

# Fermi GBM Observations of Terrestrial Gamma-ray Flashes

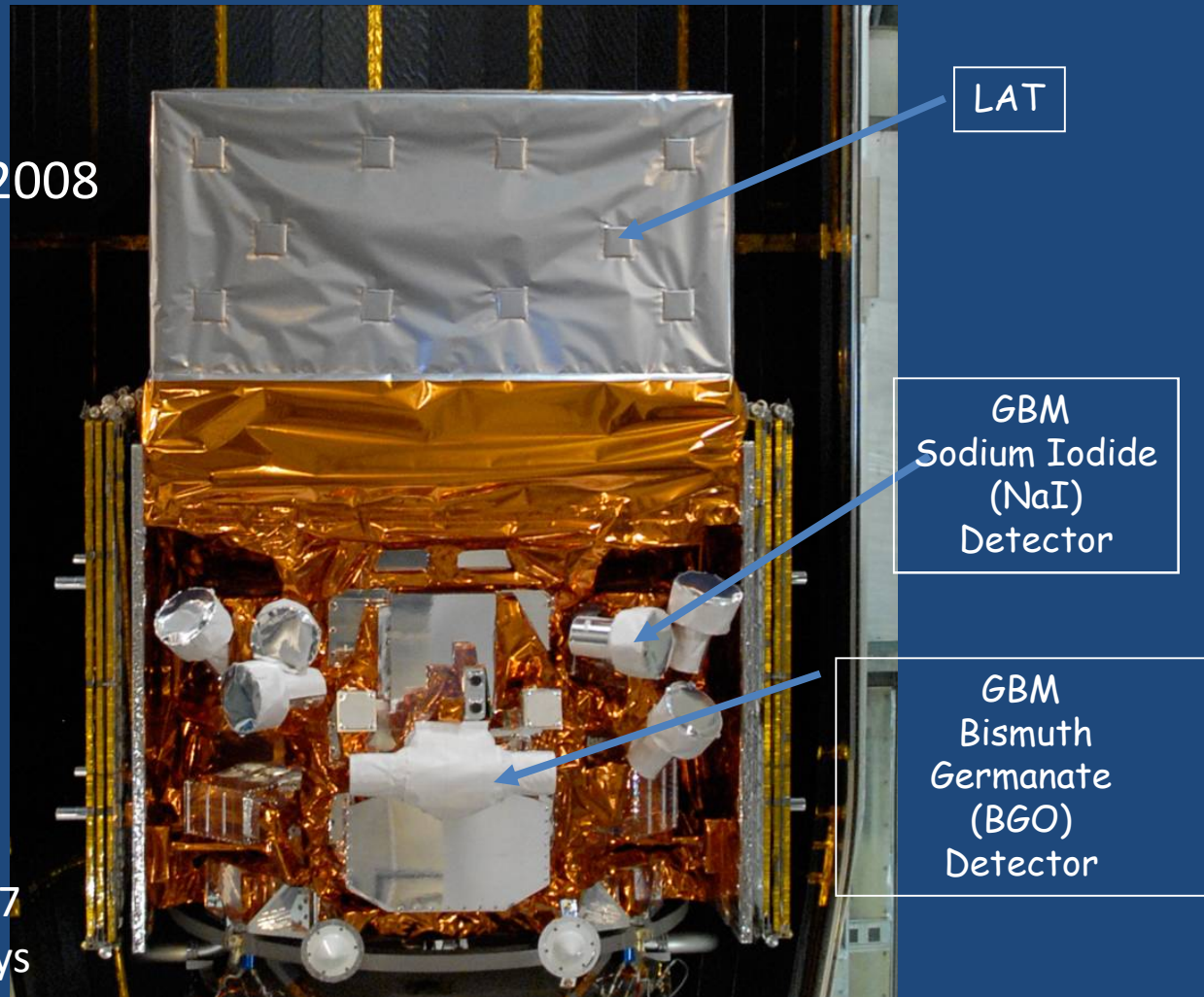
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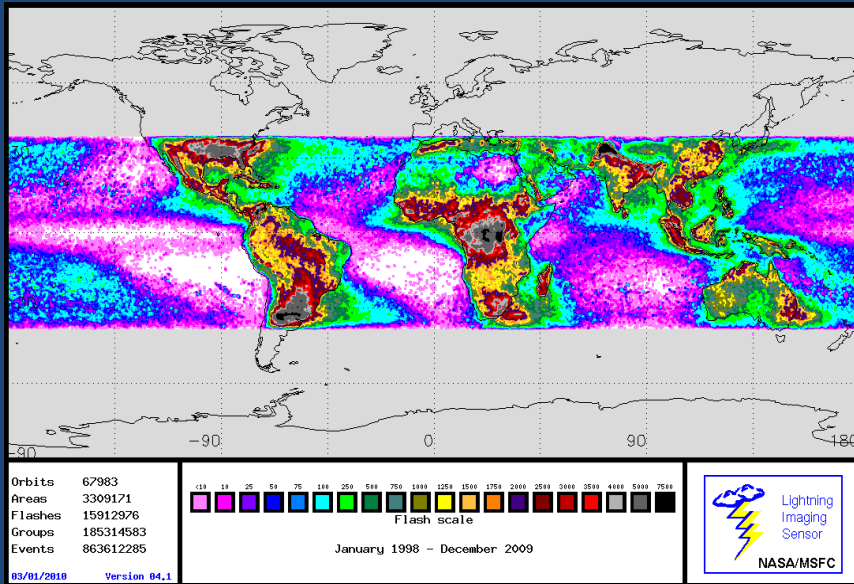
*Photo Credit: NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Laboratory (NSSL)*

# Fermi Gamma-ray Burst Monitor

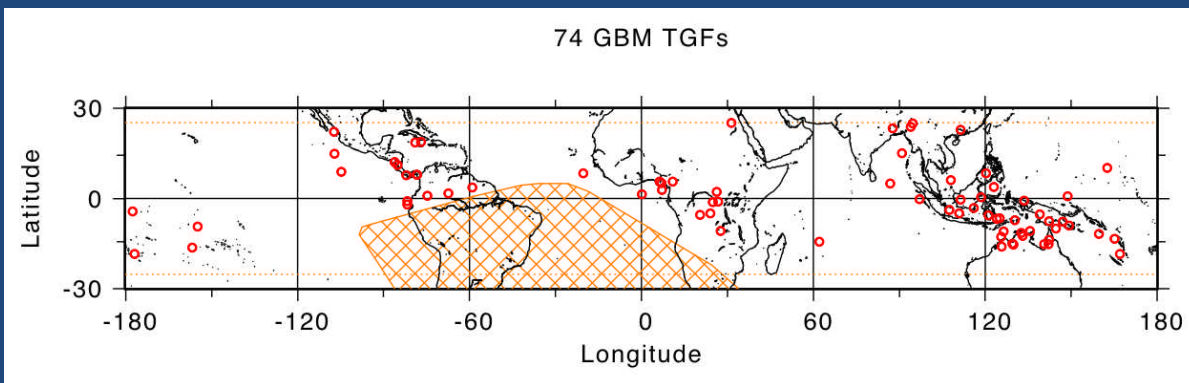
- Fermi
  - Launched June 11, 2008
  - 565 km orbit
  - 26.5 deg inclination
- GBM
  - 12 NaI detectors
    - 8 keV - 1 MeV
  - 2 BGO detectors
    - 150 keV - 40 MeV
- Triggers
  - BGO triggers for TGFs
  - Implemented Nov 2009
  - 87 TGF triggers as Aug 27
  - TGF trigger every  $\sim 4$  days



# Lightning & GBM TGF Maps



- Which comes first, lightning or TGF?
- Does one cause the other?
- Or do they have a common cause?
- Do they have a consistent time order?

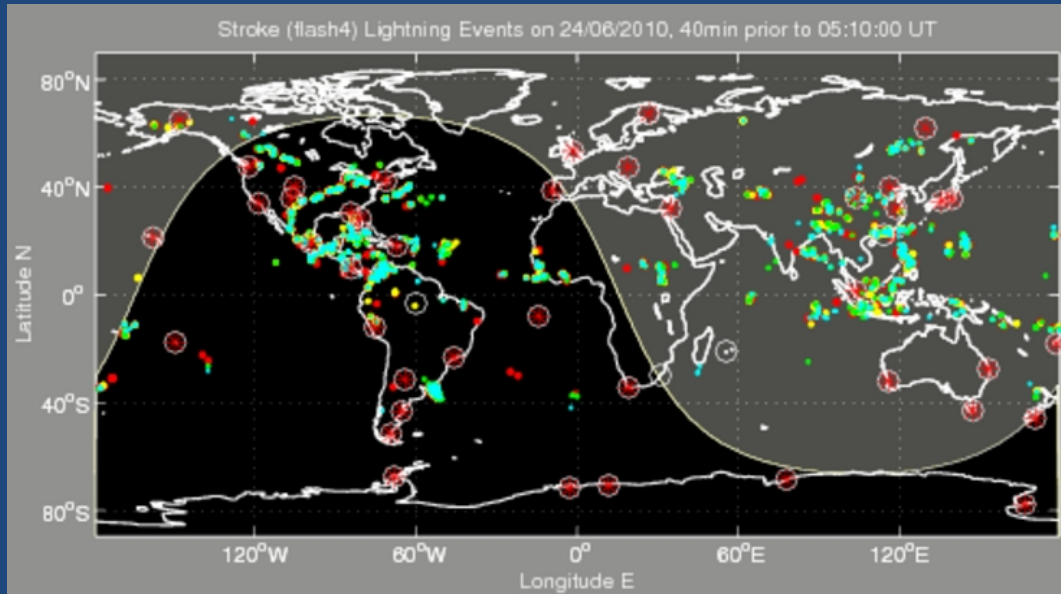


“Associations between Fermi GBM Terrestrial Gamma-ray Flashes and sferics from the WWLLN”, V. Connaughton, et al, JGR in press.



# WWLLN

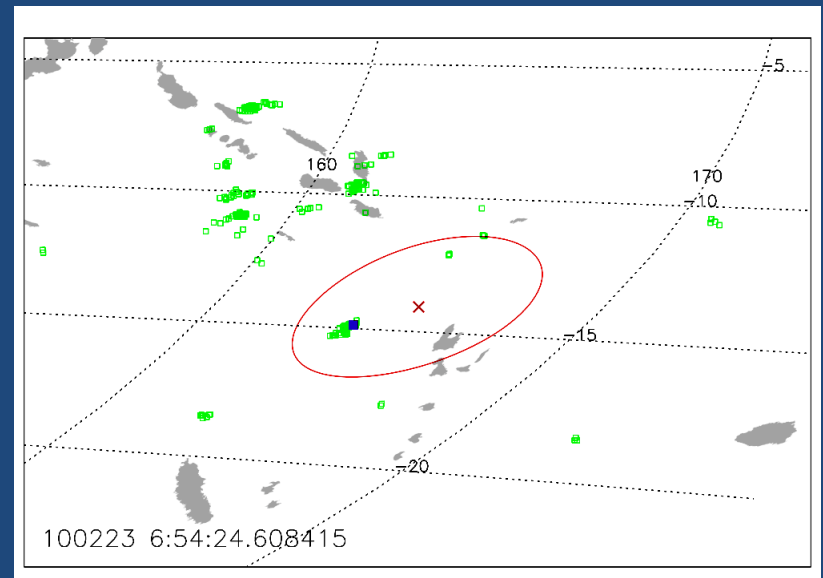
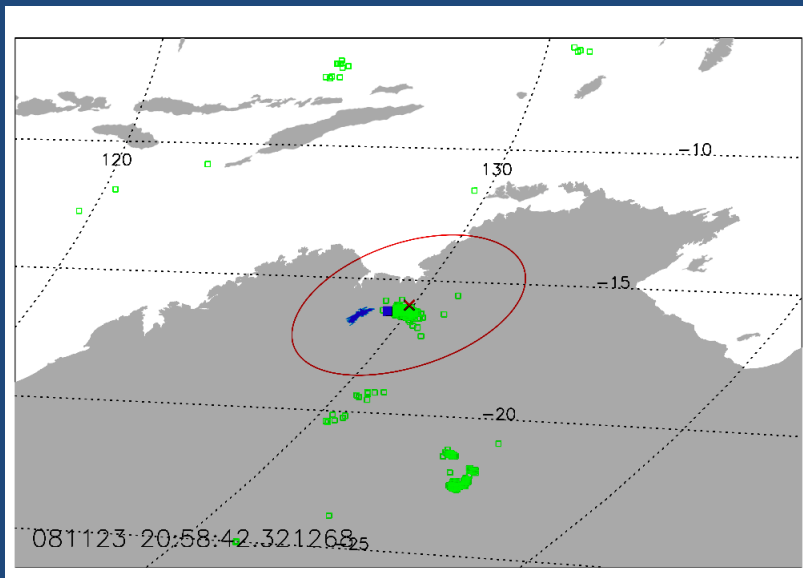
- World-Wide Lightning Location Network.
- 10% of lightning worldwide, 30% lightning with peak current  $> 30$  kA.



- Timing accuracy (with 5+ stations)  $30 \mu\text{s}$ , geolocation  $\sim 10$  km.
- No information on lightning type, discharge size, shape.
- <http://wwlln.net> headed by Bob Holzworth.

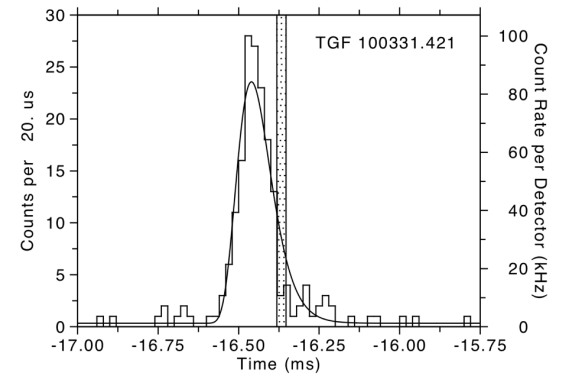
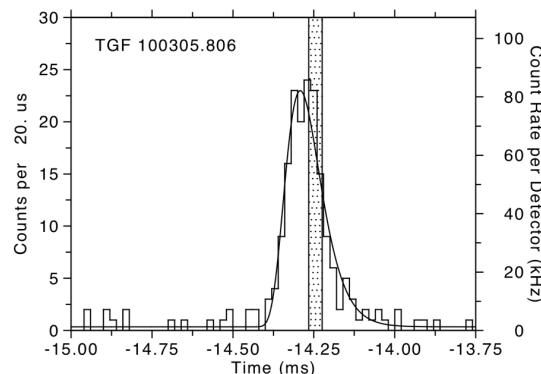
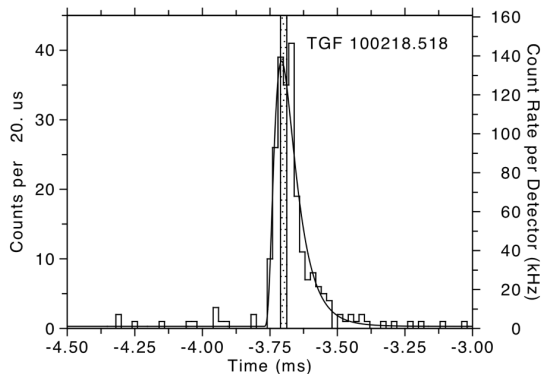
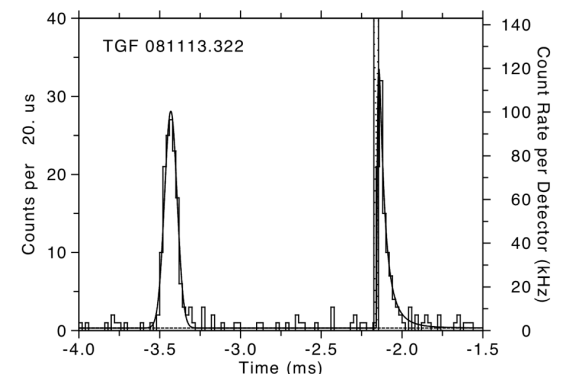
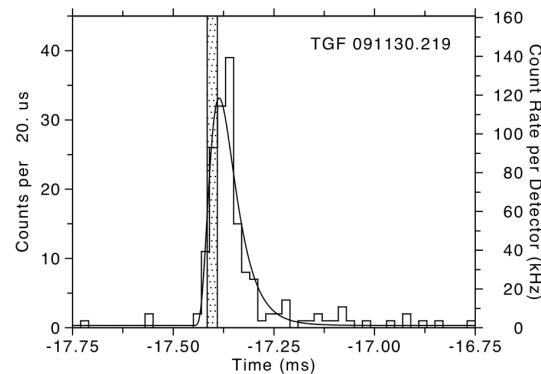
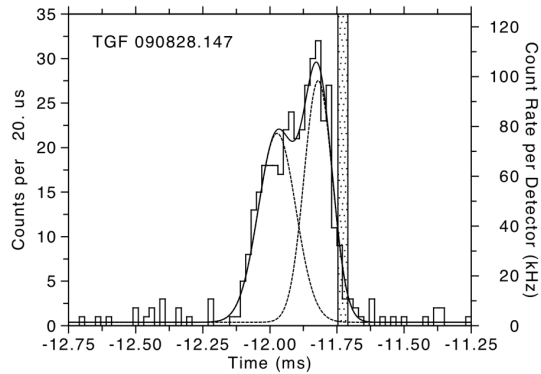
# Detection distance

- In first 50 GBM TGFs (July 2008-March 2010)
  - 30% of GBM gamma-ray TGFs have a match with individual sferic within 5 ms of TGF peak and 1000 km of sub-spacecraft position.
  - Blind searches reveal the false positive rate is very small (1-7 per 1000).
- All 15 matched sferics are within 300 km of sub-spacecraft point.



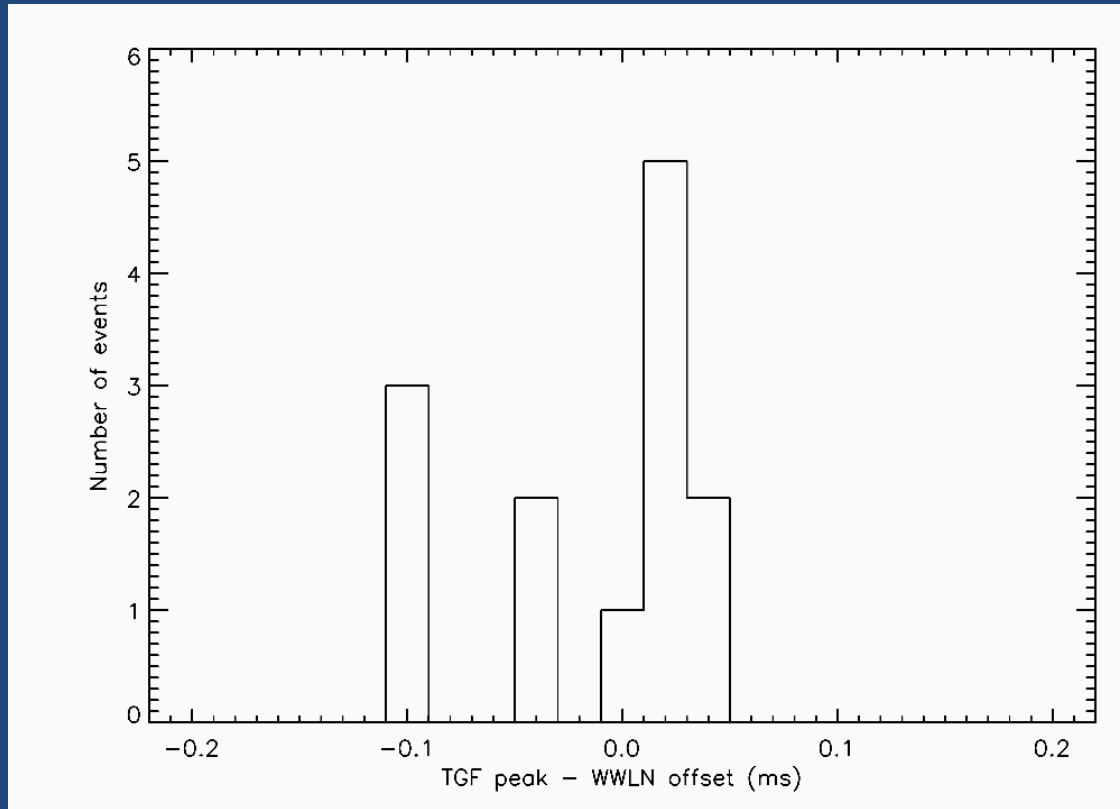
- **Red** - Fermi sub-spacecraft location with a 300 km radius
- **Green** - WWLLN lightning strokes within 10 minute of the GBM trigger time
- **Blue Square** – Exact match – sferic within 5ms and 300 km

# TGF-lightning are Simultaneous!



- GBM light curves corrected for light travel time and clock drift (histogram)
- WWLLN stroke time and uncertainty band (dotted vertical bar)

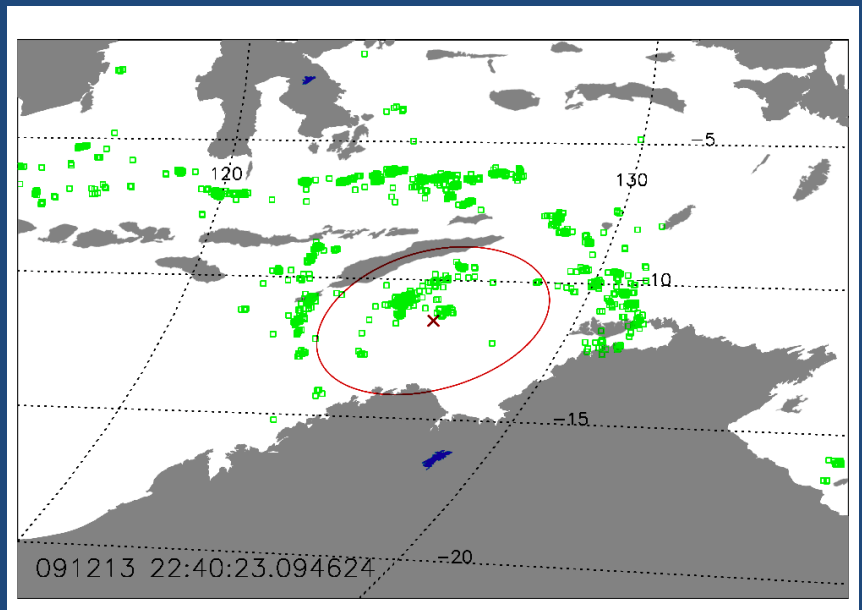
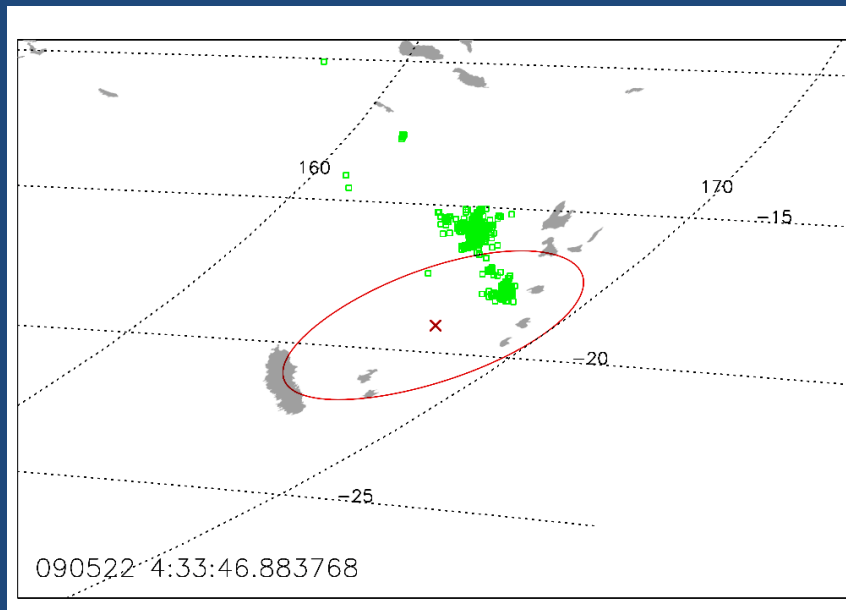
# How simultaneous?



- Peak times of simultaneous TGFs and sferics agree to within  $\sim 40 \mu\text{s}$ .
- No indication of preferred order.
- Two exceptions (not shown)
  - Within 5ms and 300km, but occur ms before or after the TGF peak.
  - Likely explanation: TGF and sferic are associated with the same storm but not with each other.

# Storms ... almost always!

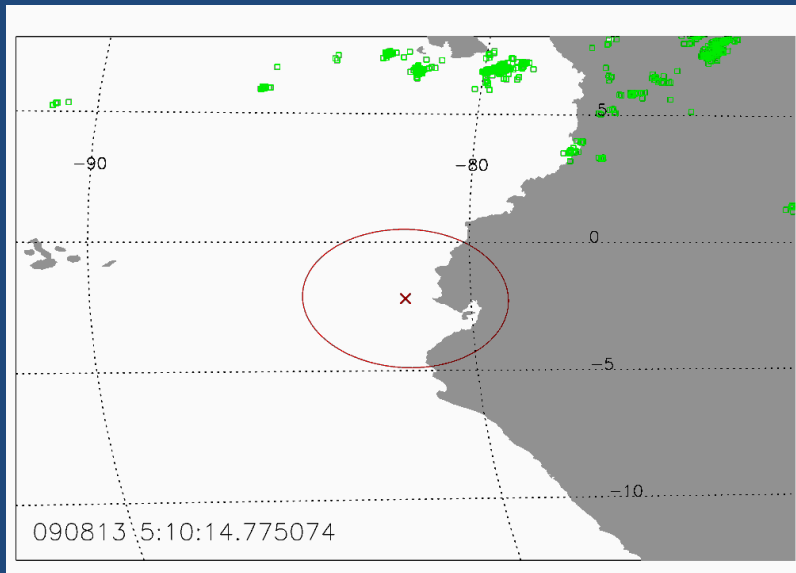
- In absence of sferic matches, (almost) always have storms within 300 km of sub-spacecraft position.
- Suggests 30 deg opening angle (including scattering) for detection from gamma-ray TGFs.



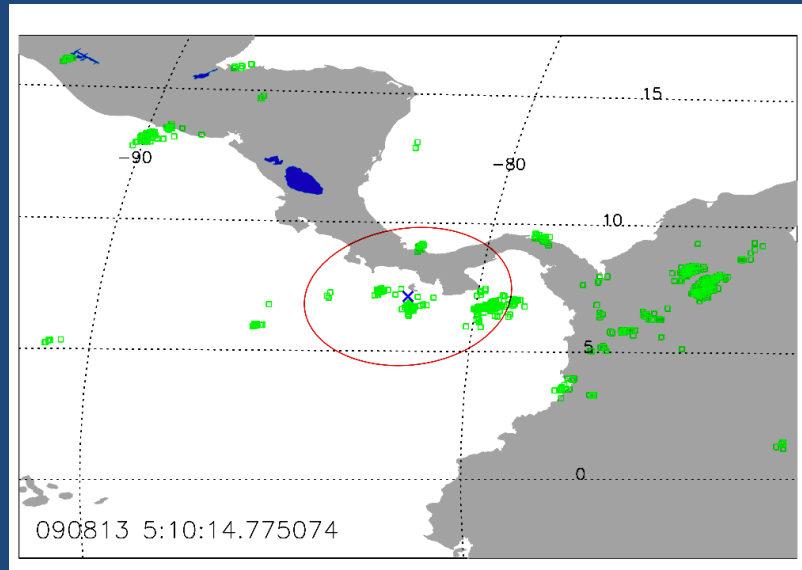


# No coincidence - no storm

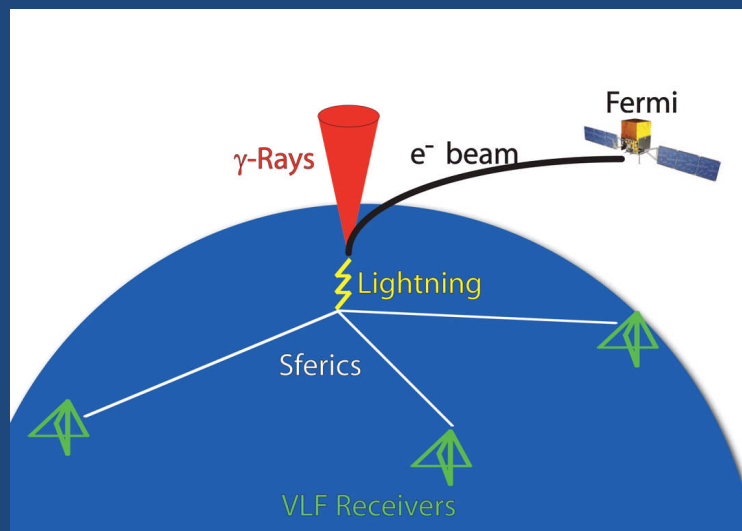
Sub-spacecraft



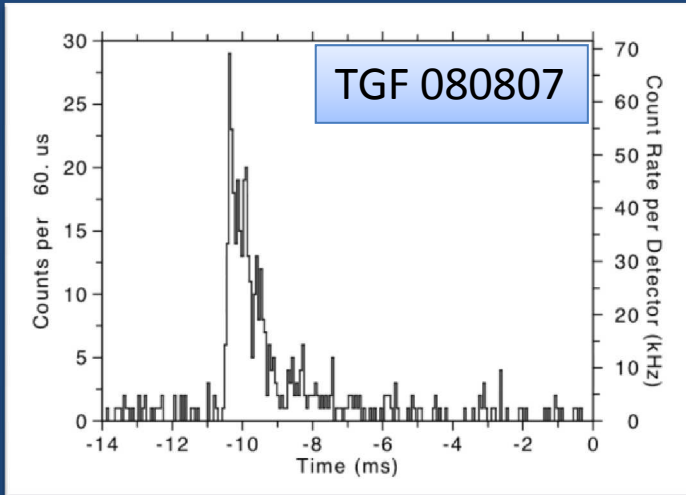
Magnetic footprint



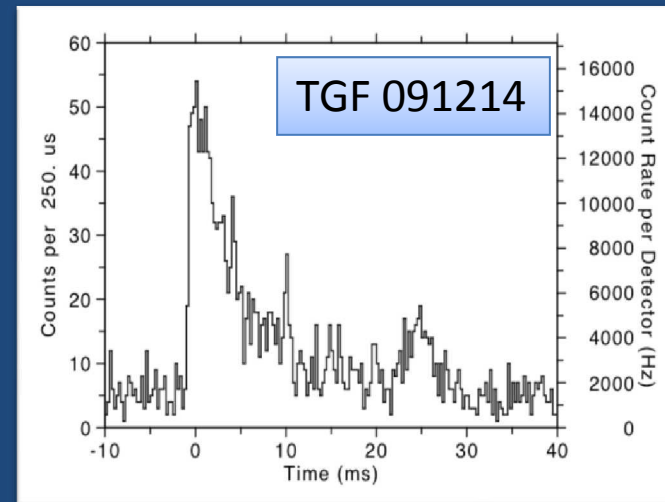
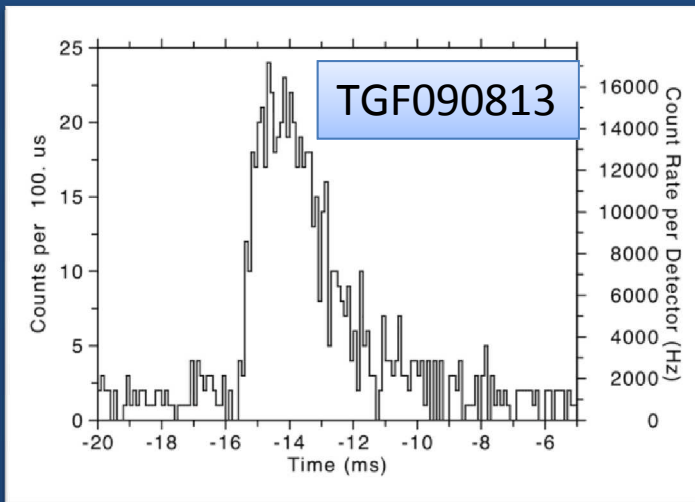
- In 3 of 4 cases with no storm under spacecraft.... storm activity at one of the geomagnetic footprints. All 4 cases look like electron TGFs.



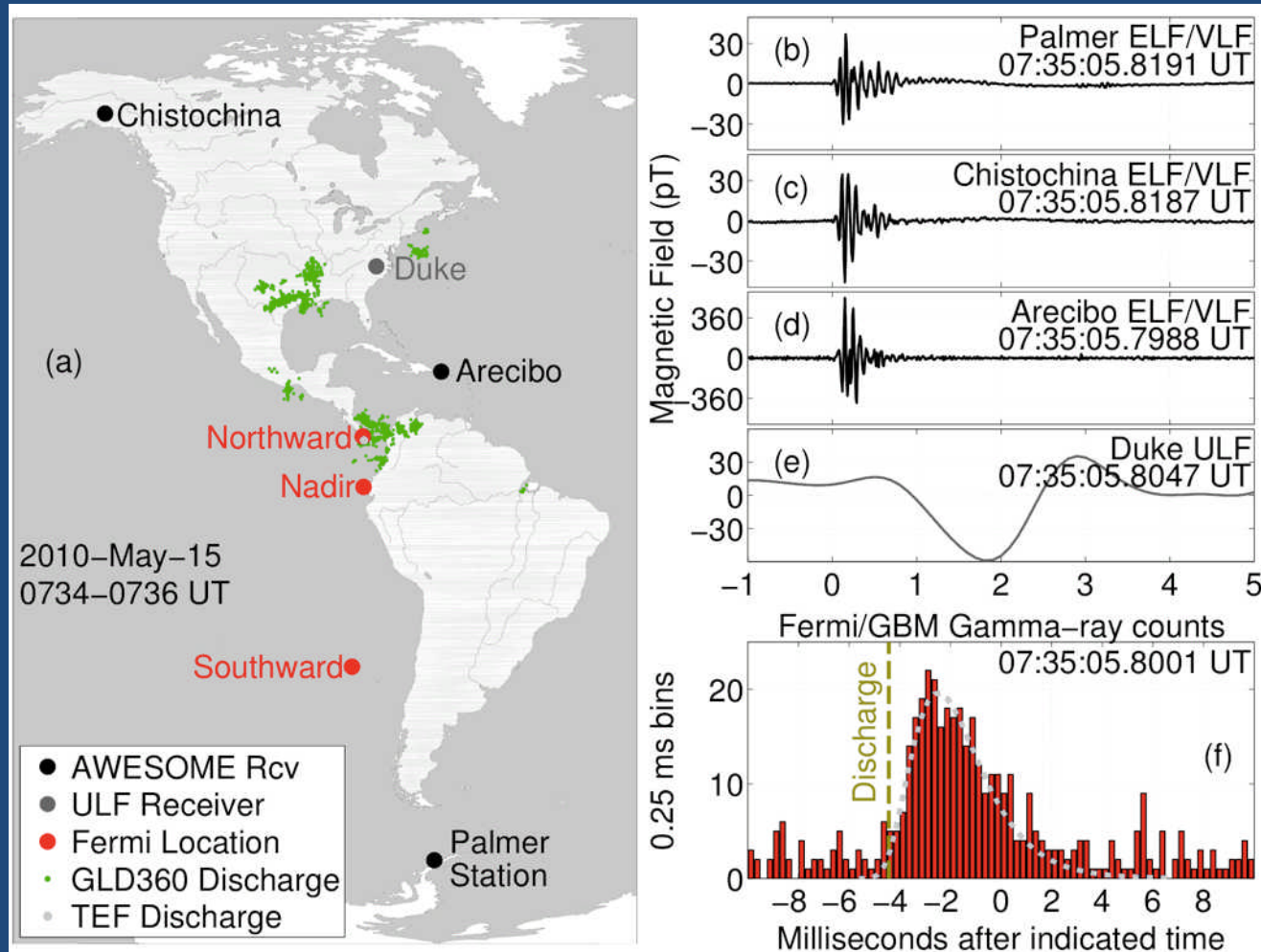
# Electron TGFs with GBM



- 4 seen to date with GBM
- Long duration ( $> 1\text{ms}$ )
  - Electrons with low pitch angles arrive at spacecraft first
- Low maximum energy  $\approx 10\text{ MeV}$
- Lightning activity within 50 km of magnetic footprint.



# Sferic with Electron TGF!



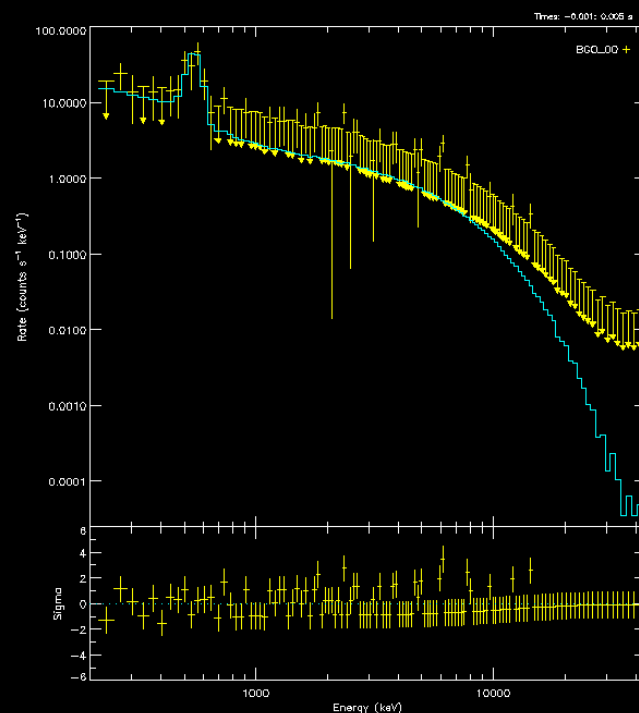
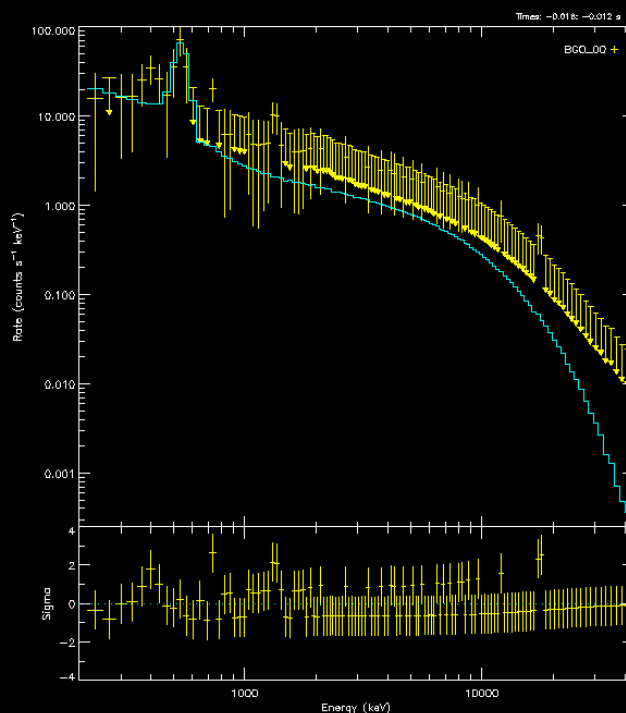
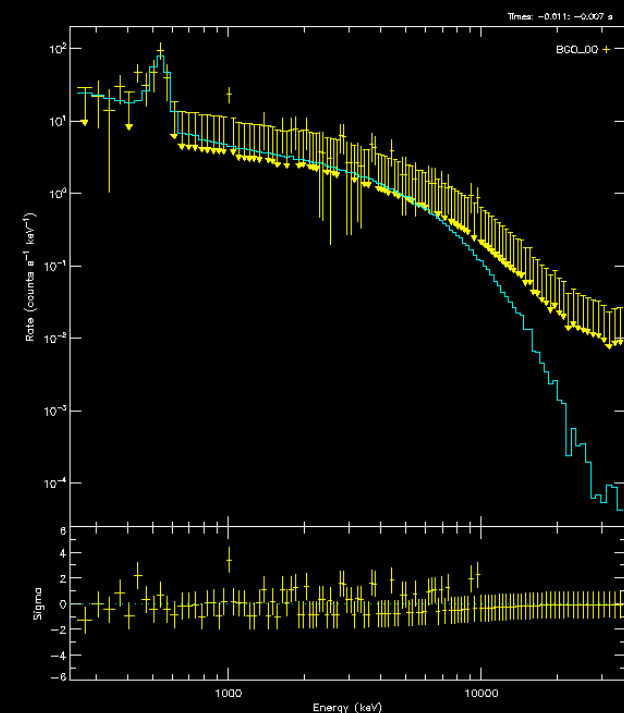
Cohen et al. 2010, to appear in GRL.

# Positron Features Detected with GBM

TGF 080807

TGF 090813

TGF 091214



- Spectra fitted by separately simulating electrons and positrons along the field lines.
- Fits require both electron and positron components
- Exponential continuum spectrum with Ecutoff=2-4 MeV.

# Summary

- TGFs and lightning are simultaneous with no preferred order.
- This supports lightning leader models for TGFs.
- GBM detects gamma-ray TGFs within 300 km of Fermi's sub-spacecraft location.
- GBM detected electron TGFs within ~50 km of geomagnetic footprint.
- Positron features detected with GBM from electron TGFs are direct evidence for relativistic phenomena in Terrestrial lightning.



# GBM TGF Papers

- “First Results on Terrestrial Gamma-ray Flashes from the Fermi Gamma-ray Burst Monitor”, M. S. Briggs, et al., J. Geophysical Res., in press,
- “Associations between Fermi GBM Terrestrial Gamma-ray Flashes and sferics from the WWLLN”, V. Connaughton, et al, to appear in JGR,
- “Catalog of Terrestrial Gamma-ray Flashes from the Gamma-ray Burst Monitor on the Fermi Observatory”, G. J. Fishman, in preparation,
- “Positrons observed from Terrestrial Lightning with Fermi GBM”, M. S. Briggs, et al., in preparation,

[http://gammaray.nsstc.nasa.gov/publications/tgf\\_journal.html](http://gammaray.nsstc.nasa.gov/publications/tgf_journal.html)