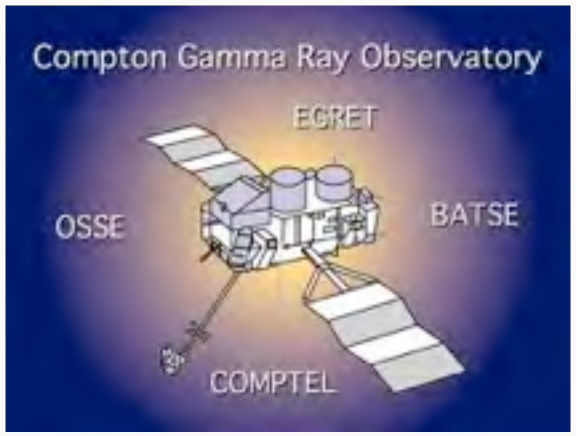
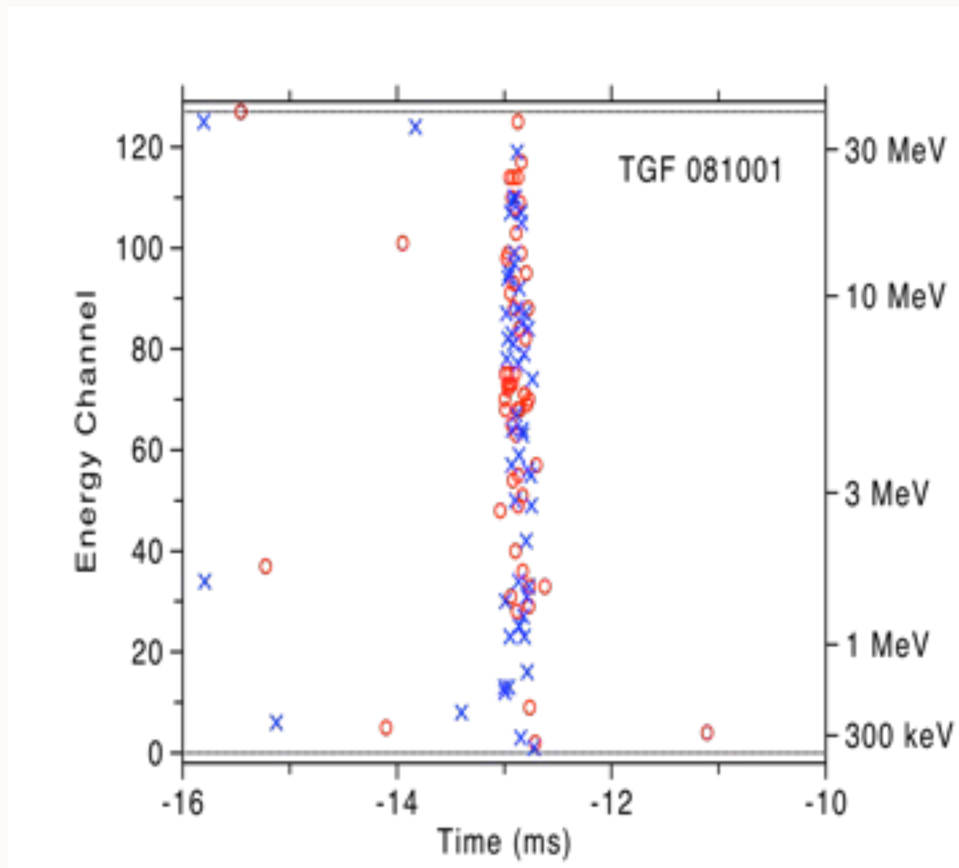
TERRESTRIAL GAMMA-RAY FLASHES: FERMI'S EMERGING ROLE AS AN EXCELLENT STORM CATCHER

Valerie Connaughton

TERRESTRIAL GAMMA-RAY FLASHES

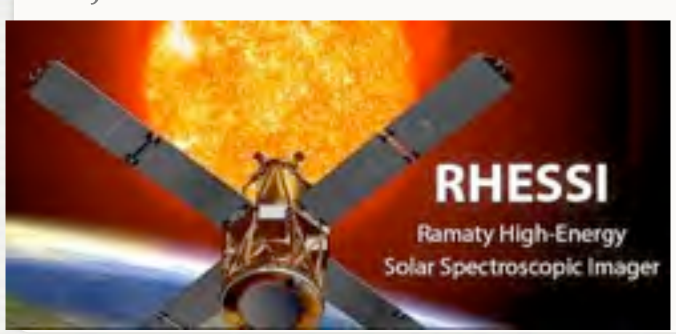


Fishman et al. 1994



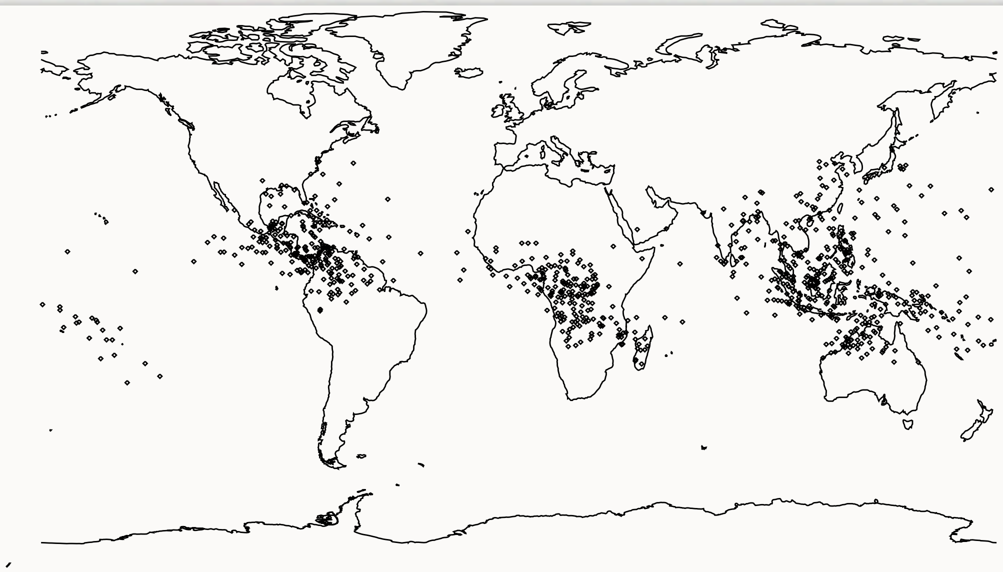
Fuschino et al. 2011

Smith et al. 2005
Grefenstette et al. 2009
Gjesteland et al. 2012



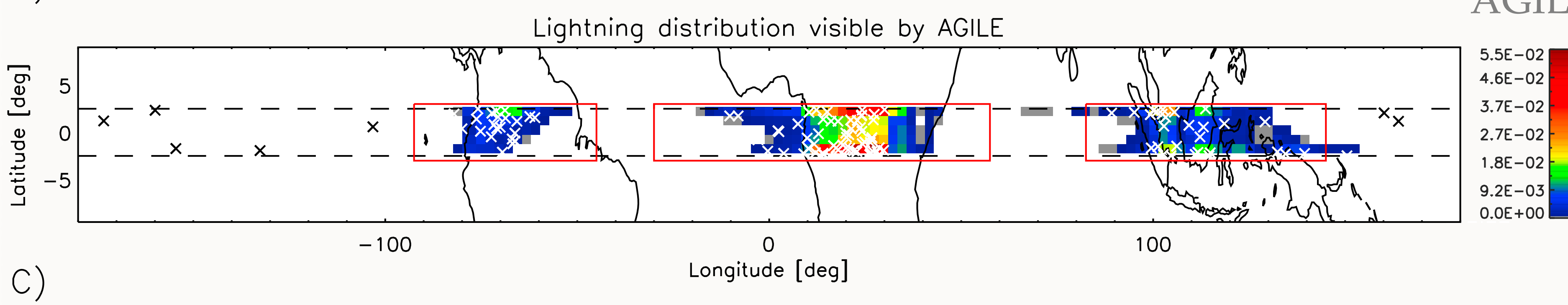
Briggs et al. 2010
Fishman et al. 2011

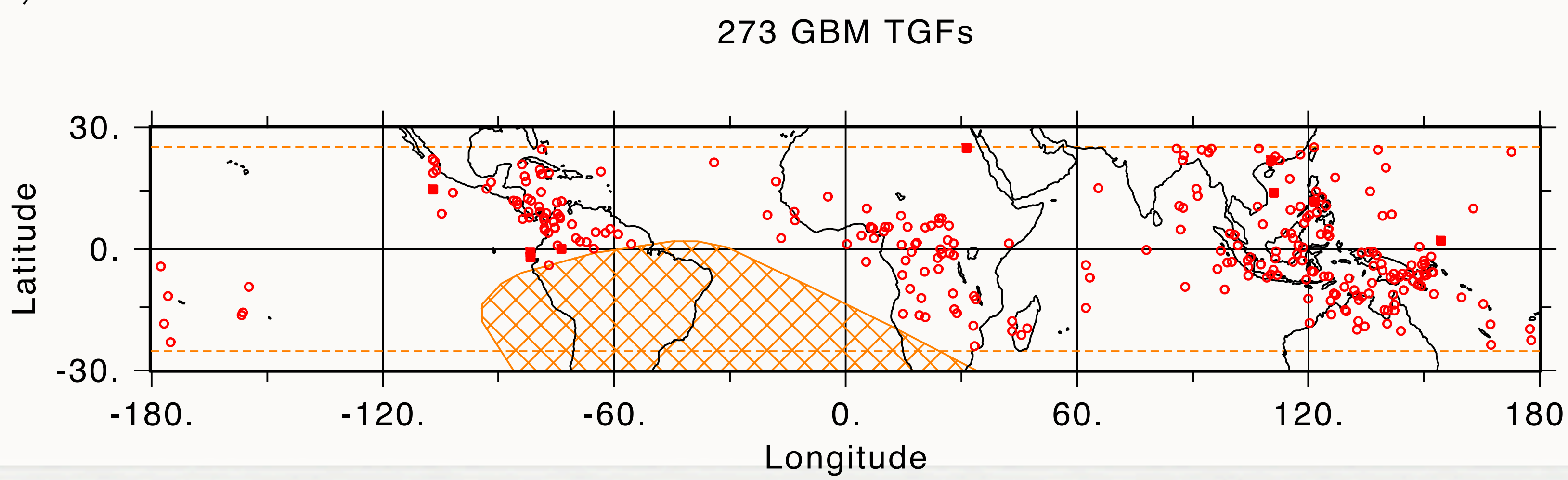
SPACECRAFT NADIRS WHEN TGFS ARE DETECTED



RHESSI: Grefenstette et al. 2009

AGILE: Fuschino et al. 2011

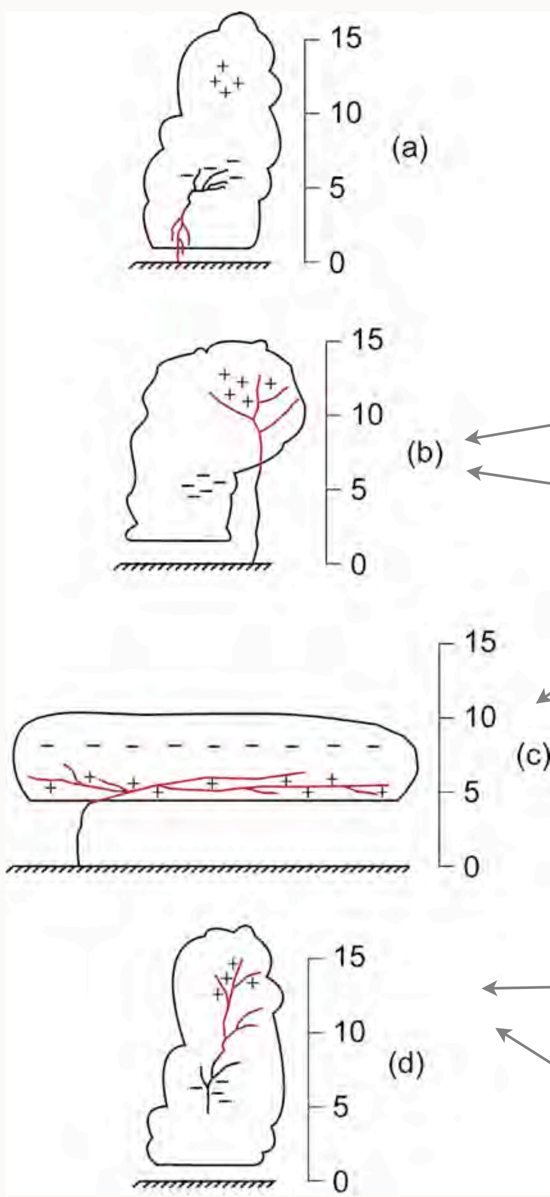




GBM Latest Map!
See also Briggs et al. 2010,
Fishman et al. 2011

A SHORT LIGHTNING PRIMER

Radio detection of lightning through sferics.
VLF 3 - 30 kHz, ELF 3 - 3000 Hz ULF < 3 Hz



Inan et al. 1996 (2 BATSE TGFs)
Positive polarity

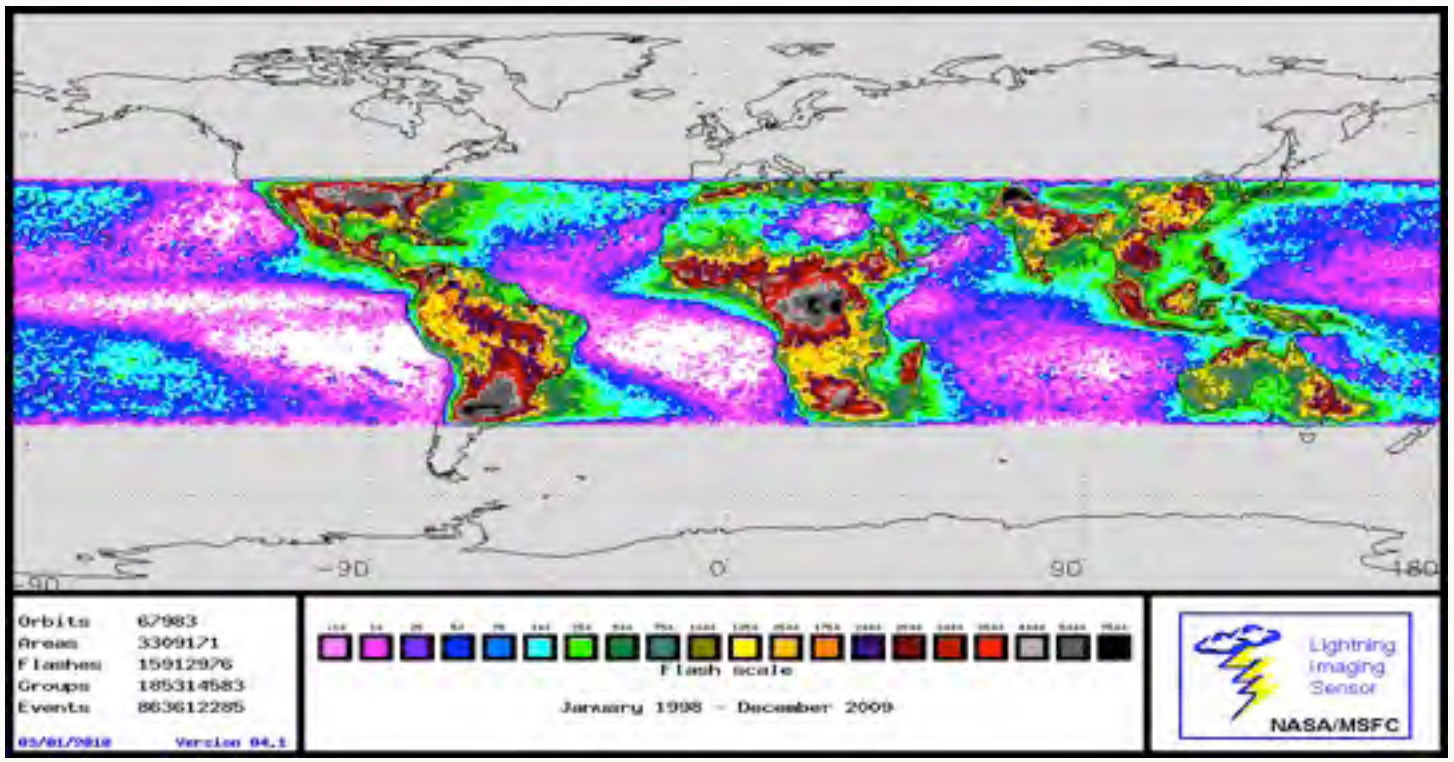
Cummer et al. 2005 (13 RHESSI TGFs)
Average charge moment 49 C km

Dwyer and Smith 2005
Source height 15-21 km
(RHESSI spectrum)

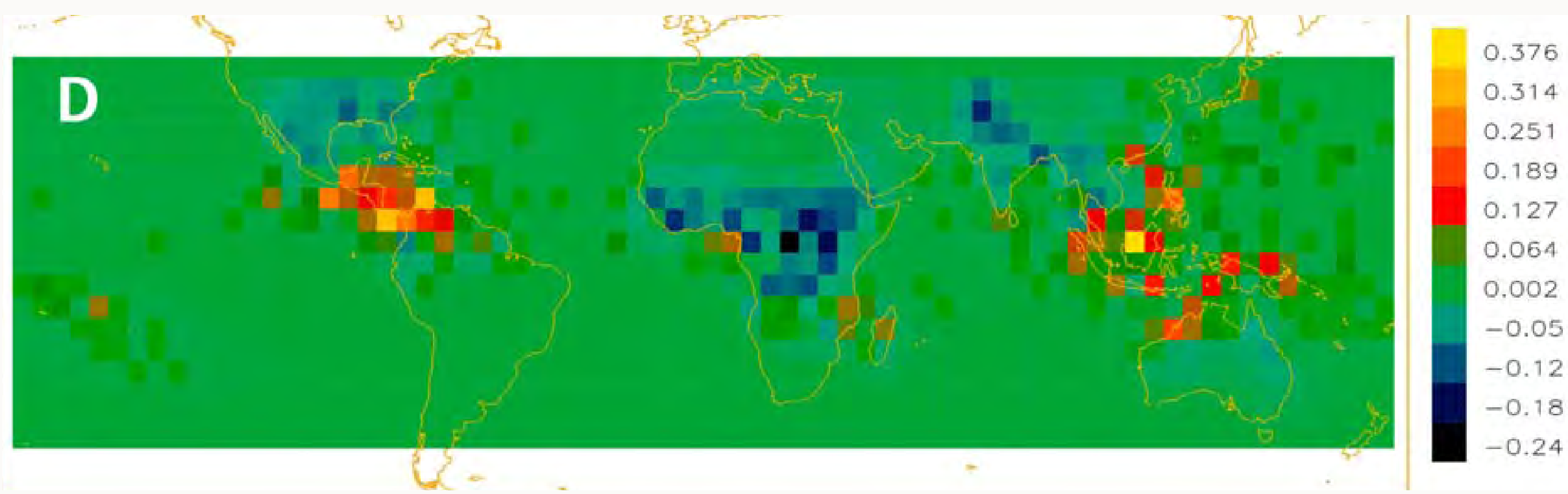
Stanley et al. 2006 (6 RHESSI TGFs)
Source heights 11-13 km

Williams et al. 2006

DO THE NADIRS FOLLOW THE GLOBAL LIGHTNING DISTRIBUTION?



LIS-OTD map

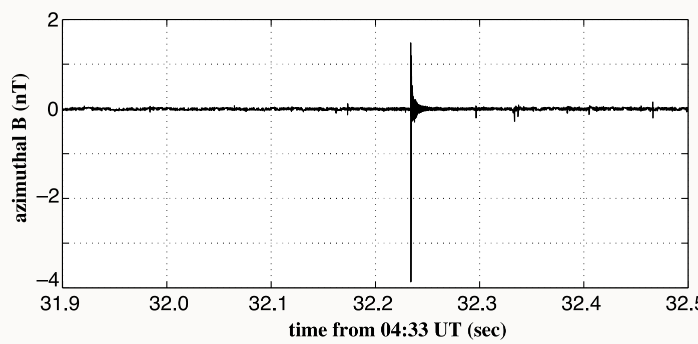


TGF excesses/deficits relative to LIS/OTD

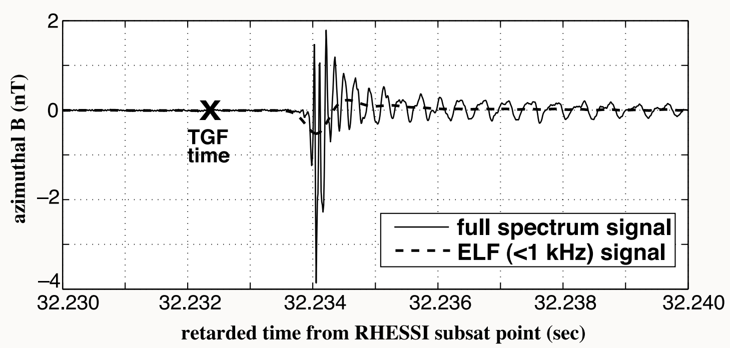
Smith et al. 2010

Not a one-to-one correspondence: instrumental effects, or meteorology affects TGF-production (Splitt et al. 2010)

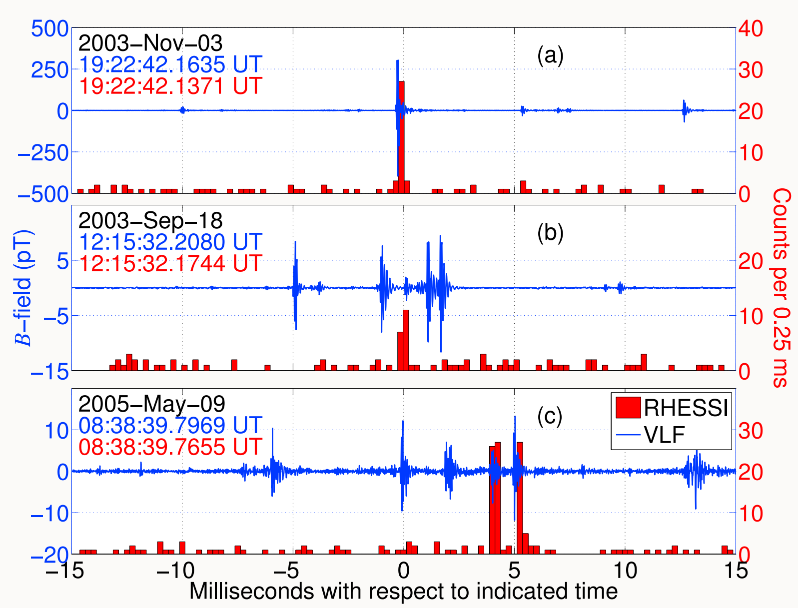
TGF CORRELATION WITH INDIVIDUAL LIGHTNING DISCHARGES: CHICKEN OR EGG?



Cummer et al. 2005 (13 RHESSI TGFs)
from -0.7 to 3 ms with average -1.24 ms



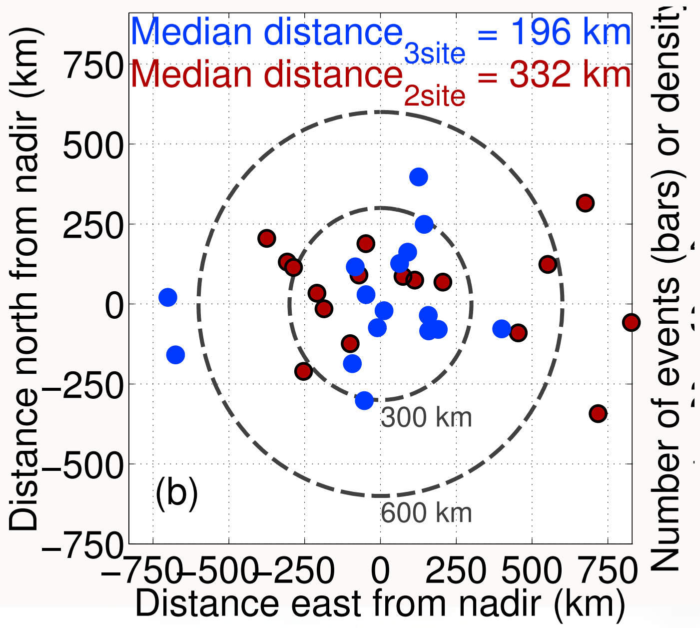
Inan et al. 2006 (88 RHESSI TGFs)
average +0.879 +/- 2.41



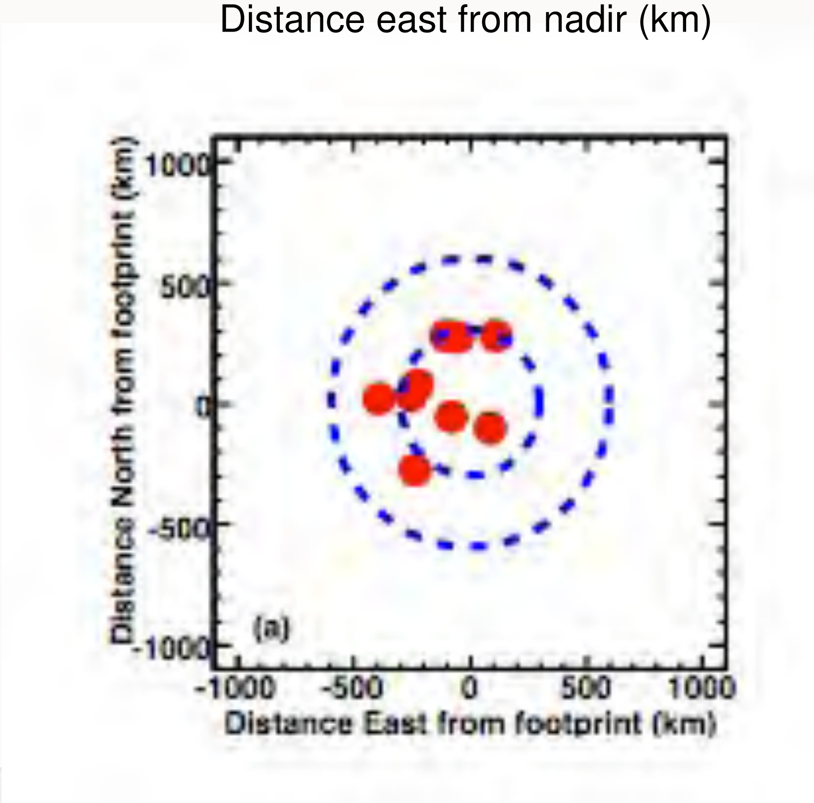
Cohen et al. 2010 (36 RHESSI TGFs)
-0.5 ms +/- 2.4 ms

RHESSI clock is uncertain to ~ 2 ms

GEOLOCATION OF TGFS USING RADIO NETWORKS

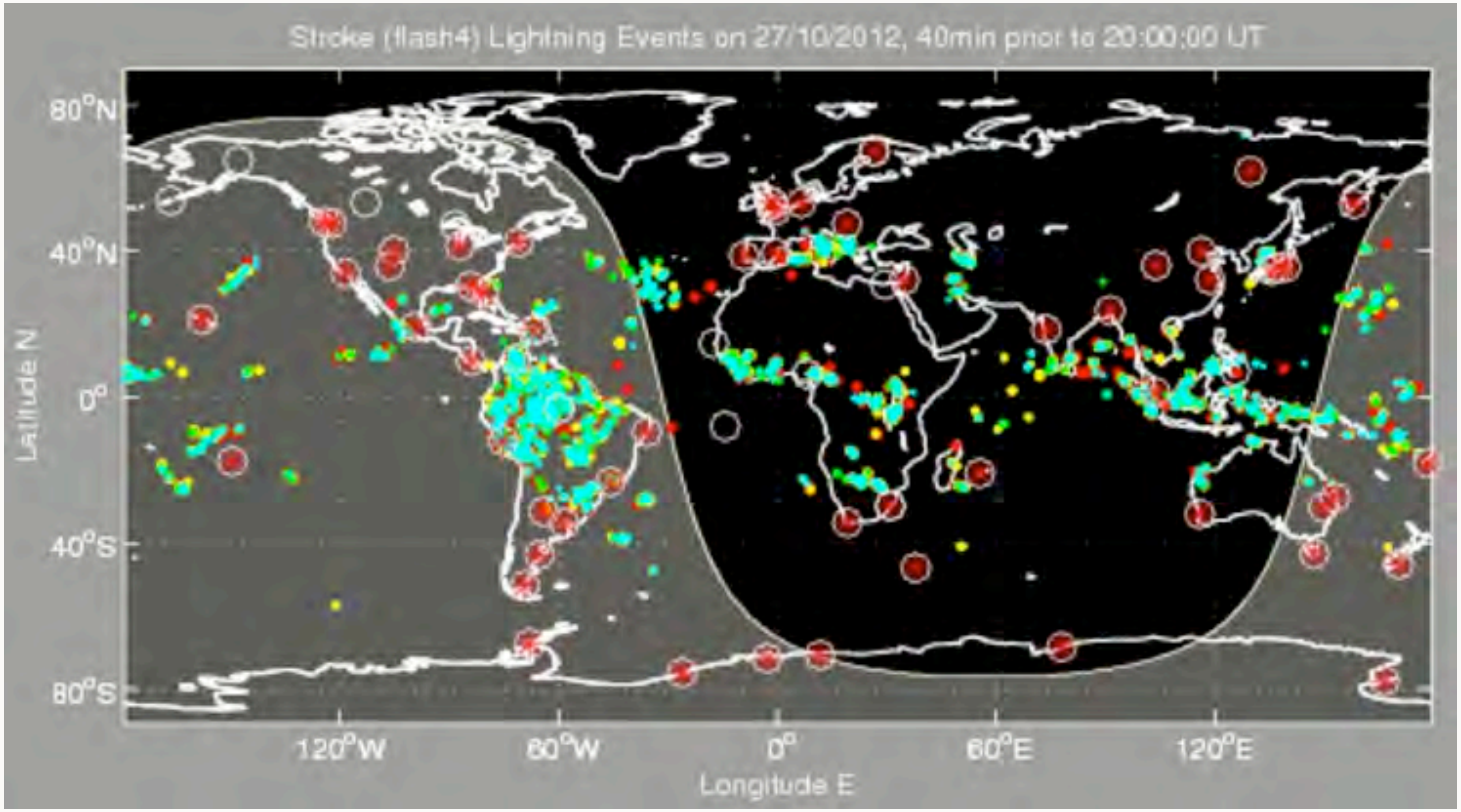


Cohen et al. 2010 (36 RHESSI TGFs)
2-3 pairs of antennae



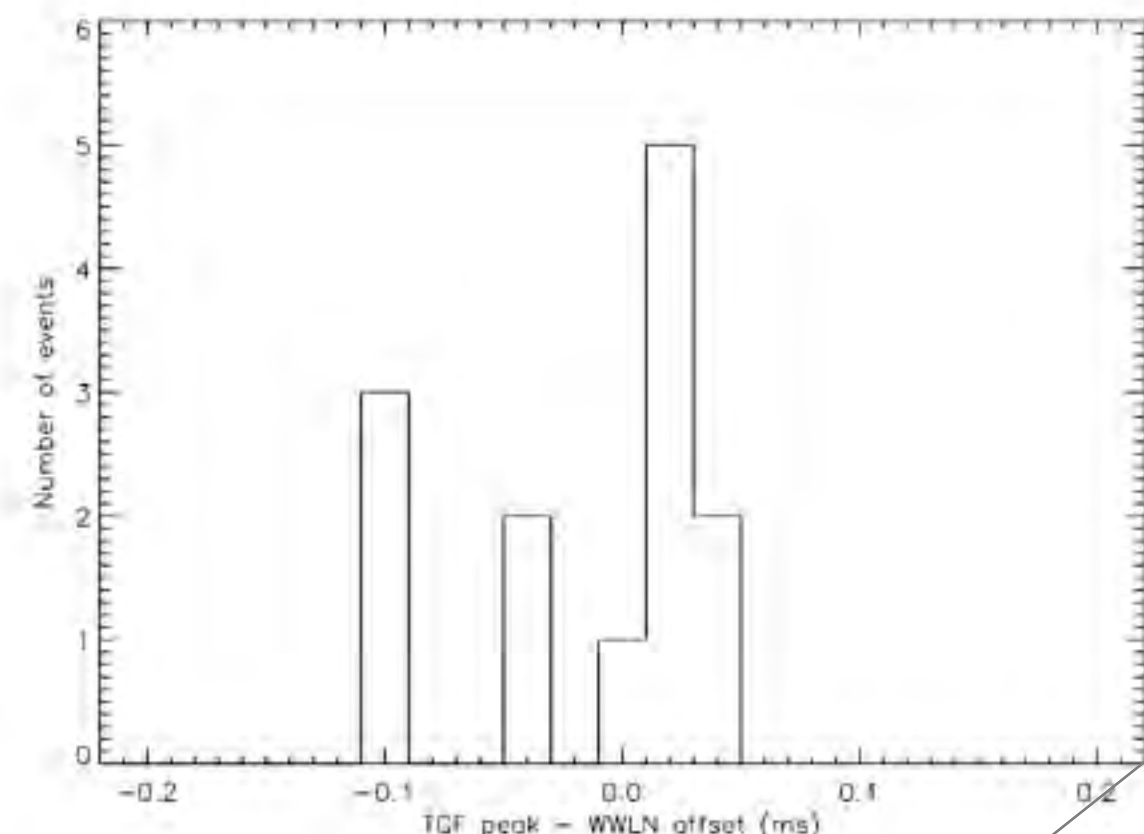
Geolocation can also be done using gamma rays: AGILE (Marisaldi et al. 2010)

WORLD WIDE LIGHTNING LOCATION NETWORK (WWLLN)



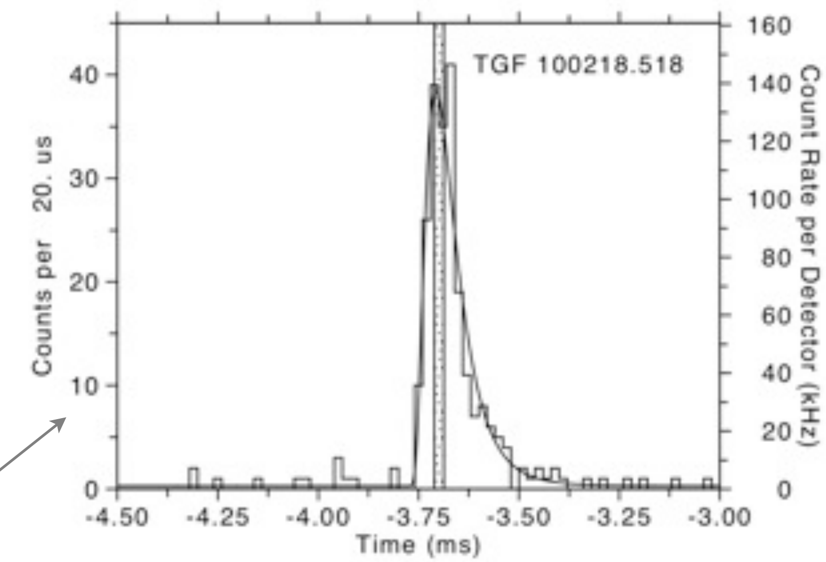
http://webflash.ess.washington.edu/

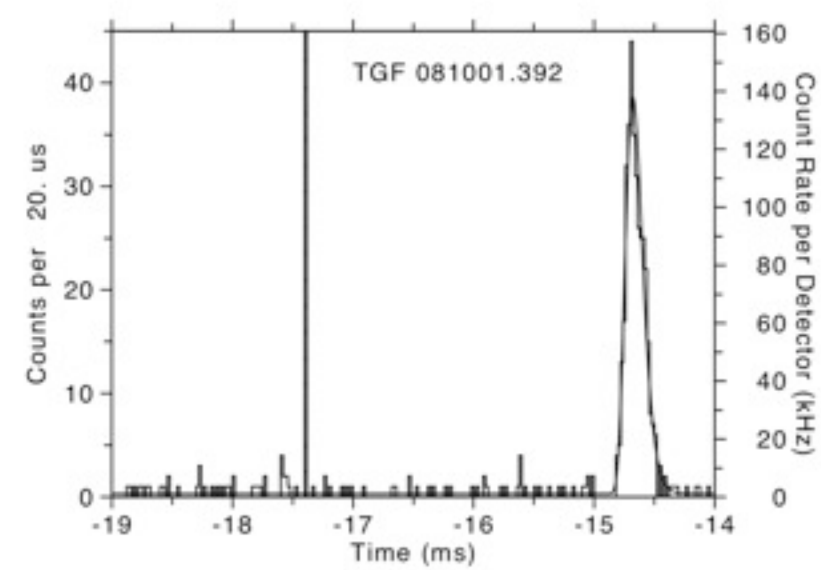
GBM TGF PEAK TEMPORAL OFFSETS FROM WWLLN DISCHARGES FOR 15/50 ASSOCIATIONS (5 MS, 300 KM)



13/15 WWLLN discharges simultaneous with TGF peak.

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





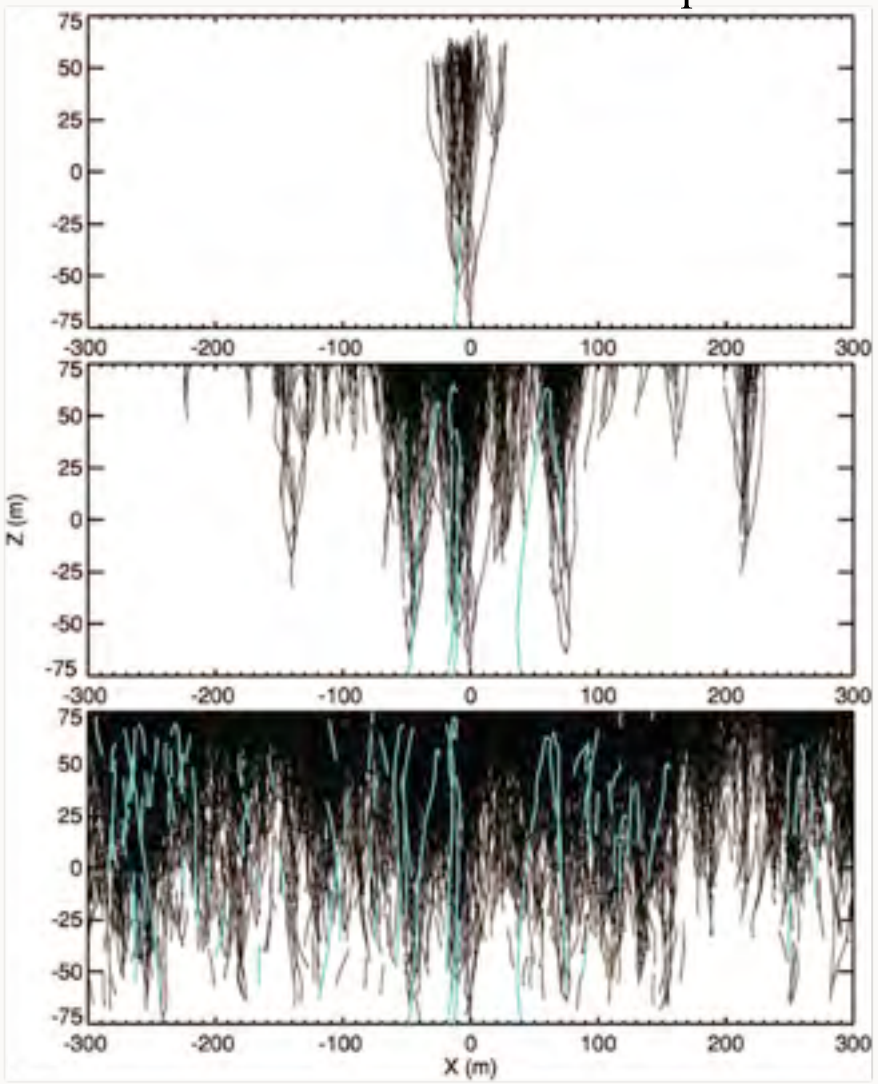
VC et al. (2010)

Monday, October 29, 12

BREMSSTRAHLUNG OF ELECTRONS ACCELERATED IN ELECTRIC FIELDS REPRESENTS WELL THE OBSERVED GAMMA-RAY EMISSION

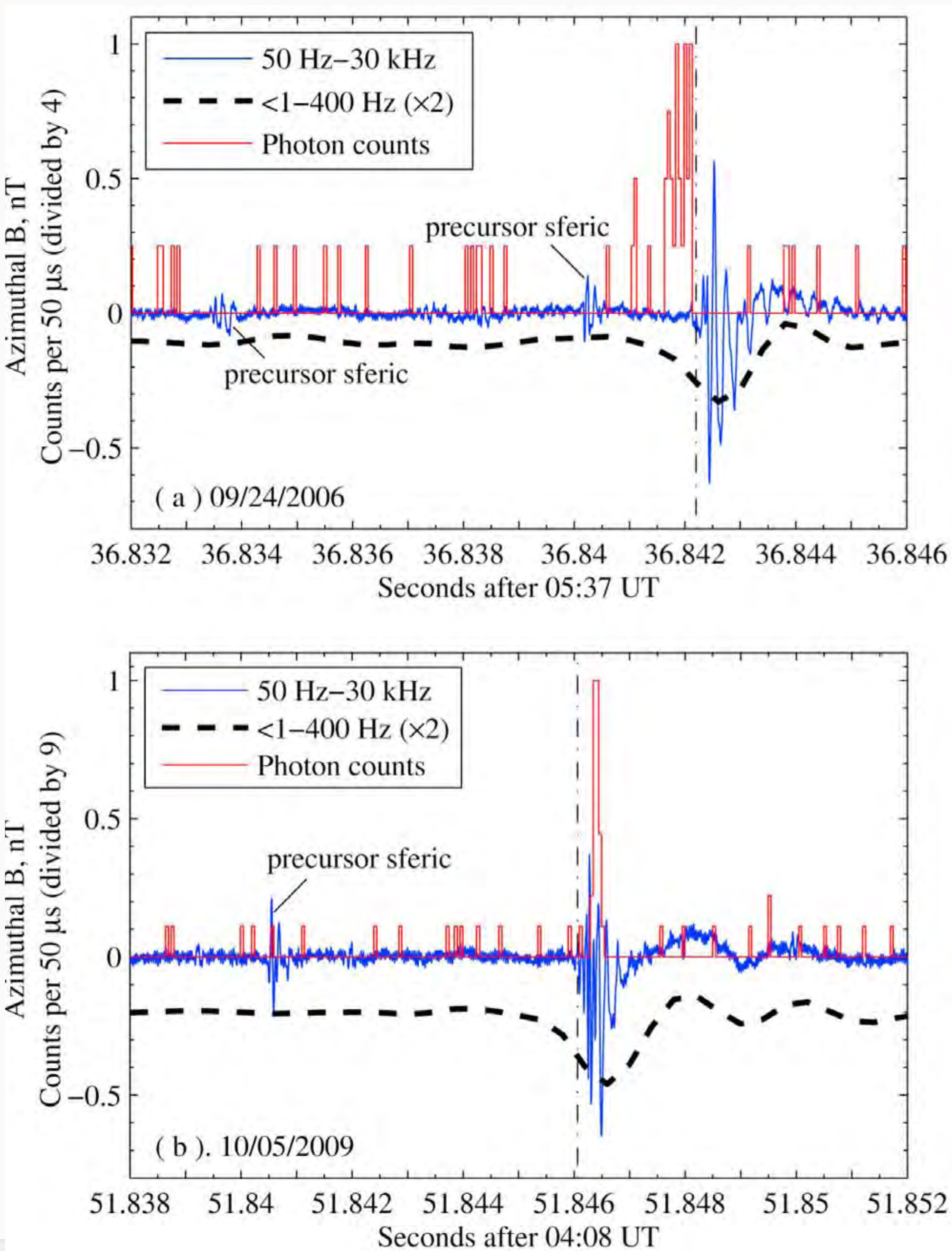
- Runaway Relativistic Electron Avalanche (Gurevich et al 92)
- Source of electrons? Need 10^{16} photons, or 10^{17} electrons, with E > 20 MeV for observed flux
- Source of electric field and potential difference?
  - Thunderstorm ambient field - feedback produces more e's (Dwyer et al. 2007)
  - Alternative: Lightning leader tips - large potentials in tips. (Carlson et al. 2009, Celestin & Pasko 2011)

E = 750 kV / m
for 150 m,
➔110 MV potential



Close temporal relation expected in leader tip model, not feedback model.

2 TYPES OF VLF RADIO PULSES ASSOCIATED WITH TGFS?



Lu et al (2010) 9 RHESSI TGFS

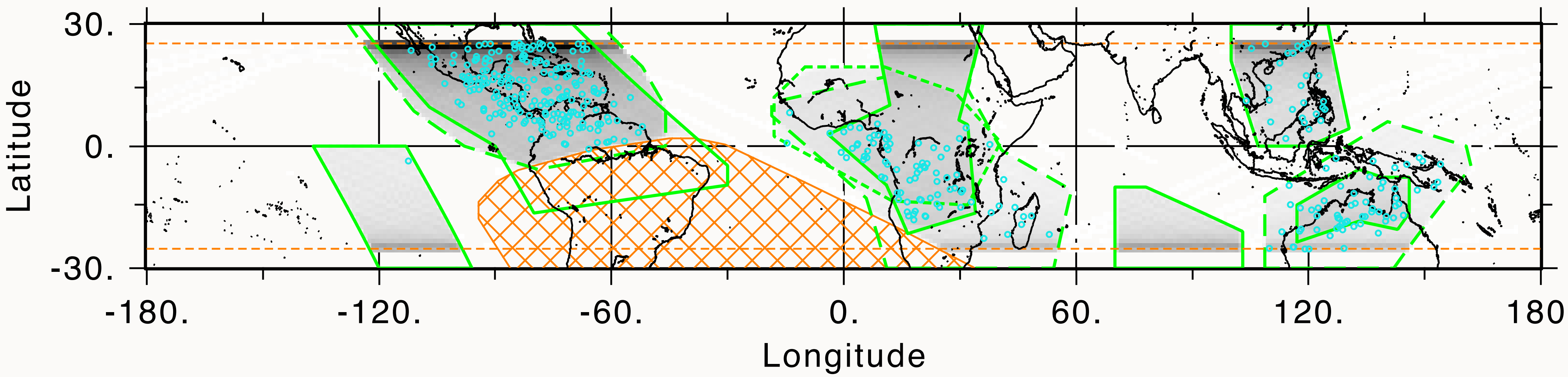
VLF and ULF pulses

Slow ULF pulse with VLF sferics

Fast VLF sferics occur too

Fast VLF sferics can occur ms away

GBM OFFLINE SEARCH



TTE event data gathered over select parts of orbit (moving boxes)

>1000 hours gathered

TGFs sought on-ground

Cosmic ray rejection critical factor

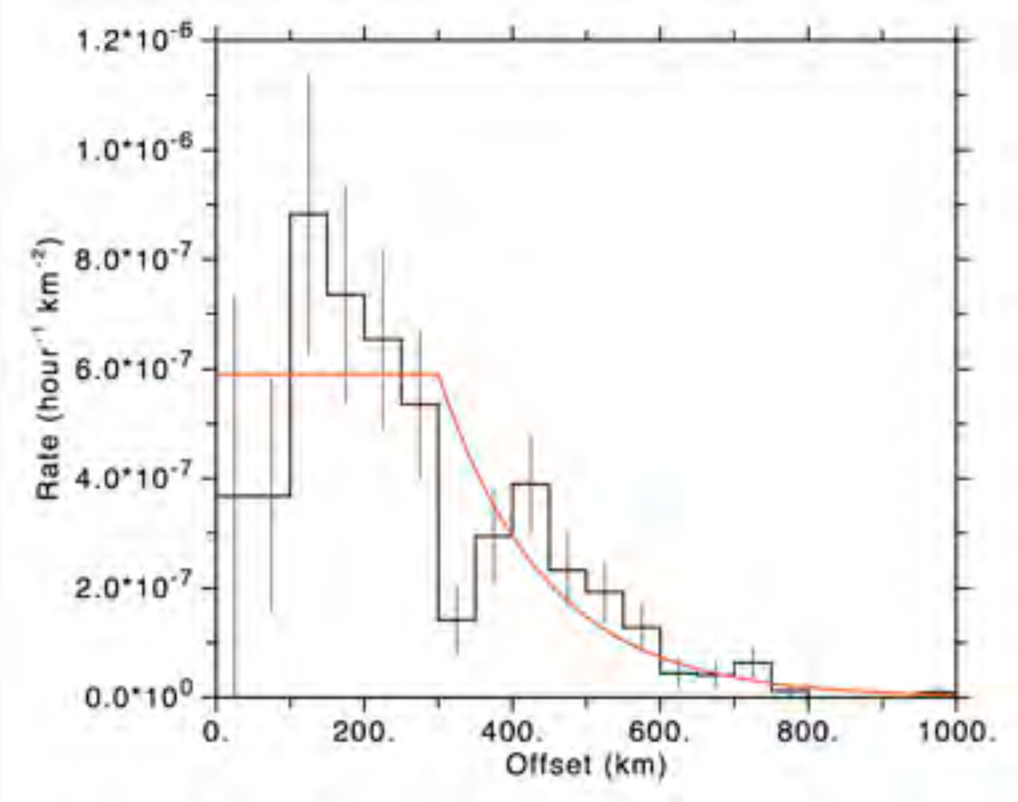
TGF rate 10x triggered rate in same region. 384 offline only vs 39 onboard.

Briggs et al. (2012)

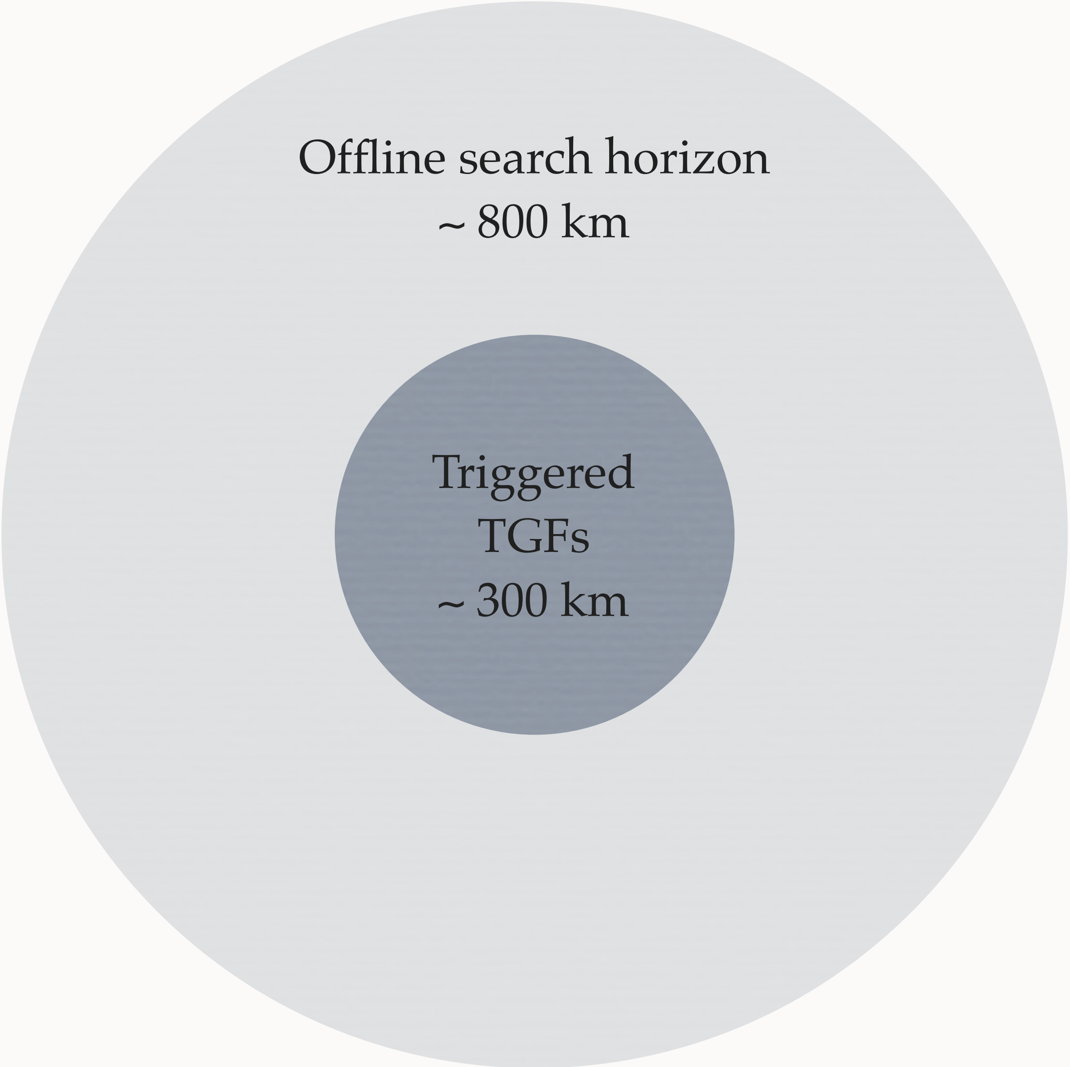
Shaolin Xiong Tuesday Instrument session

Monday, October 29, 12

WHAT IS GBM'S FOOTPRINT FOR TGF DETECTION?



Briggs et al. (2012)



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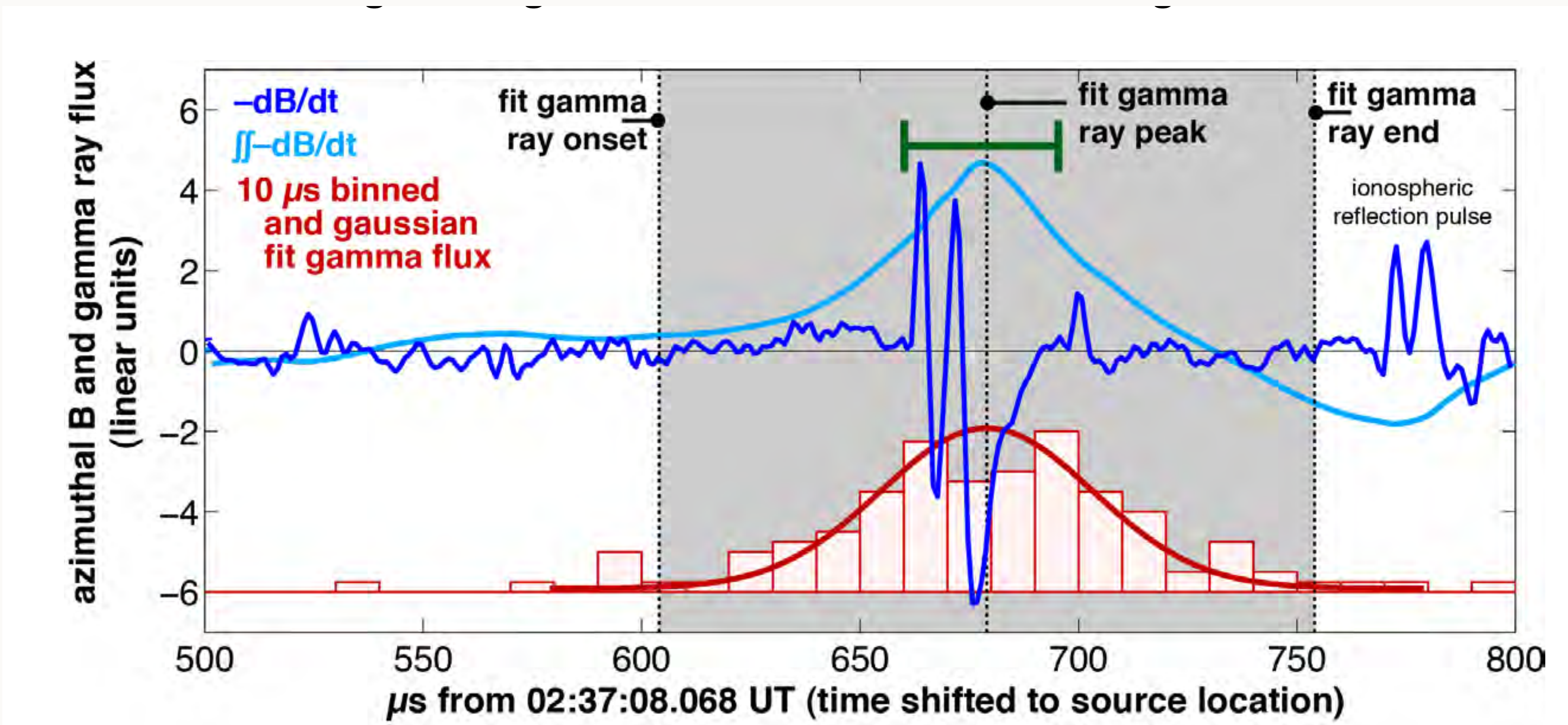
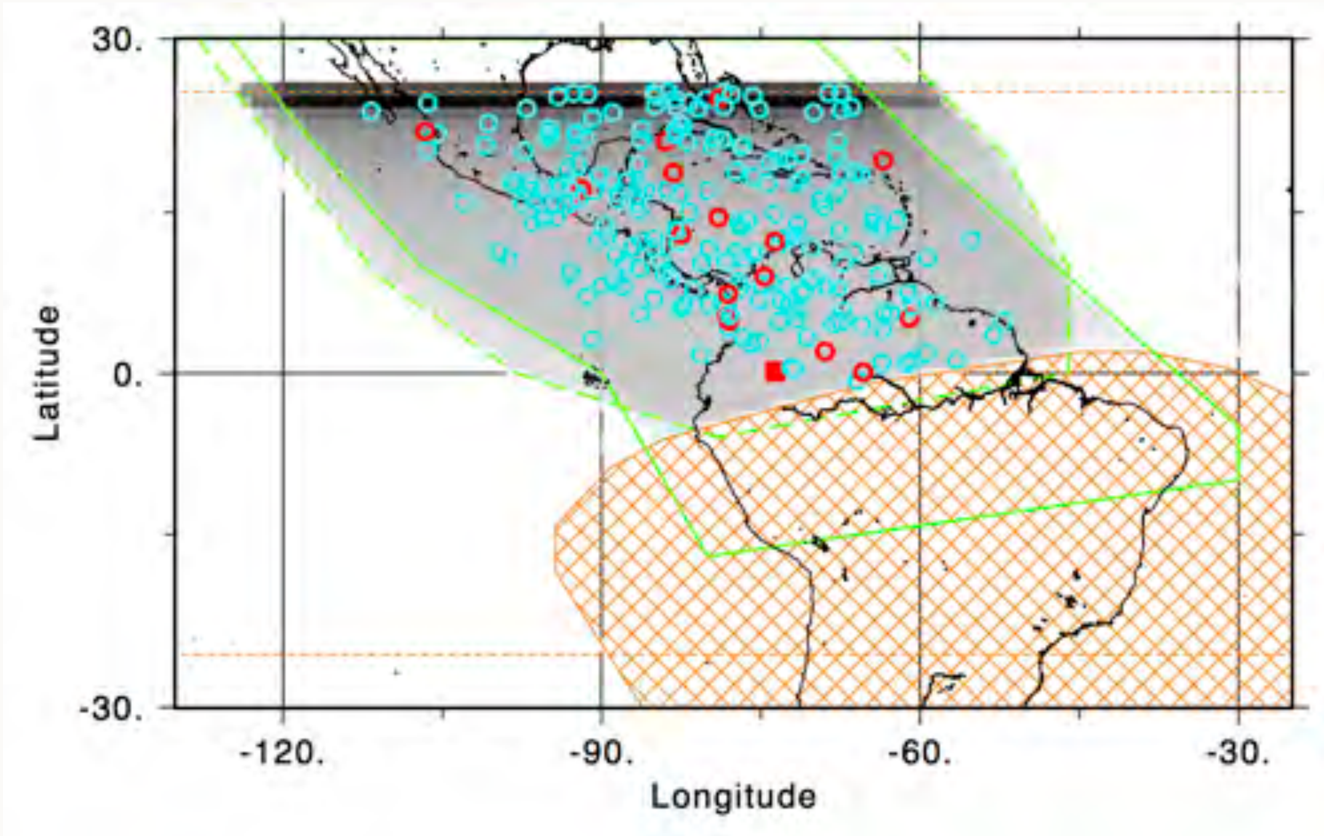
MORE ON THE TWO TYPES OF RADIO PULSES ASSOCIATED WITH TGFS

- Using the Duke sensors in the US... now within reach of Fermi



Could this slow varying component be current from the TGF itself?
Cummer et al. (2011)
Dwyer (2012)

WHAT IS THE GLOBAL TGF RATE? DOES IT FOLLOW GLOBAL LIGHTNING RATE?



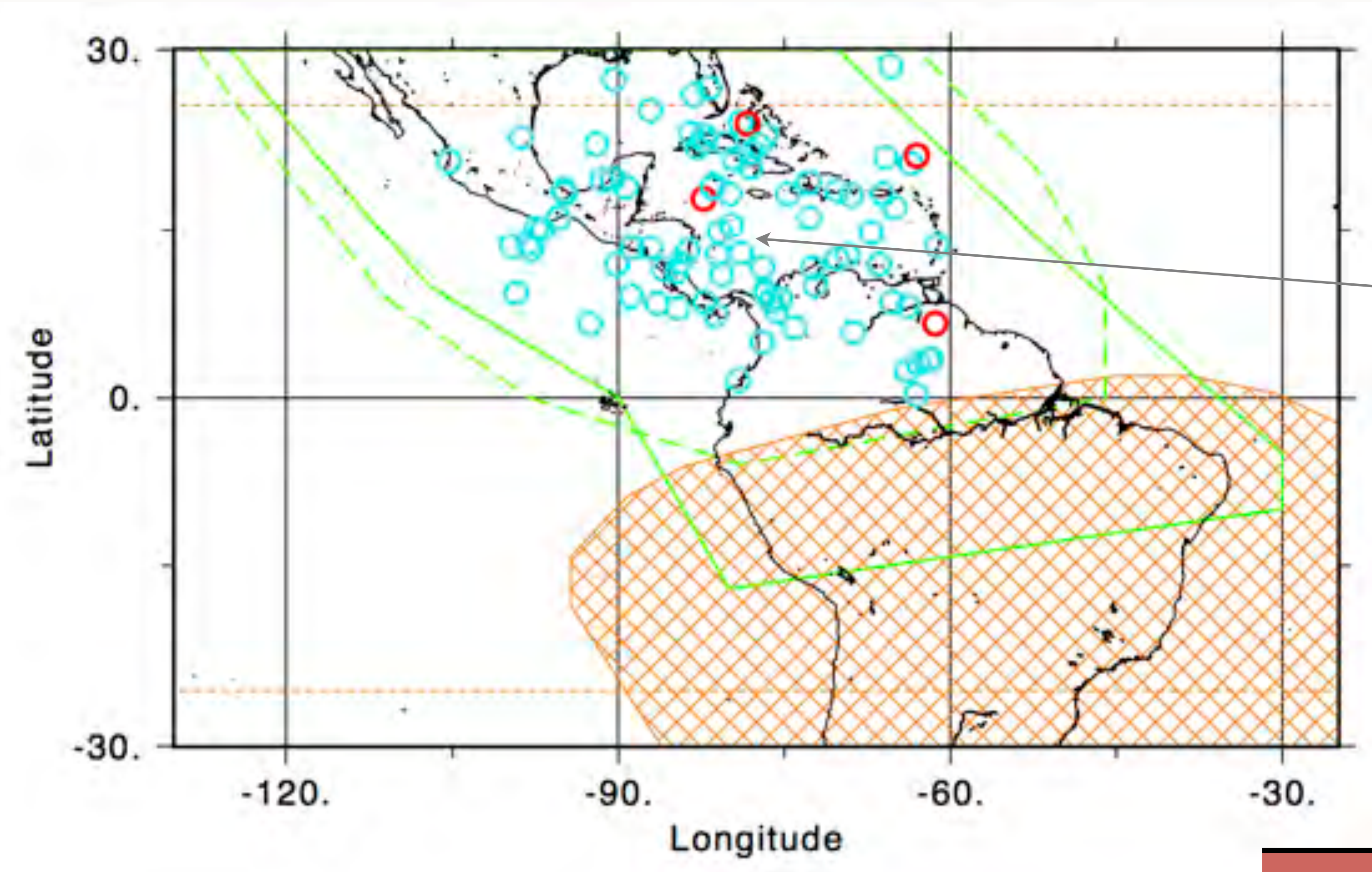
Briggs et al. (2012)

400,000 per year!

cf. Ostgaard et al. 2012
Smith et al. 2011
Fuschino et al. 2011
Carlson et al. 2011

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

DISTRIBUTION OF TGF POSITIONS USING WWLLN GEOLOCATIONS



Briggs et al. (2012)

Coastal regions
+
Intertropical Convergence Zone
(see Splitt et al. 2010)

Region	Ratio
Average	$(3.8\pm0.2) \times 10^{-4}$
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Africa	$(2.3\pm0.2) \times 10^{-4}$
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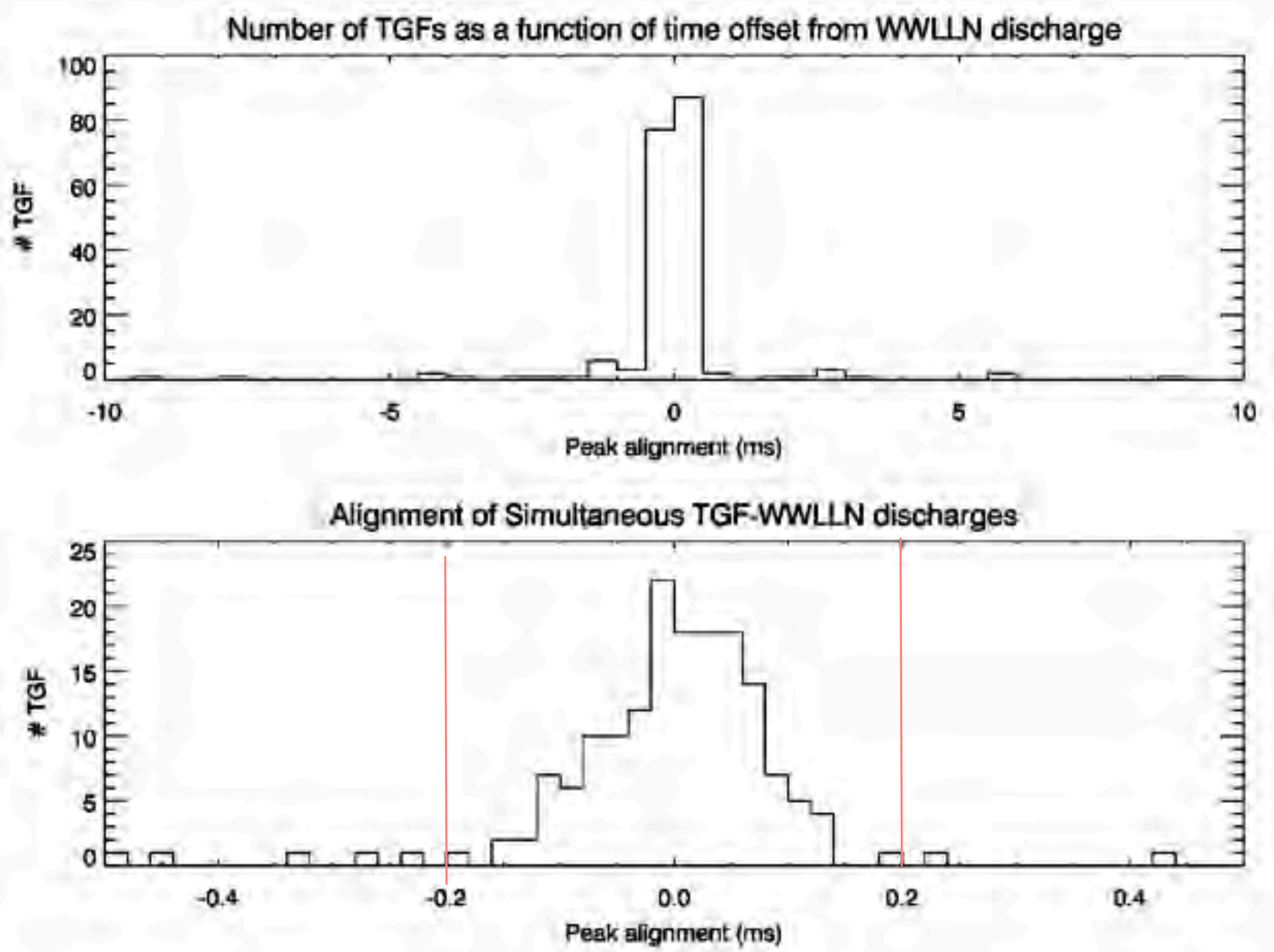
NEW GBM TGF-WWLLN DISCHARGE OFFSET DISTRIBUTION

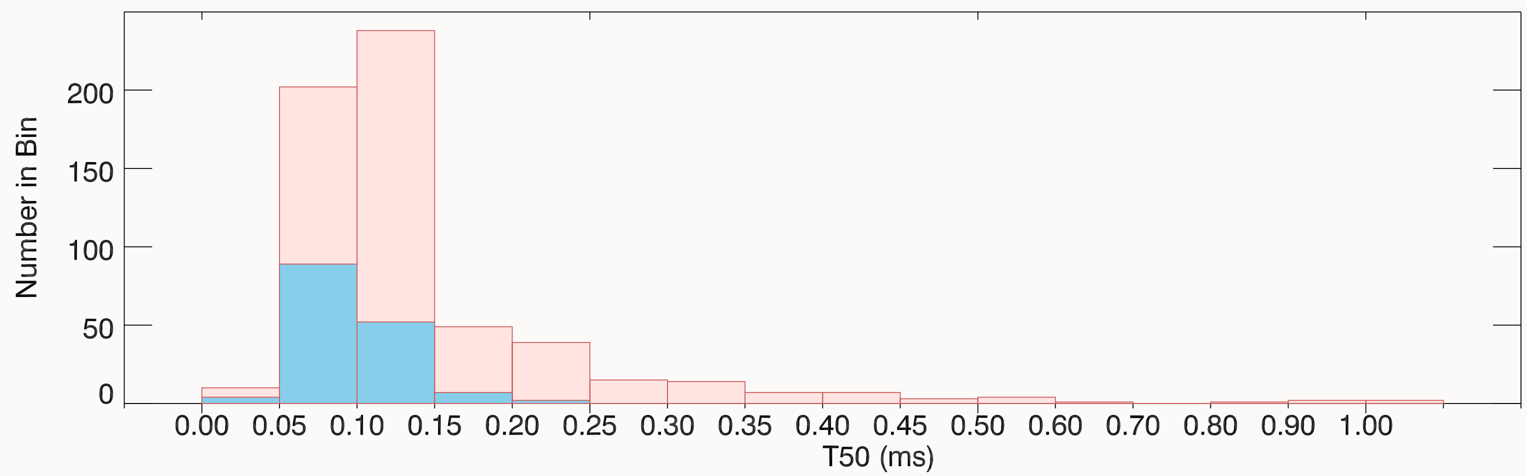


VC et al. (2012)

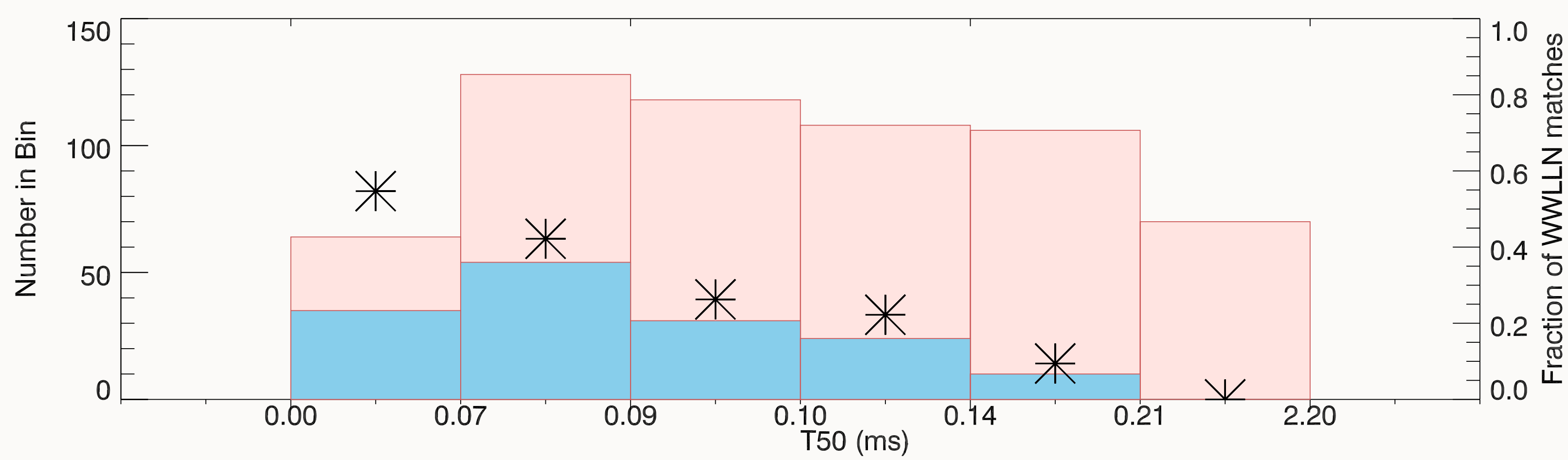
186/594 TGFs have WWLLN associations.

83% WWLLN associated discharges are simultaneous with TGF peak.

594 TGFs (triggered + offline)
154 TGFs with a simultaneous WWLLN discharge



Duration (T50) Distribution



WWLLN Match rate as function of TGF duration (T50)

VC et al. (2012)

VLF SIGNALS FROM TGFS

- Electrons in RREA generate current => for a given total charge, short TGFs will generate more current.

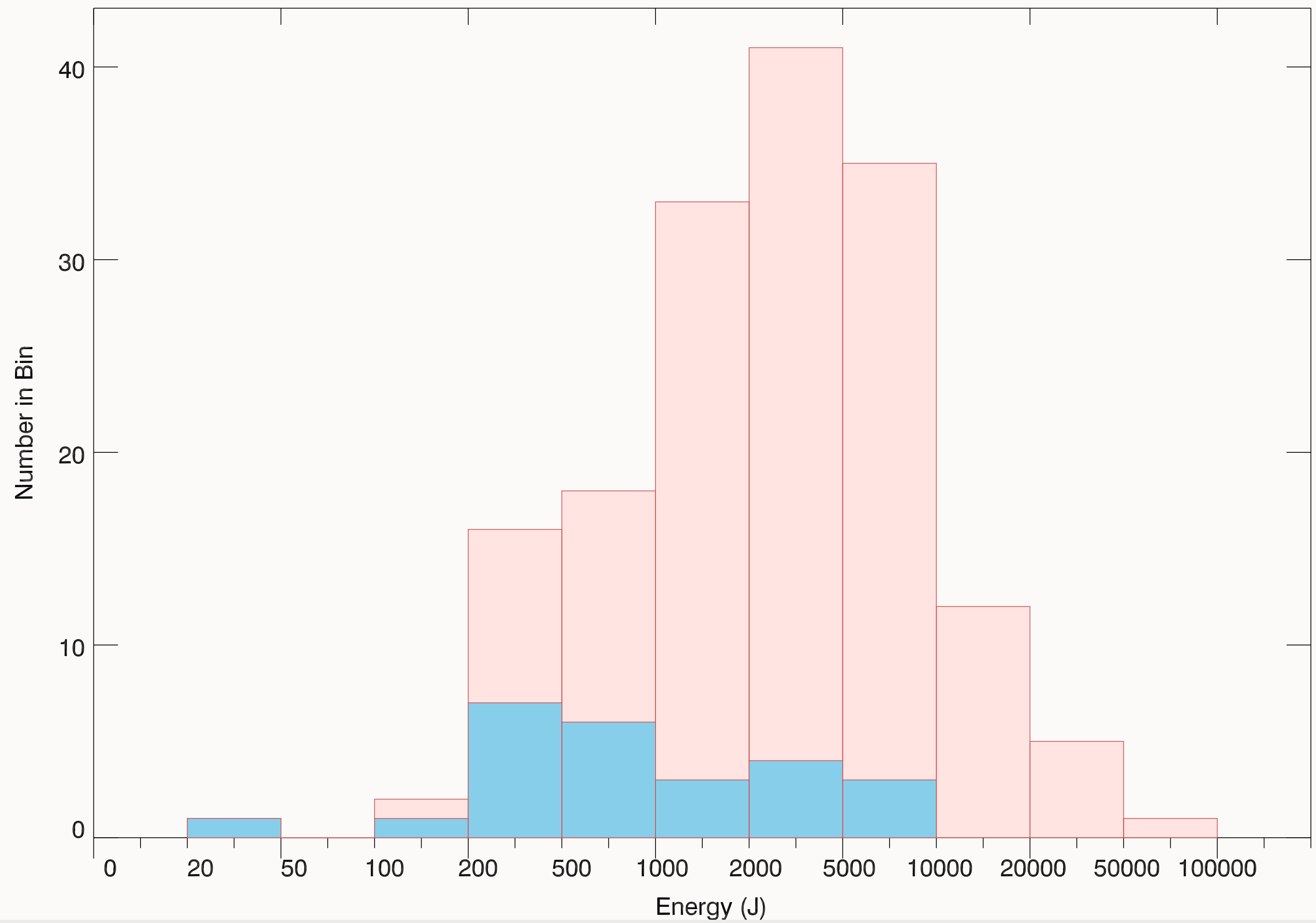
$$E(\omega) = -i\omega \frac{e\alpha\tau_a\mu_e E N_{re}\Delta z \sin\theta}{\sqrt{2\pi}4\pi\varepsilon_0 c^2 R} \exp\left(\frac{-\omega^2(0.74\mathrm{T}_{50})^2}{2}\right)$$

Eq 3 of VC et al. 2012

- Short TGFs are more likely to have a detectable WWLLN signal
- Non-simultaneous matches show no such dependence on TGF duration.
- 2 types of WWLLN signal: 1 is the TGF. The other is +IC lightning. Clears up mystery of strongest vs weak discharges associated with TGFs, and why most are simultaneous but outliers exist.

ARE THERE TWO TYPES OF WWLLN DISCHARGES ASSOCIATED WITH TGFS?

Improvements to WWLLN reveal energy of discharge (Hutchins et al. 2012)



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

Connaughton et al. (2012)

Monday, October 29, 12

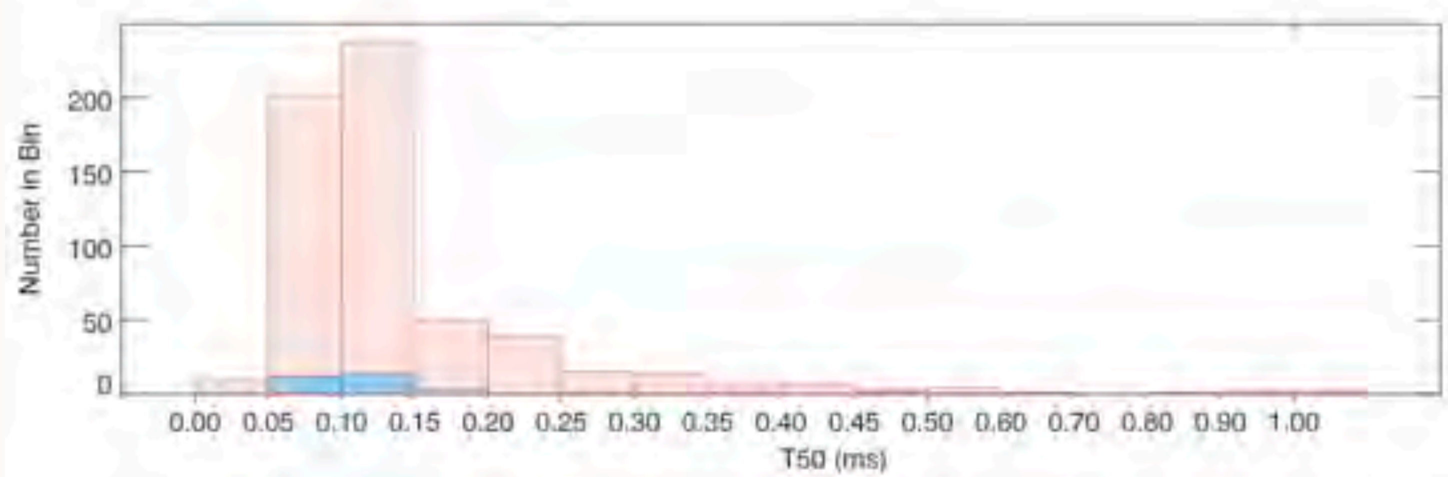
THE FUTURE

- Over 1000 TGFs from RHESSI and nearing 1000 with GBM. AGILE TGF catalogs. GBM online catalog:http://gammaray.nsstc.nasa.gov/gbm/science/tgf/
- Radio observations allow us to study relationship with lightning and to detect currents from electron avalanches, shedding light on TGF gamma-ray production mechanism. We have found 2 types of VLF signal: the TGF itself and +IC lightning from the same flash.
- ATTATT: All-TTE-All-The-Time. Imminent! Shaolin Xiong (Tuesday)
- The LAT sees TGFs! And helps us reject CRs. Eric Grove (Wednesday)
- Lightning produces gamma rays on the ground! Dwyer et al. (2012), and poster by Becky Ringuette.

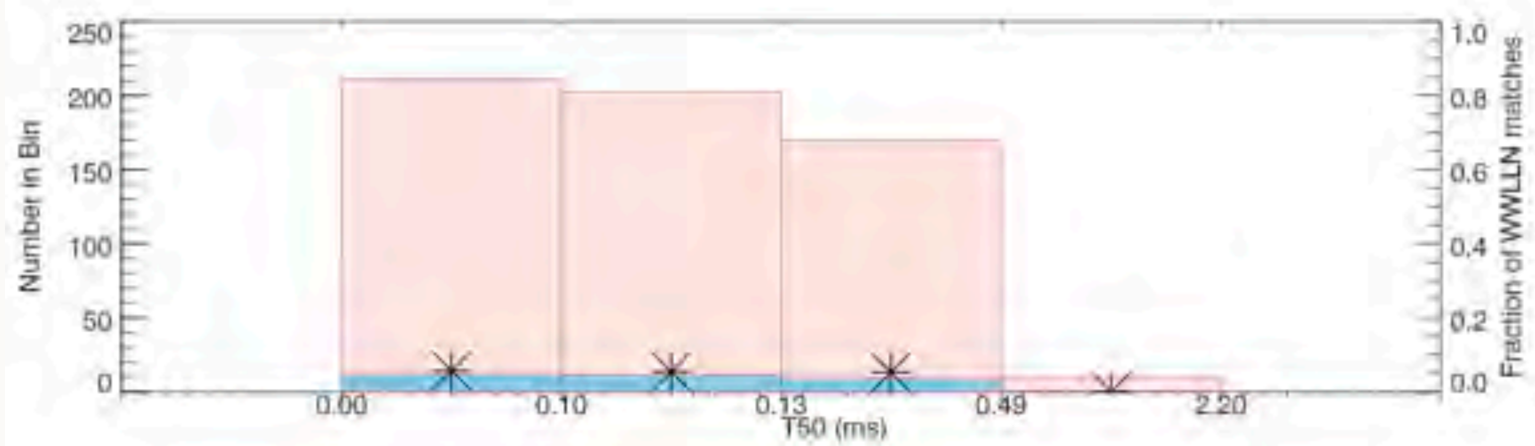
BACKUP

- Backup

594 TGFs (triggered + offline)
32 TGFs with a WWLLN discharge > 0.2 ms from peak



Duration (T50) Distribution

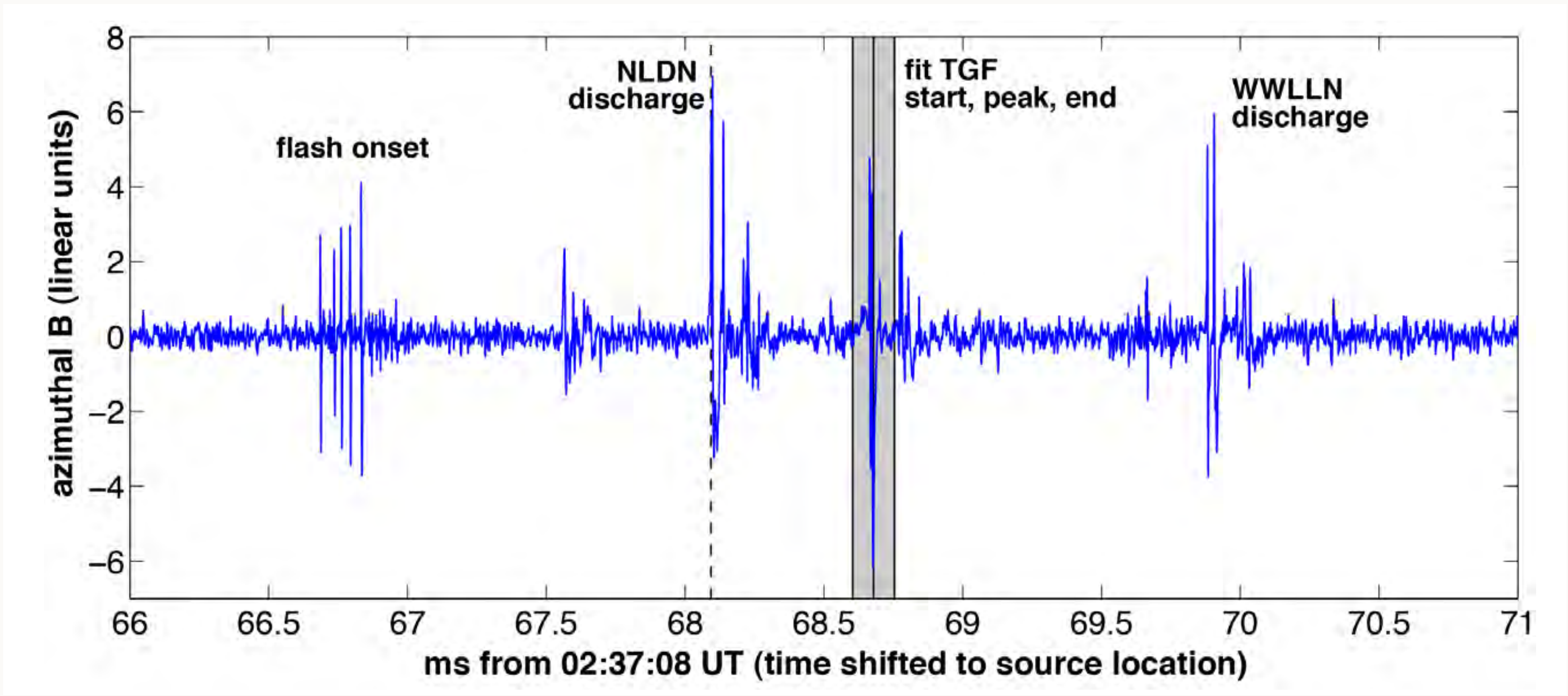


WWLLN Match rate
as function of
TGF duration (t50)

COLLIER AND GREFENSTETTE

- Explain new large catalog, including fainter RHESSI TGFs. Mention weaker ones appear more likely to have a WWLLN match. Why should a TGF property affect detection of associated lightning by WWLLN?

THE DUKE-GBM TGF IN MORE DETAIL



GBM-RHESSI T50 DISTRIBUTION

- 170 RHESSI TGFs, 593 GBM TGFs