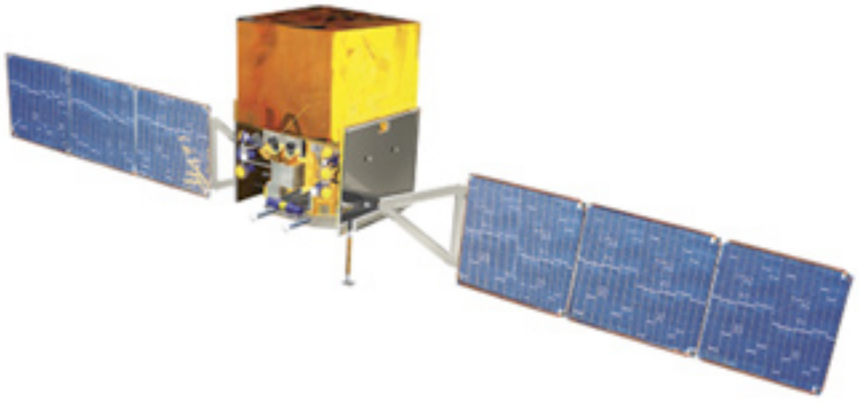
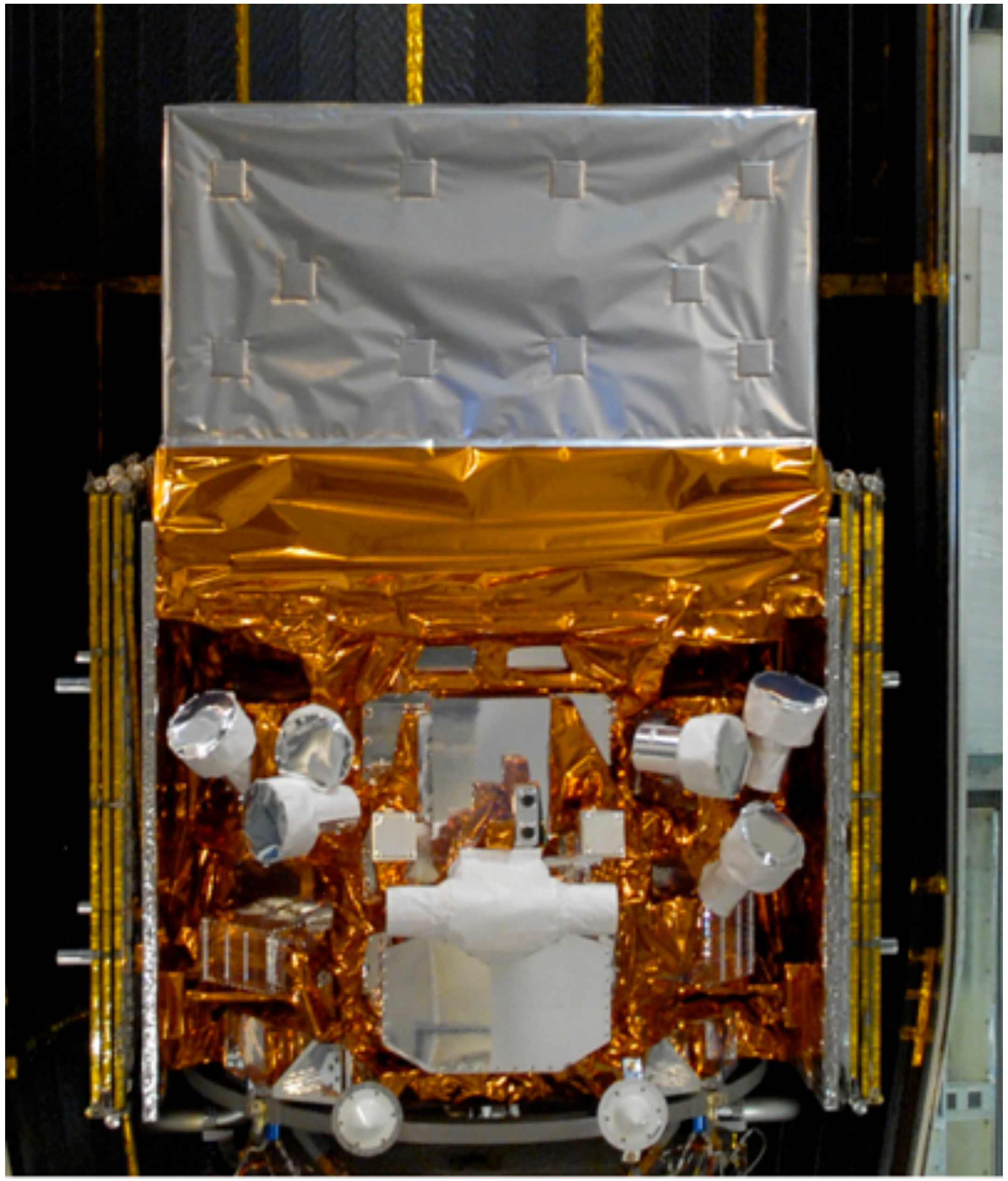


Fermi GBM observations of TGFs

on behalf of the Fermi GBM TGF team

HILITE 2013

Fermi

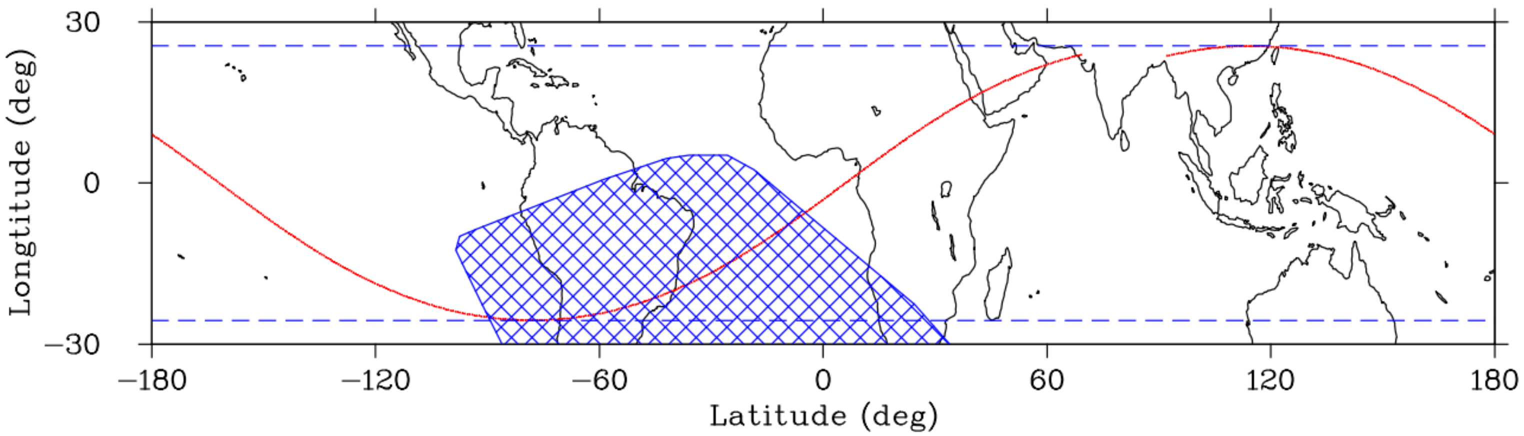


Meegan et al. (2009)

Altitude: 565 km

Inclination: 25.6^o

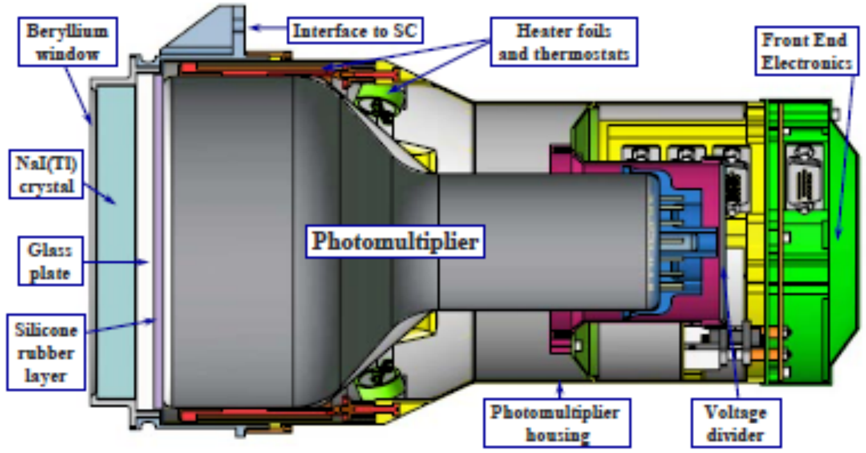
Single Orbit:



GBM Detectors

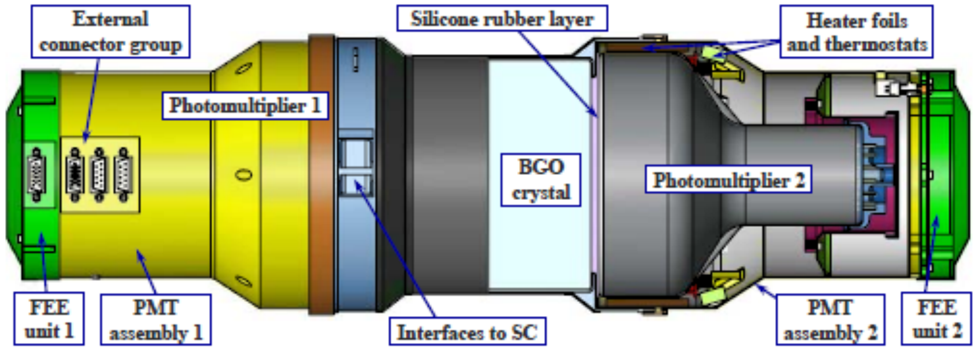
NaI Detector

Material:	Sodium Iodide
Number:	12
Diameter:	12.7 cm
Thickness:	1.27 cm
Energy Range:	8 - 1000 keV



BGO Detector

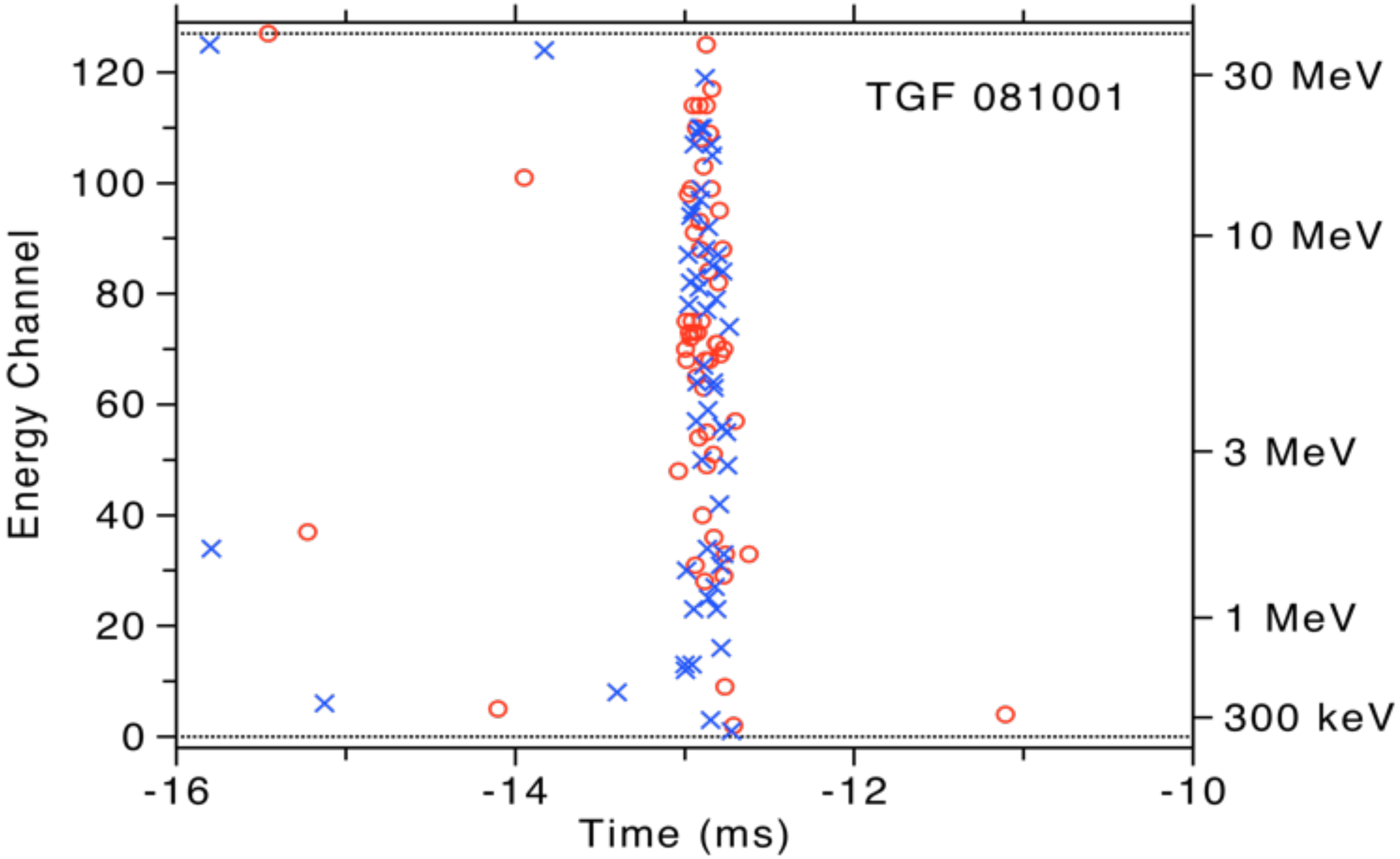
Material:	Bismuth Germanate
Number:	2
Diameter:	12.7 cm
Thickness:	12.7 cm
Energy Range:	0.2 - 40 MeV



Detecting TGFs with GBM

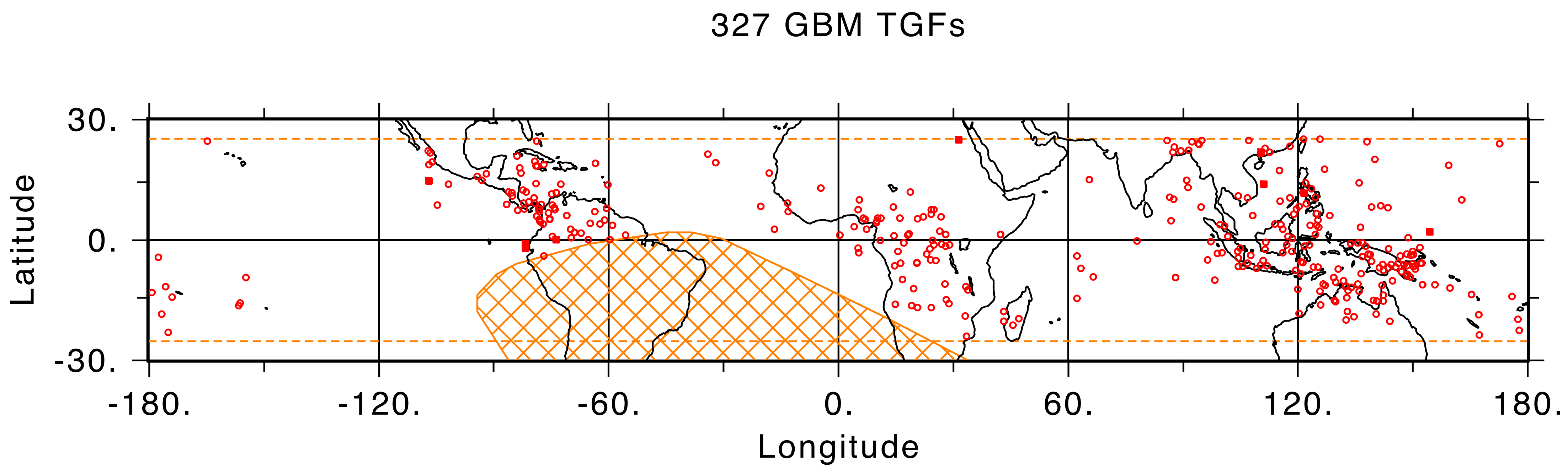
- GBM is a "triggering" instrument: statistically significant rate increase in 2 or more detectors.
- Hardware design limits binning for this purpose to 16 ms (and longer).
- Time-Tagged Event (TTE) data downlinked for triggers (individual photons recorded).
- Originally triggers based on 12 NaIs; since Nov 2009 new triggers implemented to include the BGOs.
- Rate increase from one every 32.5 days to one per 4.0 days.
- GBM is a very efficient TGF detector: 2 μs GPS time-tags on TTE data during triggers, 2.6 μs deadtime per event.

A GBM TGF

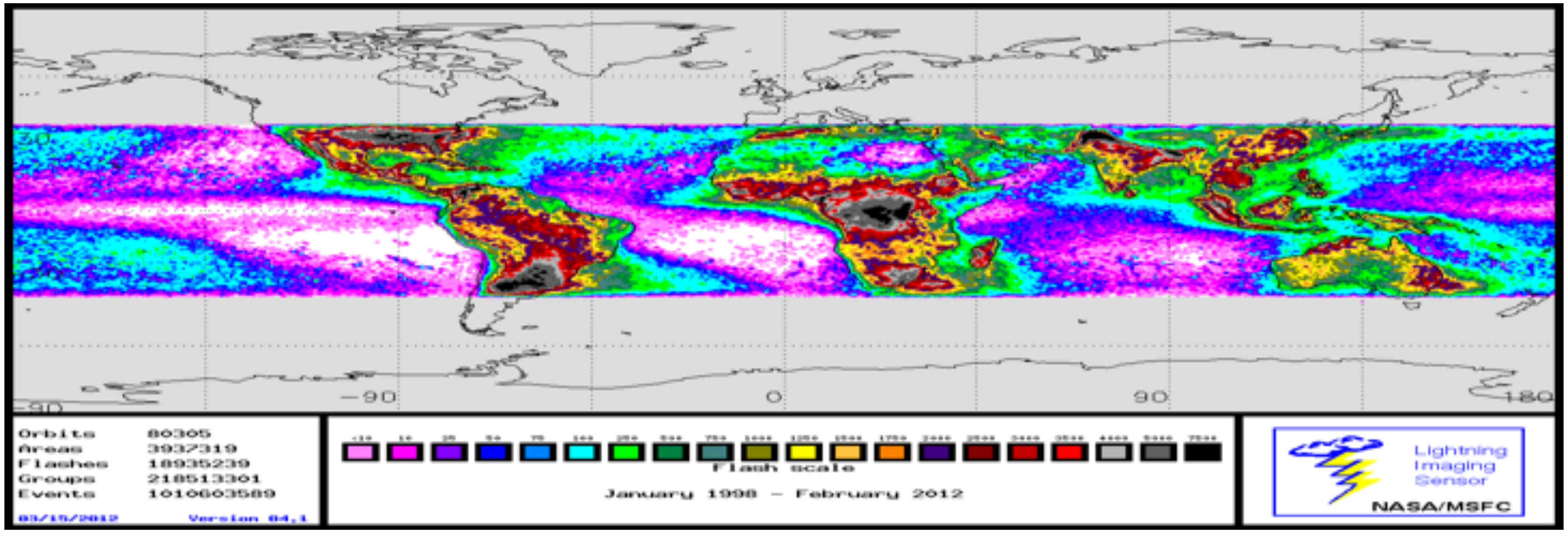


TGF 081001
Energy Channel
Time (ms)
120
100
80
60
40
20
0
-16
-14
-12
-10
30 MeV
10 MeV
3 MeV
1 MeV
300 keV

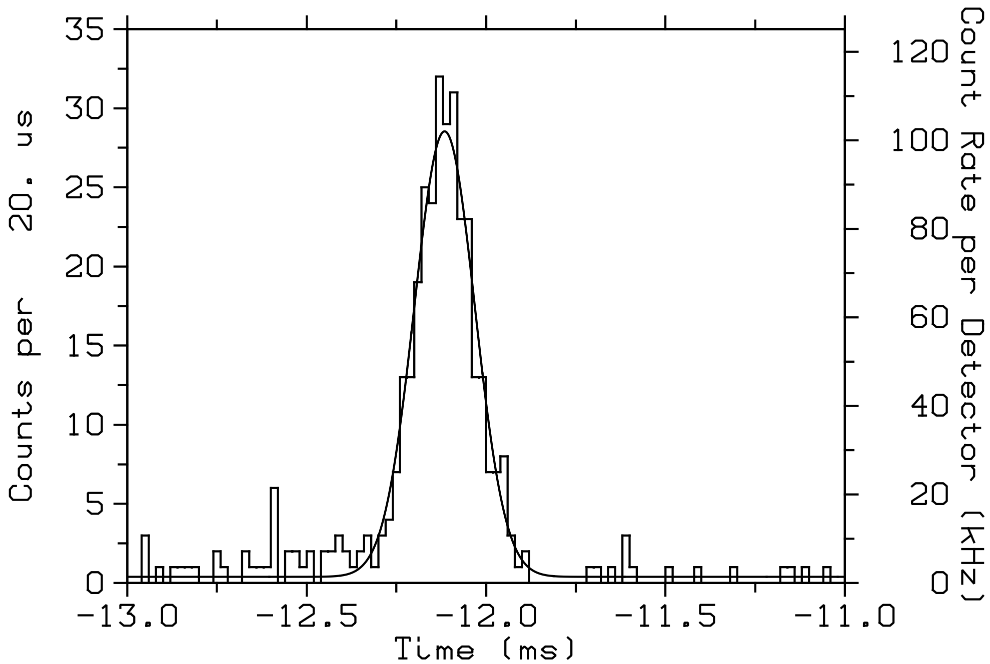
TGFs triggered by GBM

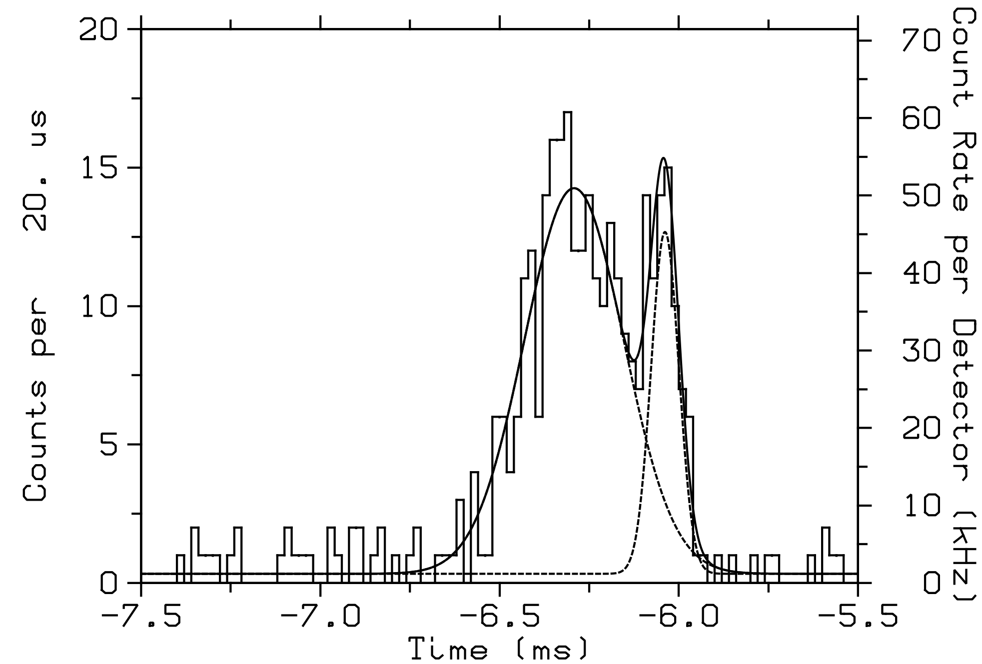


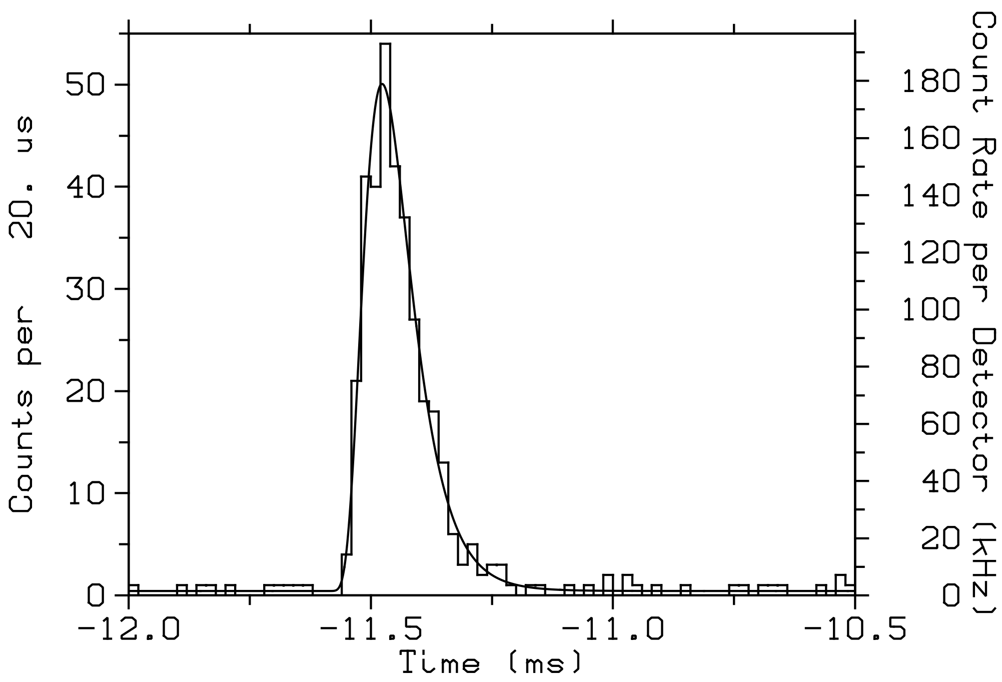
NASA/MSFC Lightning Imaging Sensor Lightning strikes since 1998

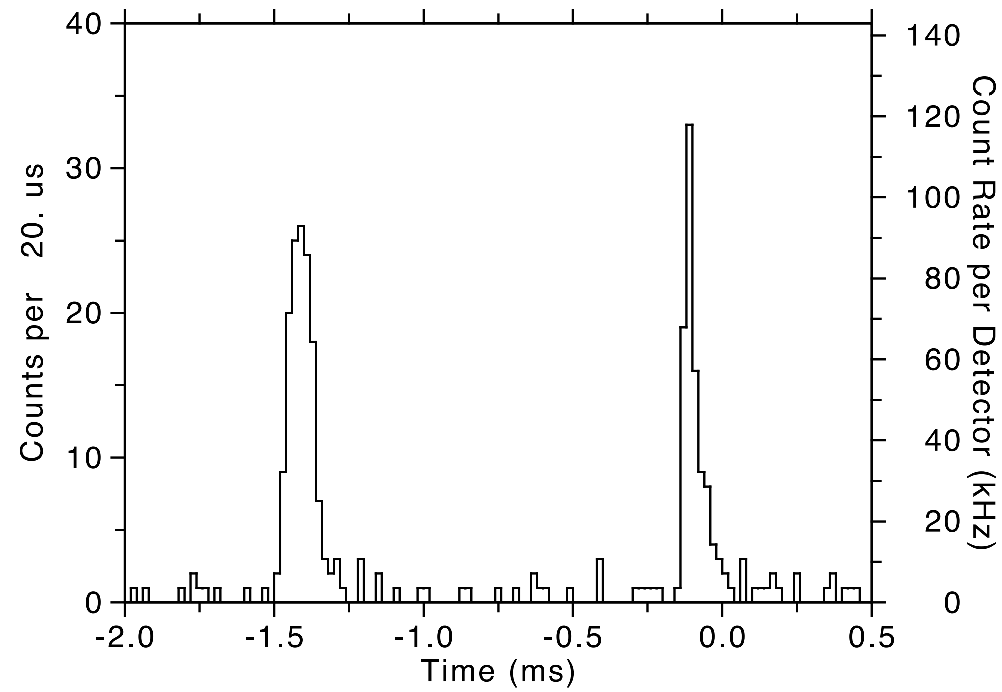


Different morphologies





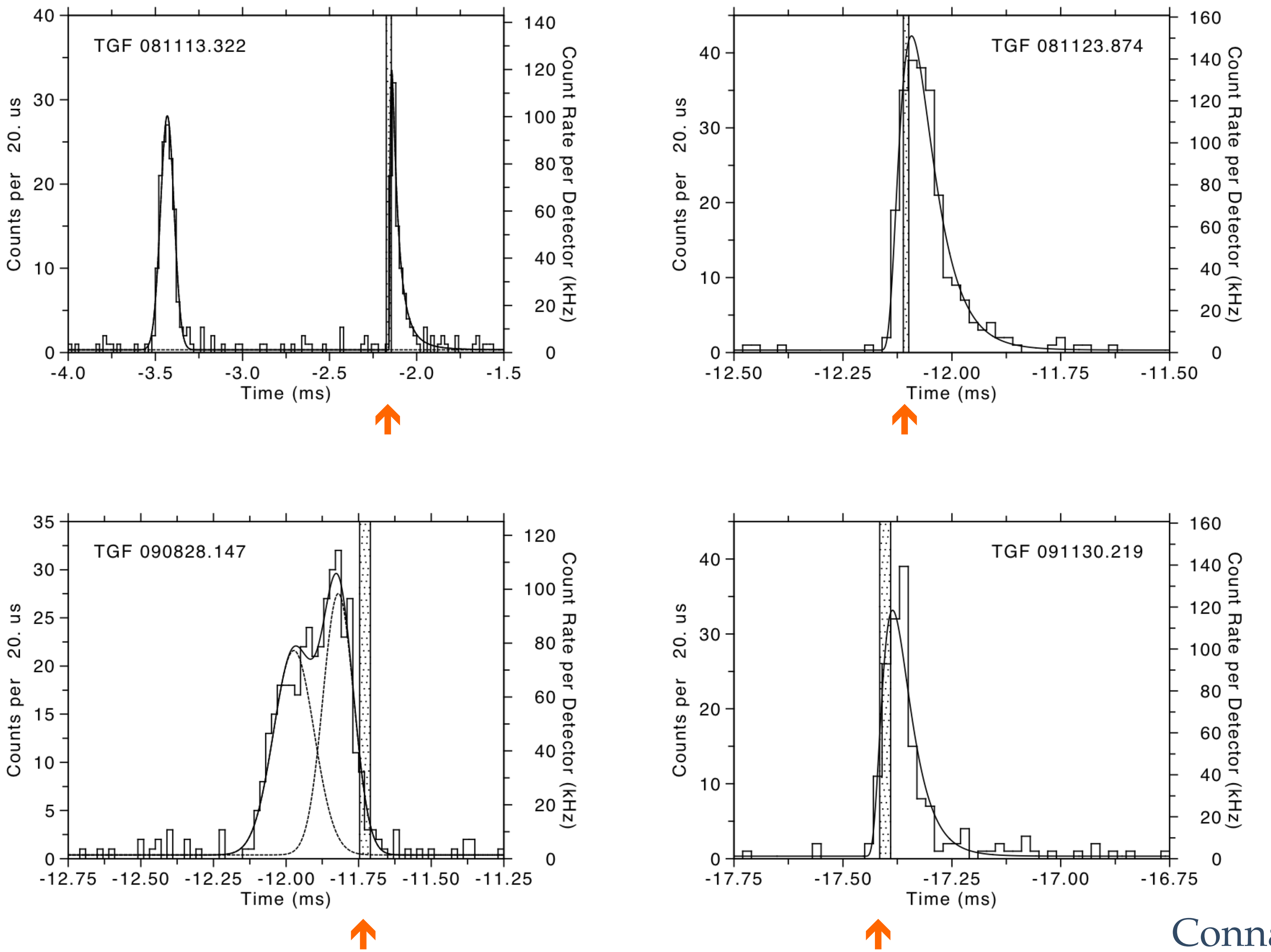




Sample differences

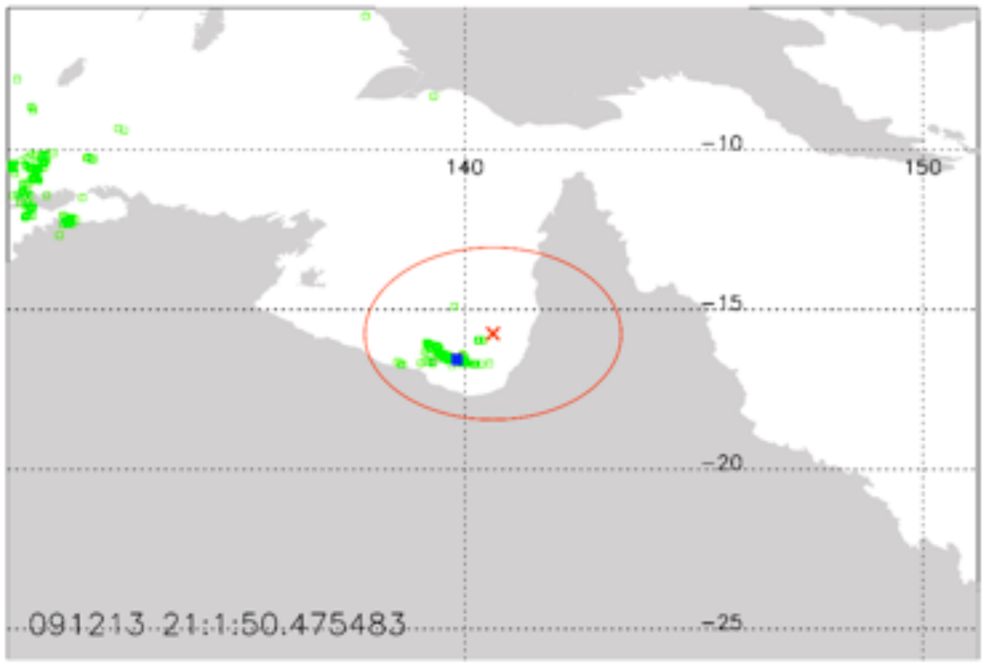
- Many more multi-pulsed TGFs with BATSE and GBM than RHESSI - due to triggering windows?
- GBM durations ~250 μs, consistent with RHESSI; AGILE TGFs much longer despite shorter triggering window than GBM.
- Instrumental effects (i.e. deadtime, pulse pile-up) become extremely important for TGF analysis because of the extremely high counting rates.

TGF and WWLLN lightning correlations



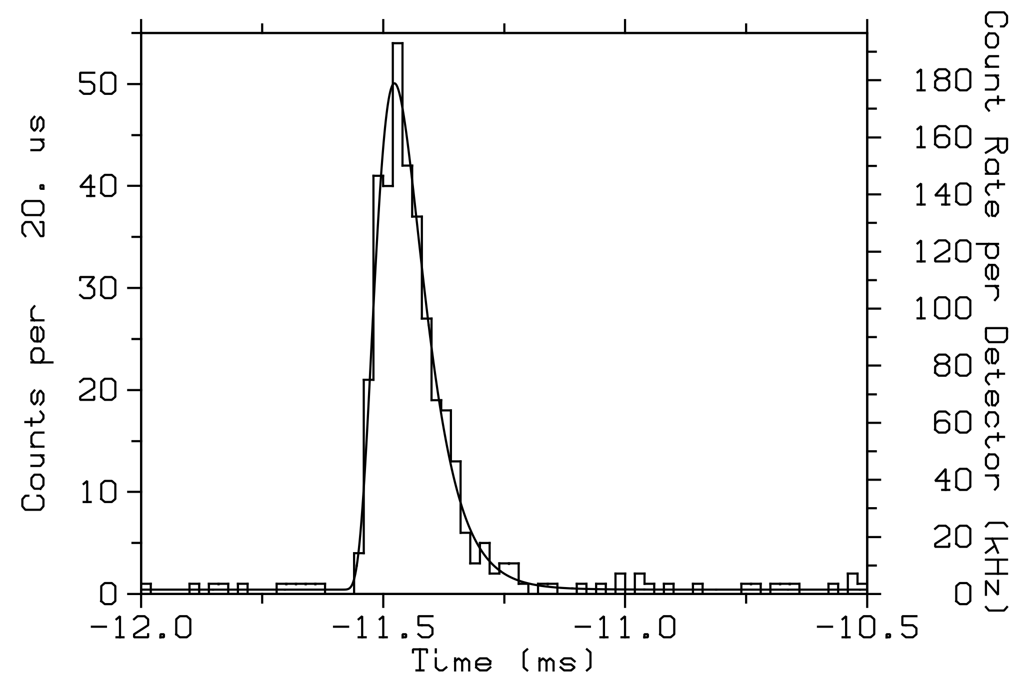
Connaughton et al. (2013)

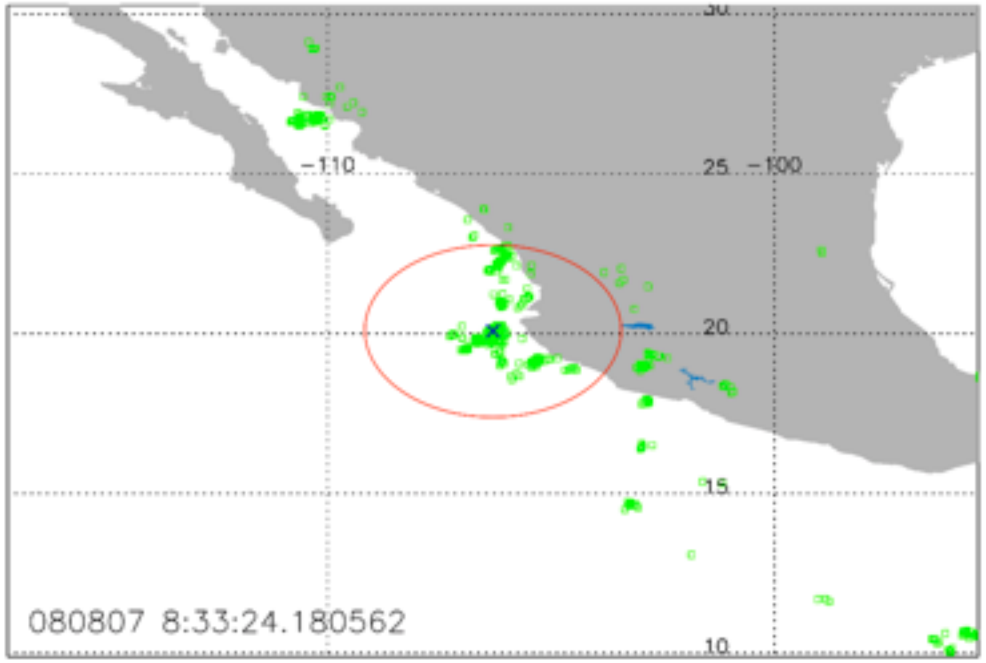
TGFs and TEBs



Storm under Fermi

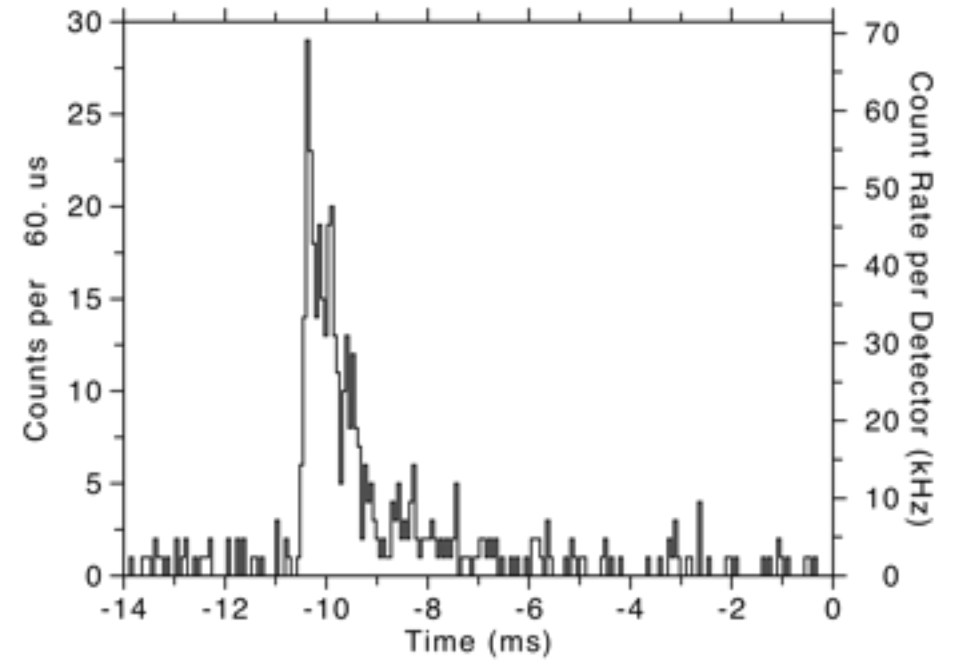
Short TGF =
γ-ray TGF





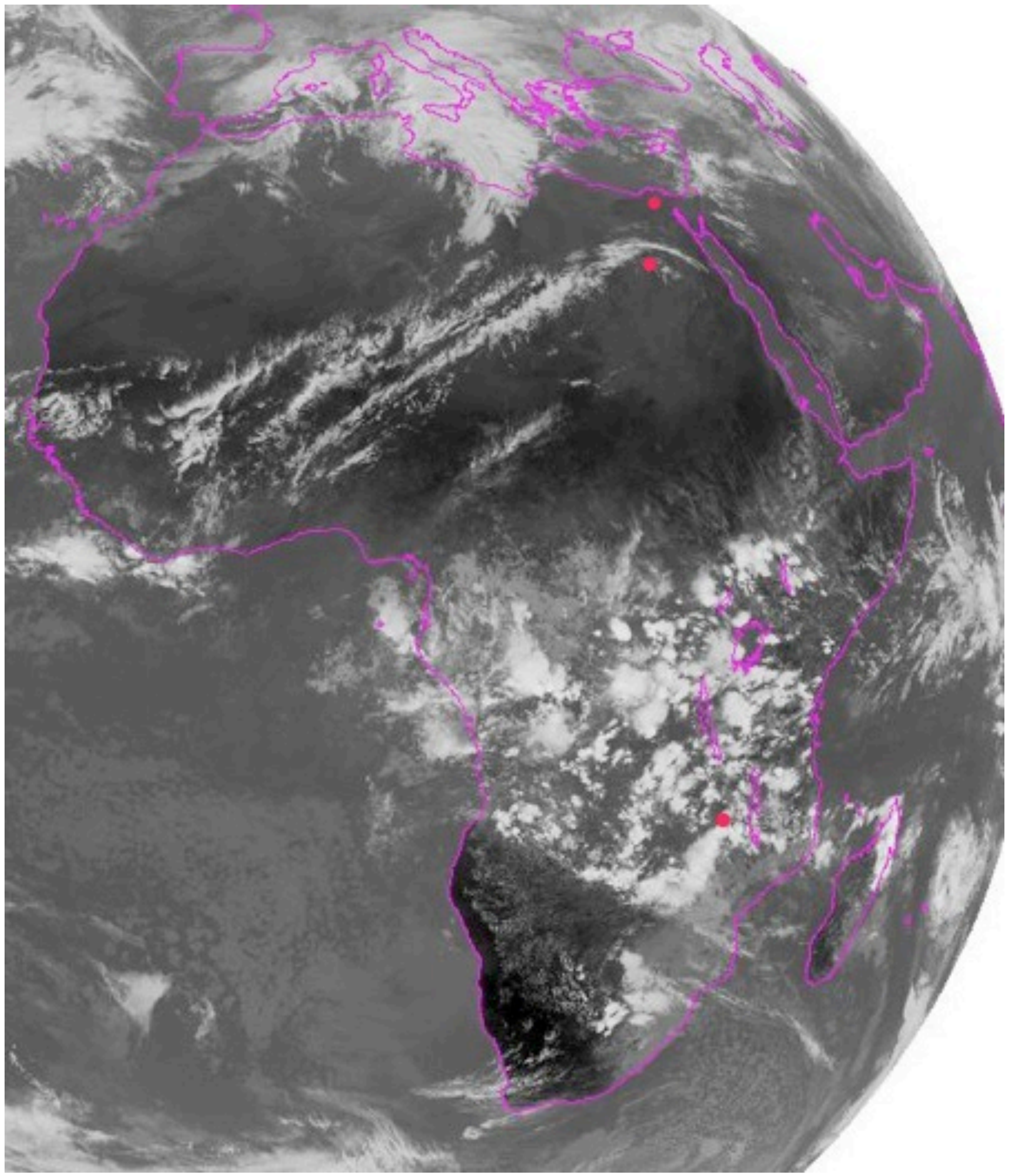
Storm at magnetic footprint

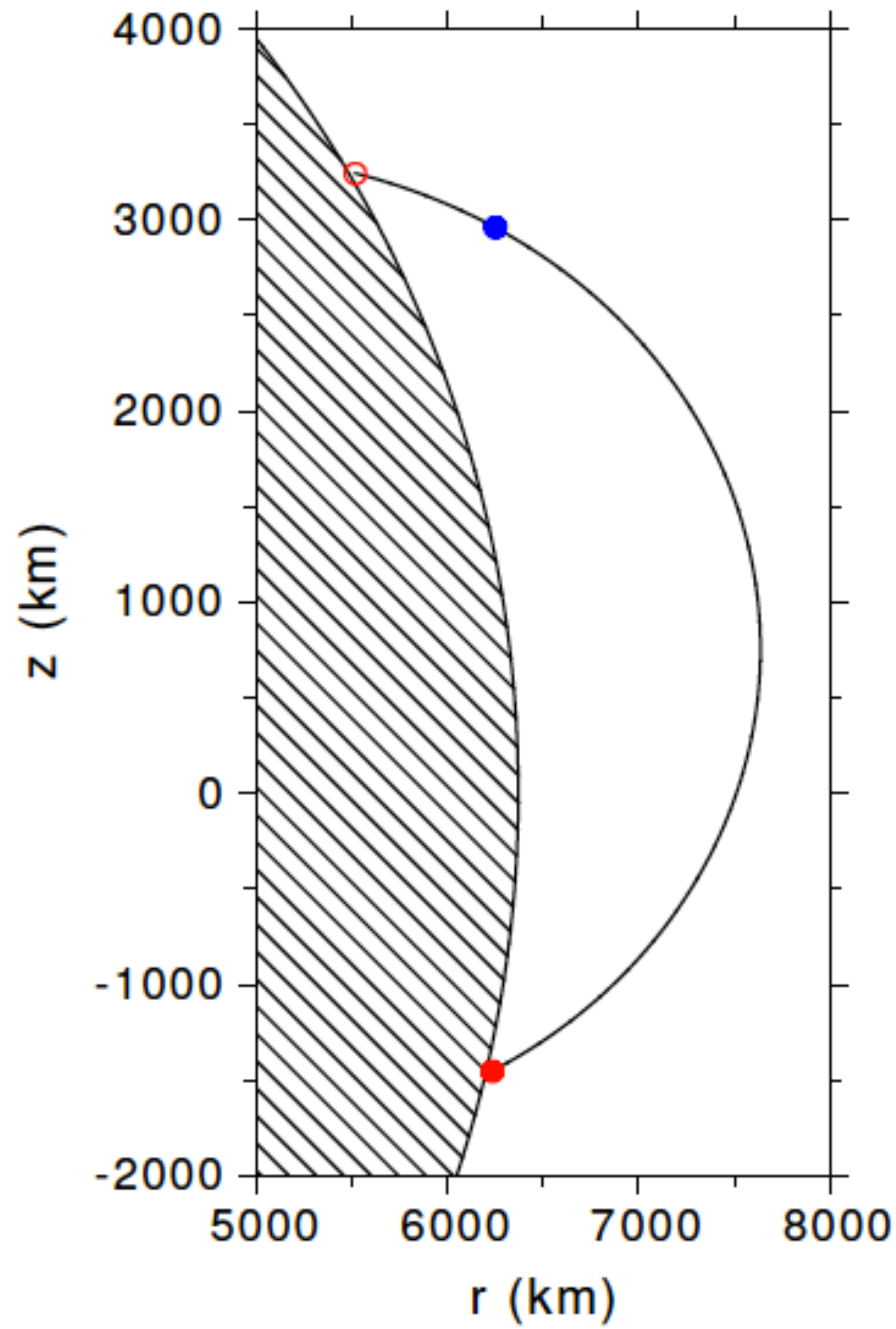
Long TGF =
e⁻ beam TGF



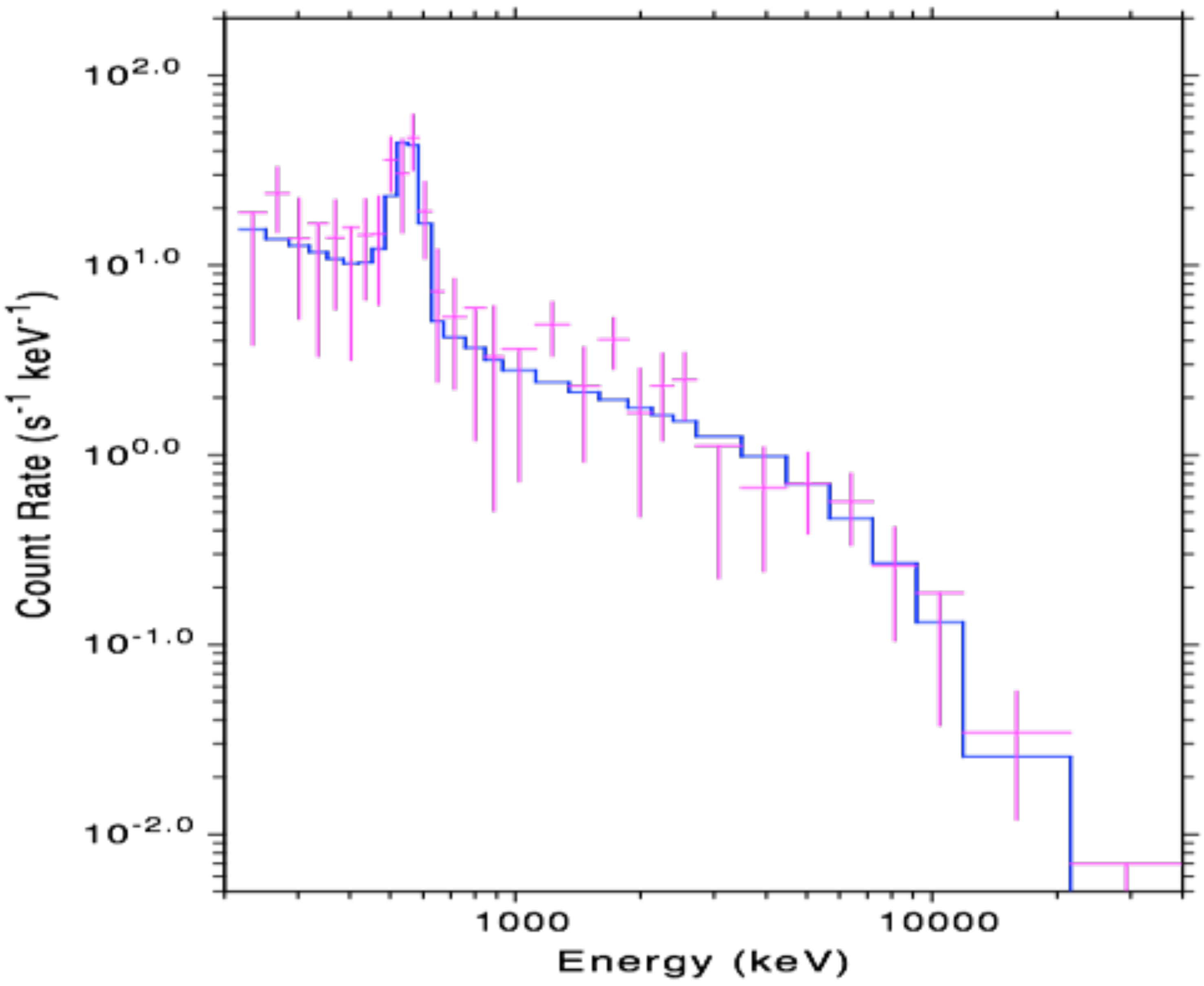
Connaughton et al. (2010)

Terrestrial Electron Beams





Also positrons

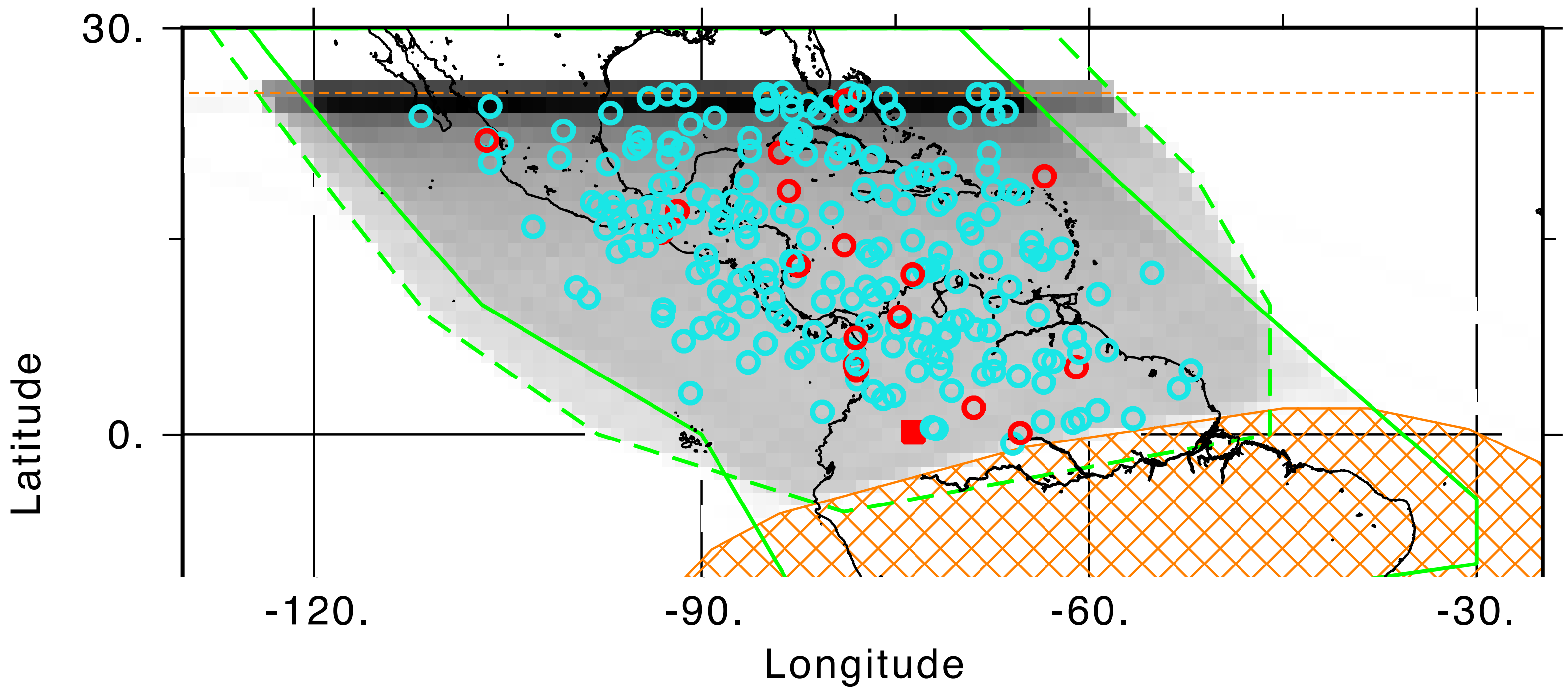


Briggs et al. (2011)

GBM TGF search eras

Method	Dates	Detection Rate ($year^{-1}$)
GRB triggers	> 2008 July 11	9.8
TGF triggers (using BGO detectors)	> 2009 Nov 10	90
TTE in “boxes”	2010 July 16 – 2012 Nov 25	estimate 850 (actual 0.51 per hour in favorable times & regions)
Continuous TTE	> 2012 Nov 26	

Continuous TTE "box"



- 210 new TGFs found in 328 hours of data, along with 17 triggered TGFs and one TEB.

- The overall detection rate improvement: x10; this is due to detecting fainter and shorter TGFs.

Briggs et al. (2013)

TGF/lightning ratios

Region	Ratio
Average	$(3.8 \pm 0.2) \times 10^{-4}$
Americas	$(4.9 \pm 0.3) \times 10^{-4}$
Africa	$(2.3 \pm 0.2) \times 10^{-4}$
Asia	$(2.7 \pm 0.4) \times 10^{-4}$
Australia	$(8.6 \pm 1.0) \times 10^{-4}$

- We use these comparisons to estimate a global TGF rate (within ±26°) of ~400,000 per year.
- With continuous TTE, GBM will detect ~850 TGFs per year.

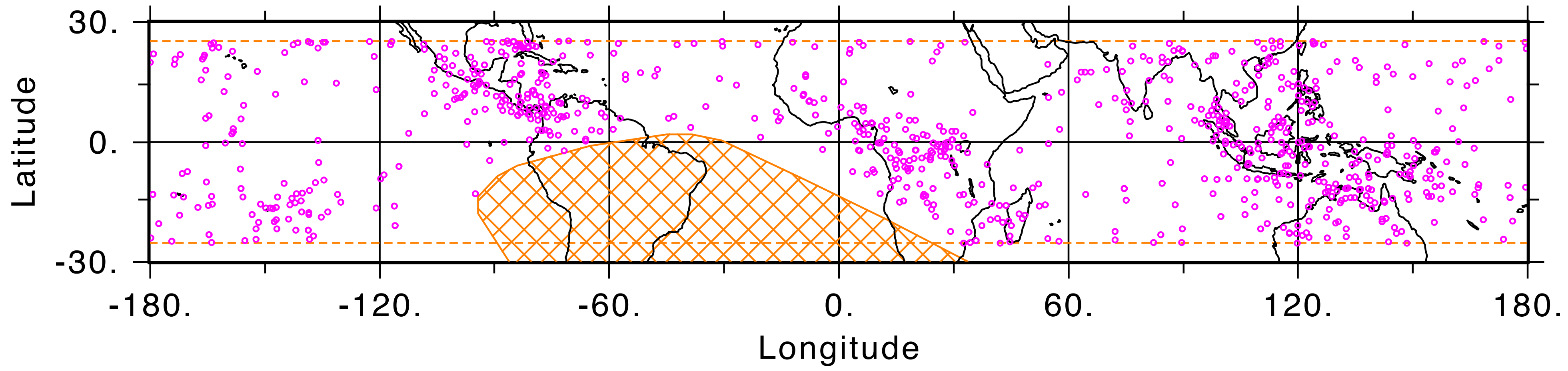
Briggs et al. (2013)

Continuous TTE all the time

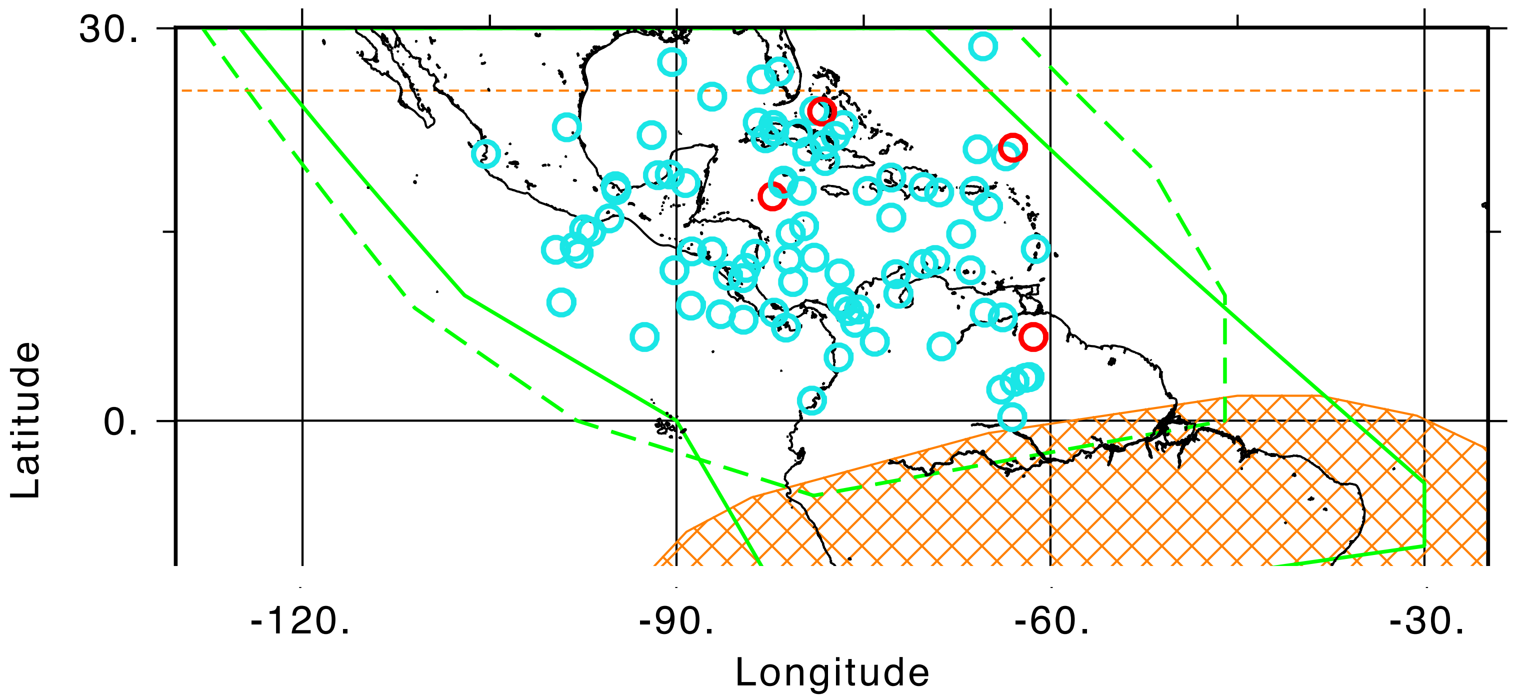
PRELIMINARY: incomplete cosmic ray removal.

813 candidates from 9 months of **continuous** TTE:

2012 Nov 26 to 2013 Aug 31



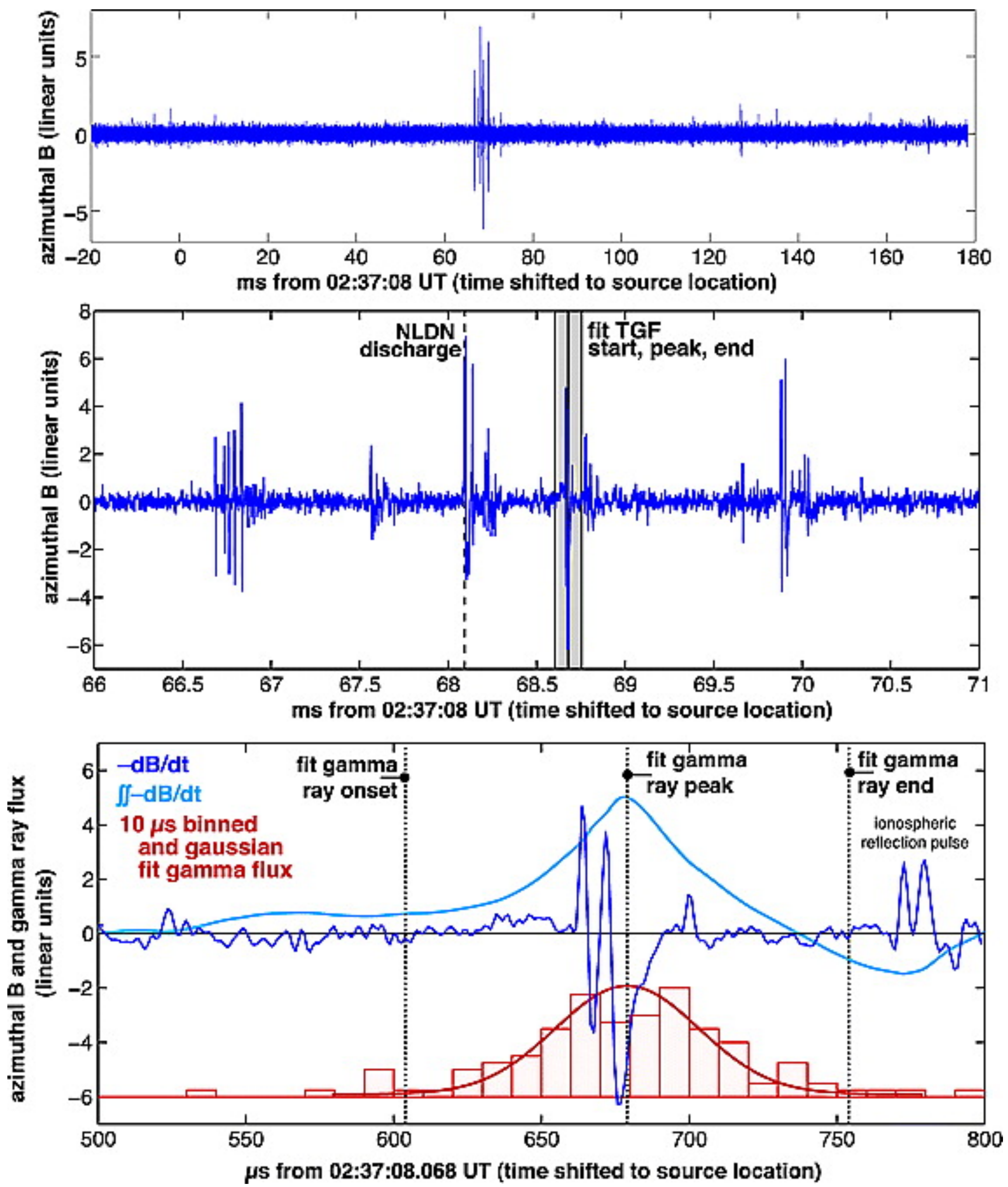
TGFs with WWLLN matches



- With this new large GBM TGF sample and the high GBM/WWLLN association rate, we now have a large sample of accurate (~10 km) locations.

- This map shows 89 TGF locations.

µs TGF/lightning relationship



200 ms

5 ms

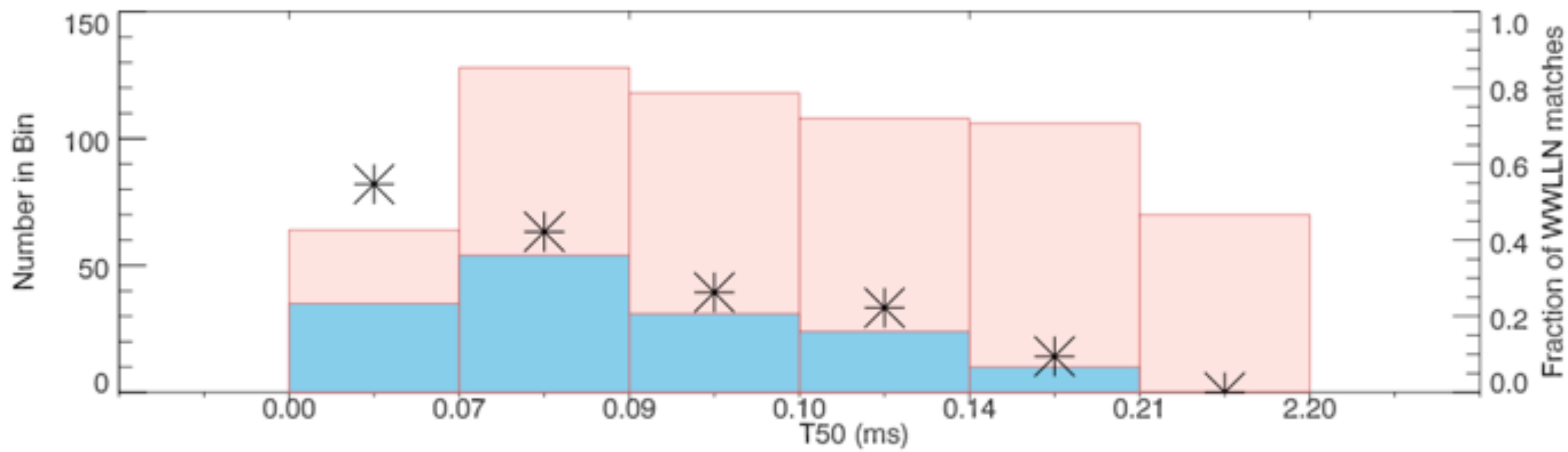
300 µs

Cummer et al. (2011)

Puzzles...

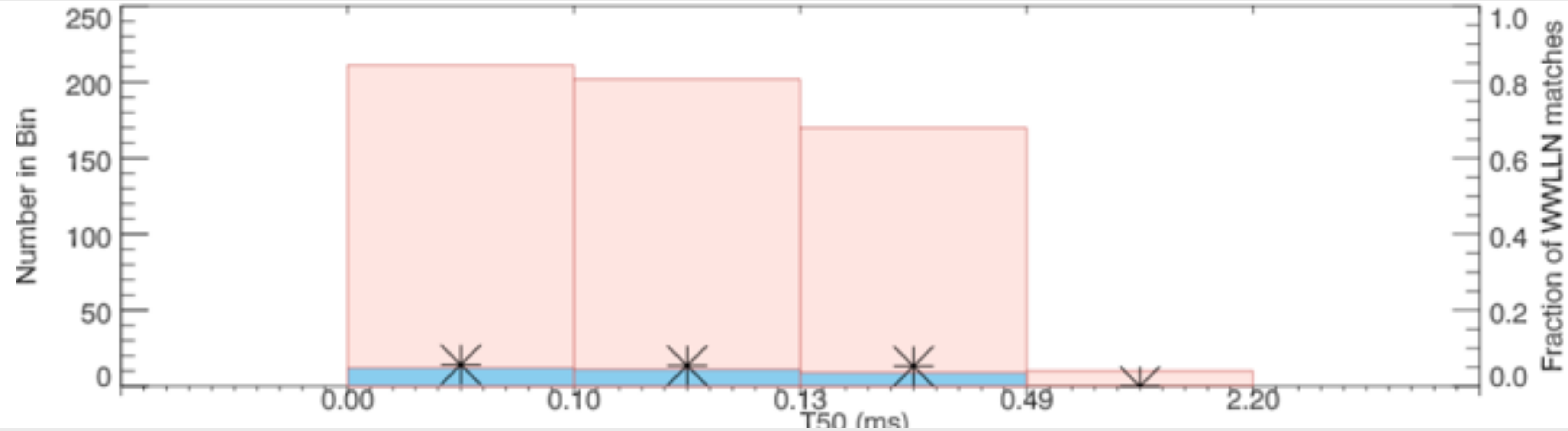
- There is a high association rate between GBM and WWLLN (~1/3), but the WWLLN detection rate for IC lightning is low (~5%).
- Two types of associations? 85% of the gamma/radio associations are simultaneous to within ~40 μs, but the remainder have ~ms separations.
- Similarity between gamma-ray and radio (twice-integrated) profiles.
- Suggestions that the radio emission is from TGF itself (Cummer et al. 2011; Dwyer 2012)

WWLLN Match vs Duration



594 TGFs (triggered + offline)

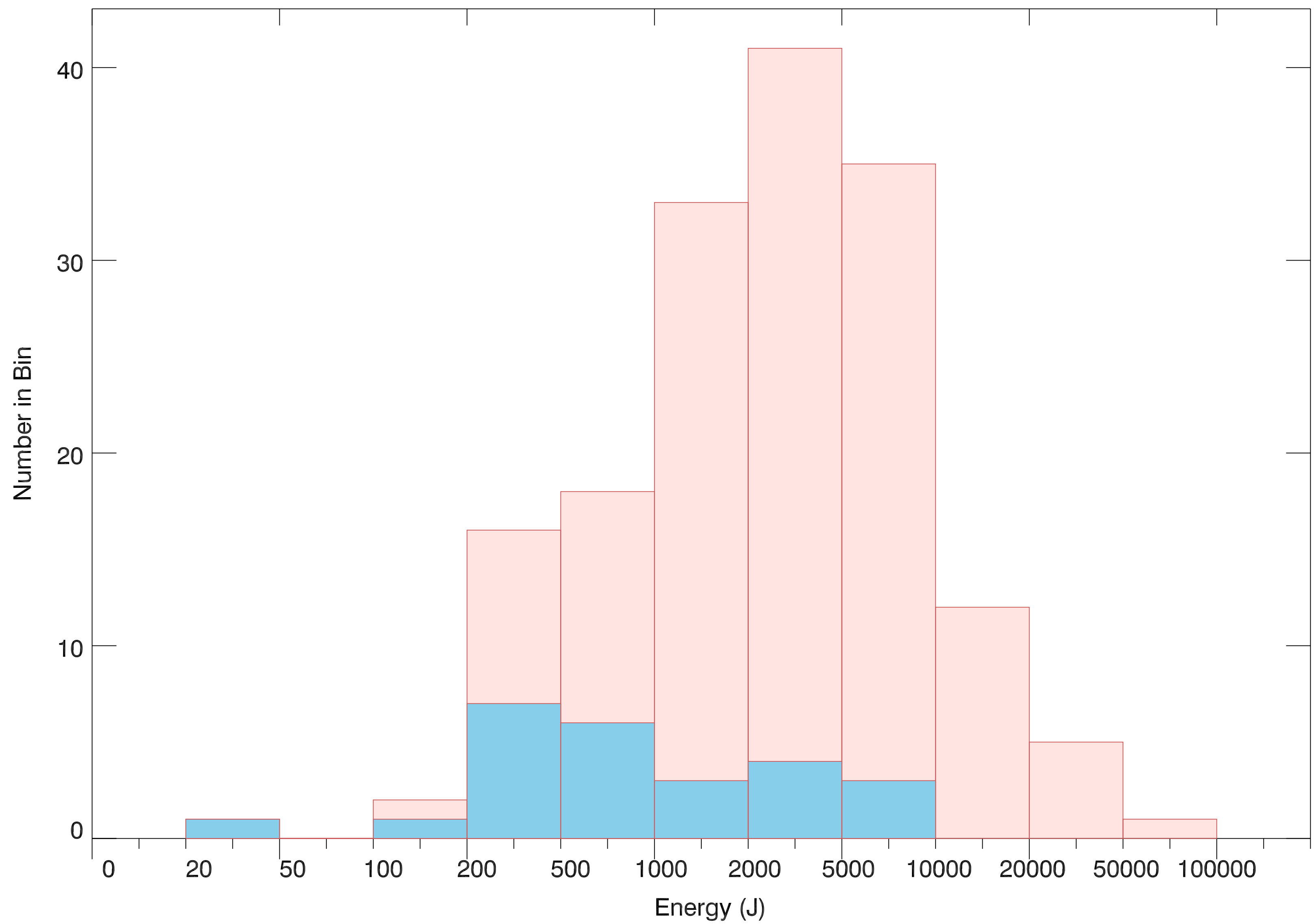
154 TGFs with a simultaneous WWLLN discharge



594 TGFs (triggered + offline)

32 TGFs with a WWLLN discharge > 0.2 ms from peak

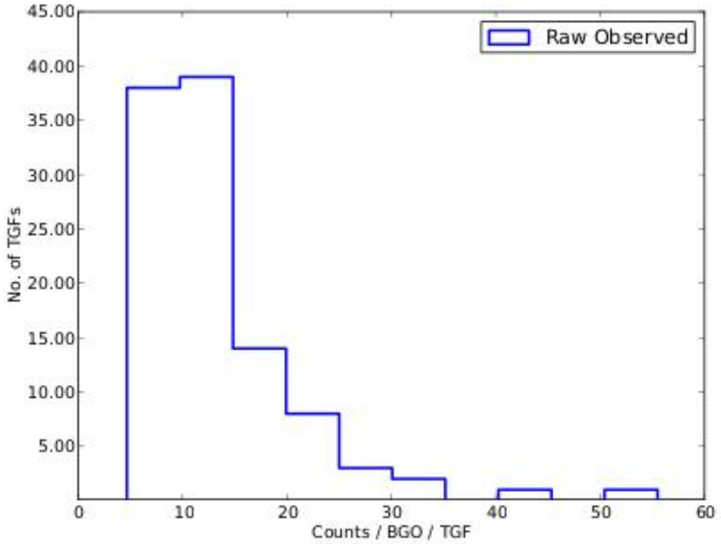
Energy distribution



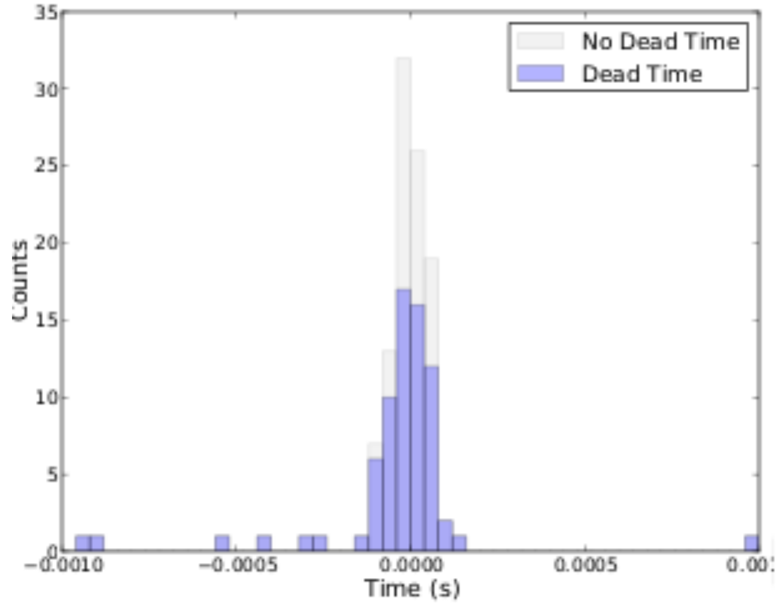
32 WWLLN discharges > 0.2 ms from TGF peak. Mean Energy: 700 J +
154 WWLLN discharges simultaneous with TGF peak . Mean Energy: 3.1 kJ

Instrumental effects

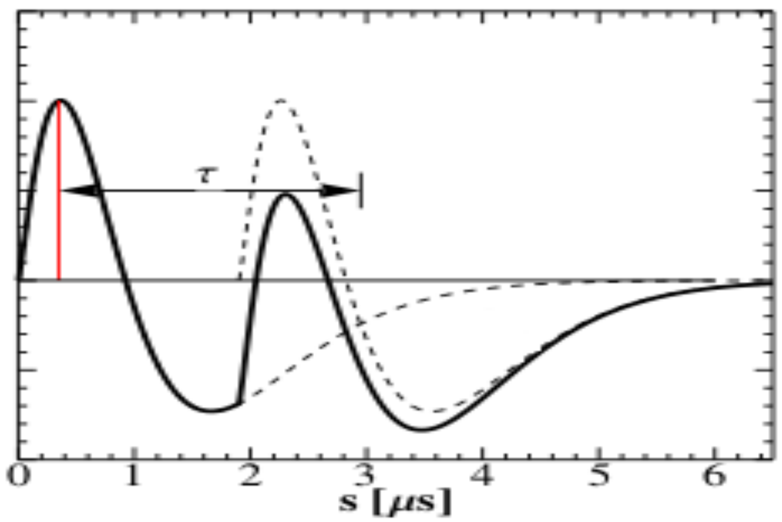
Raw Distribution



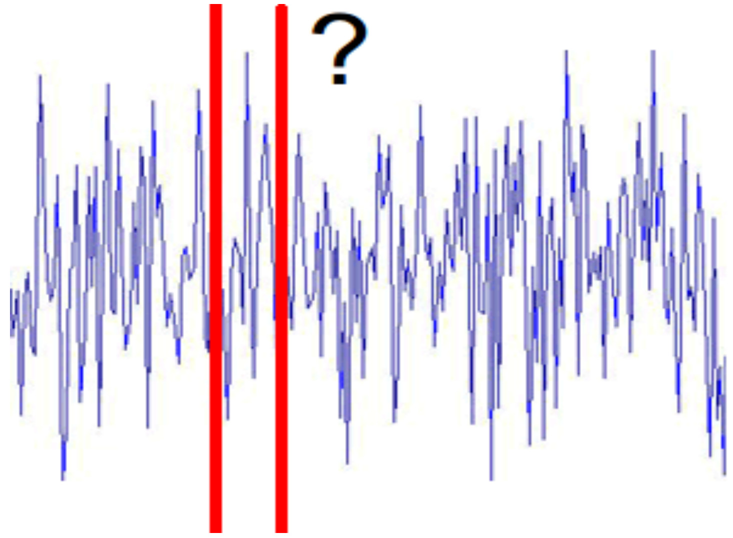
Deadtime



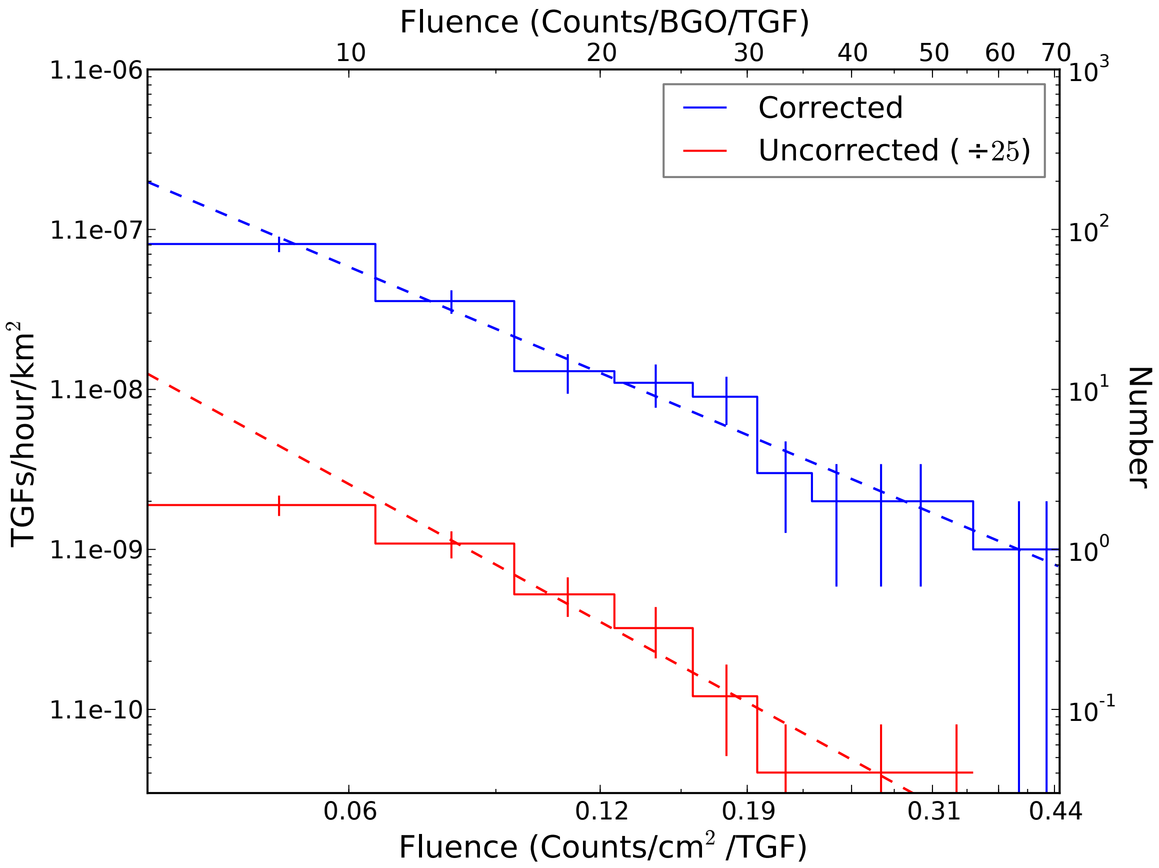
Pulse Pile-up



Detection Efficiency



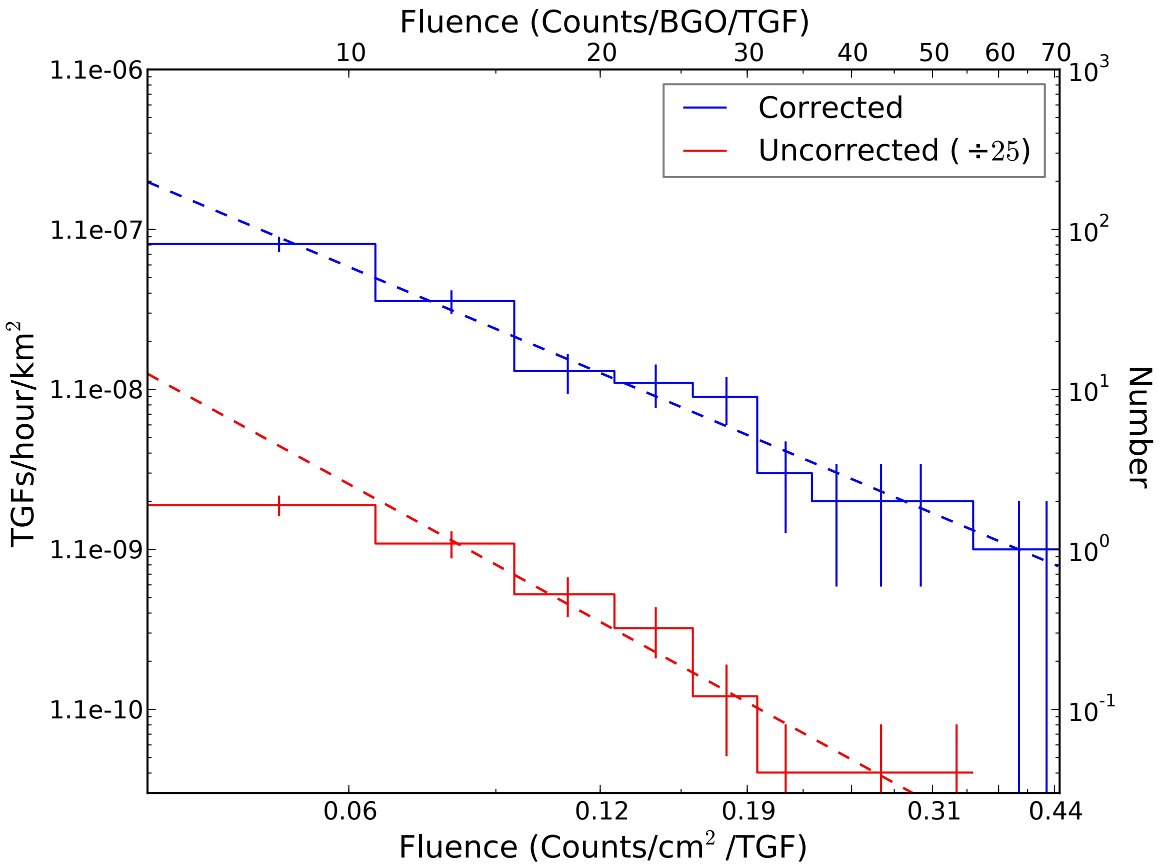
Fluence distribution



- Sample: 106 TGFs
- Blue: model independent correction of the GBM TGF fluence distribution.
- Detection efficiency by simulations: lowest bin 34 -> 89.
- Deadtime corrected by deconvolution simulations of each TGF.
- Pulse pile-up: additional 10% deadtime correction for the 7 brightest TGFs in the sample.

Tierney et al. (2013)

Fluence distribution



- Fitting a power-law to the (blue) corrected distribution: the index is -2.20 ± 0.13 (uncorrected -2.86 ± 0.32).
- Cf: Ostgaard et al. (2012), assuming a power-law form:
  1) Comparing the total numbers of GBM and RHESSI GBM TGFs and relative sensitivities, w/o deadtime correction: -2.3 ± 0.2,
  2) RHESSI with deadtime correction: -2.3 to -3.0.

What have we learned from Fermi GBM

- Short, bright and energetic with different pulse shapes.
- Can be seen through their gamma-ray or electron/positron signal.
- Generate currents that discharge the E field.
- Can also be seen through their strong VLF radio signal.
- Fluence distribution consistent with power-law of index -2.20 ± 0.13.

GBM TGF papers

http://gammaray.nsstc.nasa.gov/publications/tgf_journal.html