Terrestrial Gamma-ray Flashes after CGRO: prospects for HESSI

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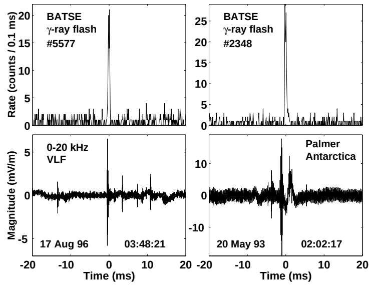

Fig. 1: Sample γ-ray recordings from a TGF (top) and associated VLF radio signatures of lightning (bottom)

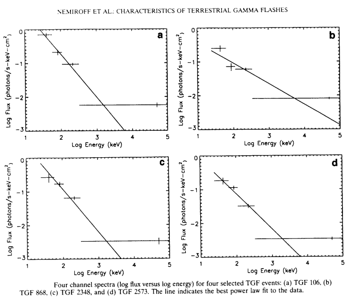

Fig. 2: TGF photon spectra approximated from BATSE's four energy channels [*Nemiroff et al*, JGR, 1997]

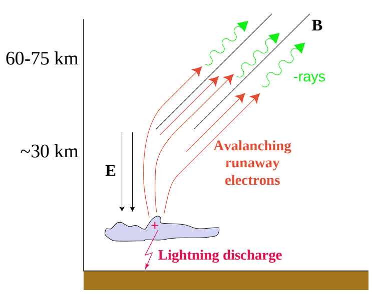

Fig. 3: Cartoon of TGF mechanism. *(Courtesy N. Lehtinen)*

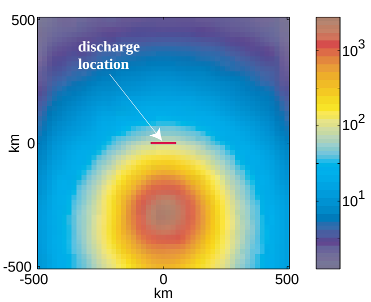

Fig. 4: Predicted spatial distribution of γ-rays at BATSE altitude. *(Courtesy N. Lehtinen)*

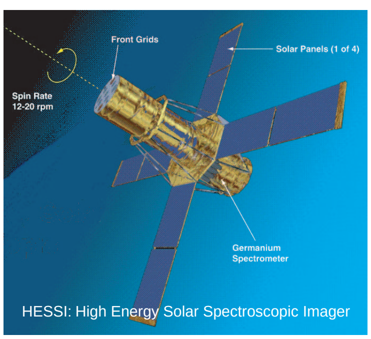

Fig. 5: The HESSI spacecraft.

Abstract

Brief (1–5 ms) flashes of gamma-rays coming from the direction of Earth's atmosphere were discovered by the BATSE instrument aboard the Compton Gamma Ray Observatory (CGRO) in 1994. CGRO was deorbited in June 2000, but during its lifetime 75 Terrestrial Gamma-ray Flashes (TGFs) were observed. The source of the photons is generally assumed to lie at atmospheric altitudes of 60–70 km, and to consist of bremmstrahlung radiation from highly relativistic electrons energized by strong mesospheric electric fields overlying thunderstorms.

Because of the high altitude and upward-directed nature of this radiation, neither the gamma-rays nor the inferred causative runaway electron beams can be directly observed except by satellite. To date, no clear optical or in situ electron data exist to shed light on this phenomenon. Since CGRO's demise, there is no longer an orbiting gamma-ray instrument that is well suited for detecting TGF's. We describe the prospects for detecting TGFs with the High Energy Solar Spectroscopic Imager (HESSI), whose launch is imminent. While the BATSE main detectors had an upper energy band of 300 keV – ∼1 MeV, which was too low to resolve the hard (>1 MeV) TGF spectrum, the nine HESSI rear germanium detectors have spectral resolution of 0.1% – 3% up to >10 MeV. In addition, BATSE's triggering circuitry integrated for at least 64 ms (much longer than the duration of a TGF) while the HESSI spacecraft records and telemeters the energy and time of arrival of each photon event. On the other hand, the geometric factor for the HESSI detectors is small compared with that of BATSE. Altogether, we expect a comparable TGF detection rate from HESSI but superior spectral (and temporal) information, which may provide key new evidence for the underlying mechanisms behind TGFs.

Introduction

Terrestrial Gamma-ray Flashes (TGFs) are poorly understood flashes of γ-ray photons observed on 75 occasions over 8 years by the Burst And Transient Source Experiment (BATSE) instrument, typically when the CGRO spacecraft was above a large thunderstorm sytem. **Figure 1** shows samples of two events recorded by BATSE, along with simultaneously measured subionospheric radio signatures of cloud-ground lightning, suggesting a link between TGFs and thunderstorm electric fields. **Figure 2** shows TGF energy spectra poorly resolved by BATSE's four energy channels.

A physical mechanism has been proposed for TGFs (**Figure 3**). It involves strong mesospheric electric fields accelerating electrons to relativistic energies and emitting γ-rays through bremmstrahlung. Detailed modelling predicts a somewhat magnetic field-aligned flux of γ's with a spatial distribution as shown in **Figure 4**.

Triggering

Discovery of TGFs by BATSE was not anticipated, and the event triggering hardware had a minimum integration time of 64 ms, much longer than the typical TGF duration (1-3 ms). Thus BATSE, while endowed with a huge sensitive area, was an inefficient detector for TGFs.

HESSI

The High Energy Solar Spectroscopic Imager (HESSI, see **Figure 5**), in comparison, telemeters to ground the time and energy of every measured photon. All event selection (and analysis) is done by software on the ground and can always be repeated or improved. *Note: the full suite of analysis software (in IDL) and all low-level data will be available without delay to the public via the WWW.*

Figure 6 depicts representative orbits of CGRO and HESSSI, showing the larger latitudinal extent ($\pm 38°$) as compared with CGRO's ($\pm 28.5°$). This figure also shows the distribution of lighting in the northern summer. Geomagnetic mid and high latitudes are expeted to be much more conducive to TGFs than low latitudes because of the pitch angle of the Earth's magnetic field (**Figure 3**). Thus, HESSI's coverage of the lightning-rich mid-latitudes may be an important advantage for measuring TGFs.

Figure 7 shows the effective detector areas for the 9 HESSI detectors (combined, side-incident) and those of each of the 8 BATSE LAD detectors. The latter had four energy channels, while HESSI detectors have ∼15000.

Predictions

Assuming a 2 MeV bremmstrahlung spectrum, **Figure 8** shows the anticipated count rate for HESSI from a TGF event, along with typical background rate and the predicted rate from bremmstrahlung caused by collision of the TGF runaway electron beam with atoms in the opposite hemisphere's atmosphere. Also shown for comparison is the expected signal level from electrons which scatter on lightning-launched whistler waves and then precipitate into the atmosphere (LEP). **Figure 9** shows the histogram of TGF events detected by BATSE and the expected range detectable by HESSI.

Conclusion

Taking into account that HESSI is sun-pointed rather than nadir-pointed, we may expect ∼1 TGF event every 2 months, but with much more spectral detail and range than provided by BATSE.

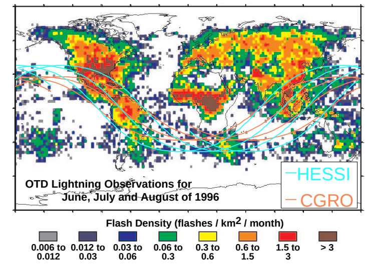

Fig. 6: Orbital extent of HESSI and CGRO.

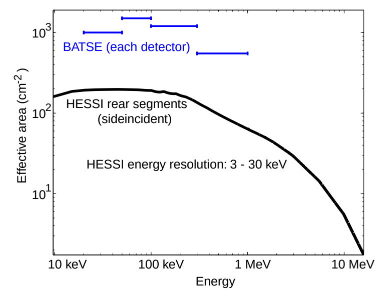

Fig. 7: Effective area and spectral resolution of BATSE LAD's and HESSI.

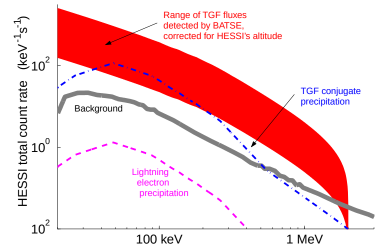

Fig. 8: Predicted HESSI count rates. Background courtesy of D. Smith. LEP flux courtesy of D. Lauben.

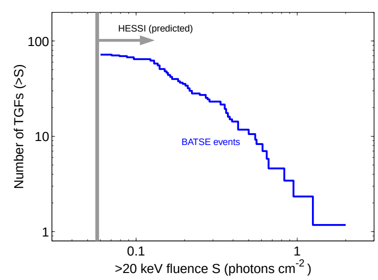

Fig. 9: Observed (BATSE) distribute of TGF intensities, and HESSI sensitivity.

Appendix

After background subtraction, the statistical significance Q of a burst of counts is

$$Q = \frac{A\Phi}{\sqrt{A\, b\, \Delta t}} \sim \sqrt{\frac{A}{\Delta t}},$$

where A is the detector effective area, Φ is the total fluence over the duration of the burst, b is the background flux, and Δt is the integration time. Thus if half of BATSE's eight detectors are sensitive for a given event, and HESSI's trigger criterion is ∼1 ms rather than 64 ms, we expect for a $\lesssim 1$ ms event

$$\frac{Q_{\rm HESSI}}{Q_{\rm BATSE}} \approx \sqrt{\frac{64}{4 \times 10}} \approx 1.25,$$

i.e., HESSI is slightly more sensitive, neglecting differences in altitude. **Figure 8** shows results of more detailed predictions and confirms that HESSI should have sensitivity comparable (**Figure 9**) to BATSE's.

Acknowledgements

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