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Fermi GBM observations of Terrestrial Gamma Flashes

Colleen A. Wilson-Hodge(1), M. S. Briggs(2), V. Connaughton(2),
G. J. Fishman(1), P. N. Bhat(2), W. S. Paciesas(2), R. D. Preece(2),
R. M. Kippen(3), A. von Kienlin(4), J. R. Dwyer(5), D. M. Smith(6)
and R. Holzworth(7)

(1) *Space Science Office, NASA/MSFC - Huntsville, AL, USA*
(2) *CSPAR, University of Alabama in Huntsville - Huntsville, AL, USA*
(3) *ISR-1, Los Alamos National Laboratory - Los Alamos, NM, USA*
(4) *Max-Planck Institut für extraterrestrische Physik - Garching, Germany*
(5) *Physics & Space Sciences, Florida Institute of Technology - Melbourne, FL, USA*
(6) *Department of Physics, University of California - Santa Cruz, CA, USA*
(7) *Earth & Space Sciences, University of Washington - Seattle, WA, USA*

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Summary. — In its first two years of operation, the Fermi Gamma Ray Burst Monitor (GBM) has observed 79 Terrestrial Gamma Flashes (TGFs). The thick Bismuth Germanate (BGO) detectors are excellent for TGF spectroscopy, having a high probability of recording the full energy of an incident photon, spanning a broad energy range from 150 keV to 40 MeV, and recording a large number of photons per TGF. Correlations between GBM TGF triggers and lightning sferics detected with the World-Wide Lightning Location Network indicate that TGFs and lightning are simultaneous to within tens of microseconds.

PACS `95.55.Ka` – X- and γ-ray telescopes and instrumentation.
PACS `92.60.Pw` – Atmospheric electricity, lightning.
PACS `92.60.Qx` – Storms.

1. – Introduction

Terrestrial Gamma Flashes (TGF) have been clearly associated with thunderstorm activity since their discovery [1] with the Burst and Transient Source Experiment (BATSE). Correlations of TGFs and individual lightning strokes have been deduced using temporal and spatial coincidences between Very Low Frequency (VLF) radio signals (sferics) and gamma ray data from both BATSE [2,3] and the Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI [4-10]). These correlations were limited by timing accuracy and uncertanties to $\sim$ 1–2 ms [11]. Since most TGFs last $<$ 1 ms, the precise relationship between the two phenomena remained unclear.

2. – Method

Sferics detected with the World Wide Lightning Network (WWLLN [12]) have an average RMS timing accuracy of 30 μs and are localized to about 20 km. The Fermi

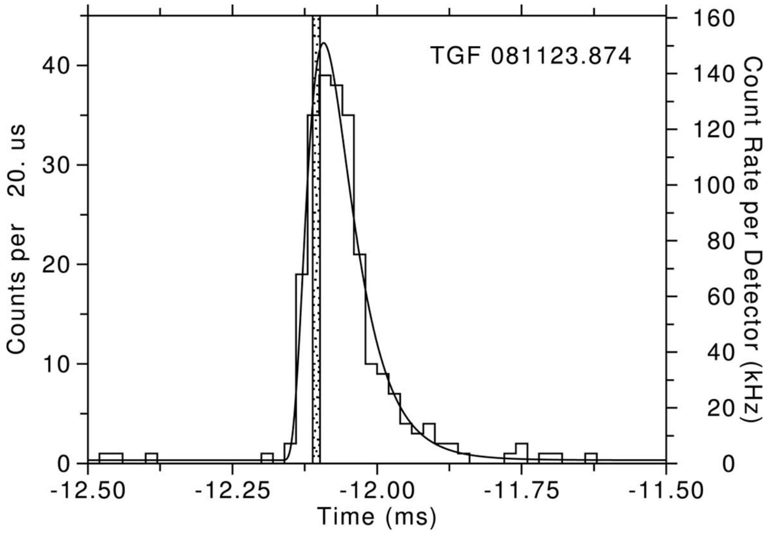

Fig. 1. – Example GBM TGF lightcurve (histogram), corrected for light travel time and clock drift, with WWLLN stroke time and uncertainty band (dotted) and lognormal fit to GBM peak time (curve).

Gamma-Ray Burst Monitor (GBM) has several microsecond accuracy provided by an on-board link to GPS timing. GBM is sensitive to gamma rays between 8 keV and 40 MeV and triggers on timescales as short as 16 ms [13]. From 14 July 2008 to 31 March 2010, GBM triggered on 50 TGFs [14, 15]. In this paper, we summarize our results fully presented in [16]. We searched for matches between WWLLN sferics and GBM TGF peaks within 5 ms (after correction for light-travel time and GBM clock drift) and within 1000 km of the spacecraft position. In many cases, a correlation between an individual sferic and a TGF may not be found, based on the WWLLN efficiency ($\sim 30\%$) and previously reported matches; however regions of strong lightning activity may still be found. We define a storm as at least 5 flashes within 500 km and 10 min of the TGF, with a rms spread in distance of < 100 km.

3. – Results

In the sample of 50 GBM TGFs, 15 have at least one WWLLN sferic within 5 ms of the TGF peak and within 1000 km of the sub-spacecraft position [16]. A maximum distance of 300 km is seen for the associated lightning strokes, equivalent to an angular distance of 31° for a TGF at a height of 20 km. We do not detect any sferics even within 10 ms at distances beyond 300 km of the sub-Fermi position, making this a firm limit on the distance out to which GBM detects TGFs. The probability that these matches occurred by chance ranges from $< 0.1\%$ (no matches in the control sample) to 0.7% [16], indicating that each match is statistically significant and that the WWLLN sferics are likely associated with the GBM TGFs. An example TGF-sferic match is shown in fig. 1.

The temporal offsets between the TGF peak and the lightning strokes are mostly consistent with zero, implying simultaneity within timing uncertainties. Figure 2 shows the distribution of offsets. The relative timing between the TGF and the lightning stroke is accurate to $< 50\,\mu$s, with the largest uncertainty due to the statistical error from fitting

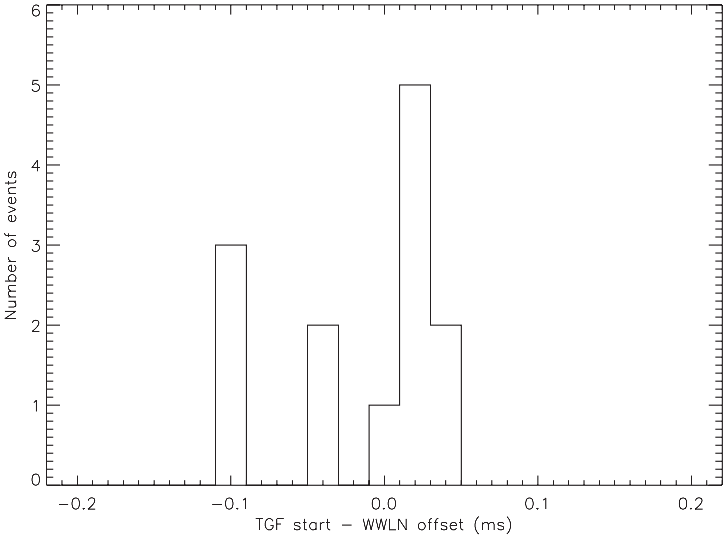

Fig. 2. – Distribution of offsets between the GBM TGF peak time (corrected for light travel time and clock drift) and the WWLLN sferic time. The two non-simultaneous matches > ±1 ms are not shown.

a profile to determine the gamma-ray peak time. (See [14] and [16] for more details.) In 13 of the 15 associations, the lightning stroke and peak of the TGF are simultaneous to ≈ 40 μs.

Of the remaining 35 TGFs in the sample, 31 have WWLLN detected lightning activity within a 300 km radius of the sub-spacecraft position. These cases are representative of all but 4 of the 50 TGFs, where there is at least one active lightning region within 300 km,

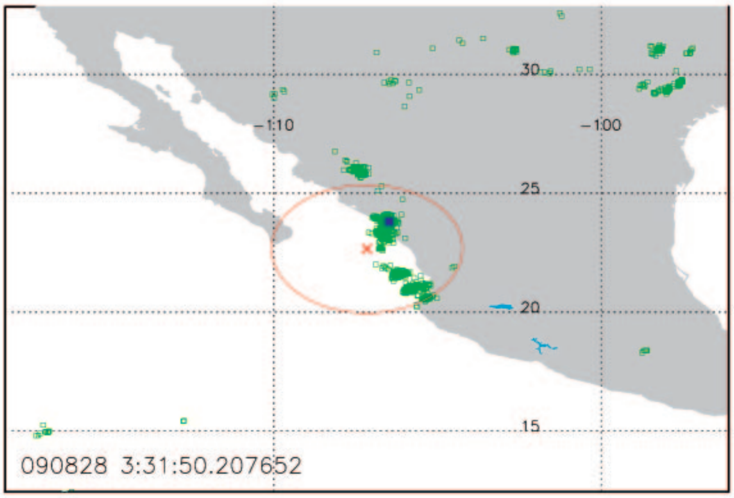

Fig. 3. – Map for GBM TGF 090828 showing sub-spacecraft location (×) with a 300 km radius circle with the sferic match (filled box) and considerable additional lightning activity (open boxes).

with some events showing more than one concentration of lightning activity. Figure 3 shows an example of a sferic match with additional lightning activity within 300 km of the sub-spacecraft point.

In all the four cases, where there is neither an exact match with an individual stroke nor a region of active lightning within the 20 min window and 300 km region, the TGFs are unusual. According to [14] and [15], most TGFs are only a few tenths of a millisecond long. These four TGFs last longer than 1 ms and show a softer spectrum [14, 17]. These events are most likely produced by electrons originating at the TGF source and traveling along the geomagnetic field lines intersecting the spacecraft. Three of the four events show lightning activity detected with WWLLN at one of the magnetic footprints. Further, Cohen *et al.* [9] report detection of a sferic at the magnetic footprint of a GBM TGF trigger on 15 May 2010 (after the sample described here). The discharge was 75 km from the magnetic footprint and was simultaneous in time.

4. – Conclusions

GBM TGF peaks are simultaneous with WWLLN detected sferics within $\approx 40\,\mu$s [16]. Simultaneous lightning and TGFs support predictions from lightning leader models [18-20], in which production mechanisms are driven by current pulses along developing lightning leader channels. In 46 of 50 TGFs, either an associated sferic or lightning activity is found within 300 km of the sub-spacecraft position. Three of the remaining four events show lightning activity near the magnetic footprint of the geomagnetic field lines intersecting the spacecraft, strongly suggesting that these events are associated with electrons traveling along field lines from the storm to the spacecraft. Full details and a discussion of the implications of these results are given in [16].

REFERENCES

[1] Fishman G. J. *et al.*, *Science*, **264** (1994) 1313.
[2] Inan U. S. *et al.*, *Geophys. Res. Lett.*, **23** (1996) 1017.
[3] Cohen M. B., Lehtinen N. G. and Fishman G., *J. Geophys. Res.*, **111** (2006) 109.
[4] Cummer S. A. *et al.*, *Geophys. Res. Lett.*, **32** (2005) 811.
[5] Stanley M. A. *et al.*, *Geophys. Res. Lett.*, **33** (2006) 803.
[6] Inan U. S. *et al.*, *Geophys. Res. Lett.*, **33** (2006) 802.
[7] Lay E. H., Ph.D. Thesis (2008).
[8] Hazelton B. J. *et al.*, *Geophys. Res. Lett.*, **36** (2009) 108.
[9] Cohen M. B *et al.*, *Geophys. Res. Lett.*, **37** (2010) L18806 [doi:10.1029/2010GL044481].
[10] Shao X.-M., Hamlin T. and Smith D. M., *J. Geophys. Res.*, **115** (2010) A00E30.
[11] Grenfenstette B. W. *et al.*, *Geophys. Res. Lett.*, **114** (2009) 314.
[12] Rodger C. J. *et al.*, in *AIP Conf. Proc. 1118, Coupling of Thunderstorms and Lightning Discharges to Near-Earth Space*, edited by Crosby N. B, Huang T.-Y. and Rycroft M. J (AIP) 2009, pp.15-20.
[13] Meegan C. A. *et al.*, *Astrophys. J.*, **702** (2009) 791.
[14] Briggs M. S. *et al.*, *J. Geophys. Res.*, **115** (2010) A07323.
[15] Fishman G. J. *et al.*, *J. Geophys. Res.*, (2010) in preparation.
[16] Connaughton V. *et al.*, *J. Geophys. Res.*, **115** (2010) A12307 [doi:10.1029/2010JA015681].
[17] Briggs M. S. *et al.*, *Geophys. Res. Lett.*, **38** (2011) L02808 [doi:10.1029/2010GL046259].
[18] Dwyer J. R., *J. Geophys. Res.*, **113** (2008) 103.
[19] Dwyer J. R. and Smith D. M., *Geophys. Res. Lett.*, **32** (2009) 804.
[20] Carlson B. E., Lehtinen N. G. and Inan U. S., *J. Geophys. Res.*, **114** (2009) A00E08.