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Doug Rowland
Space Weather Laboratory
NASA Goddard Space Flight Center

"Earth's most powerful natural particle accelerator"

Thunderstorms launch antimatter, gamma rays, and highly energetic electrons and neutrons to the edge of space. This witches' brew of radiation is generated at the edge of the stratopause, by the strong electric fields associated with lightning discharges. In less than a quarter millisecond, an explosive feedback process takes an initial seed population of electrons, perhaps produced by cosmic rays from dying stars, and amplifies them a billion billion-fold in the rarefied air over high altitude thunderheads. The electrons generate gamma radiation as they travel through the stratosphere and lower mesosphere, momentarily brighter and of harder spectrum than cosmic gamma ray bursts. These electrons ultimately are absorbed by the atmosphere, but the gamma rays continue on, into the upper reaches of the atmosphere, where they in turn generate a new population of electrons, positrons, and energetic neutrons. These secondary electrons and positrons move along the magnetic field, and can reach near-earth space, streaming through the inner radiation belts, and possibly contributing to the trapped populations there.

First postulated by Wilson in 1925, and serendipitously discovered by the Compton Gamma Ray Observatory in 1994 [*Fishman et al.*], these events, known as "Terrestrial Gamma ray Flashes" (TGFs), represent the most intense episodes of particle acceleration on or near the Earth, resulting in electrons with energies up to 100 MeV. Recent observations by the RHESSI [*Smith et al., 2004*], Fermi [*Briggs et al., 2010*], and AGILE [*Tavani et al., 2011*] satellites, and theoretical and computational modeling, have suggested that the relativistic runaway electron avalanche (RREA) mechanism [*Gurevich, 1992*], and important modifications, such as the relativistic feedback discharge (RFD) model [*Dwyer 2012*] can best explain the observations at present.

In these models, strong thunderstorm electric fields drive seed electrons, generated from cosmic ray interactions, into a runaway discharge, in which the seed electrons continually gain energy from the electric field, creating a host of secondaries as they interact with the background atmospheric gas. The feedback mechanisms include backwards-propagating positrons and gamma rays, which then can generate new "seed" electrons at the base of the acceleration region, and themselves generate further avalanche chain reactions, greatly amplifying the initial seed population. All these processes happen in the stratosphere, in the altitude range near 15-20 km, where the electric fields and mean free paths are appropriate to allow the discharge to develop.

To date, the satellite missions that study TGFs have been designed for other purposes – to image solar flares in x- and gamma rays, to study astrophysical gamma rays sources, etc. Studies of the detailed links between TGFs and the associated lightning discharges have been limited to occasional comparisons with ground-based instrumentation, or statistical studies of correlation of TGF occurrence vs. season, latitude, etc. Important open questions abound, including:

a) What types of lightning do and do not produce TGFs? Does TGF production rely on discharges at high altitude? Strong discharges? Rapid discharges? Horizontal (intra-cloud or inter-cloud) vs. vertical (cloud to ground) geometries?

b) How common are TGFs, really? The distribution approximates a power law, and it may be that events currently above the threshold of detection are just the biggest and brightest (or are those that occur at a high enough altitude to allow the radiation to reach satellite altitudes). Is gamma ray production an inherent (and even necessary?) part of lightning discharges?

c) What are the fluxes and spectra of the secondary electrons and positrons that reach high altitudes? Important circumstantial evidence for these energetic radiation beams has been provided by RHESSI, Fermi, and AGILE, but no direct measurements of electron spectra have yet been reported. What is their possible role in providing a seed population for the inner electron radiation belt?

In order to answer these questions, two dedicated projects to study TGFs have been developed: an NSF-funded CubeSat, called "Firefly", and an experiment for the International Space Station, called "FireStation". These two projects combine gamma ray and energetic electron spectrometers, radio receivers, and fast, sensitive photometers, to measure both the TGF, and the causative lightning. The two projects are very complementary, and will launch in the summer of 2013. Both projects have been developed with heavy student involvement, as a partnership between NASA GSFC and Siena College, near Albany NY.

I will present some background on TGF physics and recent research, as well as an overview of Firefly and FireStation, including the vagaries of their paths from concept to ultimate launch and operations. Next, I will describe their place in a sequence of similar missions (Japanese "SpriteSat", Russian "Chibis", French TARANIS, and the ESA ASIM and JAXA GLIMS Space Station experiments). Finally, I will discuss the student involvement and educational benefits of these projects.