32nd URSI GASS, Montreal, 19-26 August 2017

Neutrons in ground-detected terrestrial gamma-ray flashes

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Extended Abstract

Terrestrial gamma-ray flashes (TGFs) involve the fast (submillisecond) release into the atmosphere of a spectrum of bremsstrahlung gamma-rays extending up to tens of megaelectron volts (MeV) from electrons accelerated in electric fields associated with lightning and/or the overall thunderstorm charge structure. Gamma-rays and electrons of this energy can (and presumably must) eject neutrons from nuclei of nitrogen and oxygen in air when they collide with them [1]. No evidence of TGF-associated neutrons has been seen in the thousands of TGFs observed from space, which is not surprising considering the very long time delays at which they would arrive at spacecraft, and the few neutrons expected to escape the atmosphere. On the other hand, TGFs seen from the ground, if they originate at low enough altitude, might be expected to show a neutron "tail" extending many milliseconds after the arrival of the gamma rays. There have been, however, only a handful of TGF observations from the ground.

One such observation took place on 3 December 2015 at 2020 UT in the town of Uchinada, Japan, on the Sea of Japan coast. This region and season is famous for powerful, very low-lying winter thunderstorms. The TGF at this time was associated with lightning that began with an upward leader originating from a lightning protection tower associated with a wind turbine. A single burst of high-energy radiation was observed by the Gamma-ray Observations During Overhead Thunderstorms (GODOT) instrument built at the University of California, Santa Cruz, and operated in Uchinada by Tokyo Gakugei University. Unlike the submillisecond pulses seen in most TGFs, the emission took the form of a fast rise and a gradual decay over tens of milliseconds. Remarkably, the observed energy spectrum in GODOT's large plastic scintillator includes a significant peak around 2.0 MeV. This matches the expectation for a process in which thermal neutrons propagated downward from the TGF region aloft are captured by hydrogen nuclei (protons) in the plastic scintillator, emitting a characteristic gamma-ray at 2.2 MeV which then Compton backscatters in the scintillator volume before leaving; the 1.9 MeV is deposited by the Compton electron. This interpretation is supported by Monte Carlo simulations using GEANT4 that reproduce both the energy spectrum and decay time scale observed. These simulations include the propagation of gamma rays and neutrons in Earth's atmosphere and surface and their interactions in the instrument.

We will present the high-energy, radio, and video data for this lightning/TGF event, and we will use the GEANT4 simulations to estimate the original gamma-ray brightness of the TGF. We will discuss the neutron radiation fields of downward TGFs in general, and compare the Uchinada event to two others: a very bright TGF associated with triggered lightning that was observed from the ground at Camp Blanding, FL on 15 August 2014 [2], which showed no evidence of a comparable neutron signal, and a mysterious event seen in another Japan winter thunderstorm in 2012 [3], which included what appears to be positron-annihilation radiation lasting about a minute afterward.

References

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