

## **On the Relationship between Terrestrial Gamma-ray Flashes and Lightning**

Intended for Energetic Radiation from Thunderstorms and Lightning

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Terrestrial Gamma-ray flashes (TGFs) have been connected to lightning and thunderstorms since their discovery, but the relationship between TGF and lightning is still an open question. Previous studies on the TGF-associated lightning have lead to the belief that TGFs occur at the initial stage of +IC lightning. However, previous studies are limited to small sample sizes, therefore it is still unclear whether this statement holds for all TGFs. Here we matched 579 TGFs detected by Fermi Gamma-Ray Burst Monitor (GBM) to radio sferics detected by the Earth Networks Total Lightning Network (ENTLN), obtaining 195 TGF-sferic associations. By stacking the ENTLN radio measurements of the 195 sferics, with  $t_0$  defined as the time of the TGFs, we identified a clear temporal relationship between TGFs and TGF-associated lightning, in which TGFs always occur at the first  $\approx 5$ – $10$  milliseconds of the lightning process. Moreover, we found that TGF-associated lightning has similar peak current to lightning not associated with TGFs. We further confirmed the characteristics of radio signals emitted by TGFs, as reported in our previous study using sferics from the World Wide Lightning Location Network (WWLLN).