Today:

- TGFs
- Lightning in the ionosphere: unpredicted
- Significant lightning whistler wave amplitude all the way to the magnetopause
TGFs (Terrestrial Gamma Flashs)

- TGF examples
- Antimatter In lightning

Sign of antimatter seen in lightning

Gamma-ray flash energies indicate presence of positrons

By Ron Cowen

WASHINGTON — Designed to scan the heavens thousands to billions of light-years beyond the solar system for gamma rays, the Fermi Gamma-ray Space Telescope has also picked up a shocking vibe from Earth. During its first 14 months of operation, the flying observatory has detected 17 gamma-ray flashes associated with terrestrial storms — some containing a surprising sign of antimatter.

During two recent lightning storms, Fermi recorded gamma-ray emissions with an energy that could have been produced only by energetic positrons, the antimatter equivalent of electrons. The positron observations are the first of their kind for lightning storms. Michael Briggs of the University of Alabama in Huntsville announced the findings November 5 at the 2009 Fermi Symposium.

The 17 flashes Fermi detected occurred just before, during and immediately after lightning strikes, as tracked by the World Wide Lightning Location Network.

During lightning storms previously observed by other spacecraft, energetic electrons moving toward the craft slowed down and produced gamma rays. The unusual positron signature seen by Fermi suggests that the normal orientation of an electric field associated with a lightning storm is somehow reversed, Briggs said. Scientists are now working to figure out how the field reversal could have occurred. But for now, he said, the answer is up in the air.

Recording terrestrial gamma-ray flashes isn’t new. The first were found by NASA’s Compton Gamma-ray Observatory in the early 1990s. NASA’s RHESSI satellite, which primarily looks at X-ray and gamma-ray emissions from the sun, has found some 800 terrestrial gamma-ray flashes, Briggs noted.
TGF-lightning are Simultaneous!

- GBM light curves corrected for light travel time and clock drift (histogram)
- WWLLN stroke time and uncertainty band (dotted vertical bar)
• Spectra fitted by separately simulating electrons and positrons along the field lines.
• Fits require both electron and positron components
• Exponential continuum spectrum with Ecutoff=2-4 MeV.
References about lightning

- Reading Lists for Global Circuit, and lightning above the clouds:
- The Earth’s Electrical Environment (National Academy Press)
Ionosphere

 baloon

ΔV = 10^{-5} V

10 Billion Volts

100 Ω Global Total
Tzur and Roble: Dipolar Thunderstorms and Electrical Environment

Ionosphere

Cloud tops

Vertical Current
Log_{10} J (A m^{-2})

Lower Bounds
Ground based measurements

Fig. 4-3. One-hop whistler of high amplitude with three-hop echo. $a$, Curve of $1/\sqrt{t}$ versus $t$. $b$, Dynamic spectrum. $c$, Corresponding oscillogram of wide-band amplitude. $d$, A section of $c$ expanded in time by a factor of 20. In parts $c$ and $d$, filter passband was 600 c/s to 15 kc/s.
Ground based measurements

Fig. 4-20. Echoing nose whistlers. a. Even-order echo trains; four sources marked; first whistler is a four-hop echo of a preceding whistler (not shown). Note emissions triggered above nose. b. Odd-order echoes of same whistler, 0 = 6.0 kc/s, \( t_n = 1.52 \) sec. Station NPG provides relative timing. c. Odd-order echo trains, marked B to B and C, C; even-order echo train, marked A to A; nose frequencies range from less than 4.4 kc/s to 5.3 kc/s (\( t_n = 2.0 \) sec); echoes show path mixing, with average period between echo groups of 2.19 sec.
Prediction by Dejnarakarintra and Park:

Lightning E-field \(~10^{-4} \text{ V/m}\) in ionosphere

\[ E_r(r=45, Z=150 \text{ km}) \]
\[ (40, 100) \]
\[ (25, 70) \]
\[ (15, 30) \]
\[ E_r(r=5, Z=20 \text{ km}) \]
\[ Q(r=0, Z=5 \text{ km}) \]

FIGURE 5-23. PLOTS OF $E_r$ AT SELECTED VALUES OF $r$ AND $z$. The waveform of the monopole source is shown at the bottom.
Discovery paper

Ionospheric fields 10s of mV/m
Figure 4.4 Ionospheric electric field data which have been transformed into geomagnetic coordinates. Notice that the lightning transients have a significant electric field parallel to the Earth's magnetic field.
WIPP R-B-G Data (7/31/87, Holzworth)

UT 3:56:56.800 To 3:56:56.900

100 msec
Figure II.A.1. 50 msec of electric and magnetic field and optical data in the ionosphere during a lightning stroke.
WIPP ROCKET DATA (July 31, 1987)

TIME (ms)

- h = 411.56 km
- h = 383.34 km
- h = 336.35 km
- h = 288.18 km
- h = 236.83 km

VLIF

OPTICAL
Figure 5.3: Relation between the time delay of 24 kHz waves and the altitude of the rocket. Lightning events in this figure are the same events shown in Figure 5.2.
Positive CG Stroke, Peak Current = +57.2 kAmps. Rocket Altitude = 295 km

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Frequency in kHz

Frequency in kHz

Time in millisecond after NLDN detection

Pw, V^2/m^2 - Hz

Frequency in kHz
NLDN time = 522.637 at Latt.=37.90 Long.=-75.35, Ipeak=-27.9 k-Amps
C/NOFS Satellite -- Orbit 3509 -- VEFI Observations
9 December 2008
Alt: 617 km, Long: 340.4°, Lat: 11.5°, 2.4 L.T.

South Lightning Detector
(16k samples/sec)
Scatter plot of the integral of $E^2$ at the satellite vs. arc distance to the coincident WWLLN stroke location.