Recent results on TGF Observations with Fermi GBM

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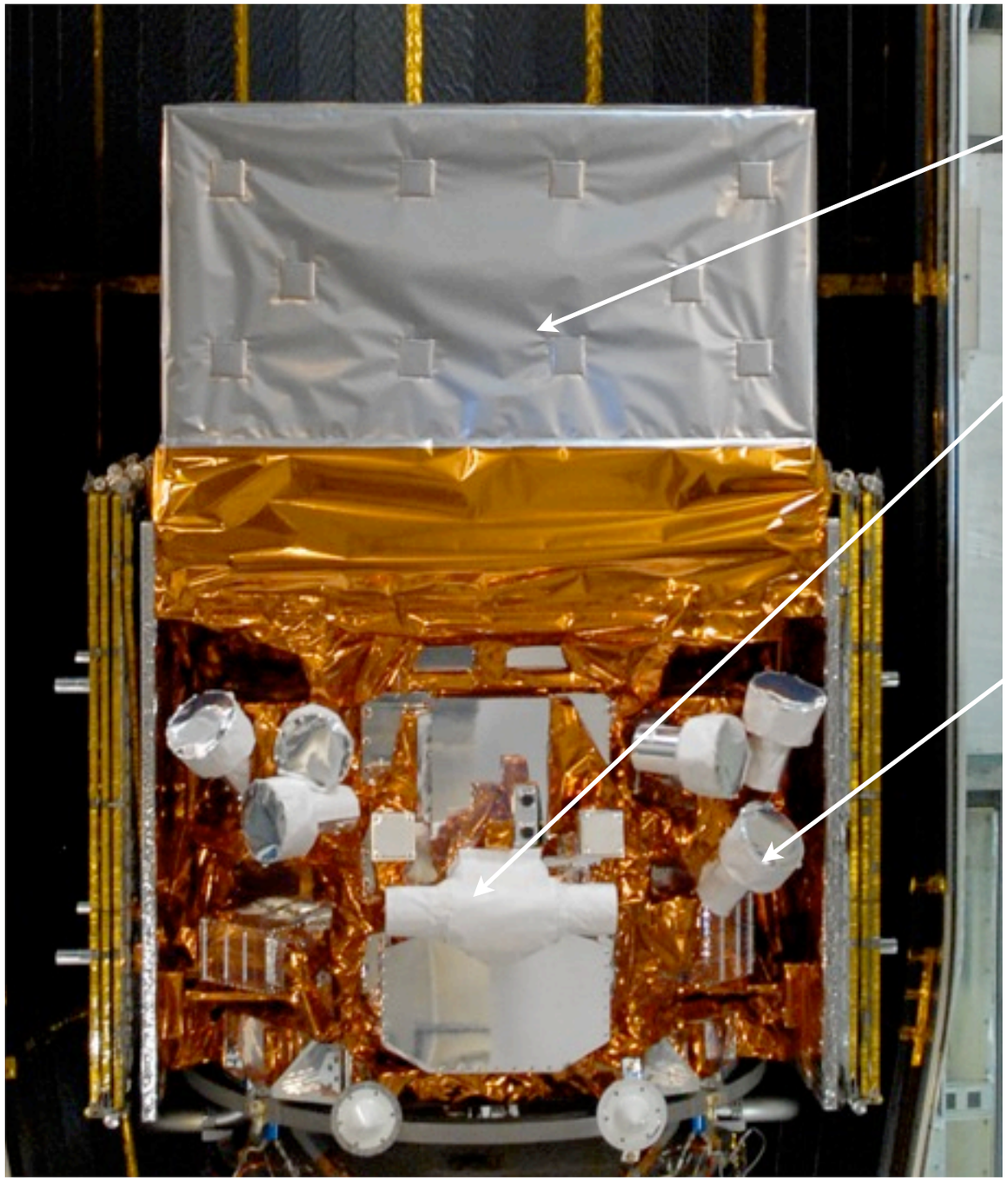
(USRA) in lieu of Michael Briggs (UAH)

Fermi detects TGFs with both GBM and LAT in connection with particle acceleration in the electric fields associated with thunderstorms

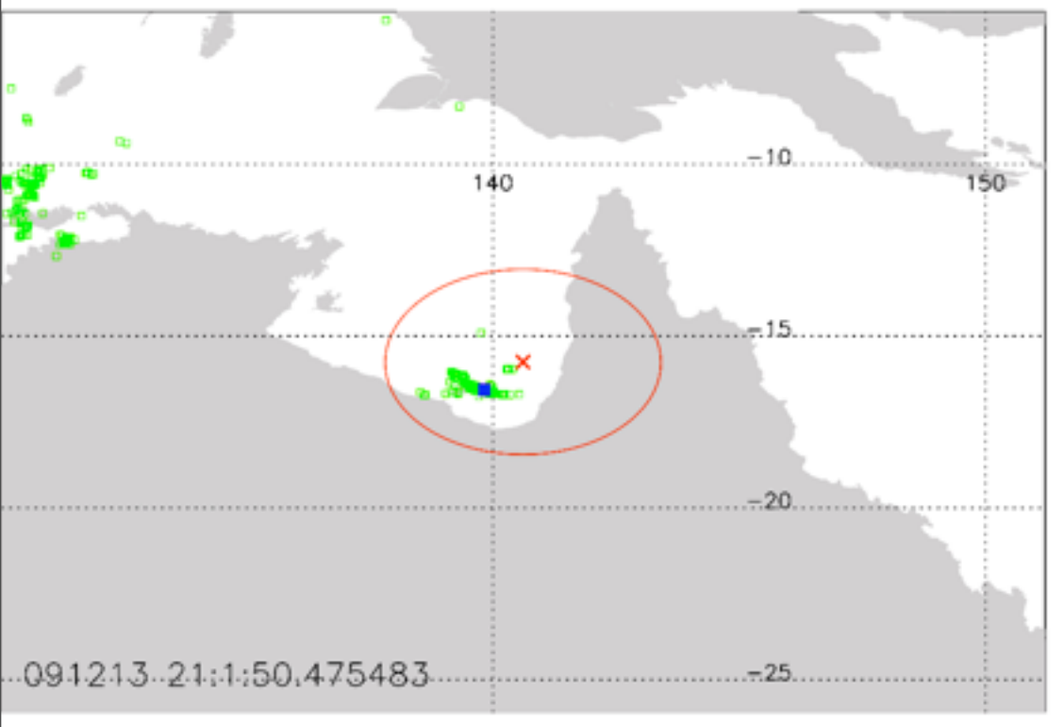


Fermi Large Area Telescope (LAT)
> 20 MeV, > 100 MeV

GBM BGO detector.
200 keV -- 40 MeV
126 cm^2, 12.7 cm

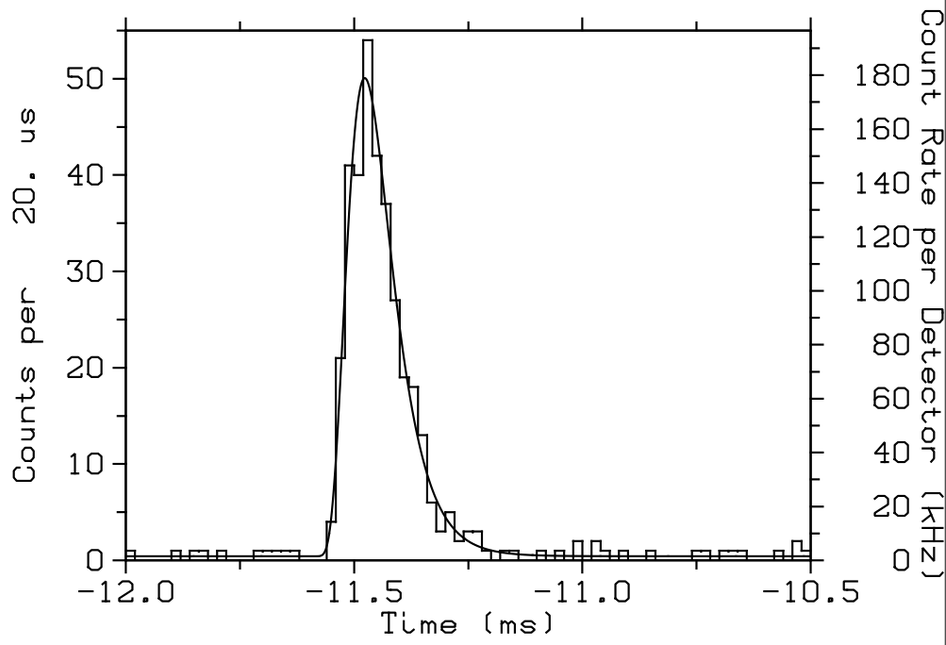
GBM NaI detector.
8 keV -- 1000 keV
126 cm^2, 1.27 cm

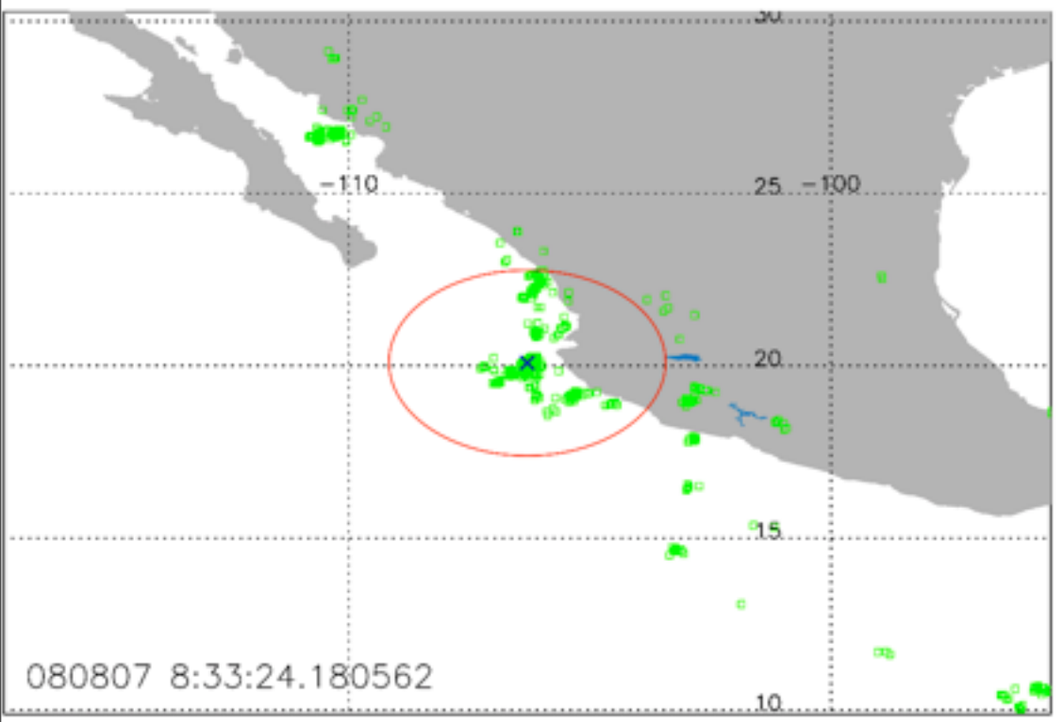
TGFs can be detected by GBM from under the spacecraft or at a distance



Storm under Fermi

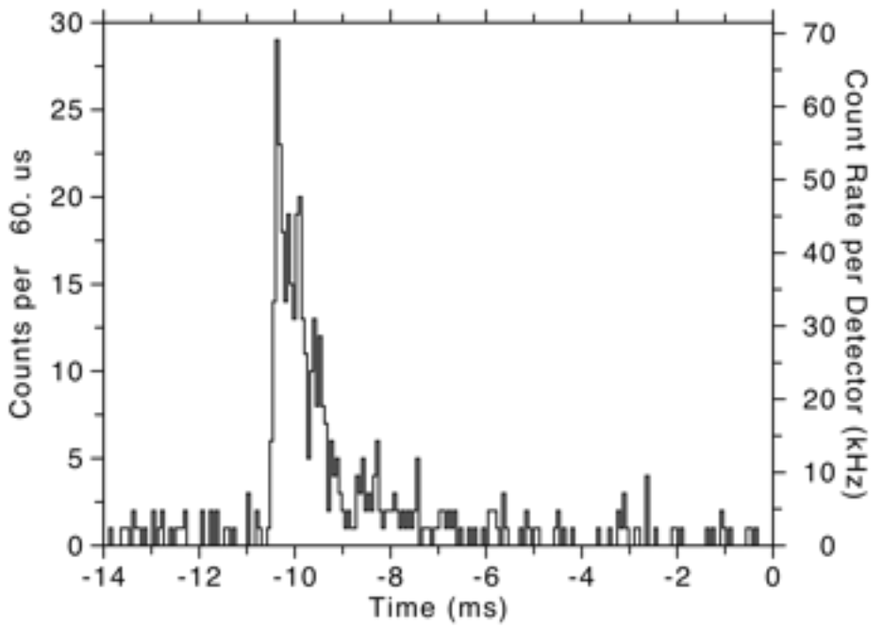
Short TGF =
γ-ray TGF



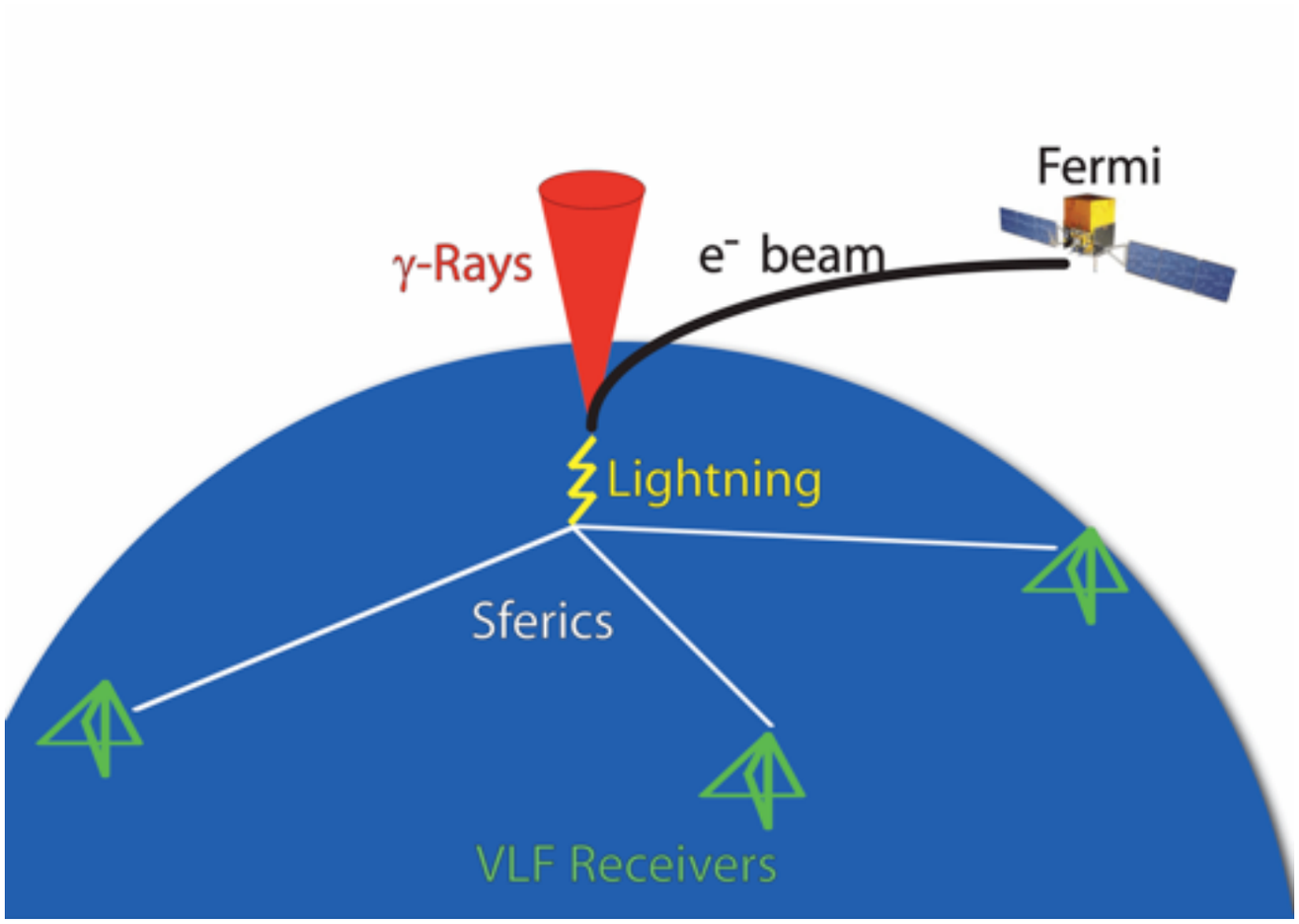


Storm at magnetic footprint

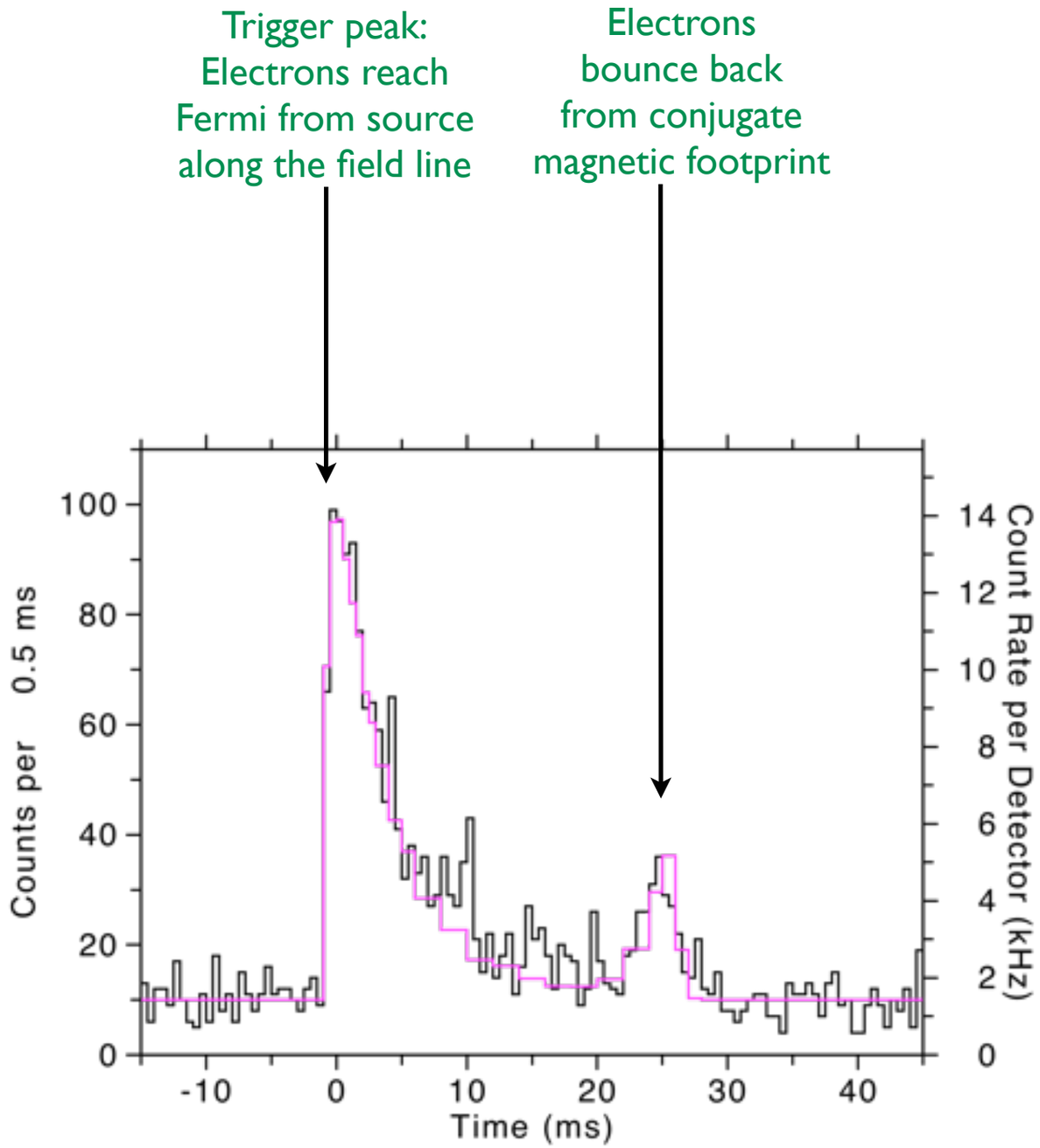
Long TGF =
e⁻ beam TGF

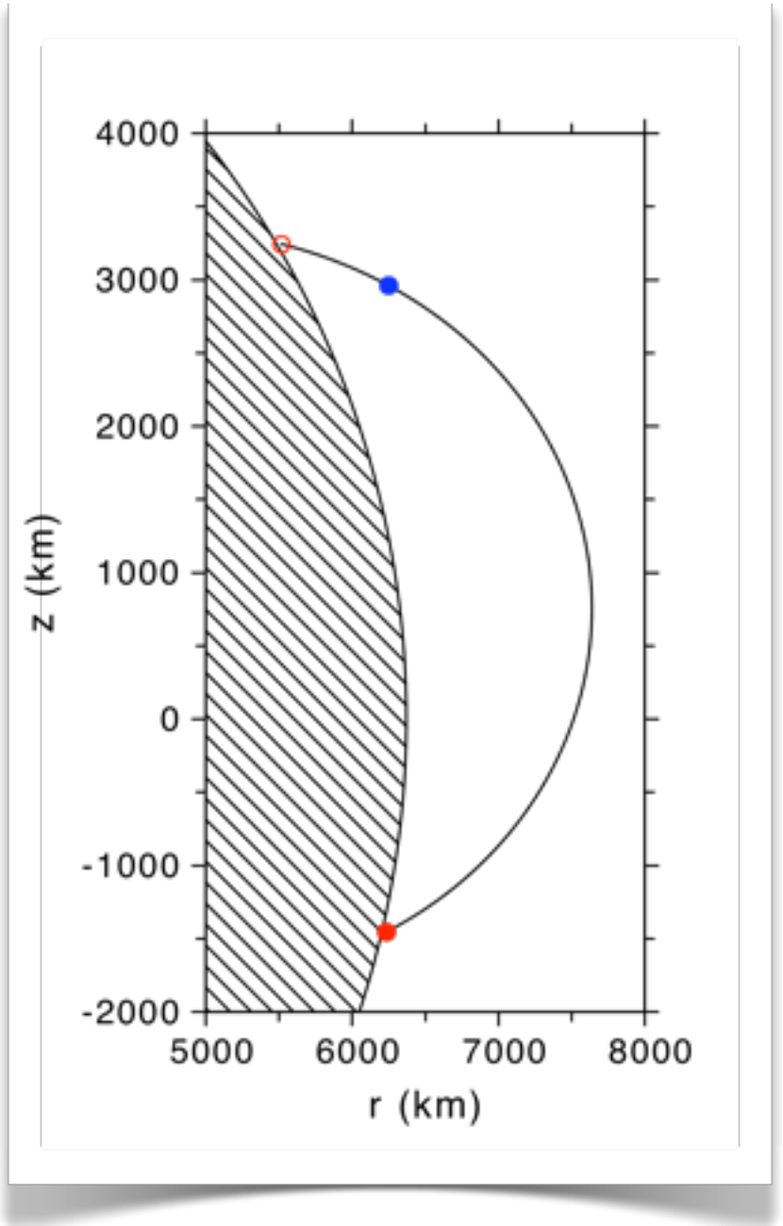


TGFs can be detected in gamma rays when Fermi is above the source or in electrons when Fermi is magnetically connected to the source

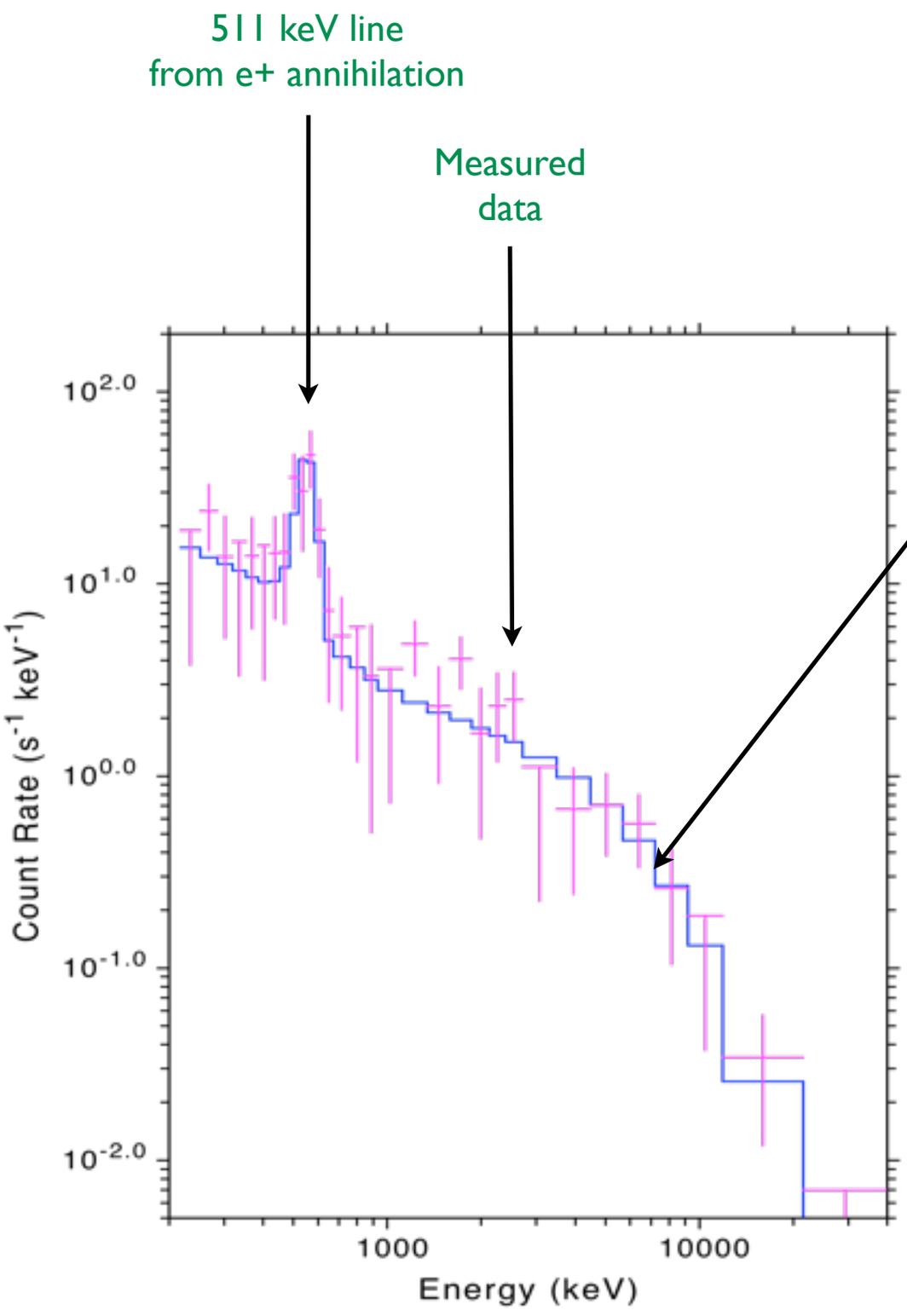


Electron TGFs can have a secondary peak through magnetic mirroring of the electrons





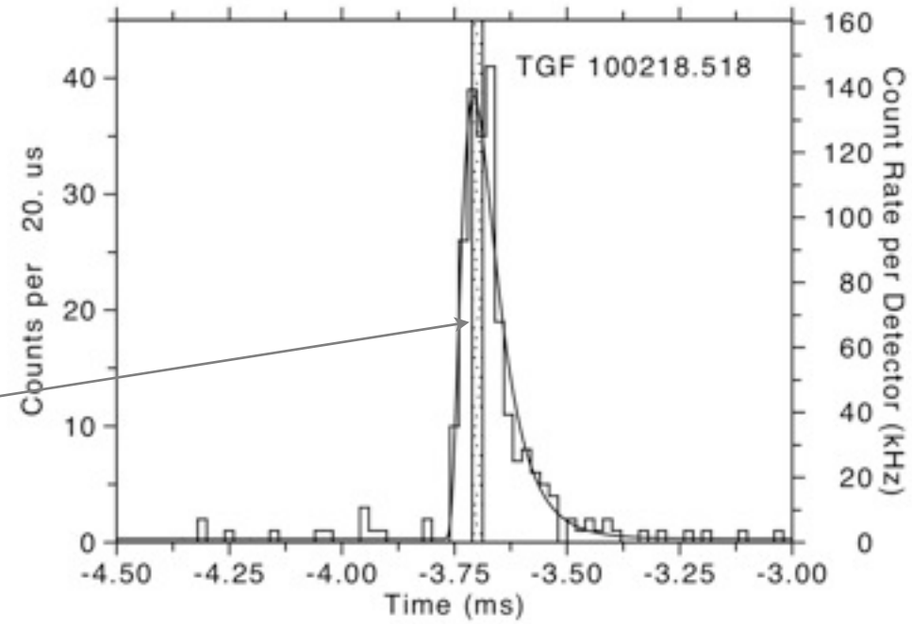
Electron TGFs have a positron component of ~20% - thunderclouds in our atmosphere generate antimatter!



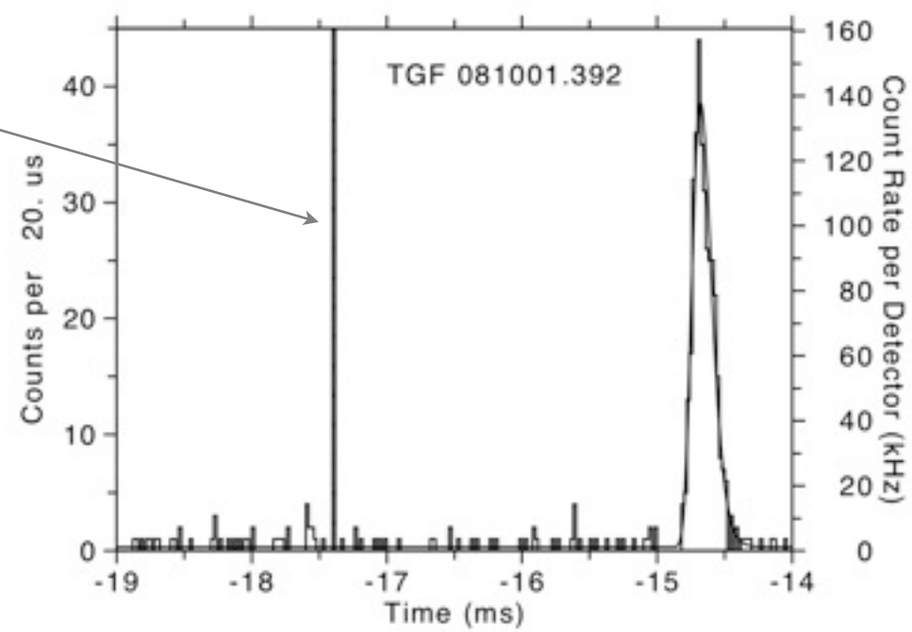
Briggs+ GRL 2010

Is there a causal relationship between TGFs and lightning?
In the first 50 GBM TGFs, 15 have associations (5 ms, 1000 km) with WWLLN events - all within 300 km of the Fermi nadir.

13/15 WWLLN discharges simultaneous with TGF peak.



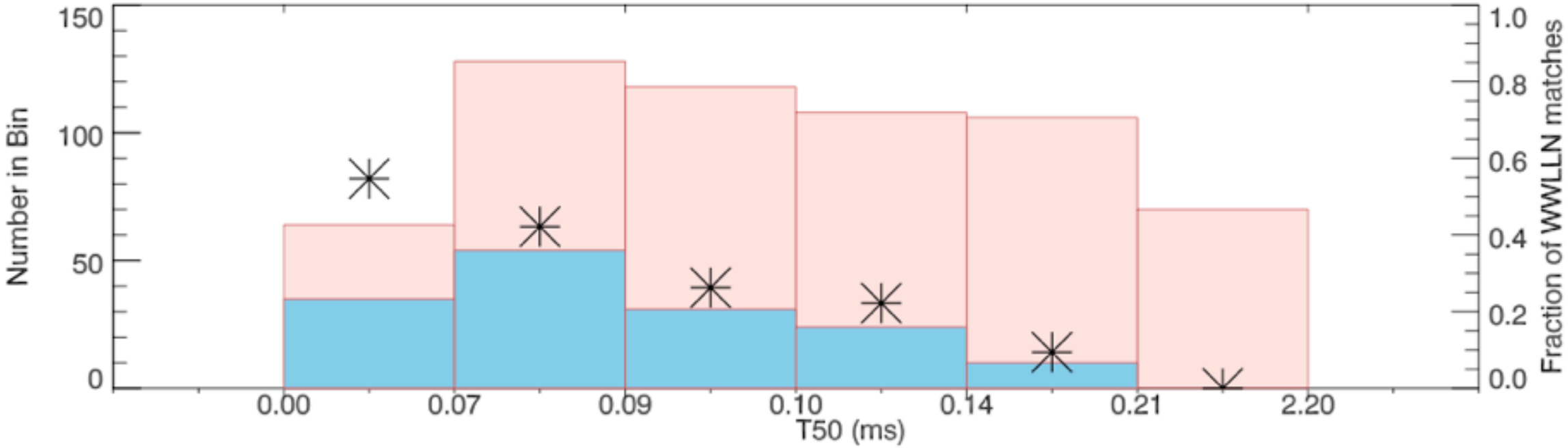
... but 2 are ms away, either side of TGF pulse



VC+ (2010)

The VLF signal from TGFs depends on TGF duration: short TGFs are much more likely to have a detectable VLF signal

VC+ (2012)



594 TGFs (triggered + offline)

154 TGFs with a simultaneous WWLLN discharge

Asterisks show VLF match rate as a function of TGF duration

Currents in TGFs: what is the expected signal?

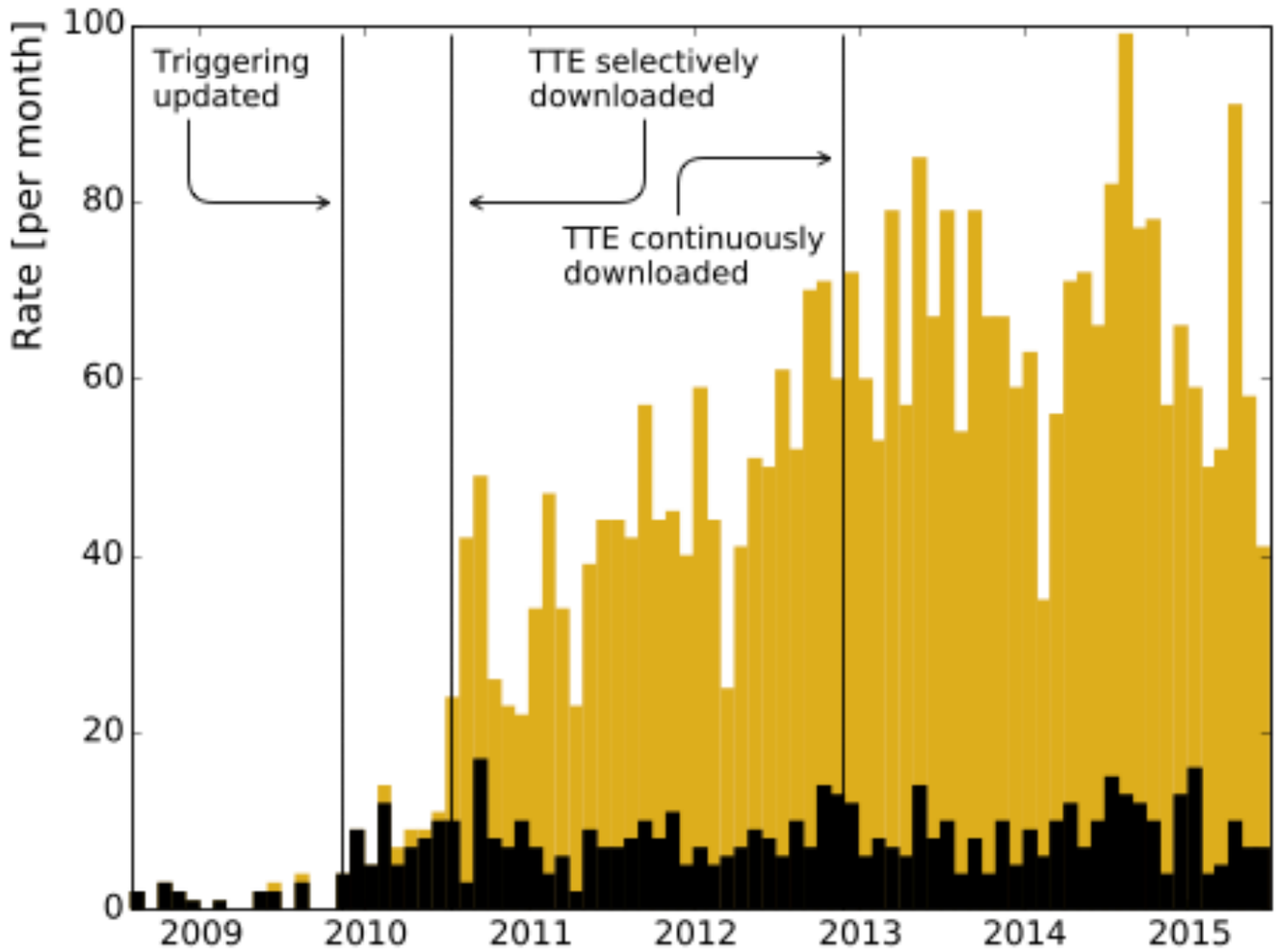
$$I_{mom} = \frac{e\alpha\tau_a\mu_e E N_{re}\Delta z}{\sqrt{2\pi}0.74T_{50}}\exp\left(\frac{-\mathrm{t}^2}{2(0.74\mathrm{T}_{50})^2}\right)$$

$$E(\omega) = -i\omega\frac{e\alpha\tau_a\mu_e E N_{re}\Delta z\sin\theta}{\sqrt{2\pi}4\pi\varepsilon_0 c^2 R}\exp\left(\frac{-\omega^2(0.74\mathrm{T}_{50})^2}{2}\right)$$

VC+ (2012)

- Current is generated by the low-energy drift electrons
- Total current larger for short TGFs
- Energy radiated in observer bandpass depends on duration
- Dark lightning - no optical emission (Dwyer, Liu & Rassoul 2013)

With increasingly sensitive searches, GBM now detects ~850 TGFs each year



The 2nd GBM TGF Catalog is here!

http://fermi.gsfc.nasa.gov/ssc/data/access/gbm/tgf/

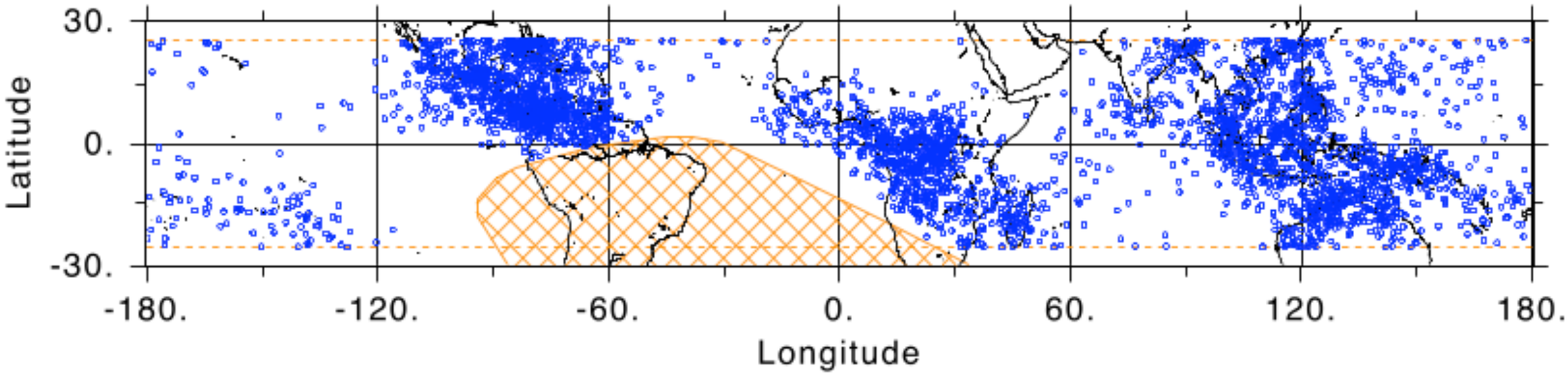
Fitzpatrick, et al., in preparation

- Offline search: 3348 TGFs,
- Triggered TGFs: 579 TGF, with 8 that are not the Offline Search Table,
- Terrestrial Electron Beams (TEBs): 16 reliable, 8 possible,

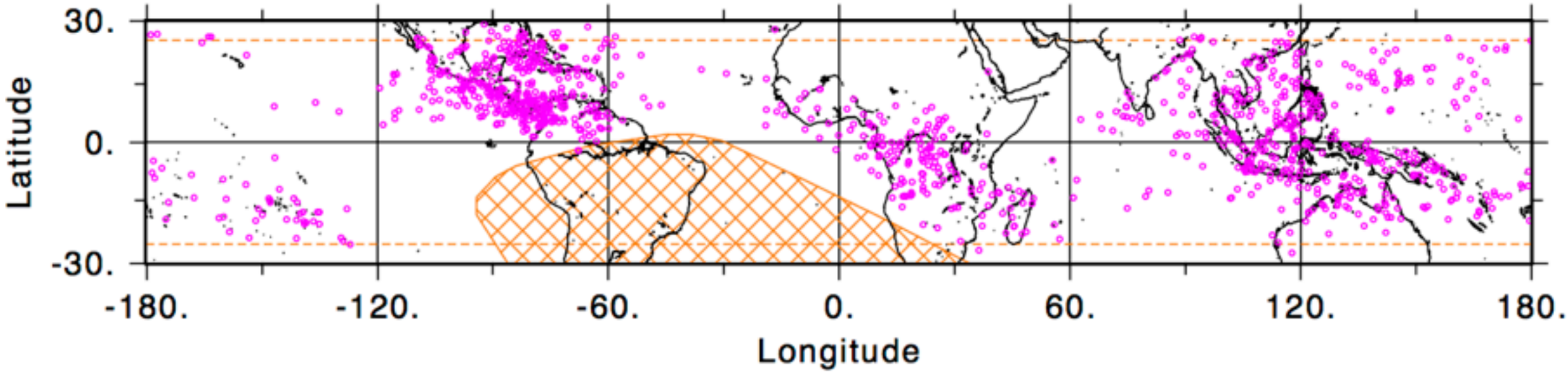
VLF geo-locations from WWLLN for 1049 TGFs!

VLF signals of TGFs provide ~10km geo-location

Sub-spacecraft positions



VLF geo-locations

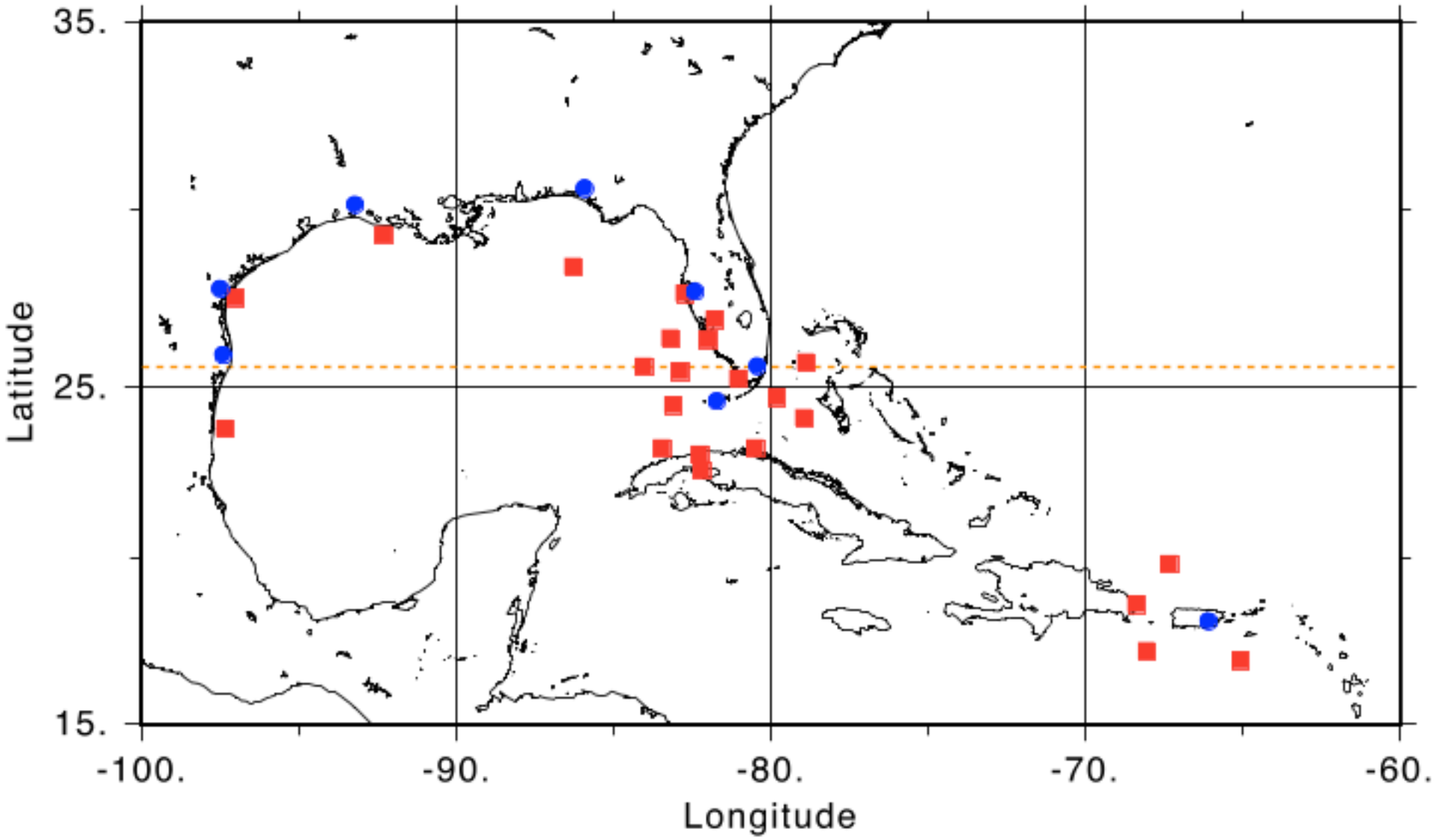


GBM confirms TGF/lightning ratio is not constant over the Earth

Region	Ratio
Average	$(3.8\pm0.2) \times 10^{-4}$
Americas	$(4.9\pm0.3) \times 10^{-4}$
Africa	$(2.3\pm0.2) \times 10^{-4}$
Asia	$(2.7\pm0.4) \times 10^{-4}$
Australia	$(8.6\pm1.0) \times 10^{-4}$

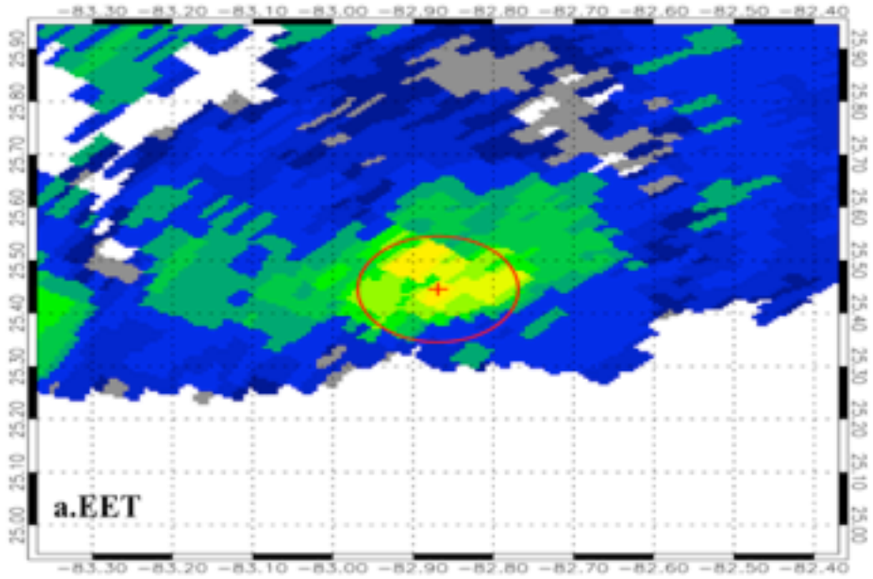
TGF geo-locations mostly favor coastal regions in Americas and Asia. Is Africa different?

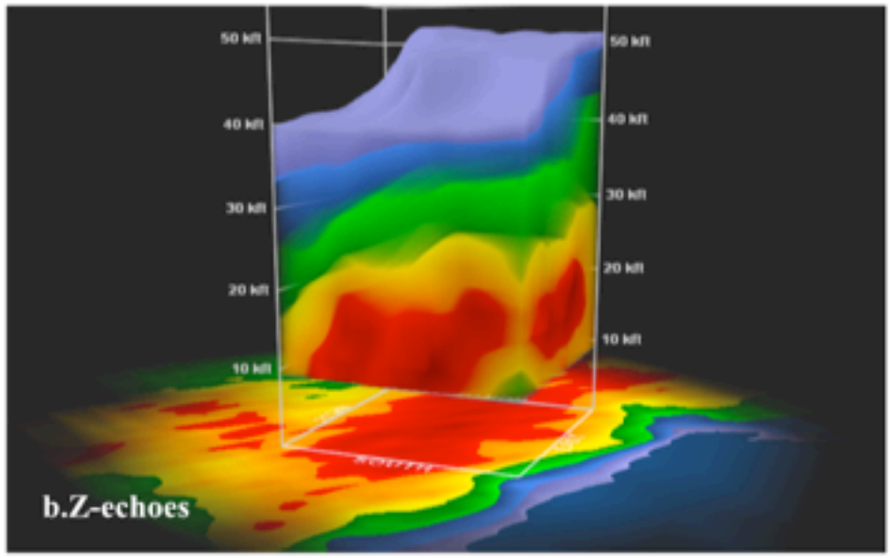
TGF-producing storms:
Observing TGF locations (red) with NEXRAD Doppler Weather radars (blue)



Chronis et al. (2015)

NEXRAD radar: Enhanced Echo Tops (EET) and radar reflectivity (dBZ)





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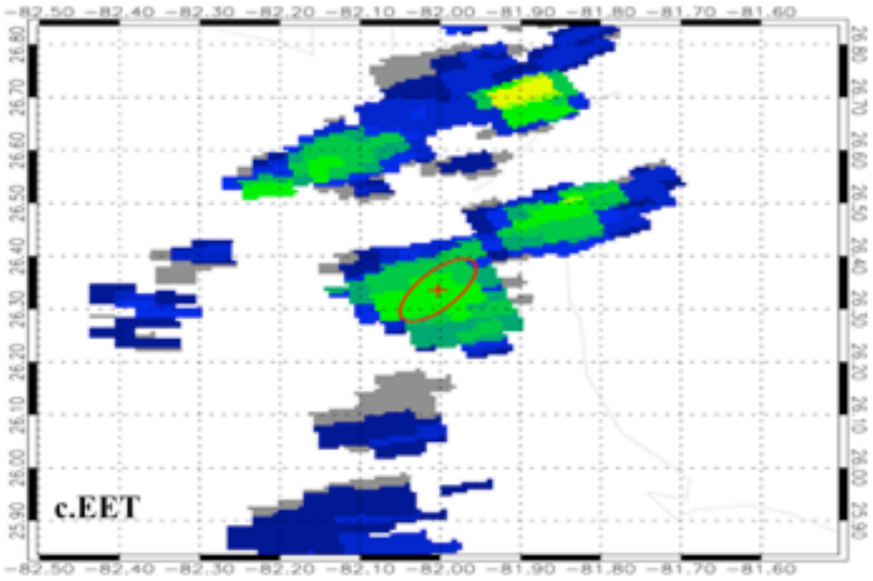
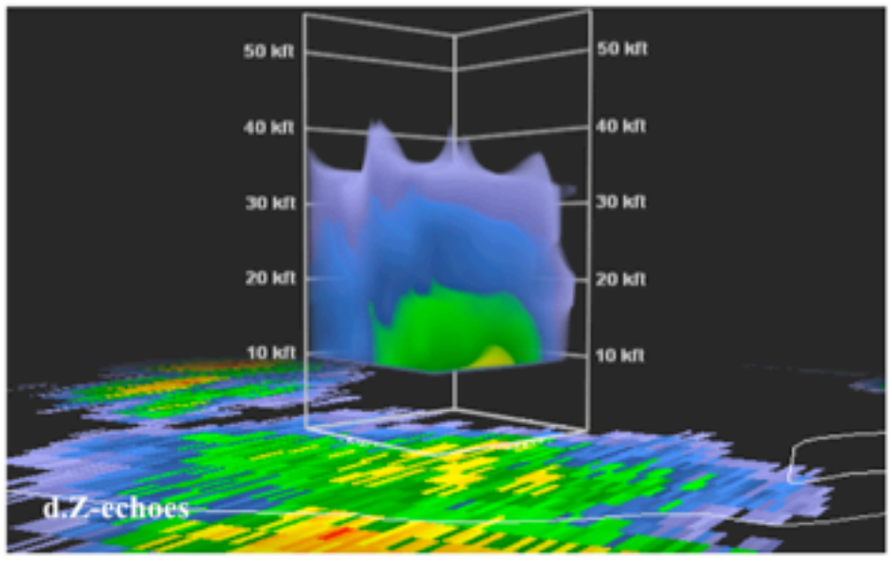
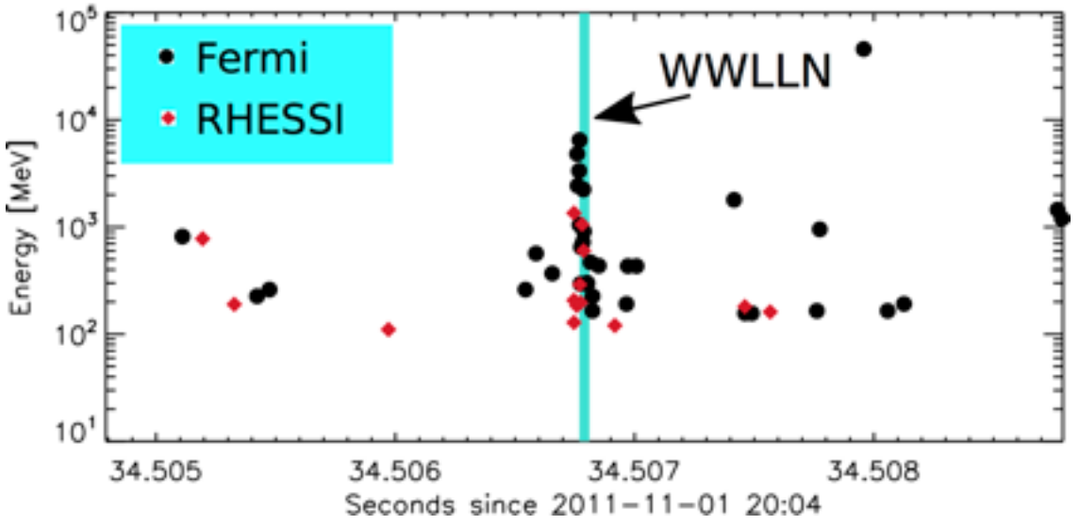




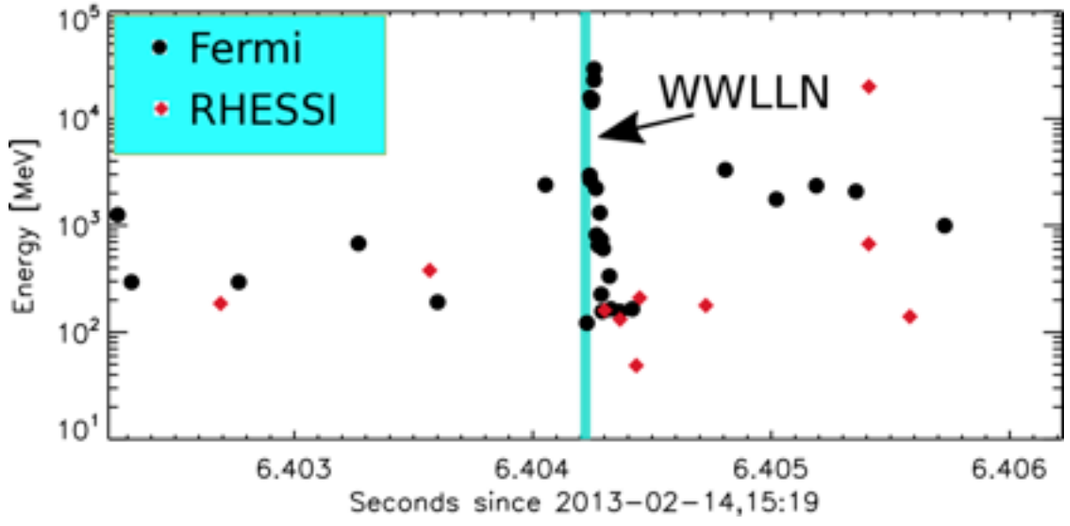
- Storms of diverse convective strengths produce TGFs
- There is always a region of high cloud top in VLF error box

Use of online catalog uncovered matches with RHESSI TGFs!

2011-11-01



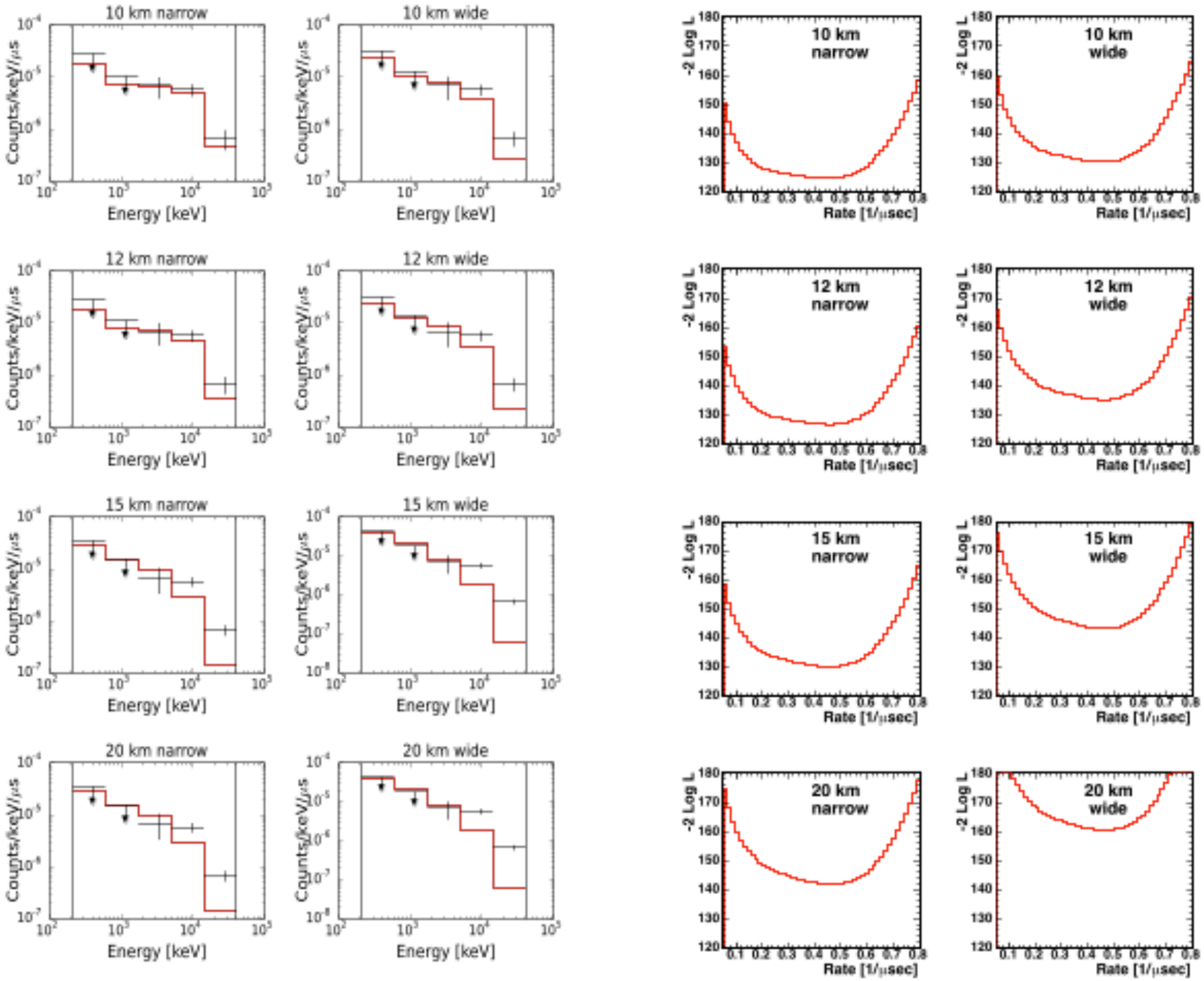
2013-02-14



2014-03-14

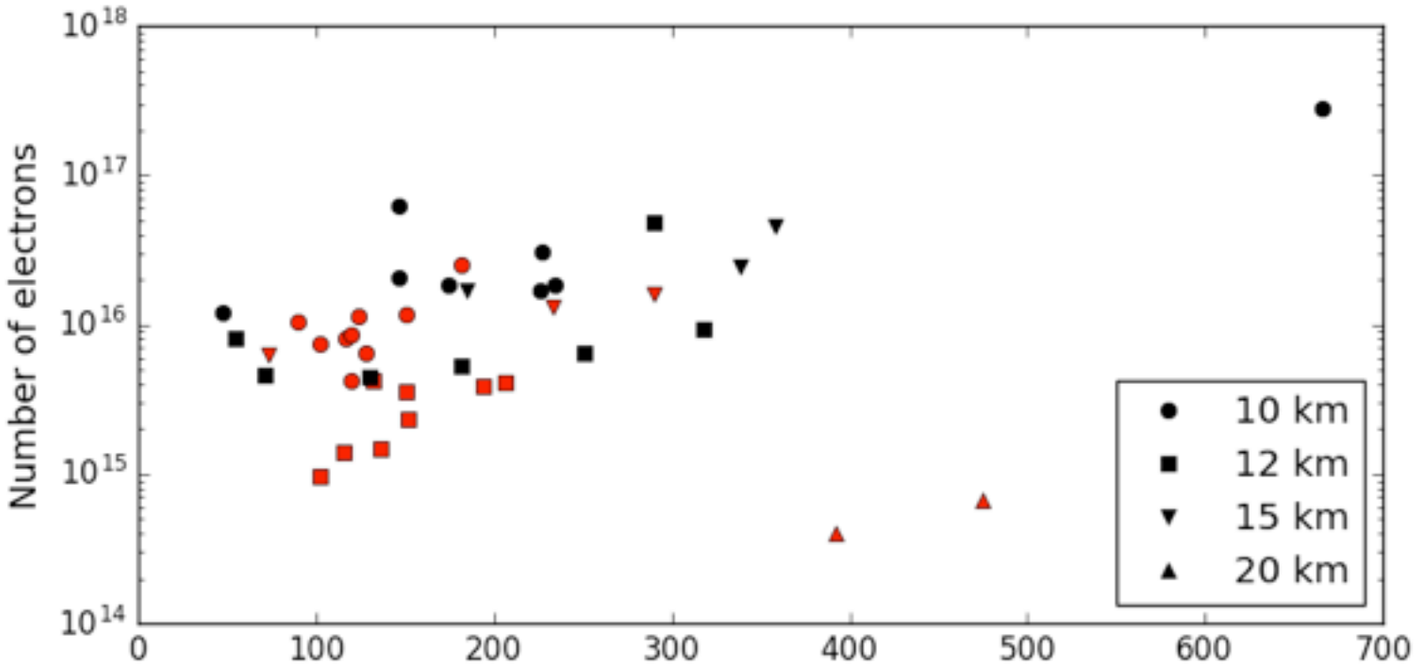
- Thomas Gjesteland finds 3 TGFs with GBM, RHESSI, and WWLLN VLF locations!

Spectral analysis of 46 TGFs shows diversity of favored source height and beaming angle - can use to distinguish between acceleration models (leader vs large-scale field)



TGF100909539: Narrow-beam at low altitude is preferred.
The actual fits are performed using Poisson likelihood at the full 128 spectral channel resolution of the GBM data. (B. Mailyan, submitted.)

By comparing the observed fluence at the detectors to the fluence of the best-fit simulation, the normalization factor between the simulation and the real TGF is obtained. The figure shows the strengths of the TGFs, expressed as the number of relativistic electrons exiting the acceleration region. To be detected at higher offsets, TGFs have to be stronger.



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Summary

- 2nd GBM TGF catalog is now online including VLF locations
- This had the first catalog of TEBs
- Over 1000 GBM TGFs have VLF geo-locations good to ~10 km.
- Large GBM TGF population has been used to perform meteorology - diverse storms, all having high cloud top region
- Common GBM/RHESSI TGFs have been found - a stereo view of TGFs!
- Spectral deconvolution of GBM TGFs is beginning - source diversity (beaming, source height) is apparent