New Results from the Fermi GBM Extended TGF Sample

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Others before launch: Giselher Lichti, Fred Berry, Ron Cantrell, Al English, Fred Kroeger, …

Fermi and GBM

Fermi Gamma-ray Space Telescope

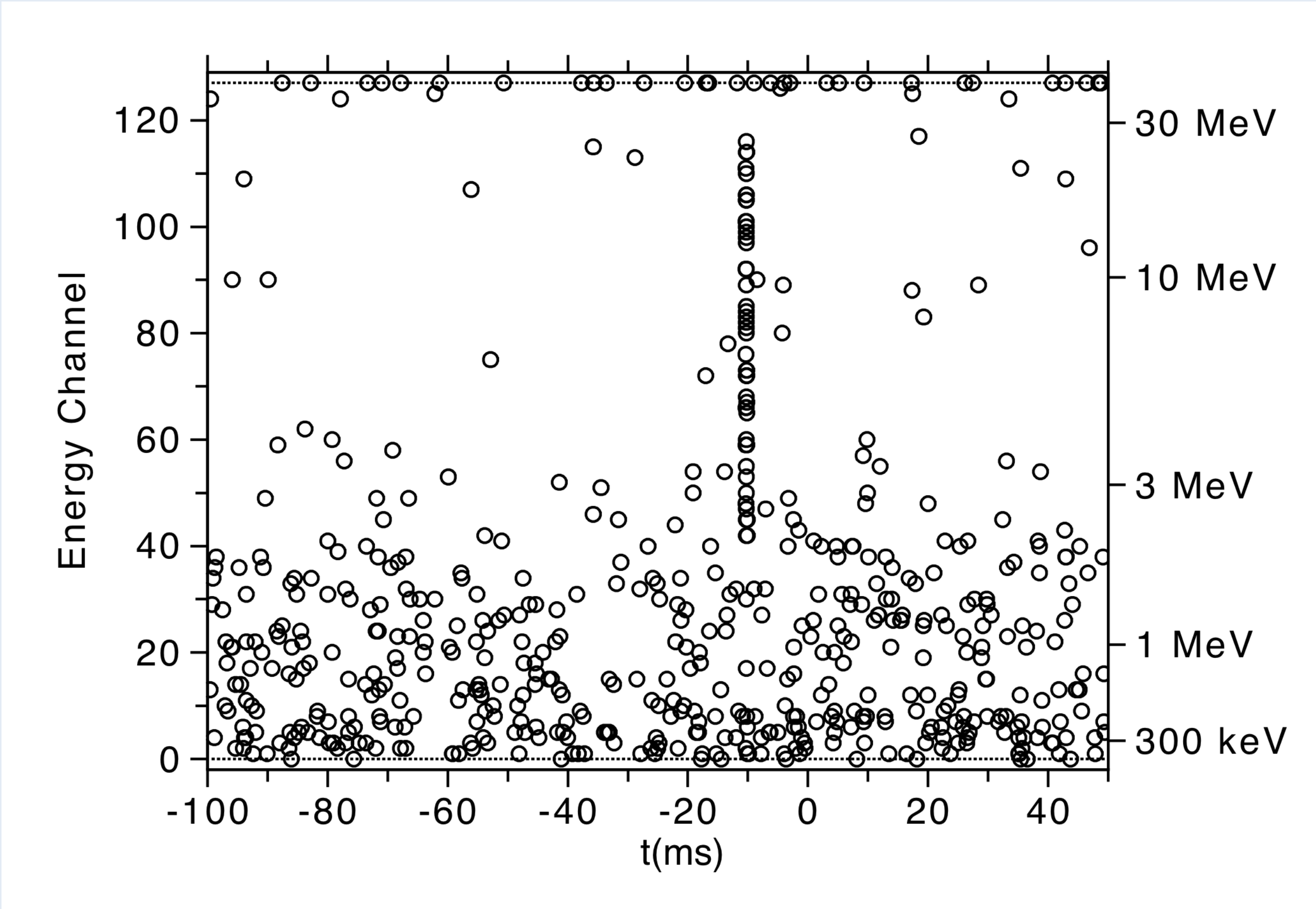
GBM BGO Detector

Finding more TGFs

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	

Finding the TGFs…



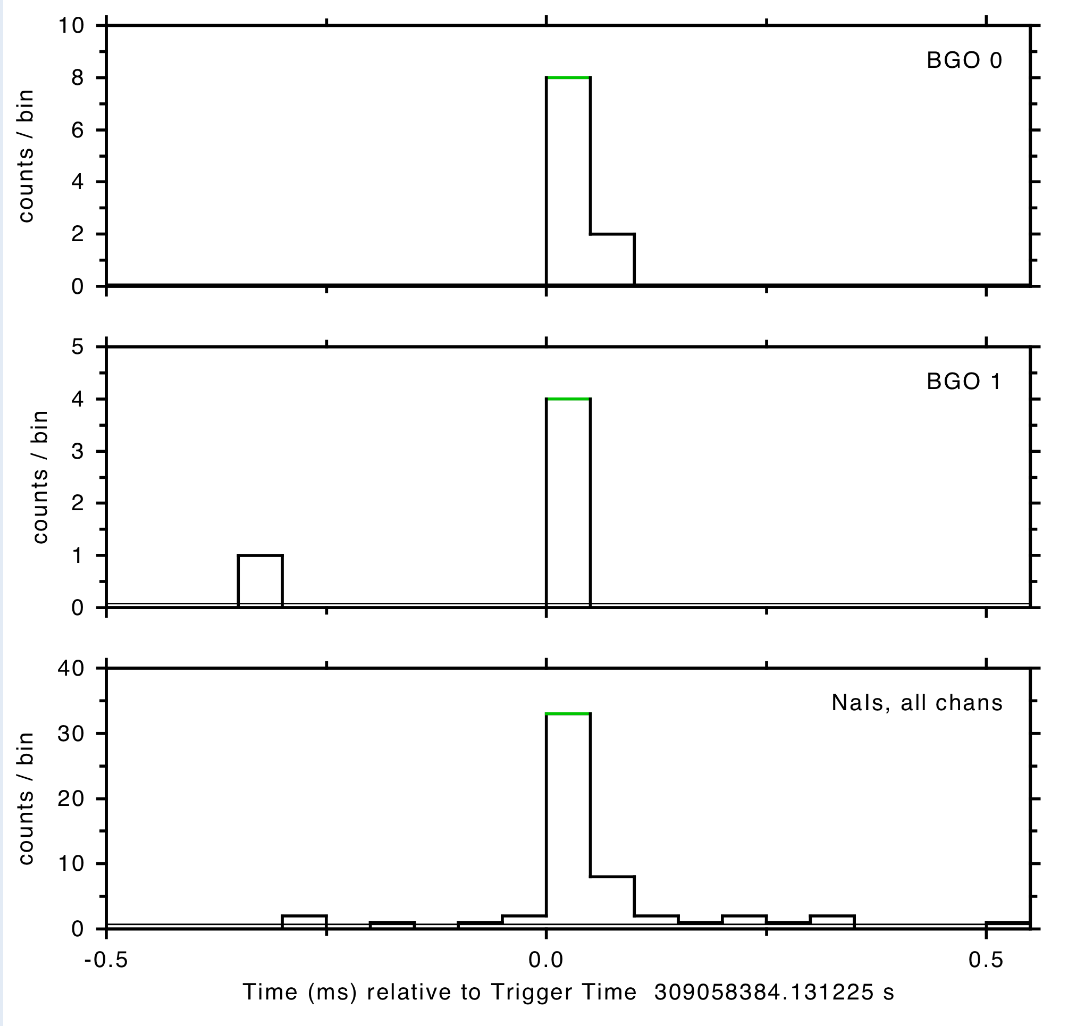
This search: 14 million 50 μs bins of a 696 s long pass through the Americas' Box.

1) Counts in each BGO ≥ 4

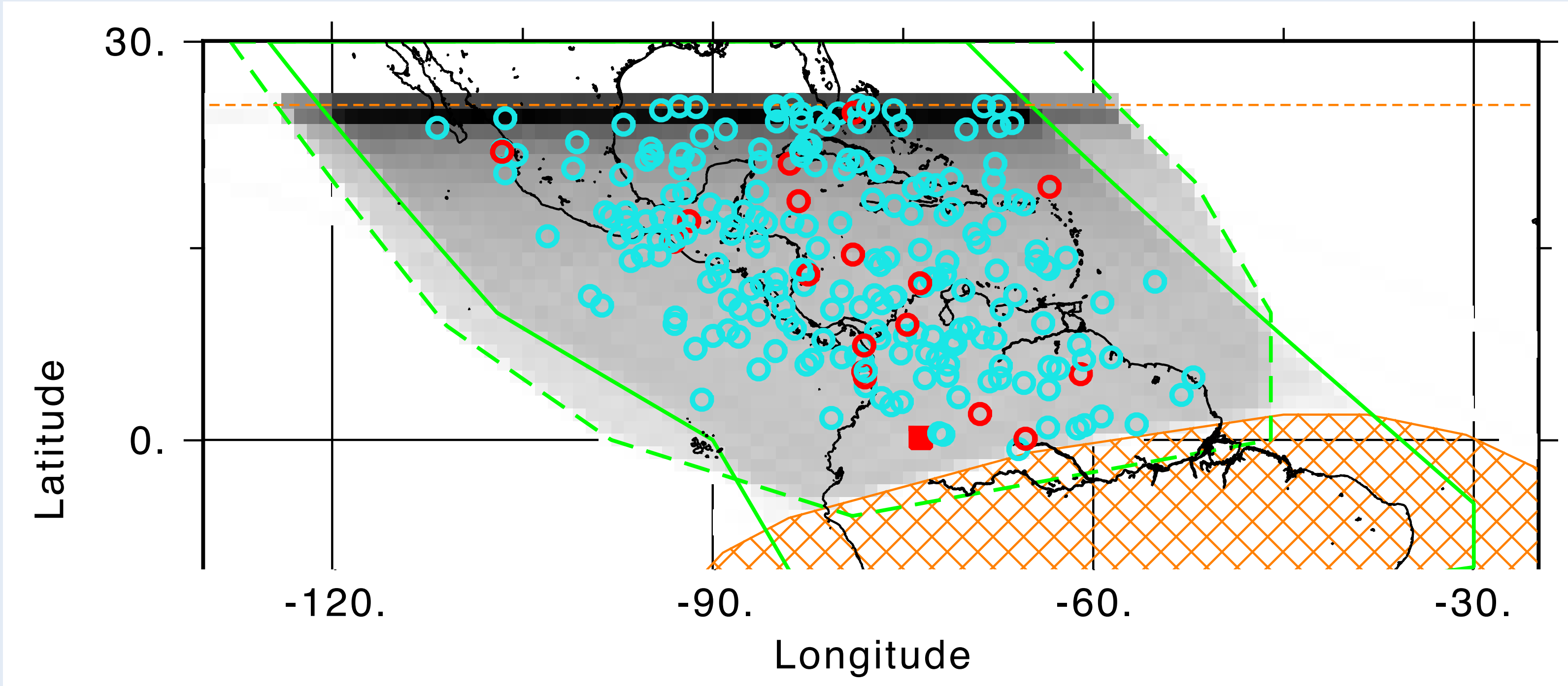
2) Three independent detections, each of $P1_i < 0.001$

3) The joint corrected probability must be $P2 < 1.0E\text{-}11$.

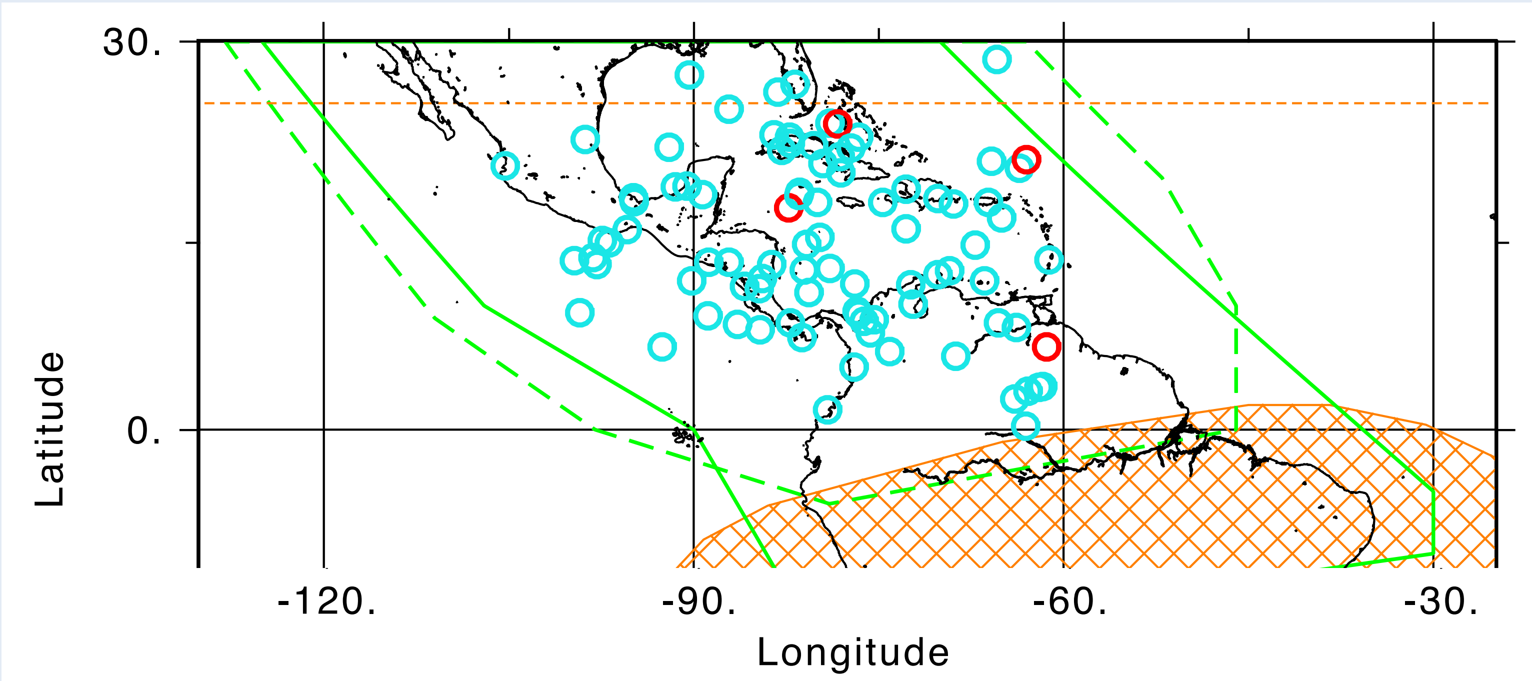
For this event, the joint corrected probability is P2 = 4.6E-55.



Properties of the Extended Sample

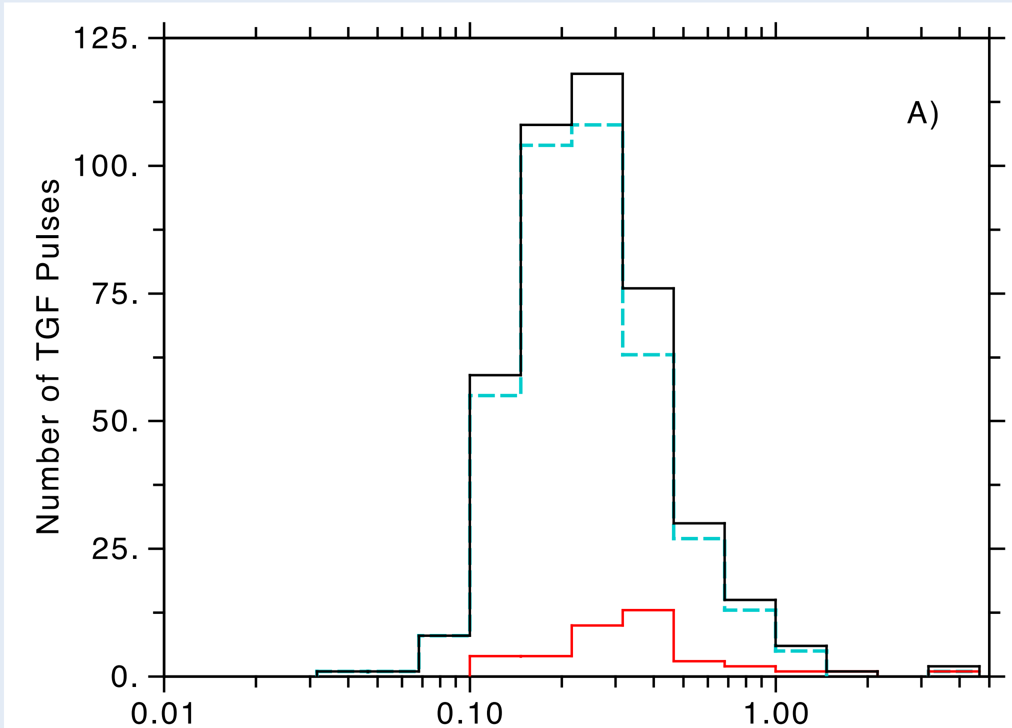


210 new TGFS found in 328 hours of data, along with 17 triggered TGFs and one TEB.   The overall detection rate improvement: x10.
This is due to detecting fainter and shorter TGFs.



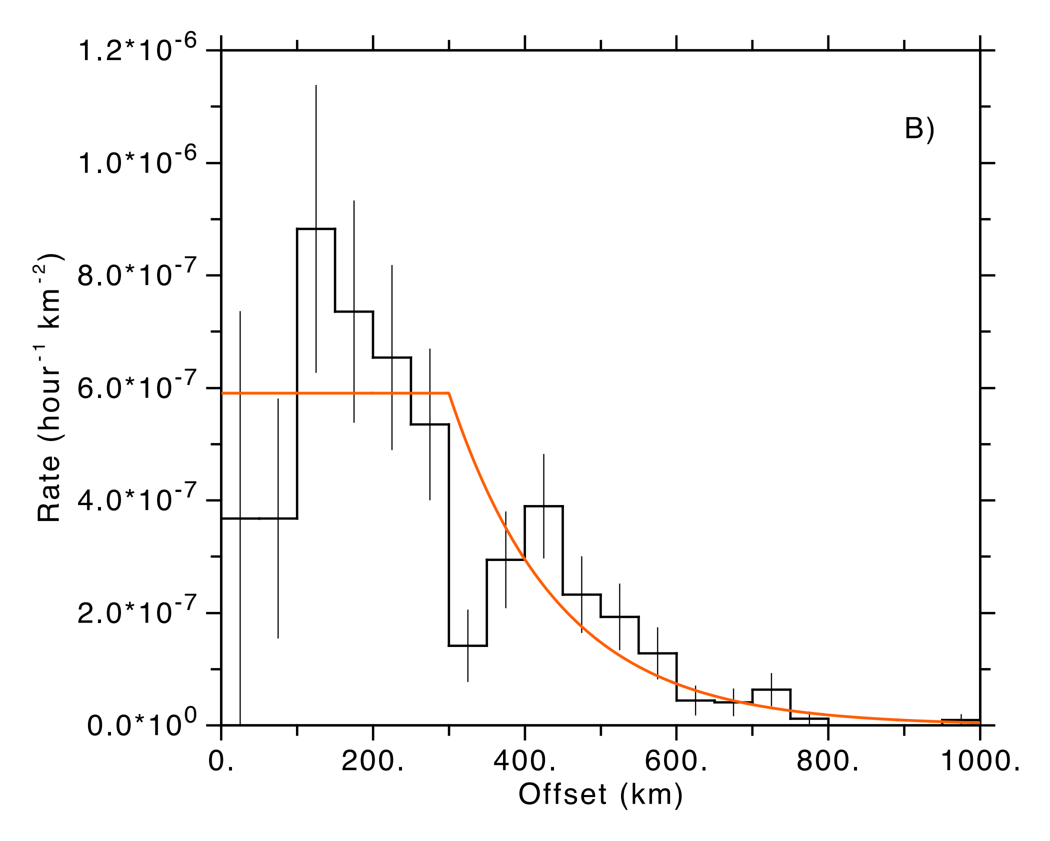
With this new large GBM TGF sample and the high GBM / WWLLN association rate we now have a large sample of accurate (≈10 km) locations. This map shows 89 TGF locations.

Shorter…



t_{90} (ms)

Yet the shortest TGFs have higher deadtime. There likely remains a bias against detecting very short TGFs.


B)
Rate (hour^{-1} km^{-2})
1.2*10^{-6}
1.0*10^{-6}
8.0*10^{-7}
6.0*10^{-7}
4.0*10^{-7}
2.0*10^{-7}
0.0*10^{0}
0.
200.
400.
600.
800.
1000.
Offset (km)

TGF / Lightning Ratios

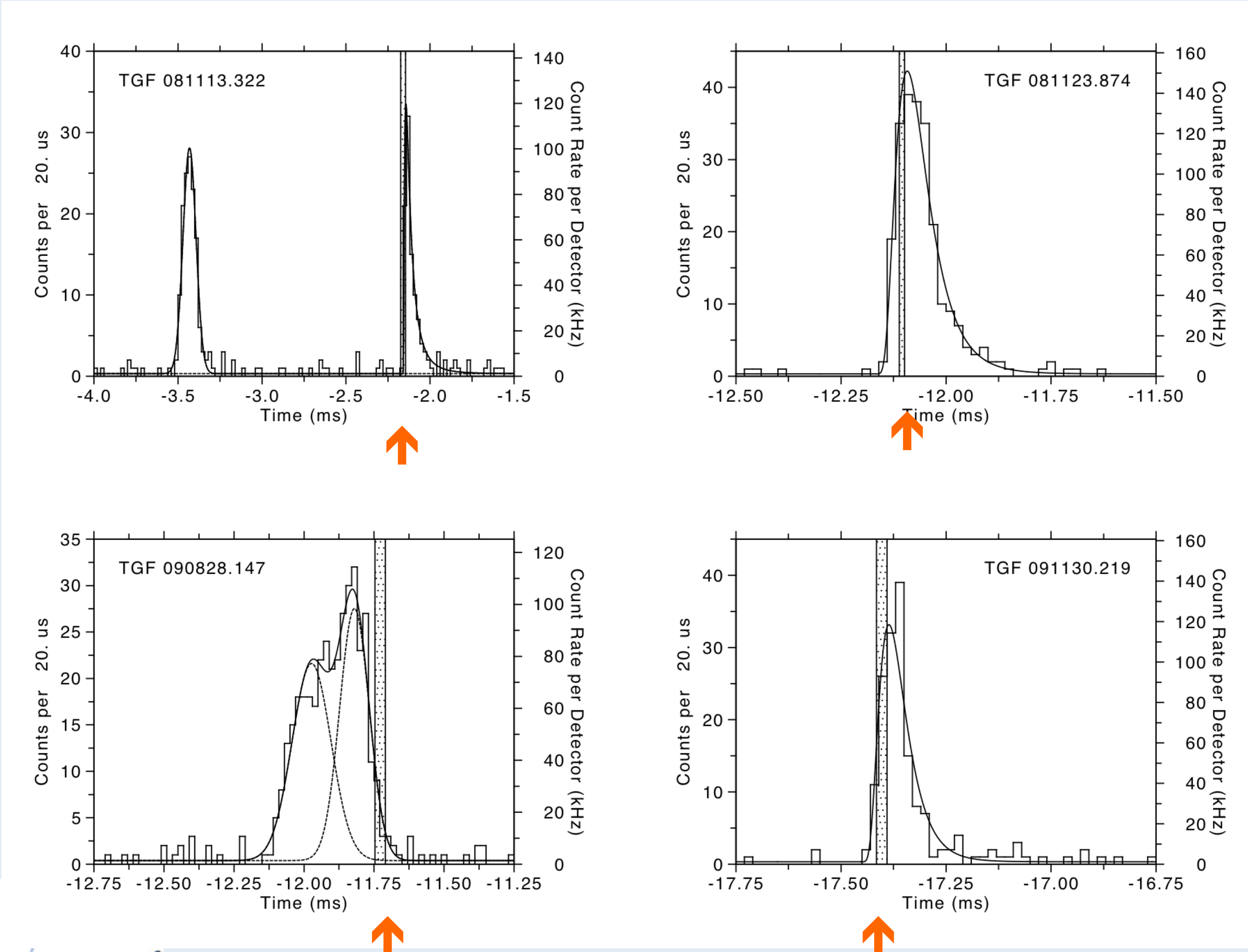
Region	Ratio
Average	$(3.8 \pm 0.2) \times 10^{-4}$
Americas	$(4.9 \pm 0.3) \times 10^{-4}$
Africa	$(2.3 \pm 0.2) \times 10^{-4}$
Asia	$(2.7 \pm 0.4) \times 10^{-4}$
Australia	$(8.6 \pm 1.0) \times 10^{-4}$

Similar to AGILE's view of the equator…

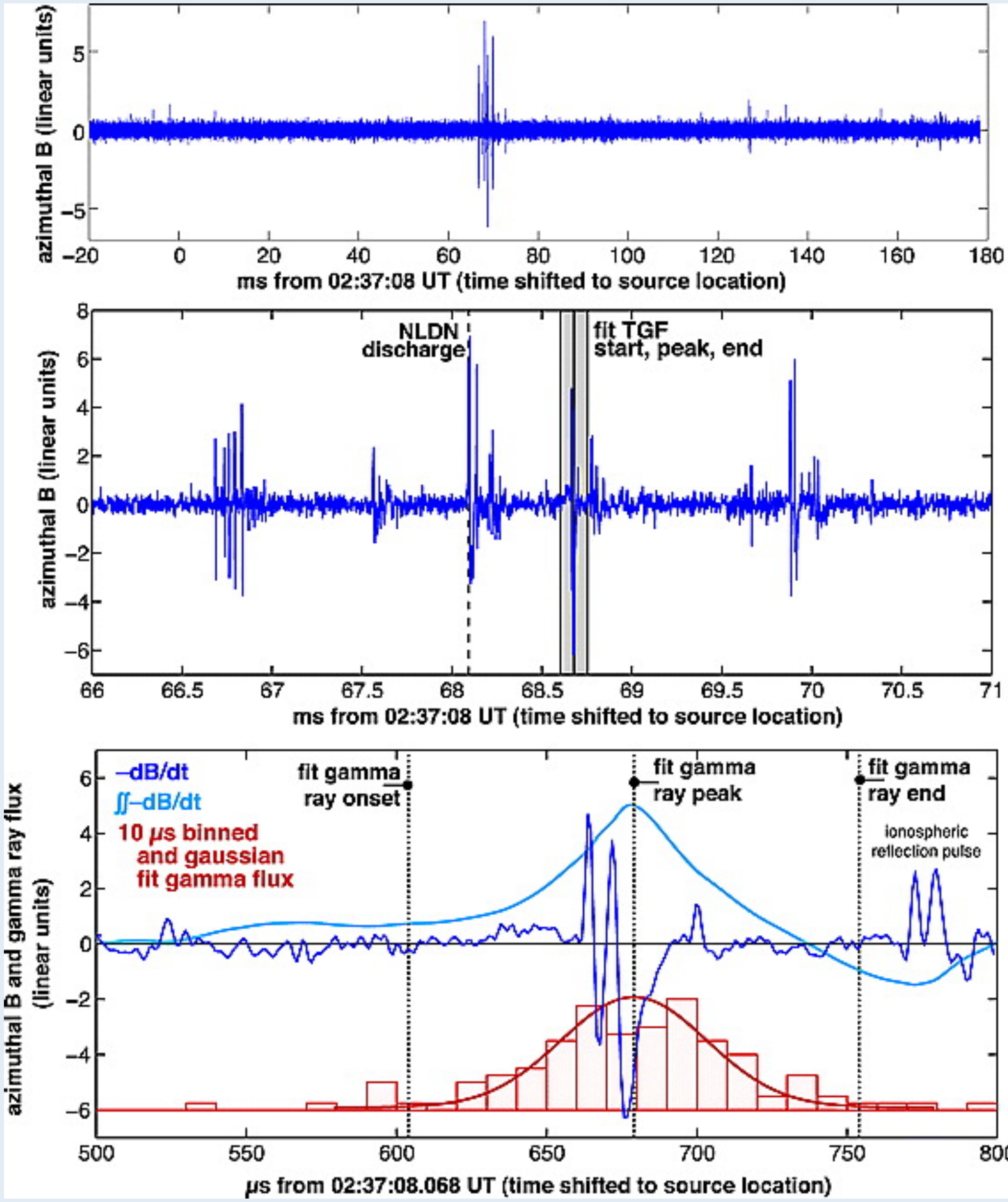
We use these comparisons to estimate at global TGF rate (within ±26°) of ≈400,000 per year, and that with continuous TTE GBM will detect ≈850 TGFs per year.

TGFs and Radio Observations

Correlating TGFs in gamma-rays (GBM) with lightning via radio (WWLLN)



Connaugton et al. (2010)



Cummer et al., GRL, 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 ≈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; Dywer 2012).

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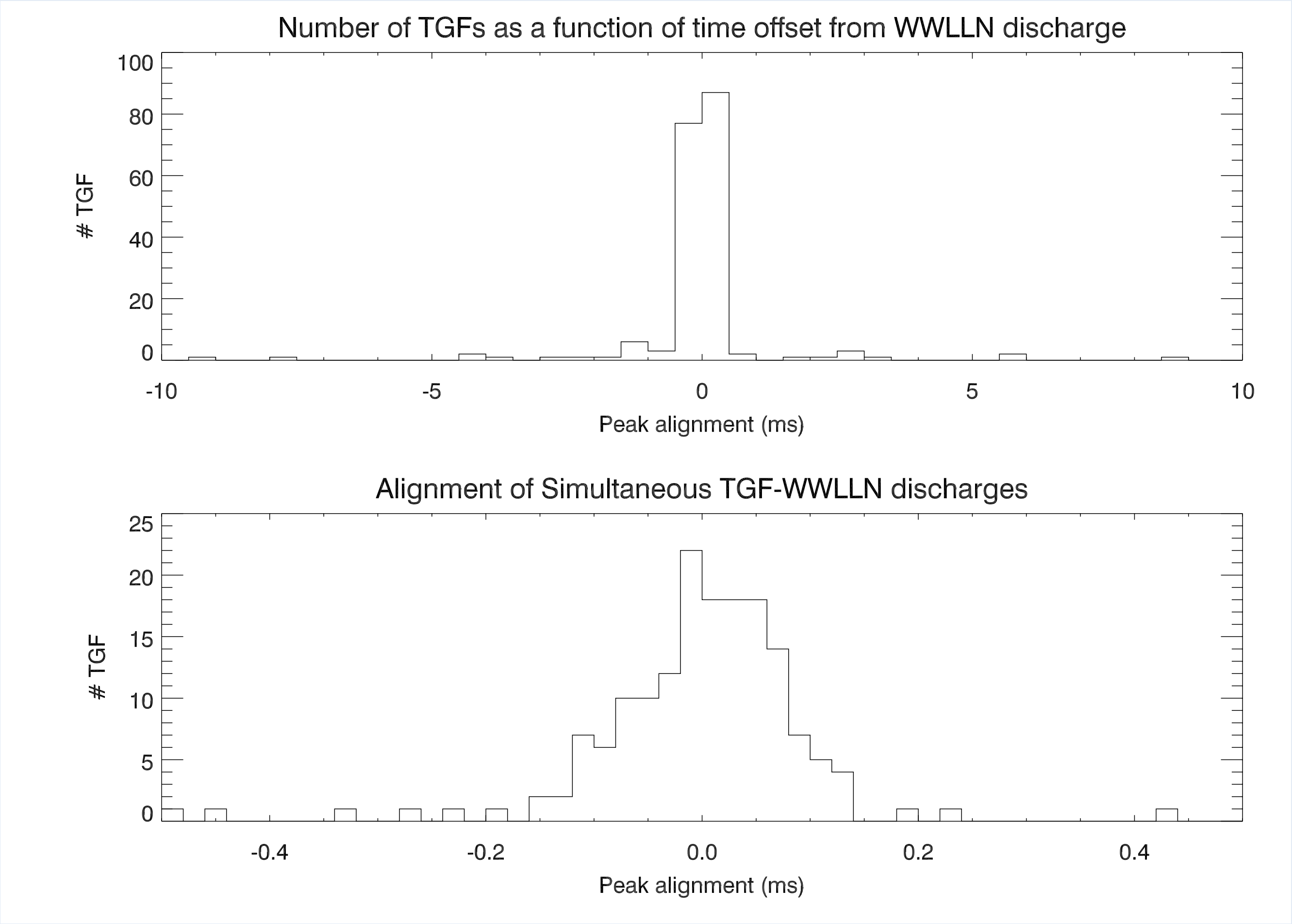
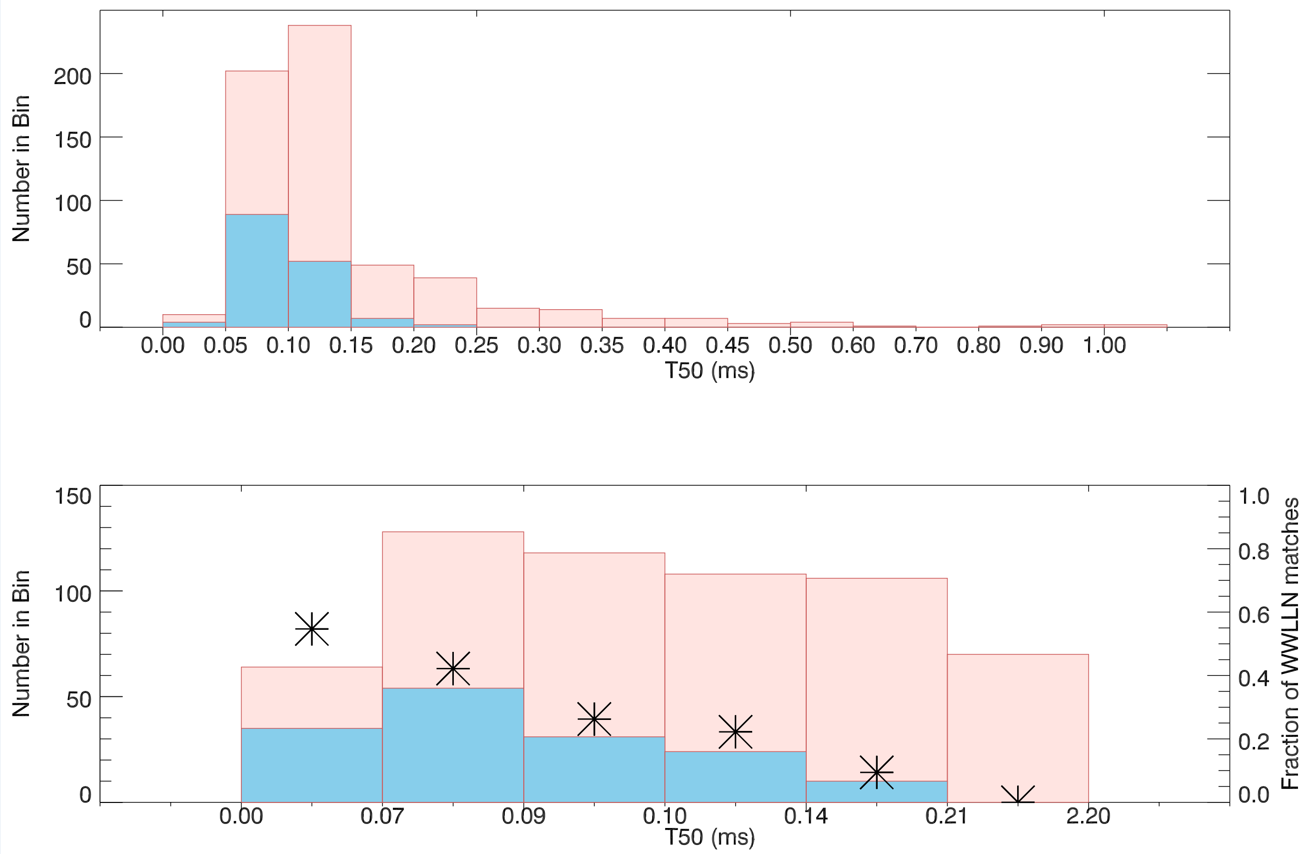


Connaughton et al. 2012



Connaughton et al. (2012)

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

□

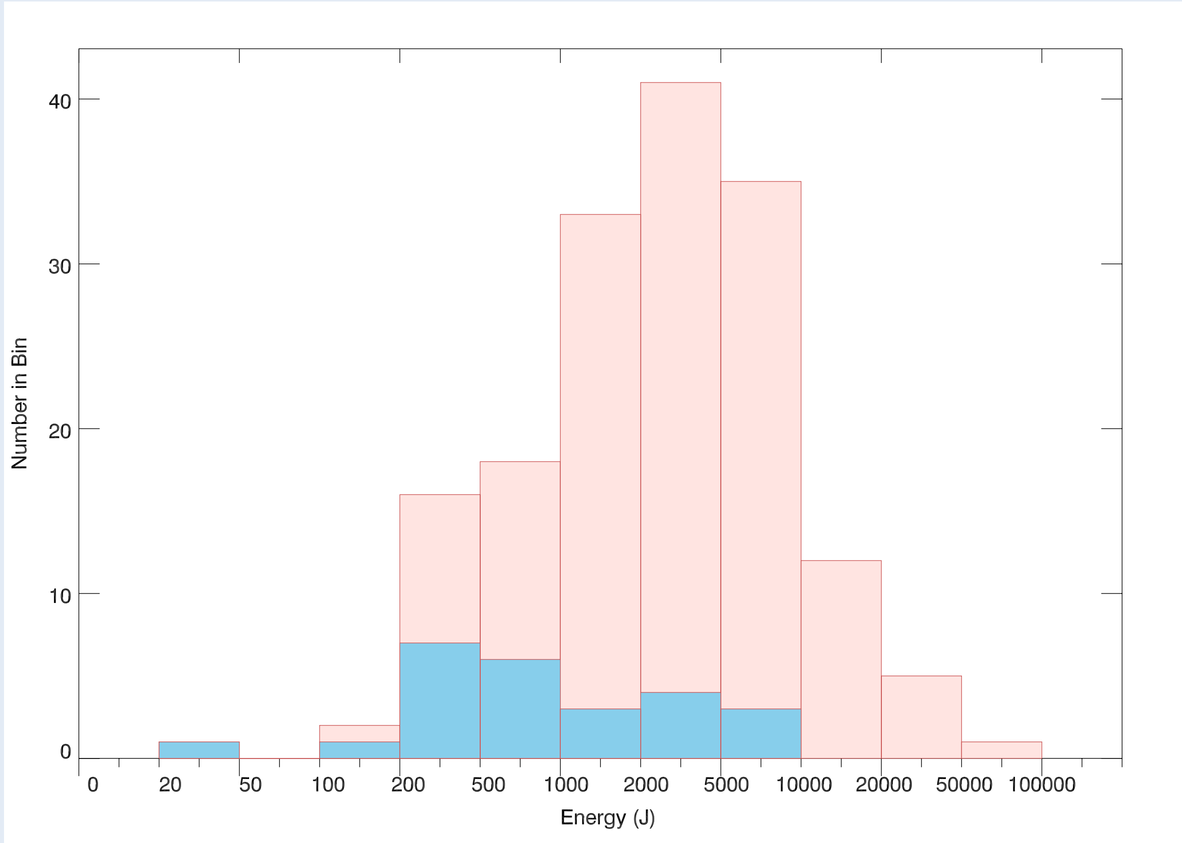
$$E(\omega) = -i\omega\frac{e\alpha\tau_a\mu_e E N_{re}\Delta z\sin\theta}{\sqrt{2\pi}4\pi\varepsilon_0 c^2 R} \exp\left(\frac{-\omega^2(0.74\mathrm{T}_{50})^2}{2}\right)$$

The current is generated by the low-energy drift electrons.

The total current larger for short TGFs.

The energy radiated in the observer band pass depends on the TGF duration.

Connaughton et al. 2012; Dwyer and Cummer 2013



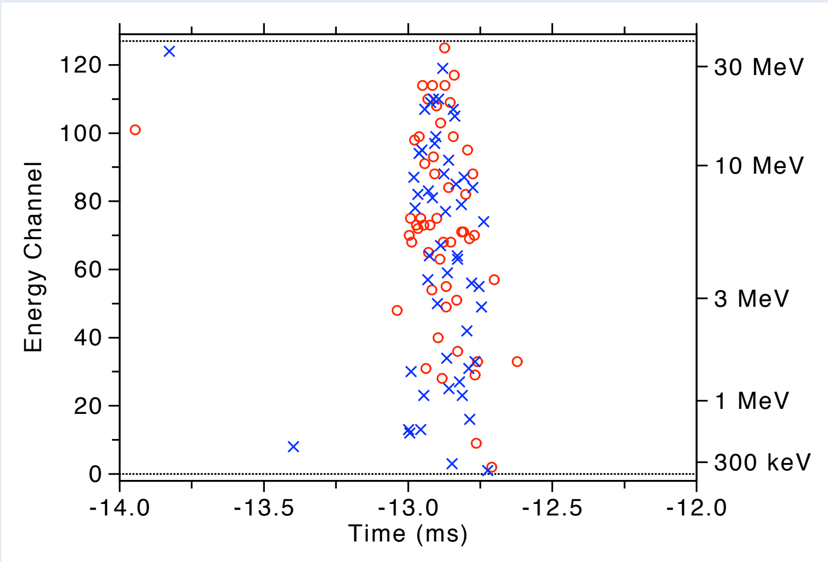
Blue: 32 WWLLN discharges > 0.2 ms from TGF peak. Mean Energy: 700 J
Pink: 154 WWLLN discharges simultaneous with TGF peak. Mean Energy: 3.1 kJ

TGF Fluence Distribution

Reasons that the measured TGF Fluence Distribution differs from that arriving on the detector. (Which itself differs from the source fluence distribution…)

Detection efficiency, e.g., weaker TGFs are less likely to be detected.

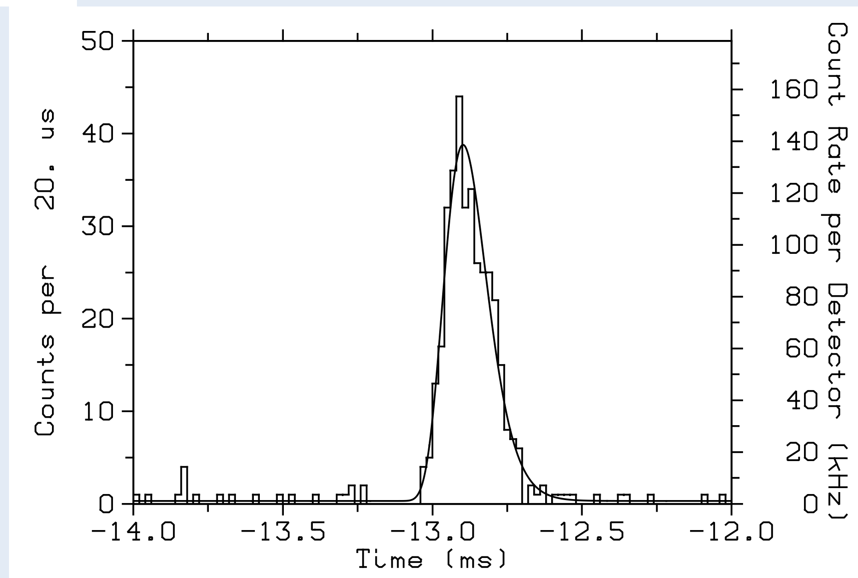
Deadtime reduces the measured number of photons., including higher-order deadtime from pulse pile-up.



An exceptionally strong TGF.

Basic GBM deadtime: non-paralysable, τ = 2.6 μs

1 / 2.6 μs ≈ 400 kcps



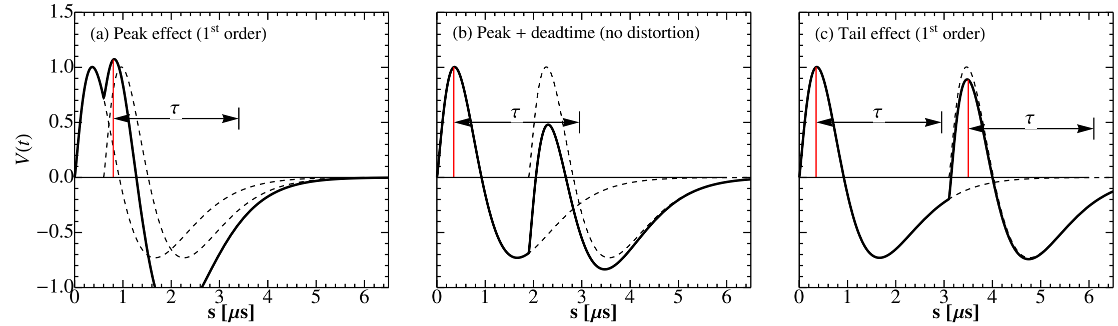


Figure 2: The three cases of 'first order' pileup, ⟨100⟩, ⟨010⟩, and ⟨001⟩, showing the measured peak for two events of equal energy, and the dead time τ as imposed by GBM hardware. (a) shows the *peak* effect, and (c) the *tail* effect. Panel (b) depicts a nominal case where one count is accurately measured and the next is lost. Typically this is not regarded as 'pulse pileup' as there is no associated spectral distortion of the pulse height, only the count rate, which can be corrected by simpler means.

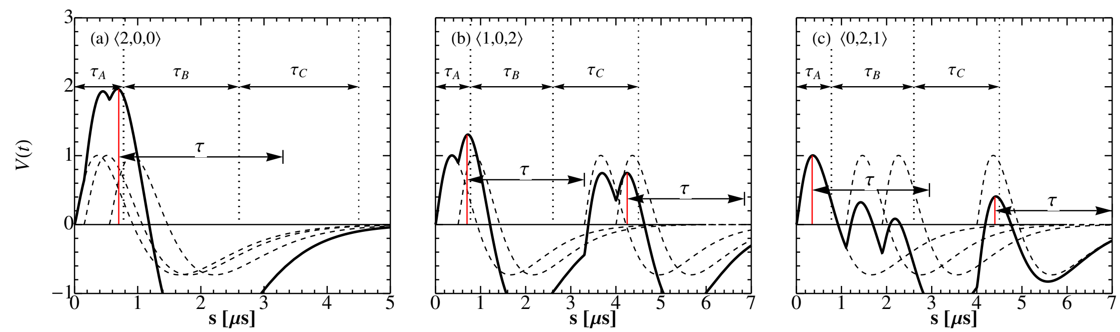


Figure 3: Higher order pileup examples, with the A-B-C partitions shown. (a) second order peak pileup. (b) third order pileup, with peak *and* and tail effects. (c) a third order case of the deadtime+tail effect. Recorded pulse height in C depends on the tail from pulses in A and B.

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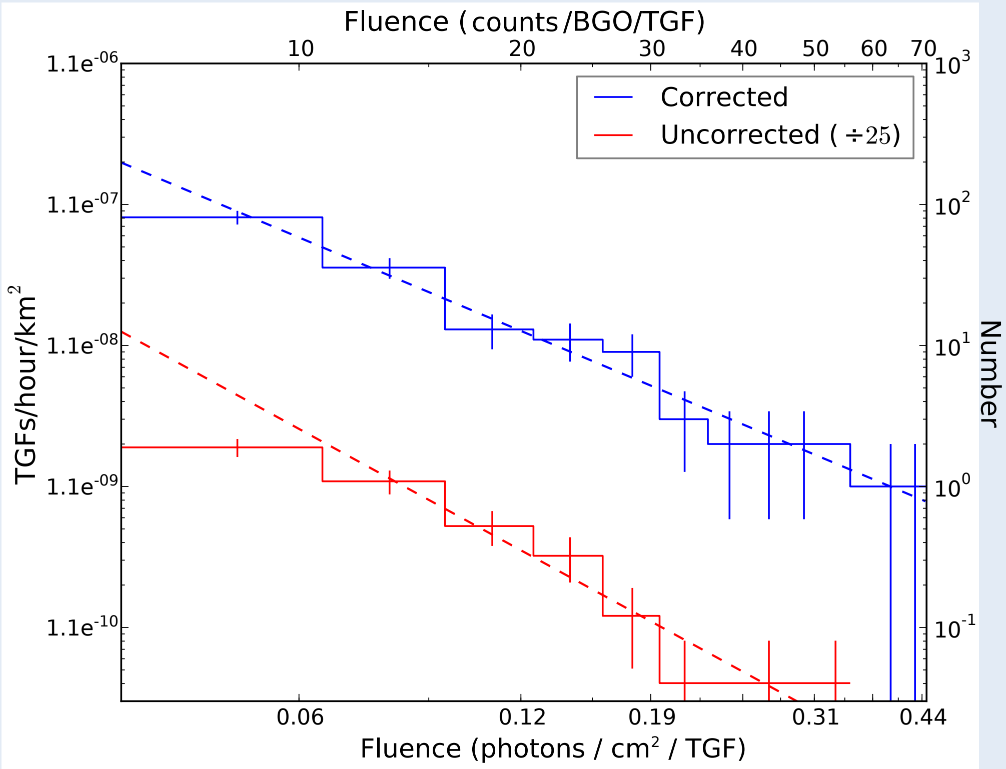
Chaplin et al., (2013) Nucl. Instrum. Methods A

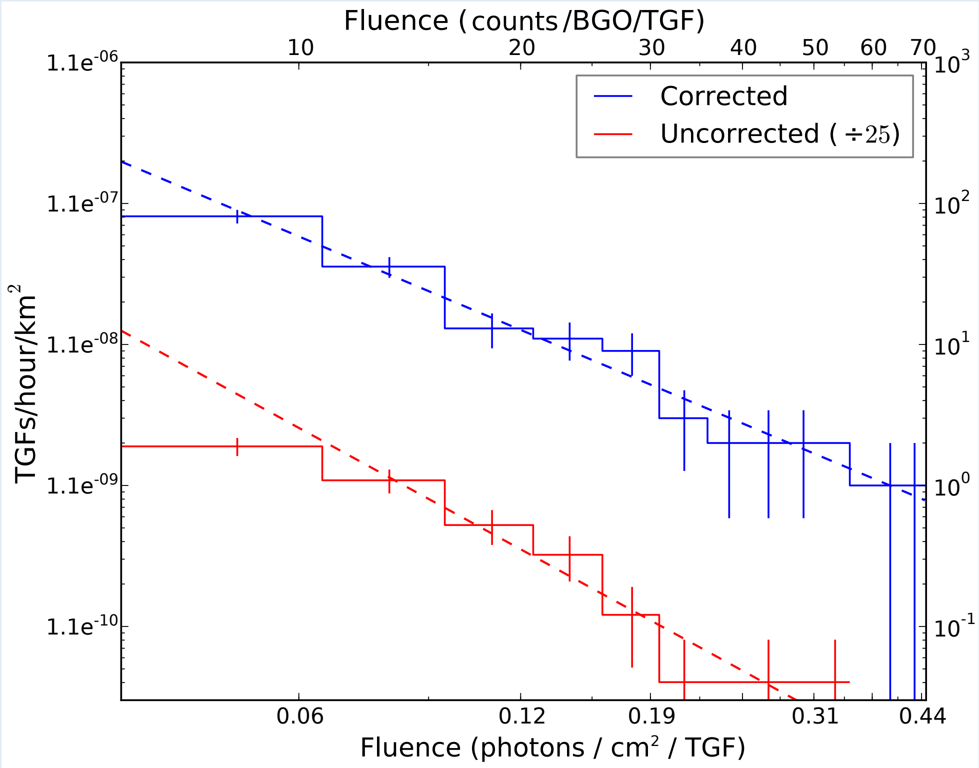


Tierney et al., (submitted)

Sample: 106 TGFs.

Red (÷25) ➔ 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-pulse up: additional 10% deadtime correction for the 7 brightest TGFs in the sample.



Tierney et al., (submitted)

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.

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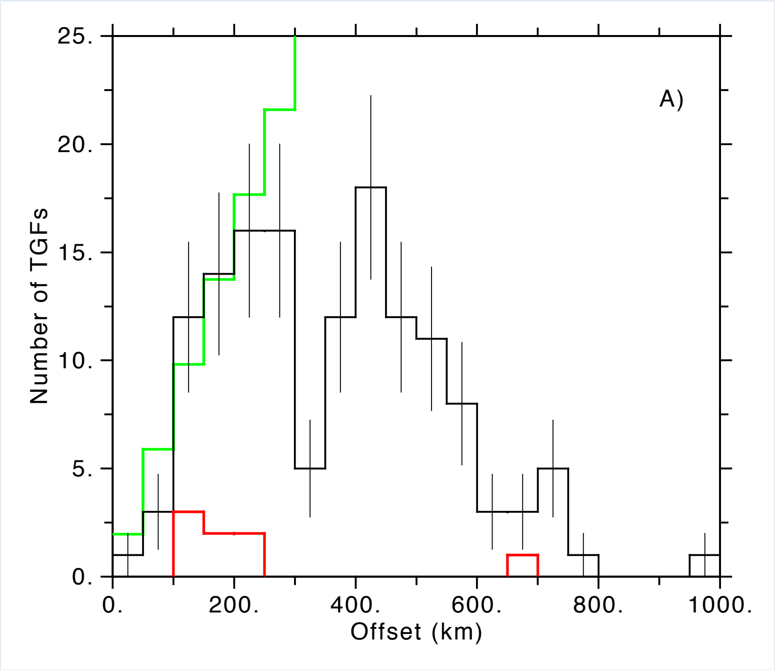
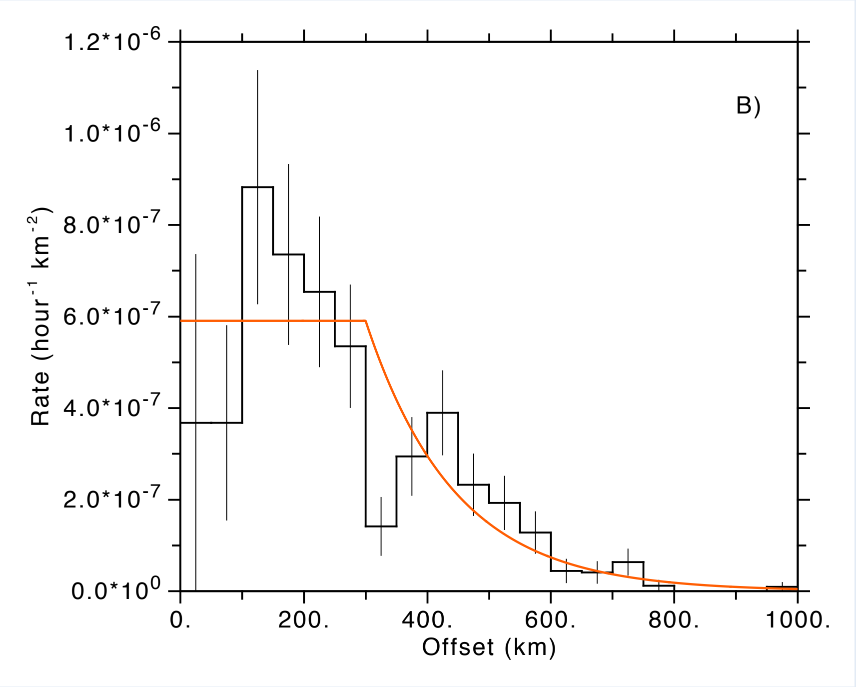
GBM TGF papers:

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

BACKUP SLIDES


A)
Number of TGFs
25.
20.
15.
10.
5.
0.
0.
200.
400.
600.
800.
1000.
Offset (km)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0.0*10^{0}
0.
200.
400.
600.
800.
1000.
Offset (km)