A Downward Beam of Energetic Positrons from the Eyewall of Hurricane Patricia

G. S. Bowers*(1), D. M. Smith (1), N. A. Kelley(2), S. A. Cummer(3), J. R. Dwyer (4), S. Heckman (5), R. H. Holzworth(6), J. Gamache(7), P. Reasor(7), F. Marks(7), and T. Richards(8), H. K. Rassoul(9)
(1) University of California Santa Cruz, California, USA, (2) Berkeley Applied Analytics, California, USA, (3) Duke University, North Carolina, USA, (4) University of New Hampshire, New Hampshire, USA, (5) Earth Networks, Washington, USA, (6) University of Washington, Washington, USA, (7) NOAA/Atlantic Oceanographic and Meteorological Laboratory/Hurricane Research Division, Florida, USA, (8) NOAA/Aircraft Operations Center, Florida, USA, (9) Florida Institute of Technology, Florida, USA

Abstract

While aboard the Hurricane Hunters WP-3D Orion during reconnaissance in the eyewall of Hurricane Patricia on October 23rd 2015, the Airborne Detector for Energetic Lightning Emissions (ADELE) observed the first Terrestrial Gamma-ray flash (TGF) ever seen in that context, and the first ever viewed from below. ADELE measured 184 counts of ionizing radiation within 150 µs, coincident with the detection of a nearby lightning flash. Lightning characteristics inferred from the associated sferic and comparison of the observed gamma-ray spectrum to simulations suggests that this is first observation of a TGF's reverse positron beam, as predicted by the leading TGF production model, Relativistic Runaway Electron Avalanches (RREA).

1. Introduction

Terrestrial Gamma-ray Flashes (TGFs) are avalanches of relativistic electrons created in thunderstorm electric fields that scatter off molecules in the Earth's atmosphere and produce intense, sub-millisecond beams of bremsstrahlung x-ray and gamma ray emissions routinely observed by detectors aboard satellites [1,2,3,4]. Most TGFs are associated with positive intracloud (+IC) lightning discharges [5,6], and their observed energy spectra and radio emissions are consistent with production at altitudes of 10-14km [7,8].

The Airborne Detector for Energetic Lightning Emissions (ADELE) measures x-rays and gamma-rays aboard aircraft flown into or above thunderstorm systems, to observe TGFs up close. In 2014 and 2015 ADELE flew aboard NOAA's WP-3D Orion during the Atlantic hurricane season, targeting thunderstorm systems in hurricane rainbands [9] and the increased eyewall lightning associated with the intensification of strong hurricanes [10].

2. A TGF Observed from a Hurricane Eyewall

On October 23rd, ~1733 UTC, NOAAs Hurricane Hunters' WP-3D flew through the center of Hurricane Patricia during meteorological reconnaissance. At 1732UTC, at an altitude of ~2.5km (figure 1), coincident with a nearby lightning flash (figure 2), ADELE measured 184 counts of ionizing radiation within 150 µs among three scintillation detectors (figure 3).

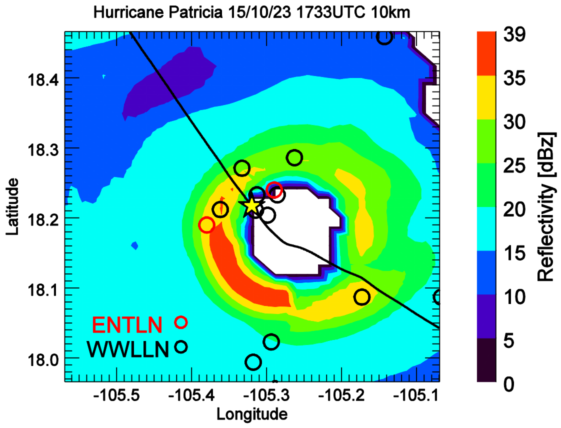

Figure 1. Horizontal cross section of radar reflectivity at 10km inside Hurricane Patricia. The star indicates the location of ADELE at an altitude of ~2.5km during the observation. Red circles indicate two possible locations of the associated TGF flash calculated from Earth Networks Total Lightning Network (ENTLN) data. Black circles show other World Wide Lightning Location Network located lightning flashes within 5 minutes of the TGF observation.

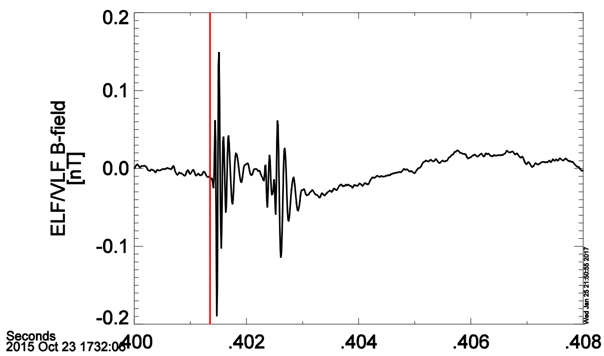

Figure 2. Associated sferic waveform recorded at Duke University. Vertical bar shows time of TGF observation.

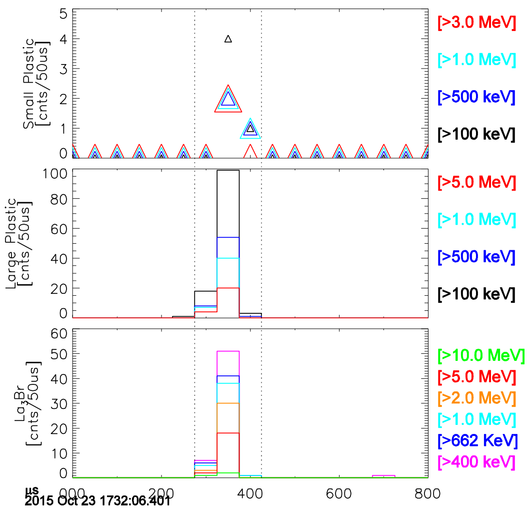

Figure 3. Raw count rate data of the Hurricane Patricia TGF observed by ADELE showing scintillation counts per 50µs in 15 integral energy channels over three detectors: **A** (Top) – 1x1" plastic scintillator, **B** (Middle) 5x5" plastic scintillator, **C** (Bottom) 3x3" Lanthanum Bromide ($LaBr_3$) scintillator. 184 unique counts were observed within the 150 µs indicated by the vertical dashed lines.

The radio signal from the nearby lightning flash indicated that this was a typical TGF, with a beam of (RREA) moving upwards. RREA theory also predicts a beam of positrons moving downward, produced by the interaction of gamma-rays with atomic nuclei [11]. Both beams are expected to produce bremsstrahlung x-rays and gamma-rays in their direction of travel by colliding with atomic nuclei, but only the bright gamma-ray beam produced by the electrons has ever been observed from a TGF. In the feedback model of TGFs [12] it is the downward positron beam that is responsible for the enormous brightening of TGFs by seeding new electron avalanches at the bottom of the avalanche region.

3. Comparison of Observed Energy Spectrum to Simulation

The energy spectra of counts recorded within the 150µs event interval were compared to Monte-Carlo simulations using GEANT4 [13] of ADELE's response to the downward beam of positrons produced from an upward TGF occurring at 8, 10 and 12 km.

In each simulation, several billions of gamma-rays with energies distributed according to the energy spectrum expected from the RREA TGF positron beam were released at the specified altitude and allowed to propagate through and interact with a mass model of the atmosphere, and the resulting radiation field produced at the planes altitude of 2.5km was captured. For each simulated TGF altitude, a mass model of ADELE in the NOAA aircraft was positioned at several radial distances from the nadir of the downward positron beam at 0 degrees. The radiation field captured from the first stage of the simulation was then allowed to scatter and be absorbed in the instrument and aircraft. The shape of the simulated spectra in all three detectors closely resembles the observed spectra in ADELE (figure 4).

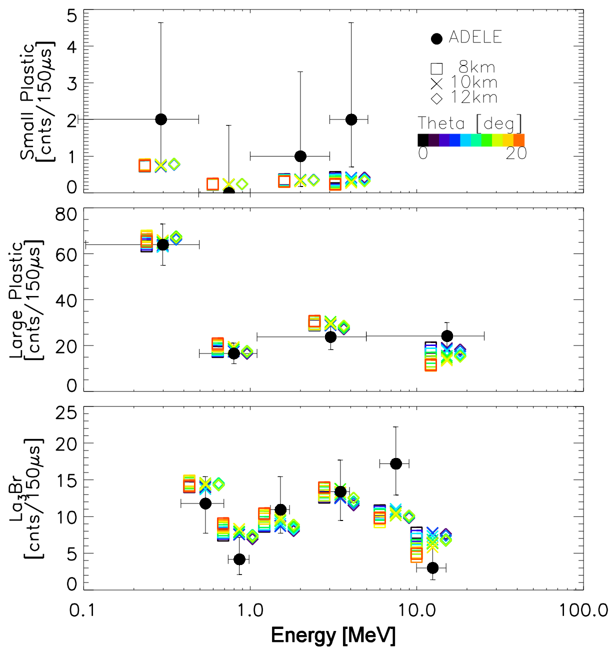

Figure 4. Number of deadtime corrected scintillator counts observed by ADELE (black circles) in each detector. The colored symbols (square, x, and diamond) for comparison are simulated counts from a Monte-Carlo simulation of ADELE at an altitude of 2.5km, below the downward positron beam of an upward pointing TGF at an altitude of 8, 10, and 12 km. The colors indicate the angular offset of ADELE at 2.5km with respect to the nadir of the positron beam. The vertical bars on the observed counts are the 84% confidence limits in the observed counts [14]. The horizontal bars correspond to the widths of the energy channels in the detectors.

4. Summary and Conclusion

From our observations and the simulated response of ADELE in the positron beam of a downward TGF, we can infer the total number of gamma rays >1 MeV produced for a given range of TGF altitudes and nadir angles. For angles relatively far from the nadir (which are more likely), the total number of inferred gamma-rays is consistent with the observed brightness (10^{16} – 10^{19} gamma-rays) of ordinary TGFs seen from space [15,16]. We therefore conclude that the most likely scenario is that the TGF reverse positron beam, never before observed but predicted by RREA theory, is indeed present.

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6. References

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