New class of RHESSI TGFs

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The frequency of terrestrial gamma-ray flashes (TGFs) is still unknown. It is possible that there are many weaker TGFs that cannot escape to space to be detected by gamma-ray satellites or that the events are difficult to find in the satellite data because of deadtime and saturation issues. New events found in the Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) satellite data may give some insight into this question. We will present a new class of super-bright terrestrial gamma-ray flashes (TGFs) that has been found in the RHESSI data. In this class of events, the instrument is completely saturated and using the Compton tail of these events the intrinsic brightness can be found. We shall present detailed analysis of specific events when the distance or source altitude is known.

1. Introduction

Terrestrial gamma-ray flashes (TGFs) were first discovered in 1994 by the BATSE instrument aboard the Compton Gamma-ray Observatory (CGRO) [1]. TGFs are bright, millisecond bursts of gamma rays that are seen coming from thunderstorms. Since BATSE observations, RHESSI, Fermi, and AGILE have observed thousands of TGFs from space [2]. The Airborne Detector for Energetic Emissions (ADELE) observed one TGF from an airplane [3] and two TGFs have been observed from the ground at Camp Blanding, FL [4].

Relativistic Runaway Electron Avalanches (RREA) best explain the TGF spectrum that extends up to 40 MeV, and possibly 100 MeV [5]. Wilson first proposed that electrons could runaway to relativistic energies from the electric fields inside thunderclouds [6]. When Møller scattering is included, the runaway electrons can scatter with other electrons, causing them to runaway as well as causing an avalanche of electrons [7]. TGFs are the gamma rays produced from the bremsstrahlung of those electrons. To explain the brightness of observed TGFs, Dywer proposed the relativistic feedback model [8] which builds upon RREA by including the physics of backscattered photons and positrons and following their creation of new avalanches that allows for an exponential growth in avalanches.

Another model proposed by Celestin and Pasko that can explain the brightness of TGFs without feedback is one in which lightning stepped leaders provide a large energetic seed population. RREA can then amplify the electron population to generate the brightness of observed TGFs [9]. This model also can explain the AGILE results of TGFs that extend up to 100 MeV [10].

TGFs can be as common as lightning [11] or as rare as one in a thousand lightning flashes [12]. Since TGFs are not observed as frequently as either of those limits, we must assume that most TGFs are unable to escape to space to be observed from satellites or are normally too attenuated to be measurable from the ground. The fluence distribution of TGFs follows a power law with index between 2.1 and 2.5 [13][14]. We shall present a new class of super bright RHESSI TGFs that cause the RHESSI instrument to saturate for the majority of the event.

2. Instrument

The RHESSI satellite is a NASA Small Explorer spacecraft that has been in operation since 2002. It consists of nine germanium detectors with the upper and lower portion of the detectors read-out separatly. When two counts arrive at the detector within 800 ns, they are piled up. When too much charge builds up in one segment, that segment resets and is inactive for a short period of time. The TGFs presented here are all indicative of high count rates, they saturate and reset during the middle of the event. Figure 1 shows an example of a saturating TGF.

3. Data

During the middle of these TGFs, the total energy cannot be known because of pileup and resets. However, the Compton tail that arises from gamma rays that have been Compton scattered on their way to the detector can be used to find the intrinsic brightness of the event. These gamma rays arrive later because they have travelled a farther distance to reach the detector.

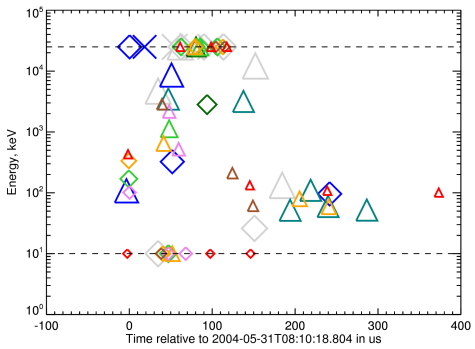

Figure 1. Saturated TGF above Spratley Islands in the South China Sea, WWLLN sferic match is 240 km away

Events are selected when the event is saturating and has a distinct Compton tail. If there is a WWLLN match, that distance is used when modelling the TGF.

3. Modelling

To model these events, a four stage Monte Carlo model is used. The first stage is a TGF modeled using the relativisitic feedback model [8]. The TGF is then propogated through the atmosphere and then through the RHESSI detector using GEANT3 simulations. Finally, the RHESSI electronics are simulated to simulate vetos, resets and pileup. Since the electronics are so complicated, these results are approximate during the middle of the TGF. The results during the Compton tail are valid.

Figure 2 shows a good match of the TGF shown in Figure 1. It was a Gaussian time-convolved TGF at 15 km altitude, 240 radial km away. While 400 counts hit the RHESSI detectors, only 27 normal counts are registered. This flux corresponds to 1.33 photons/cm^2 in the detector. This is brighter than any other RHESSI TGF. Figure 3 shows the intrinisic brightness of the TGF at different source altitudes. These are an order of magnitude brighter than previously observed TGFs but still agree with theoretical brightness distributions [13][14].

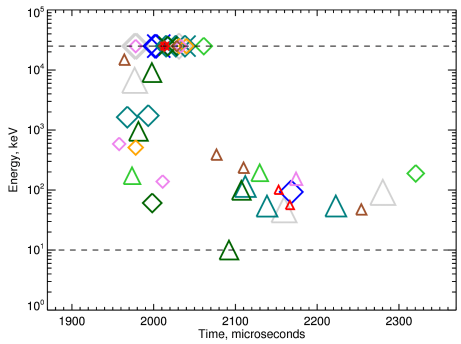

Figure 2. Modelled gaussian time-convolved TGF at 15 km altitude, 240 km radial distance through atmosphere, RHESSI detectors and electronics

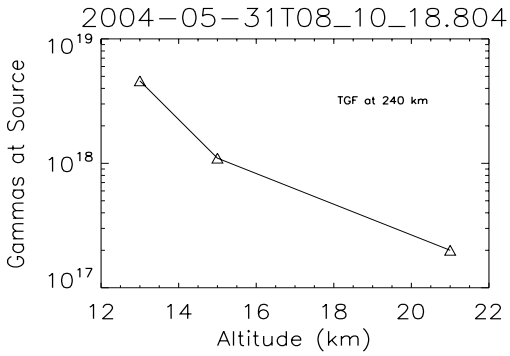

Figure 3. Instinsic brightness of the saturated TGF

4. References

[1] G.J. Fishman et al., *Science* **264**, 1313 (1994).

[2] J.R. Dwyer et al., *Sp. Sci. Rev.* **173**, 133-196 (2012).

[3] D.M. Smith et al., *J. Geo. Res.***116**, D20 (2011).

[4] J.R. Dwyer et al., *J. Geo. Res.***117**, A10 (2012).

[5] M. Tavani et al., *Phys. Rev. Lett.* **106**, 018501 (2011).

[6] C.T.R. Wilson, *Proc. Cambridge Phil,* **22**, 534-538 (1925).

[7] A.V. Gurevich et al., *Phys. Lett. A* **165**, 463 (1992).

[8] J.R. Dwyer, *Geophys. Res. Lett.* **31**, 2055 (2003).

[9] S. Celestin & V.P. Pasko, *Geophys. Res. Lett.* **39**, 2 (2012).

[10] S. Celestin et al., *J. Geophys. Res.,* **117**, A5 (2012).

[11] N. Østgaard et al., *J. Geophys Res.*, **117**, A3, (2012).

[12] D.M. Smith et al., *Geophys. Res. Lett.*, **38**, 8 (2011).

[13] D. Tierney et al., *J. Geophys. Res: Sp. Phys,* **118**, 10 (2013).

[14] N. Østgaard et al., *J. Geophys Res.*, **117**, A3 (2012).