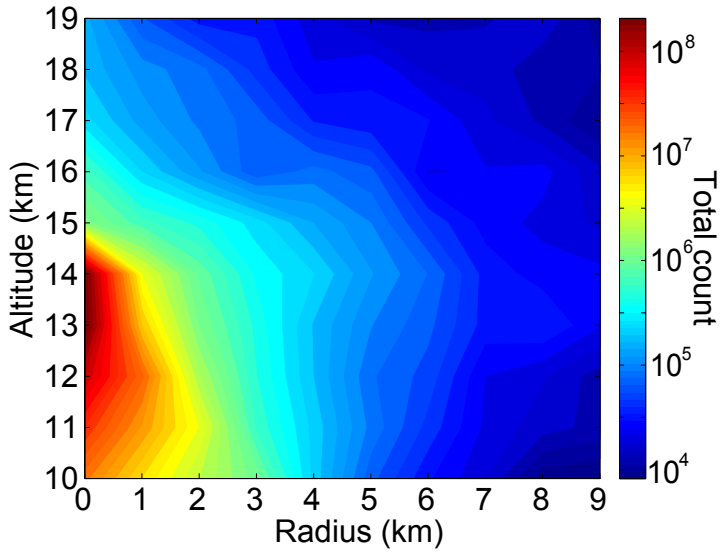
# Test surface




- Test surfaces with horizontal orientation are placed in source region to record the counts of gamma-rays.

# Counts of gamma-rays received by test surface




- This simulation is done to be compared with results of the ADELE experiment [*Smith et al.*, GRL, 38, L08807, 2011]. A test surface of 65 $cm^2$ that represents a "perfect" detector is placed at 14 km altitude while the source is launched from different altitudes (10 km–19 km) and different radial distance (0 km–9 km).

- Our results are in good agreement with [*Smith et al.*, 2011, Figure 1].

# Conclusions

- A detailed Monte Carlo model that simulates bremsstrahlung radiation and photon transport has been developed.
- TGF spectrum is reproduced by the bremsstrahlung radiation produced by electrons accelerated during negative corona flashes.
- We found that a TGF source of photons produced by the stepping of a long unbranched lightning leader, located at around 10 km best fits the RHESSI spectrum. As expected, the initial altitude and the angular distribution both contribute to the TGFs spectrum. However, a broad-beam geometry is consistent with the electric field in the vicinity of a lightning leader tip [*Carlson et al.*, JGR, 114, A00E08, 2009].
- Studies about fluence of TGF photons in thunderstorm launched from 10 km to 19 km altitude have been carried out. Our results are in good agreement with [*Smith et al.*, GRL, 38, L08807, 2011, Figure 1].

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Thank you for your attention!