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Variability in High-Energy Photon Bursts Produced by Lightning Discharges

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Terrestrial gamma-ray flashes (TGFs) are bursts of high-energy photons originating from the Earth's atmosphere in association with thunderstorm activity. They have been discovered by Fishman et al. [Science, 264, 1313, 1994] using BATSE detectors aboard the Compton Gamma-Ray Observatory originally launched to perform observations of celestial gamma-ray sources. These events have also been detected by the RHESSI [Smith et al., Science, 307, 1085, 2005], AGILE [Marisaldi et al., JGR, 115, A00E13, 2010], and the Fermi Gamma-ray Space Telescope [Briggs et al., JGR, 115, A07323, 2010]. Moreover, measurements have correlated TGFs with initial development stages of normal polarity intra-cloud lightning that transports negative charge upward (+IC) [e.g, Lu et al., JGR, 116, A03316, 2011]. Photon spectra corresponding to relativistic runaway electron avalanches (RREAs) in large-scale thunderstorm electric fields usually provide a very good agreement with satellite observations [Dwyer and Smith, GRL, 32, L22804, 2005]. However, it has been suggested that high-potential +IC lightning leaders could produce a sufficient number of energetic electrons to explain TGFs [Celestin and Pasko, JGR, 116, A03315, 2011], and Xu et al. [GRL, 39, L08801, 2012] have shown that this mechanism could explain the TGF spectrum for lightning potentials higher than 100 MV. In addition to TGFs, X-ray bursts are produced by negative cloud-to-ground (-CGs) lightning leaders in association with stepping processes and are observed from the ground [Dwyer et al., GRL, 32, L01803, 2005].

In this work, we will investigate the variation of photon spectra and photon fluences with respect to the electrical properties of the causative lightning discharge in a unified fashion for TGFs and CG-lightning-produced X-ray bursts. We will show how the lightning-produced X-ray spectrum converges toward the RREA spectrum for very high potential drops in the vicinity of the lightning leader tip, and demonstrate why only the most energetic TGFs can be detected from low-orbit satellites.