Terrestrial Gamma Flashes at Ground Level -- TETRA-II

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Abstract

An upgraded version of the TGF and Energetic Thunderstorm Rooftop Array (TETRA-II) consists of an array of BGO scintillators to detect bursts of gamma rays from thunderstorms at ground level in four separate locations: the campus of the University of Puerto Rico at Utuado; the campus of Louisiana State University in Baton Rouge, Louisiana; the Severe Weather Institute and Radar & Lightning Laboratories in Huntsville, Alabama; and the Centro Nacional de Metrologia de Panama (CENAMEP) in Panama City, Panama. TETRA-II began operation in May 2016. The original TETRA-I array of NaI scintillators at Louisiana State University detected 37 millisecond-scale bursts of gamma rays at energies 50 keV-2 MeV associated with nearby (< 8 km) thunderstorms. When TETRA-II is fully operational, it will have approximately an order of magnitude greater sensitivity than TETRA-I. The ability to observe ground-level Terrestrial Gamma Flashes from close to the source allows a unique analysis of the storm cells producing these events. A brief description of the TETRA-I observations, a description of TETRA-II, and preliminary results will be presented.

1. Introduction

Lightning provides the most powerful natural accelerator available on Earth for the production of high-energy particles. Satellite instruments have detected gamma ray bursts at energies in excess of tens of millions of electron volts as a result of this acceleration. Initially, these Terrestrial Gamma Flashes (TGFs) were detected by the Burst and Transient Source Experiment (BATSE) onboard the Compton Gamma Ray Observatory [1], and have since been detected by other satellites, including RHESSI [2,3], AGILE [4,5,6], and the Fermi Gamma Ray Telescope [7]. These observations, associated mainly with positive polarity intracloud lightning to generate the upward trajectory of the electrons and photons, were correlated with regions of intense lightning typically at 10-25 km above the ground.

In 2010 the TGF and Energetic Thunderstorm Rooftop Array (TETRA) began operation at Louisiana State University with sensitivity for downward directed TGFs known as Thunderstorm Ground Enhancements (TGEs) [8] associated with negative polarity lightning. In its first four years of operation, 37 millisecond-scale bursts of gamma rays were detected associated with nearby lightning. An overview of the project, its analysis, and results are presented. The new TETRA-II detectors were deployed in 2016-17 with increased size and sensitivity, and with the main sites located in regions where Fermi has detected many of its events. An overview of TETRA-II, its current status, and initial event candidate results are also presented.

2. TETRA-I Experiment

TETRA consisted of twelve 19 cm x 19 cm x 5 mm NaI(Tl) scintillators spread across the Louisiana State University campus in 4 separate boxes to detect gamma ray emissions during thunderstorms in the 50 keV to 2 MeV energy range. Each box contained 3 NaI scintillators that were each viewed by individual self triggered photomultiplier tubes (PMTs) [9].

TETRA detected 37 millisecond bursts of gamma rays associated with thunderstorms in its approximately 4 years of full operation. Events were associated with lightning strikes observed within 5 miles and 5 minutes of the gamma ray events. Typically a T90 duration on the order of hundreds of microseconds is seen with a range of 7 to 45 photons detected in each event and currents ranging from -19 to -158 kA [9]. In a number of events, the gamma ray burst occurred at approximately the same time as the collapse of the thunderstorm updraft, suggesting a connection between the electromagnetic shower and the fundamental structure of the storm.

3. TETRA-II

TETRA provided evidence that negative polarity lighting strikes accelerate particles downward and produce gamma rays with energies of at least 2 MeV. To improve on this, TETRA-II was designed to measure more abundant small TGFs from the ground with better statistics and a higher energy range. TETRA-II consists of individual detector boxes each with six 1 inch x 1 inch x 10 inch BGO scintillators from the ATIC cosmic ray balloon experiment [10]. The BGO are viewed by 1.5 inch PMTs at either end, and are spring mounted into a PVC housing. The PMTs are read out by National Instruments PCIe 6351 high speed data acquisition (1 Msample/sec) cards, and the data are pushed to a server at LSU for analysis (Fig 1).

Two TETRA-II boxes (12 BGO scintillators) are located on the rooftop of the Physics building at Louisiana State University, and have been operational since the Summer of 2016 together with one of the boxes from the original

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Fig. 1. Detector box during assembly, showing 6 PVC BGO assemblies and fast electronics.

TETRA-I experiment. In December 2015, 10 boxes were mounted on the roof of Building B at the University of Puerto Rico in Utuado, a location chosen because of its high lightning rate, good infrastructure, and its location sufficiently far south that the Fermi orbit passes overhead. The 10 Utuado boxes have been calibrated and running since Fall of 2016. Two boxes are installed at the Severe Weather Institute and Radar & Lightning Laboratories (SWIRLL) in Huntsville, Alabama and have been taking data since October 2016. Five more boxes were installed at the Centro Nacional de Metrologia de Panama (CENAMEP) in Panama City, Panama, in January 2017, in a location near where Fermi GBM has detected high rates of TGFs (Fig 2). In all three TETRA-II locations, typical box separations are 5-15 m.

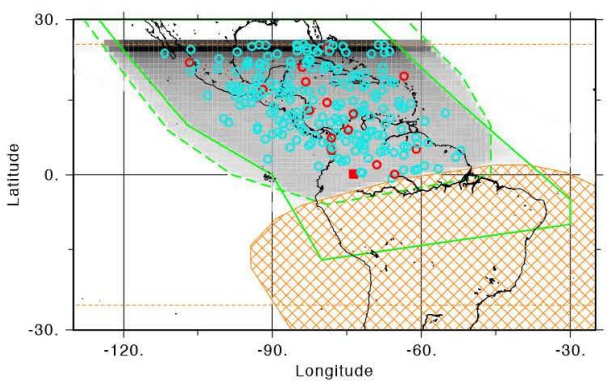

Fig. 2. Map of TGFs seen by GBM in the Americas [11].

4. Summary

The TETRA-I experiment successfully detected bursts of gamma rays associated with thunderstorms from the ground with a small array of NaI scintillators in Louisiana. The TETRA II array of BGO scintillators has been designed with improved sensitivity and resolution, and installed at four separate locations where lightning rates are high.

Initial data analysis has begun, observing one candidate event at Louisiana State University on August 24, 2016 and one candidate at the University of Puerto Rico on September 19, 2016. Further work looking at lighting, weather, and radar data at the time of these events is underway.

6. Acknowledgements

We gratefully acknowledge funding from the US National Science Foundation (Office of Atmospheric and Geospace Sciences and Research Initiation Award), NASA EPSCoR, the Louisiana Board of Regents, and Louisiana Space Consortium for the development and operation of TETRA-II. We appreciate the valuable contribution of ATIC BGO scintillators by J. Wefel and G. Guzik and the very helpful support of Edgar del Toro and Milton Riutort at Univ. of Puerto Rico-Utuado, J. Arias at CENAMEP, and P. Bitzer at SWIRLL.

7. References

1. Fishman, G.J. et al. (1994), Discovery of intense gamma ray flashes of atmospheric origin. Science 264, 5163,1313.
2. Gjesteland, T. et al. (2012), A new method reveal more TGFs in the RHESSI data. Geophys. Res. Lett. 39, L05102.
3. Grefenstette, B. W. et al. (2009), First RHESSI terrestrial gamma ray flash catalog. J. Geophys. Res. 114, A02314.
4. Marisaldi, M. et al. (2010), Gamma-ray localization of terrestrial gamma-ray flashes. Phys. Rev. Lett. 105, 128501.
5. Marisaldi, M. et al. (2011), AGILE observations of terrestrial gamma-ray flashes. Nuovo Cimento C034N3, 279.
6. Tavani, M. et al. (2011), Terrestrial gamma ray flashes as powerful particle accelerators. Phys. Rev. Lett. 106, 018501.
7. Fishman, G. J. et al. (2011), Temporal properties of the terrestrial gamma-ray flashes from the Gamma-ray Burst Monitor on the Fermi Observatory. J. Geophys. Res. 116, A07304.
8. Chilingarian, A. et al. (2010), Ground-based observations of thunderstorm-correlated fluxes of high-energy electrons, gamma rays, and neutrons, Phys. Rev. D 82, 043009.
9. Ringuette, R. et al, (2013), TETRA observation of gamma-rays at ground level associated with nearby thunderstorms. J. Geophys. Res. Space Phys. 118, 7841.
10. Chang, J. et al. (2008), An excess of cosmic ray electrons at energies of 300-800 GeV. Nature 456, 362.
11. Briggs, M.S. et al. (2013), Terrestrial Gamma ray Flashes in the Fermi Era: Improved Observations and Analysis Methods. J. Geophys. Res. Space Phys. 118, 3805.

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