Fermi observations of Terrestrial Gamma-ray Flashes (TGFs)

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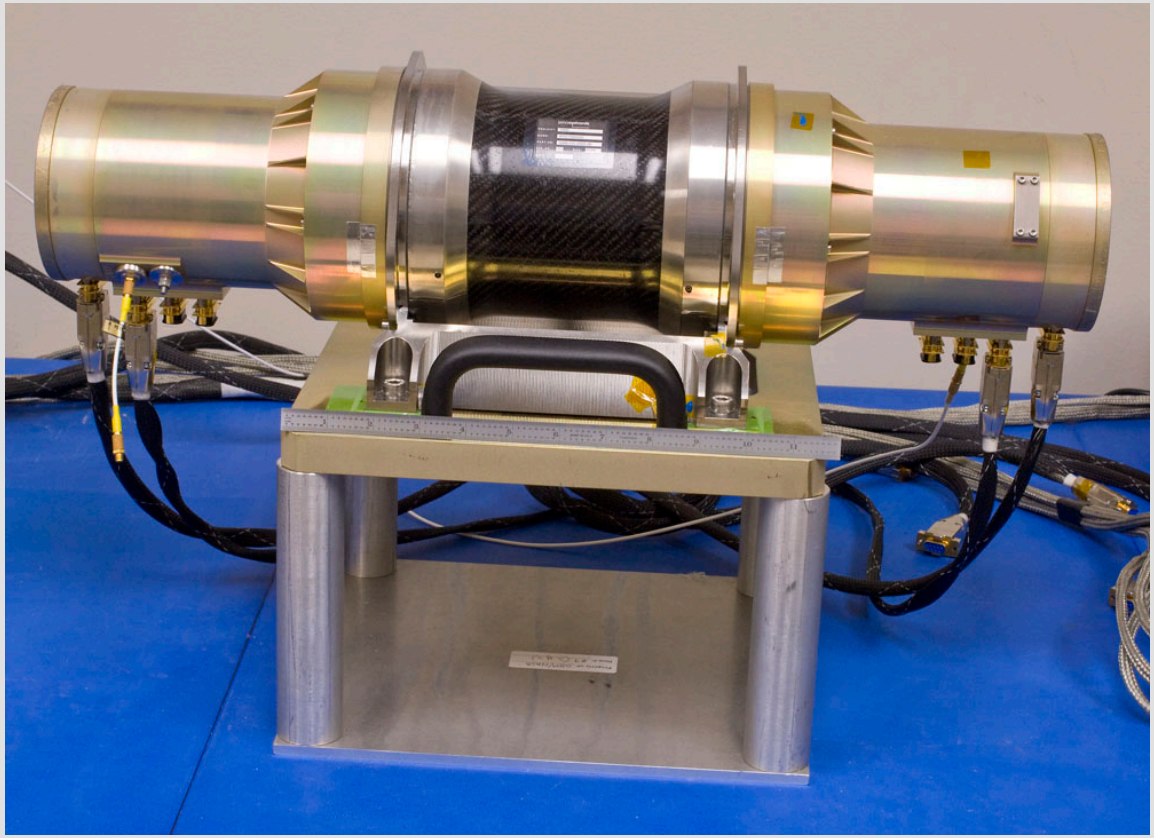
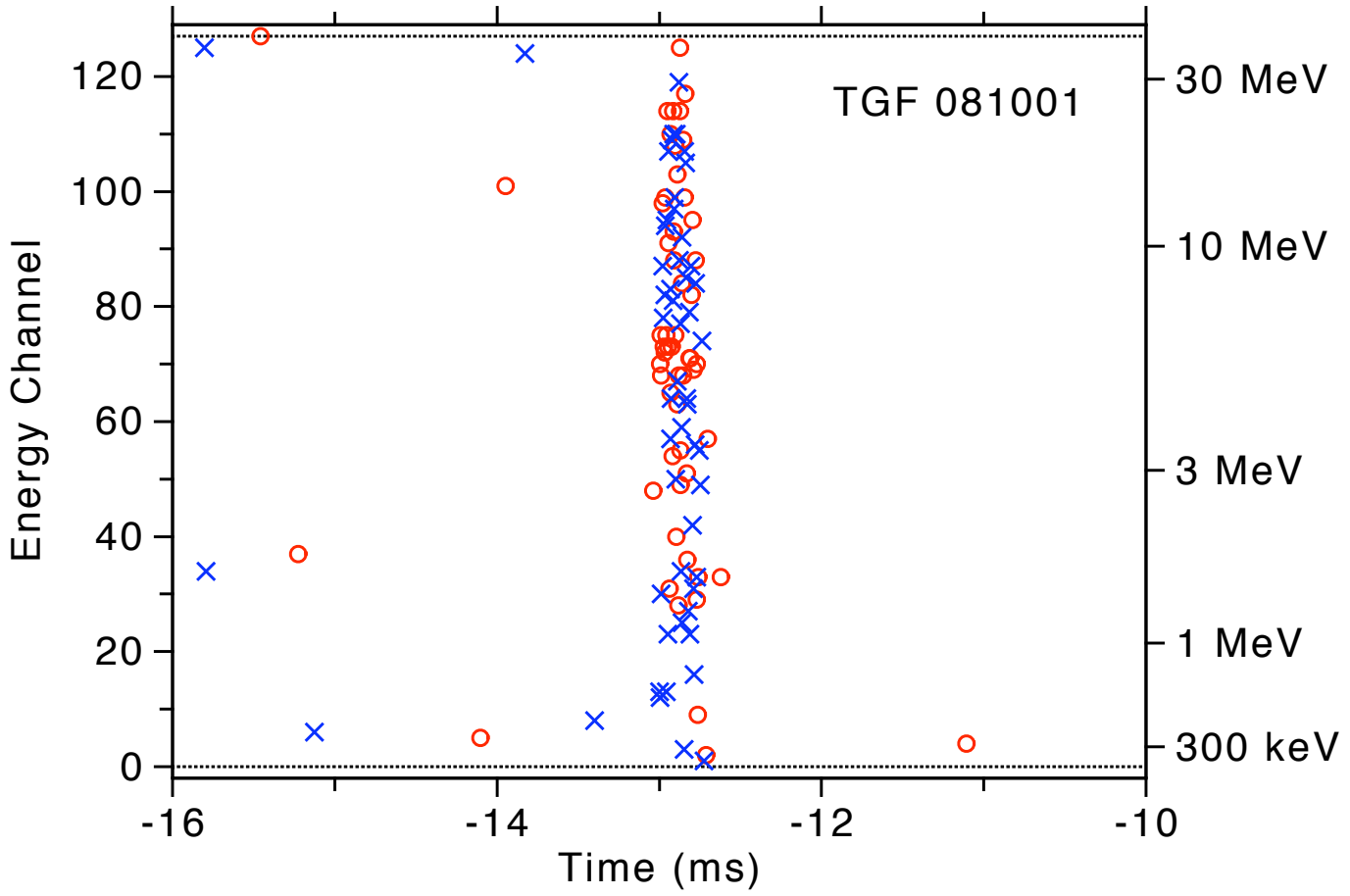
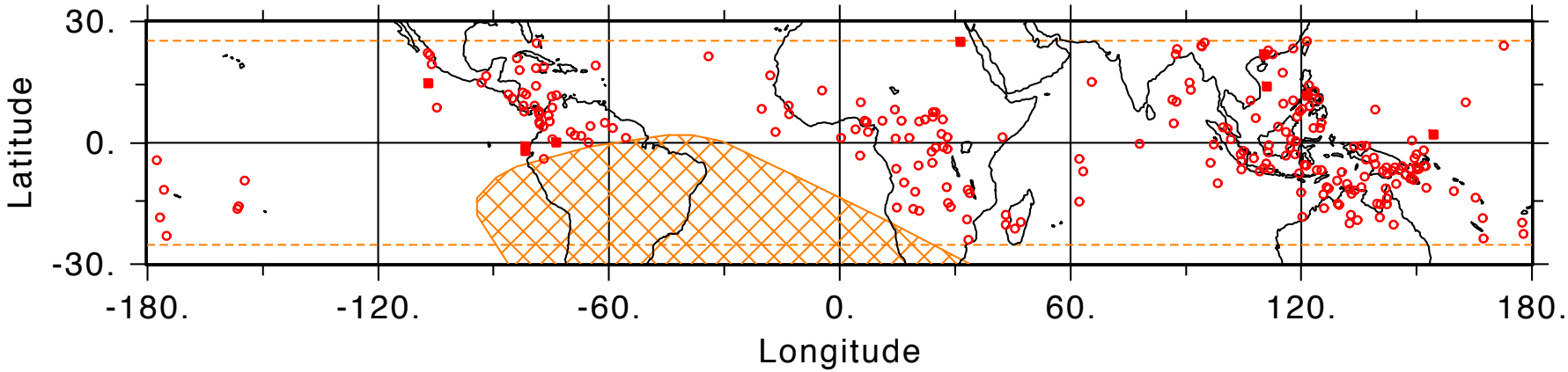
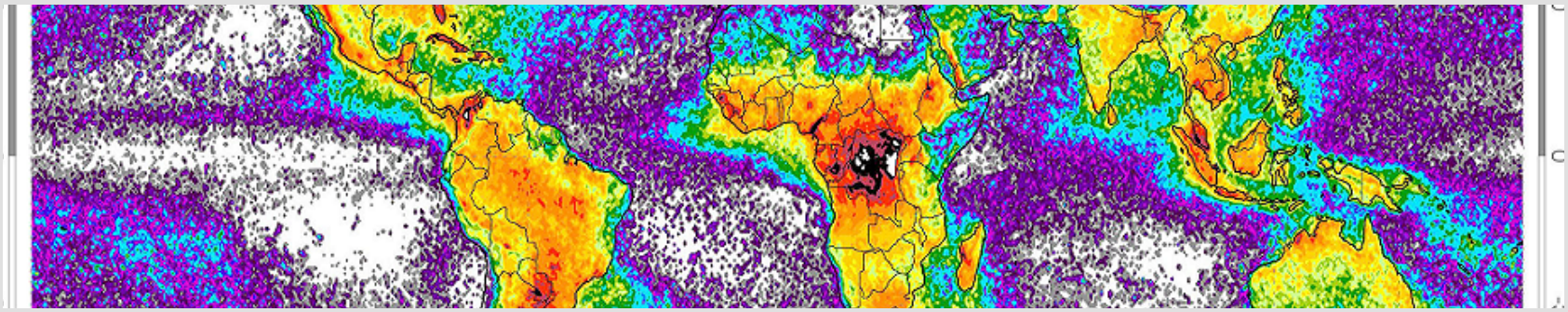
Others before launch: Giselher Lichti, Fred Berry, Ron Cantrell, Al English, Fred Kroeger, …




TGF 081001
Energy Channel
120
100
80
60
40
20
0
-16
-14
-12
-10
Time (ms)
30 MeV
10 MeV
3 MeV
1 MeV
300 keV

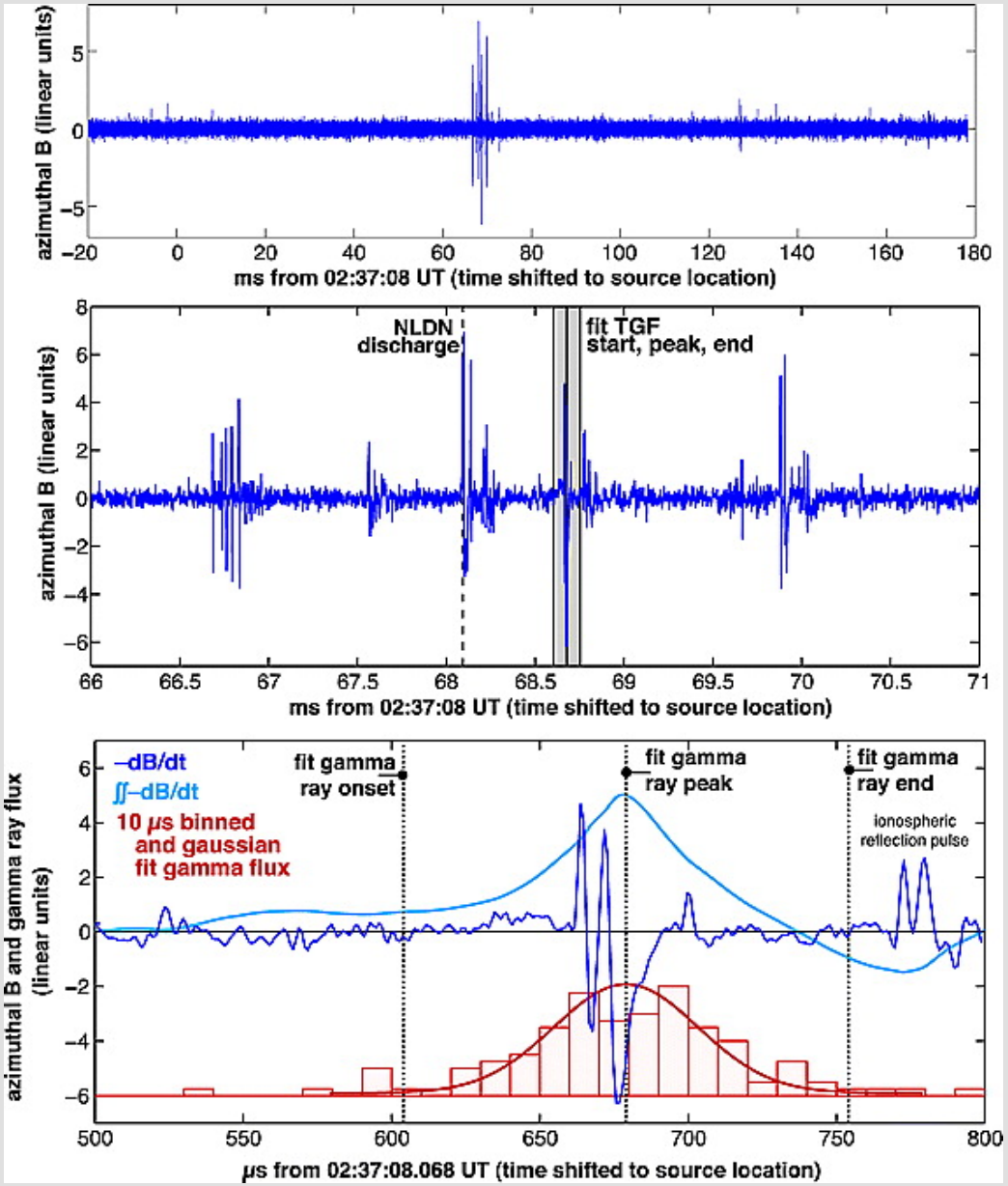
237 GBM TGFs





Lightning Imaging Sensor (LIS)

Fermi Gamma-ray Space Telescope



Cummer et al., GRL, 2011

Fermi Gamma-ray Space Telescope

TGF Instruments

Discovered with BATSE of the Compton Observatory in the early 1990's.

Currently being observed with:

- the RHESSI Solar Explorer – sample size approaching 1000 TGFs,
- AGILE
- and the Gamma-ray Burst Monitor (GBM) of Fermi

Key Theory Papers

• Relativistic Runaway Electron Avalanche process: Gurevich et al., Physics Letters A (1992),

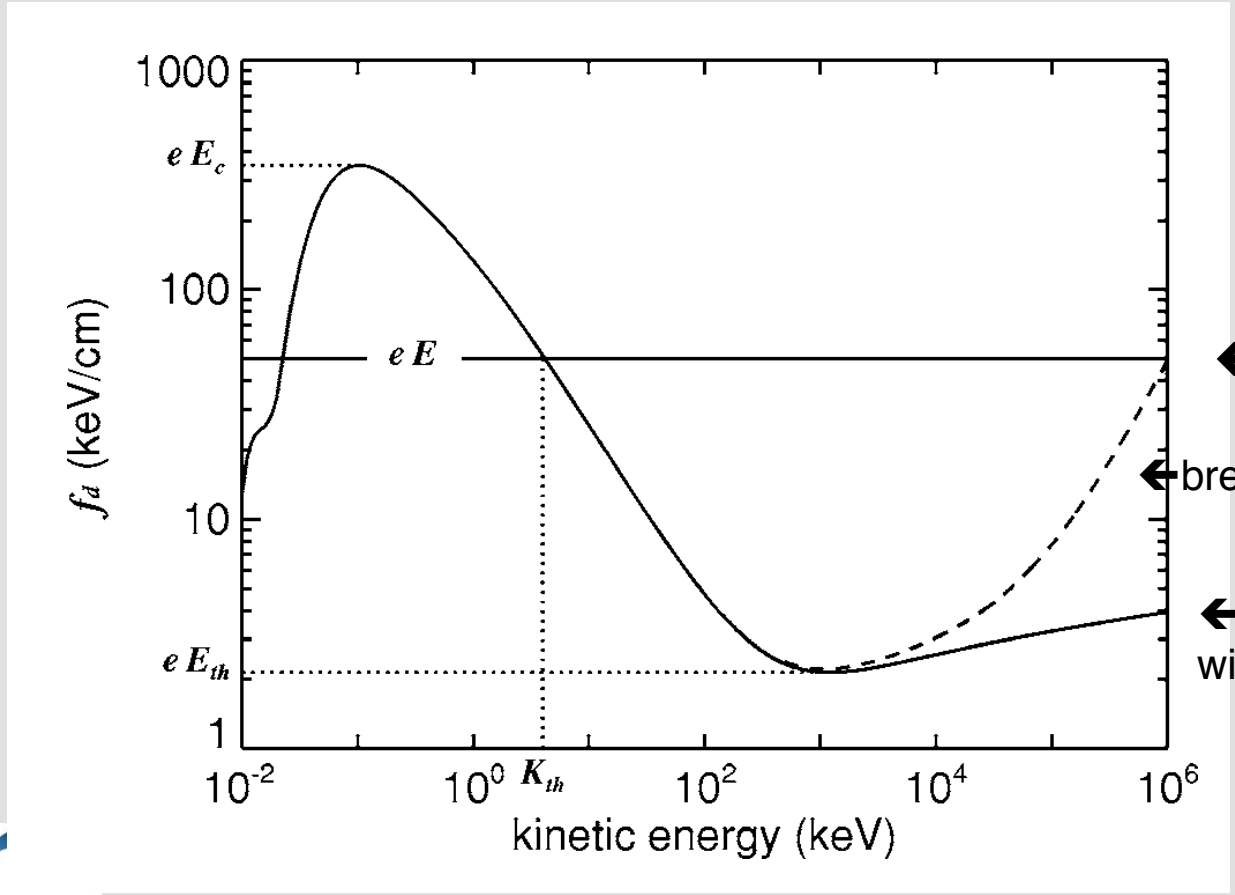
• Relativistic feedback: Dwyer, Geophys. Res. Lett. (2003)

The gamma-rays originate from bremsstrahlung emission from energetic electrons accelerated in strong electric fields associated with thunderstorms or lightning.

Pasquale Blasi's first case: $\langle E \rangle \neq 0$ – this is possible because of the low conductivity of air.

The electrons are produced by the Relativistic Runaway Electron Avalanche Model (RREA), likely with Relativistic Feedback to increase the multiplication.

Relativistic Runaway Electron Avalanche (RREA) Model of Gurevich, Milikh & Roussel-Dupre (1992):
Drag force f_d as a function of electron energy



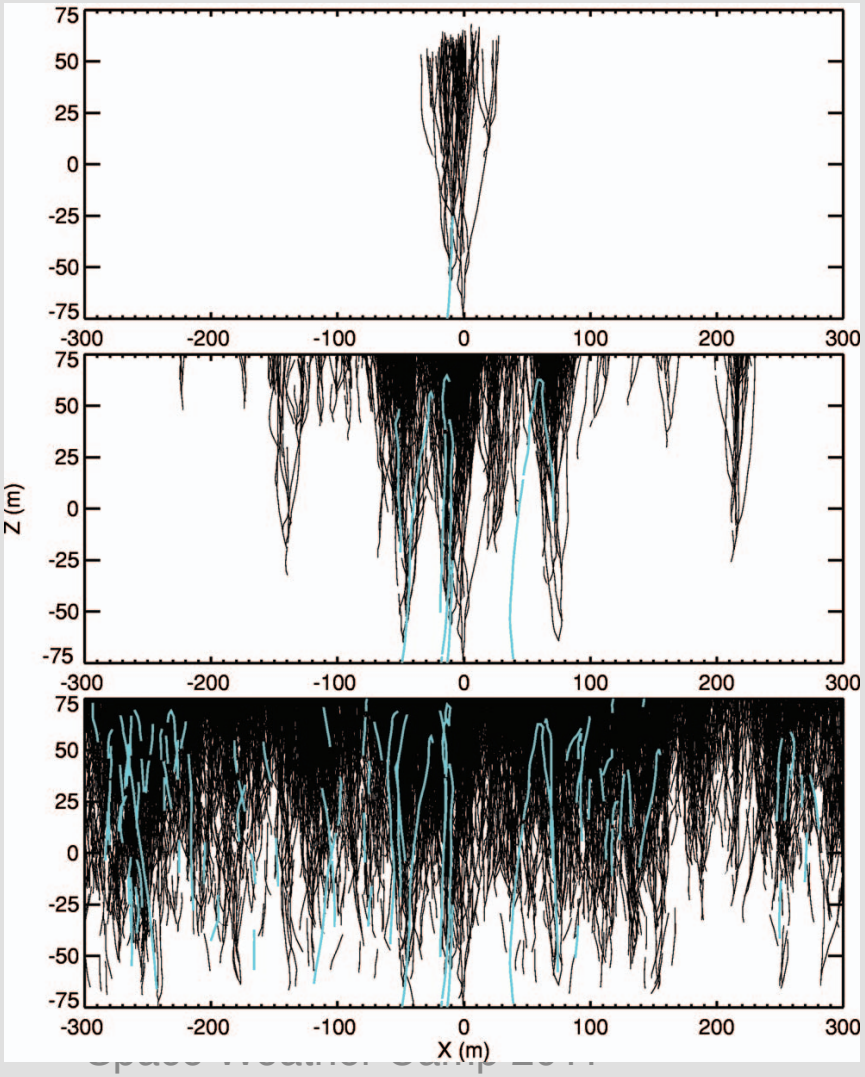
Runaway Electron Avalanches by Relativistic Feedback
J. Dwyer (2007)

E = 750 kV / m
for 150 m,
➔110 MV potential

Initial avalanche from a single 1 MeV seed electron.

Additional avalanches produced by x-ray and positron feedback.

Black = Electron
Blue = Positron

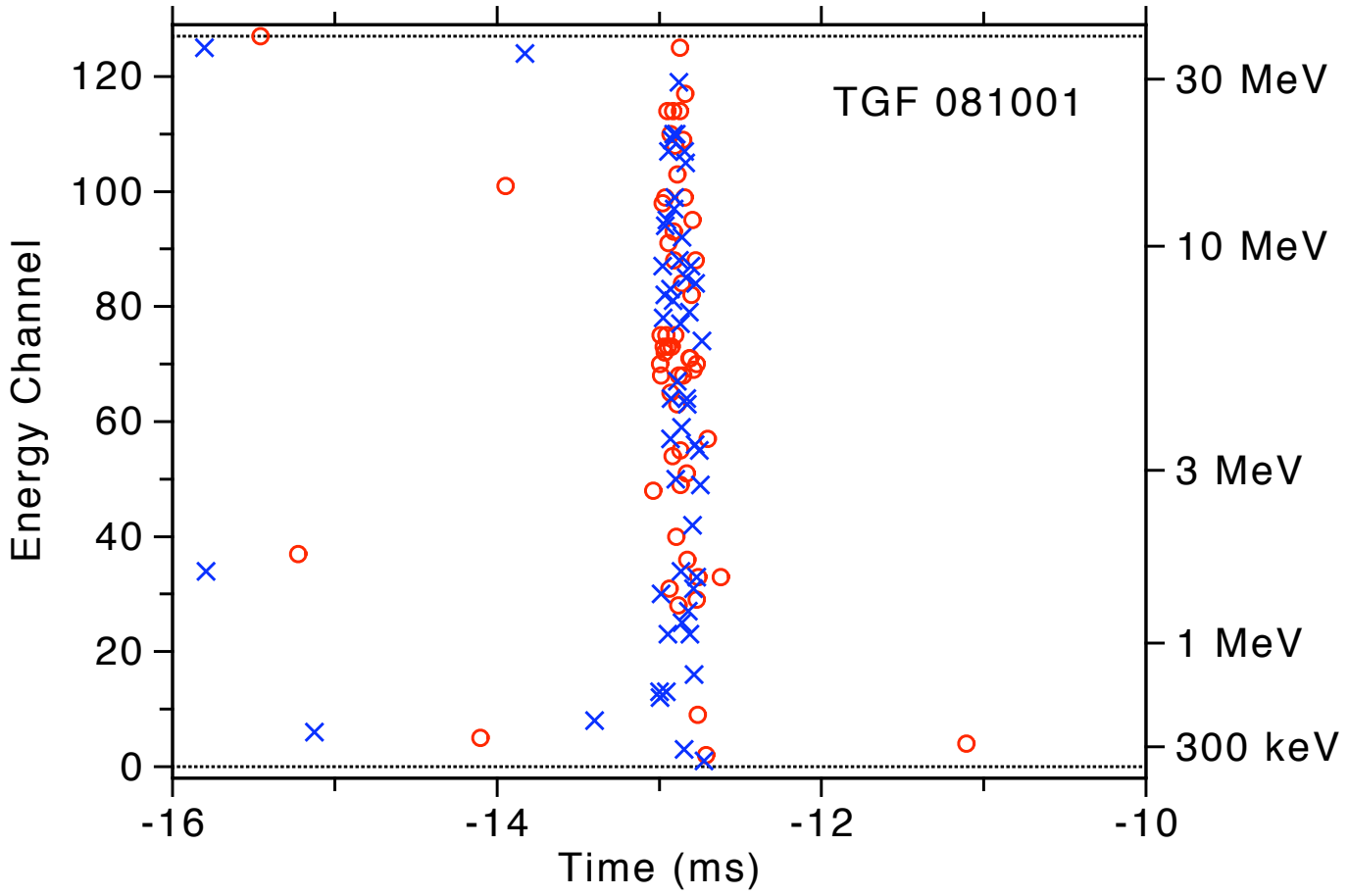


t < 0.5 μs

t < 2 μs

t < 10 μs

Gamma-ray Space Telescope


TGF 081001
Energy Channel
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Time (ms)
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3 MeV
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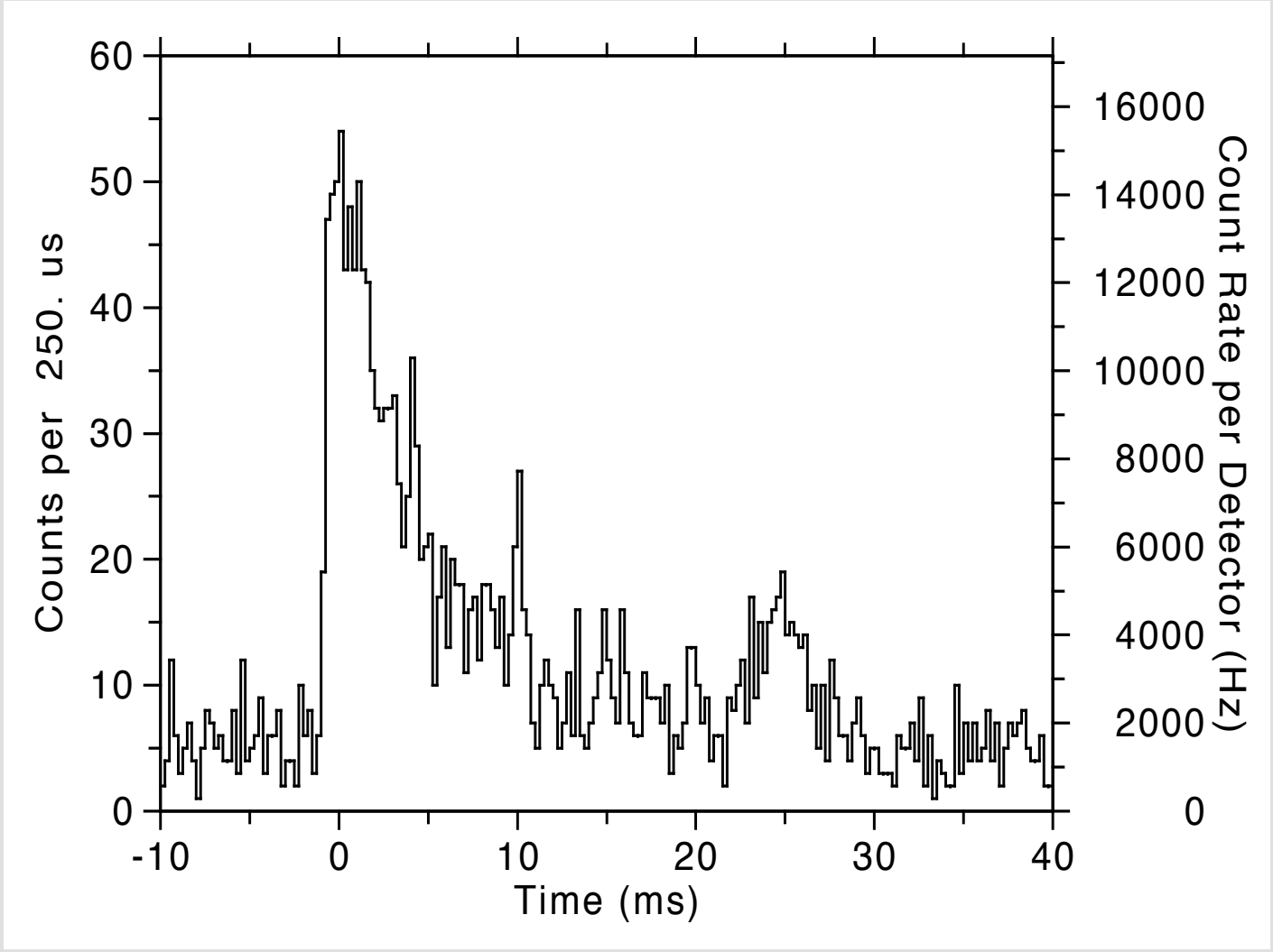
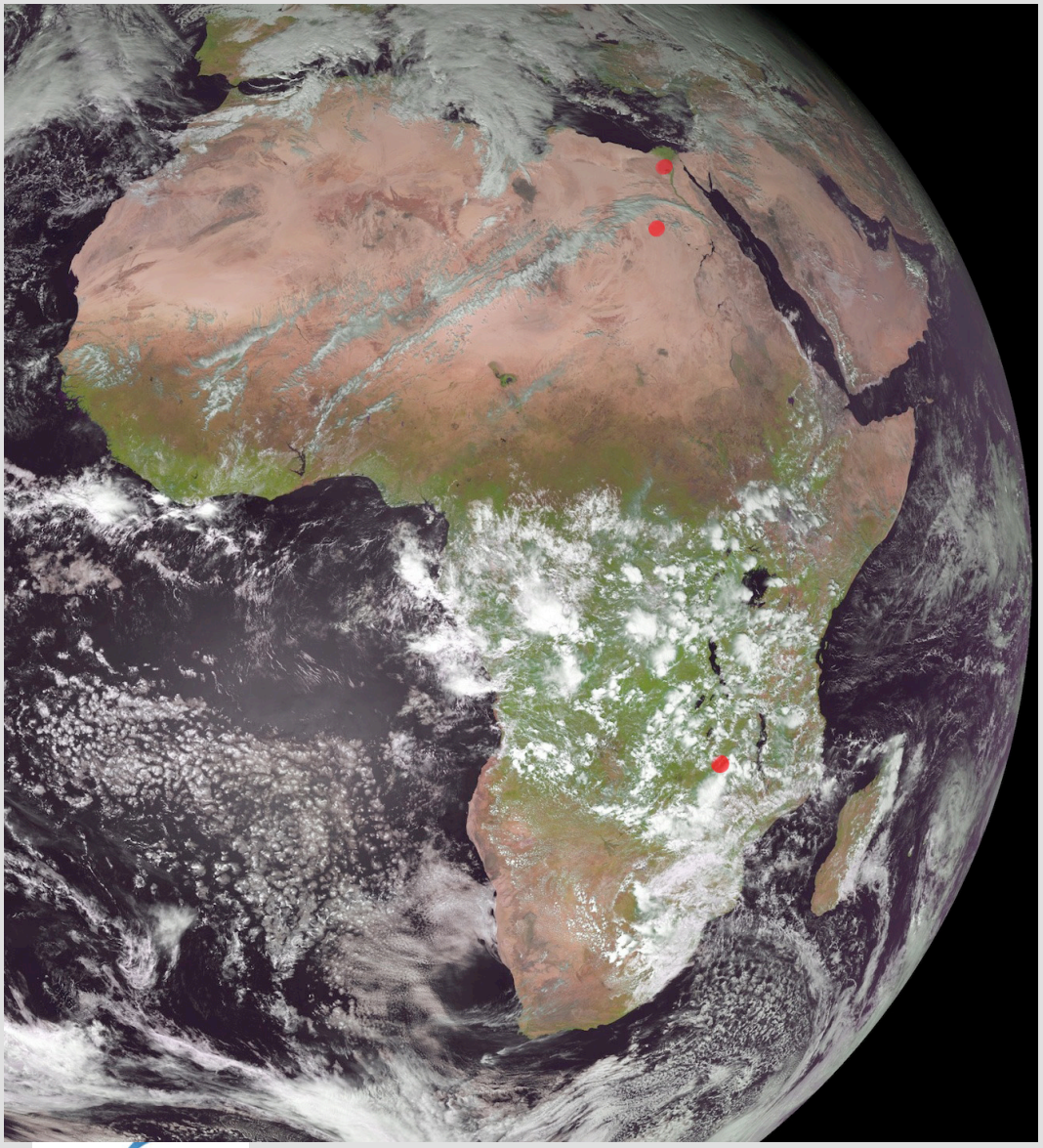
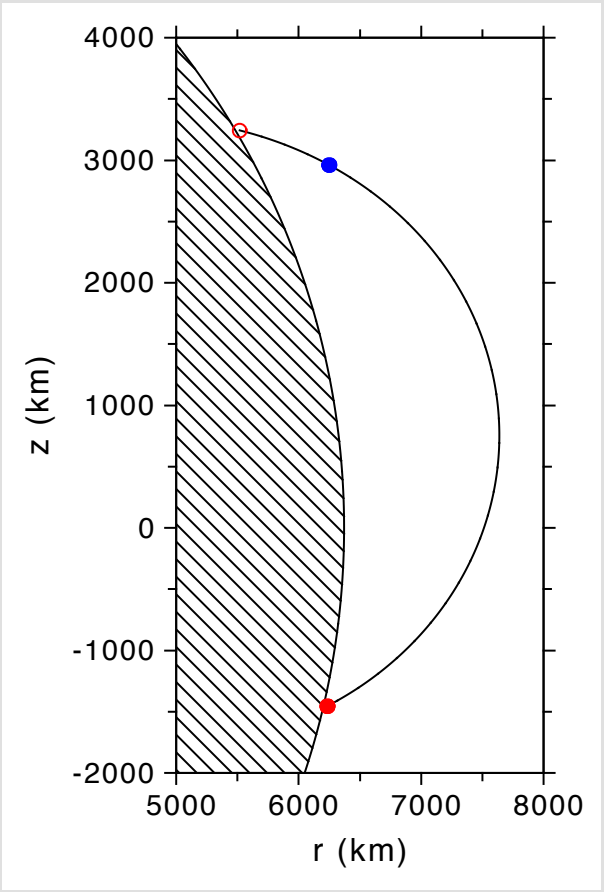
300 keV


Counts per 250. us
Count Rate per Detector (Hz)
Time (ms)
60
50
40
30
20
10
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-10
0
10
20
30
40

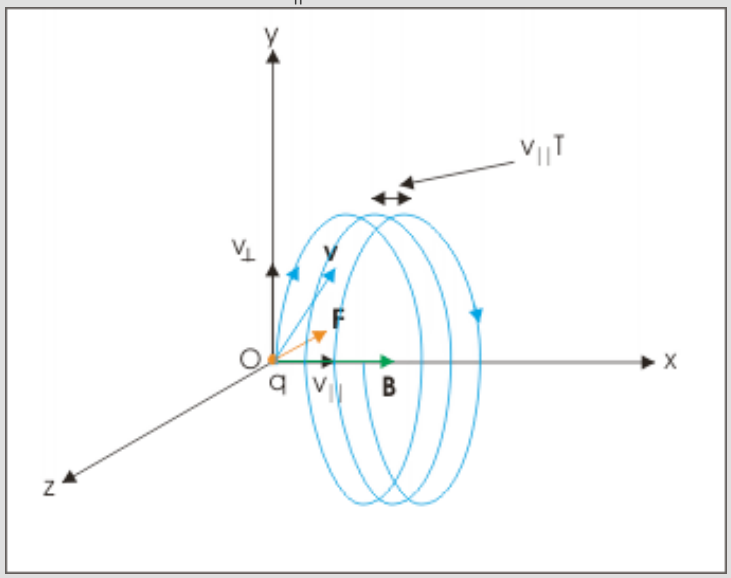


Meteosat 9 image



A pure **B**-field $\Rightarrow$ kinetic energy is conserved.

A homogenous **B**-field $\Rightarrow$ helical motion:
uniform translation $v_{\parallel}$ along the field and circular motion $v_{\perp}$ about the field.

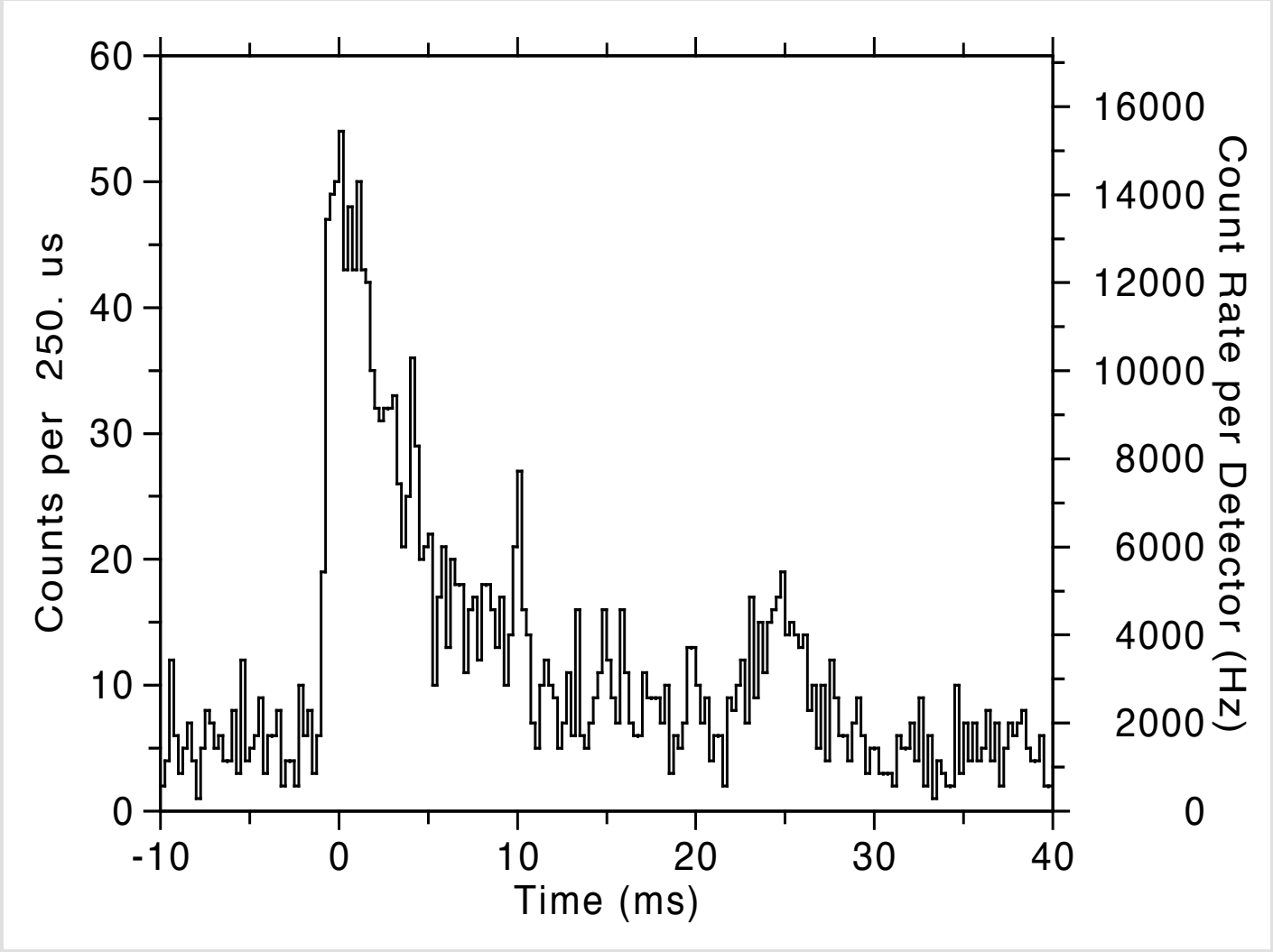


Pitch angle α:

$$\tan\alpha = \frac{v_{\perp}}{v_{\parallel}} \tag{1}$$

Relevant values:
$B \sim 30,000$ nT $= 0.3$ G

For an electron energy ~ 1 MeV: $r_L \sim 100$m,
$\omega_B \sim 1$ MHz.


Counts per 250. us
Count Rate per Detector (Hz)
Time (ms)
60
50
40
30
20
10
0
16000
14000
12000
10000
8000
6000
4000
2000
0
-10
0
10
20
30
40

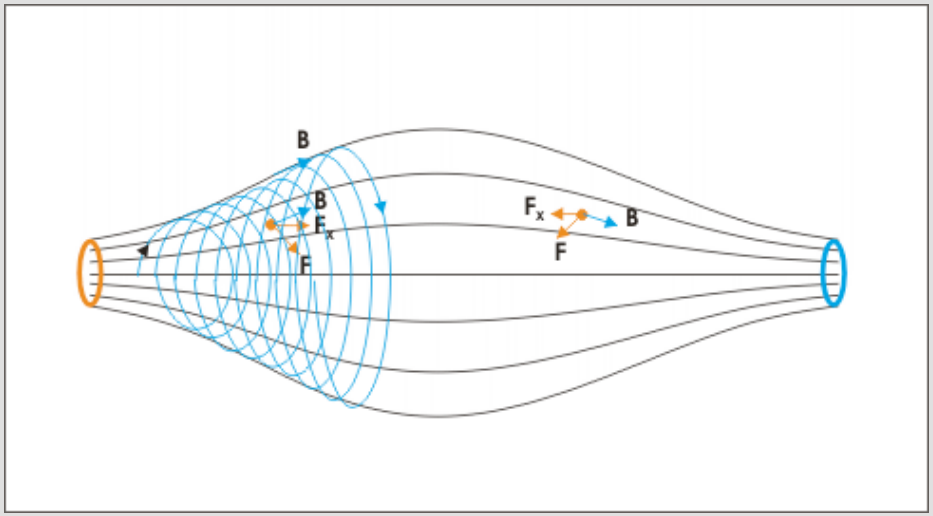
The geomagnetic field is not homogenous...

Adiabatic invariant:

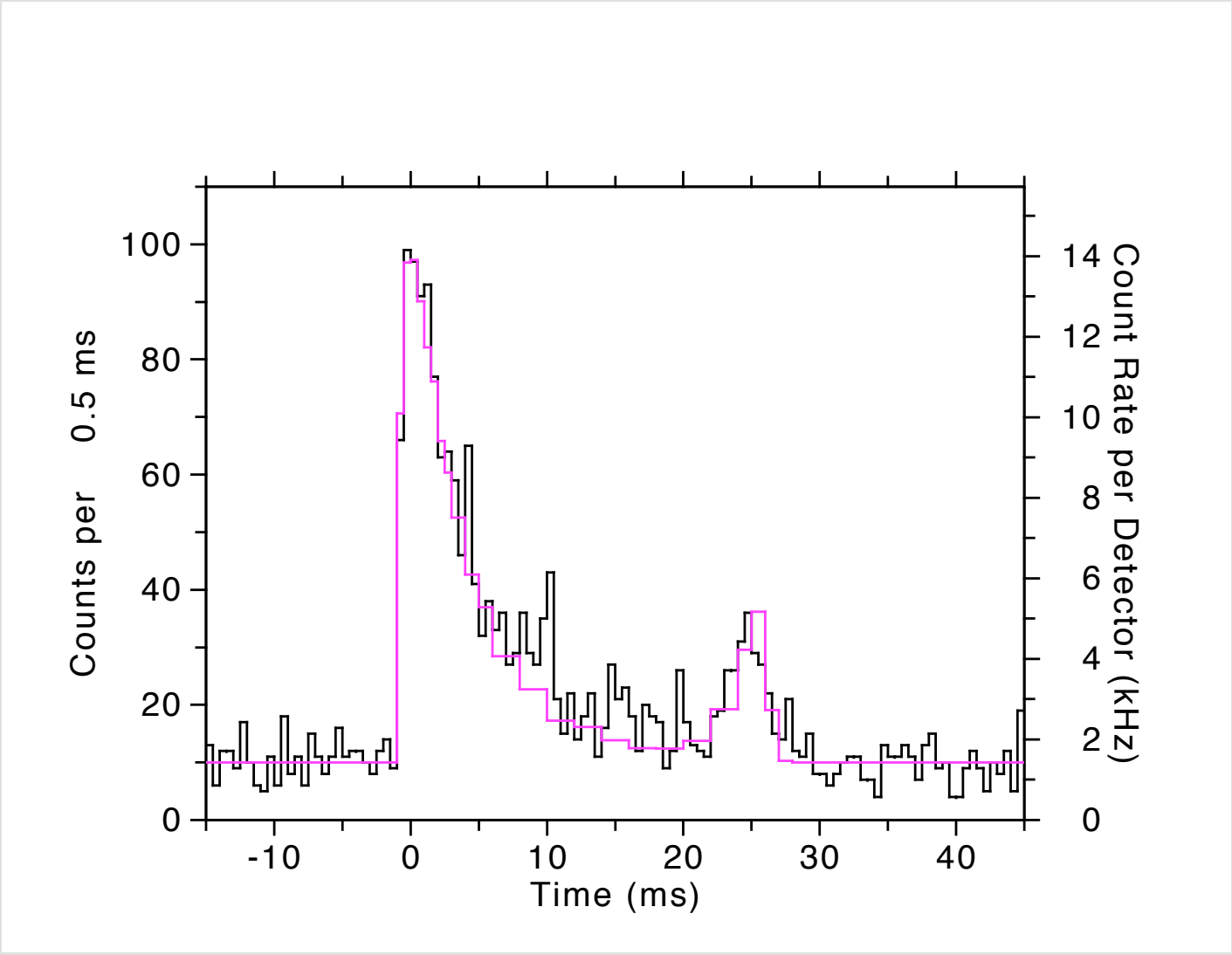
$$J = \oint \mathbf{p}_\perp \cdot d\mathbf{l} = \text{constant} \tag{2}$$

$$= \frac{e}{c} B \pi r_L^2 \tag{3}$$

$$= \frac{c^2}{e^2} \frac{p_\perp^2}{B} \tag{4}$$

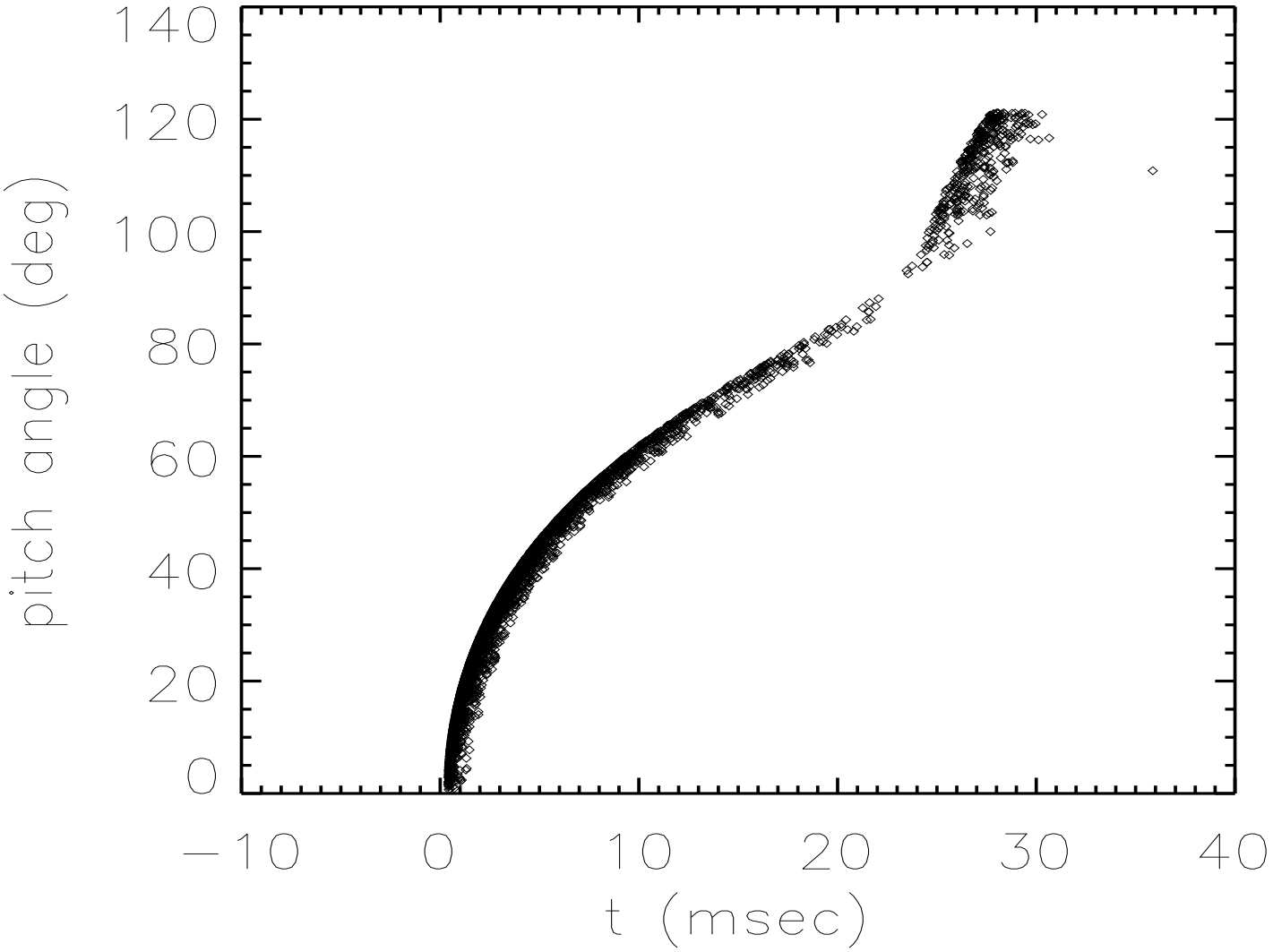


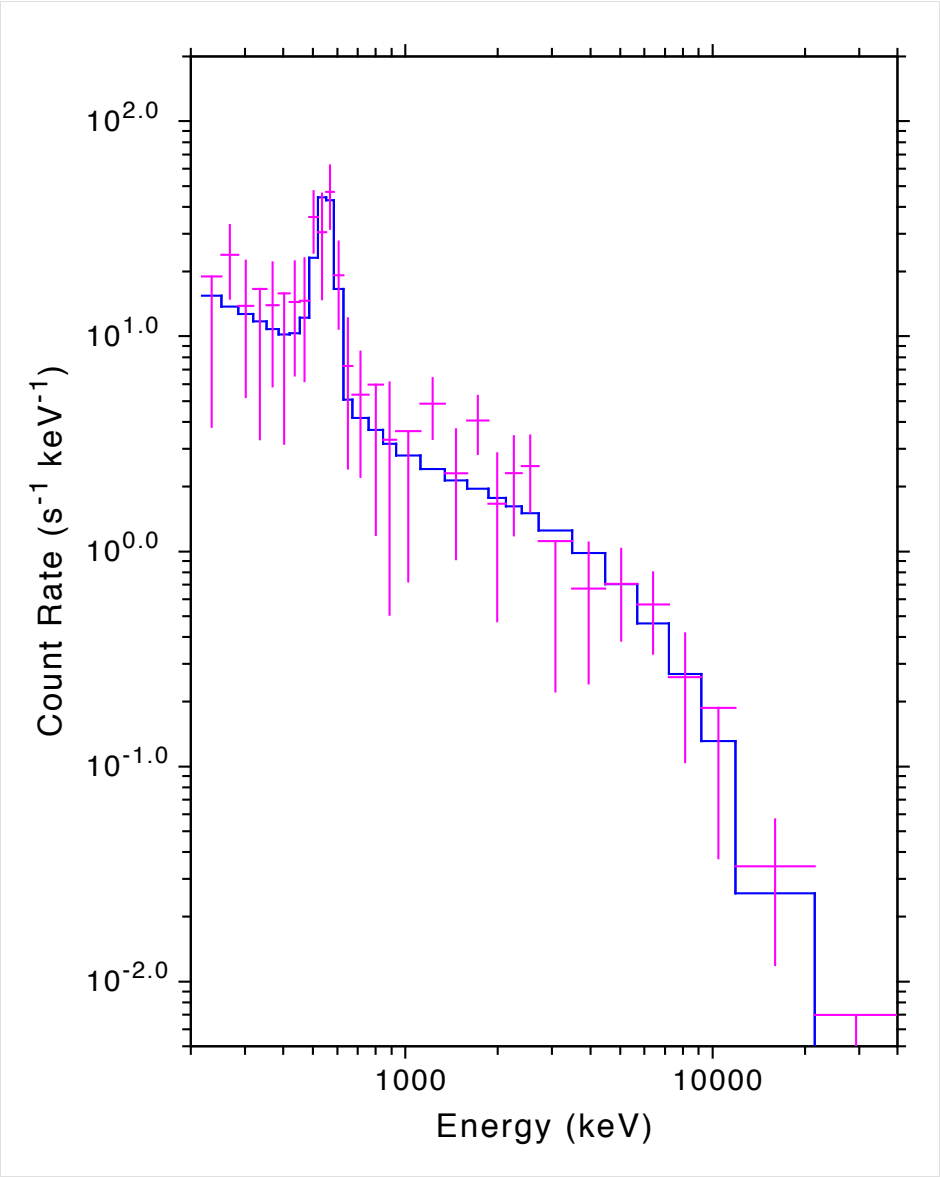
So as the particles approach the Earth and B increases, $p_\perp$ must increase. As $v_\perp$ increases, by energy conservation $v_\parallel$ decreases. Eventually $v_\parallel$ reaches zero and changes sign – magnetic mirroring!



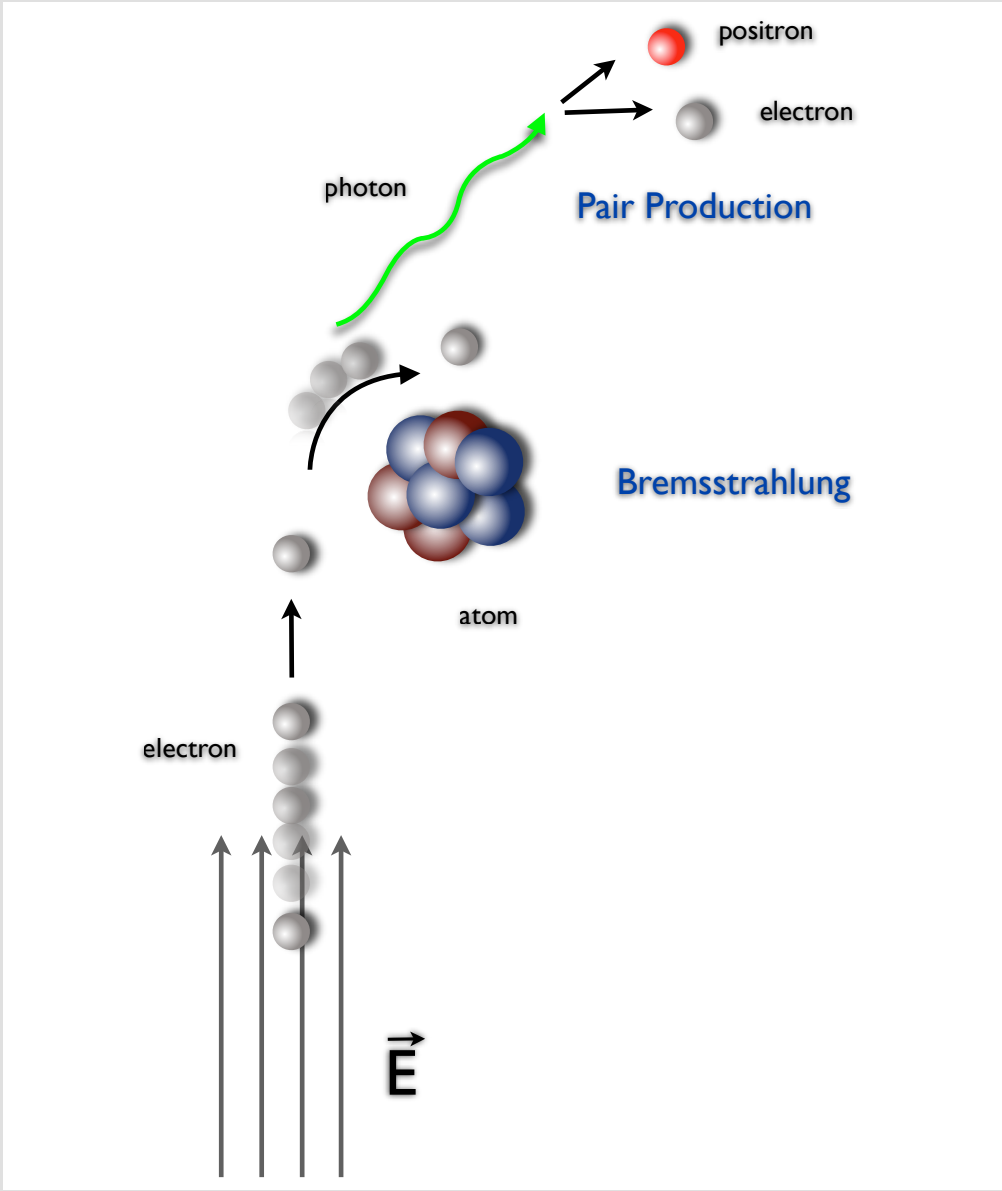
Magenta: simulation by J. Dwyer

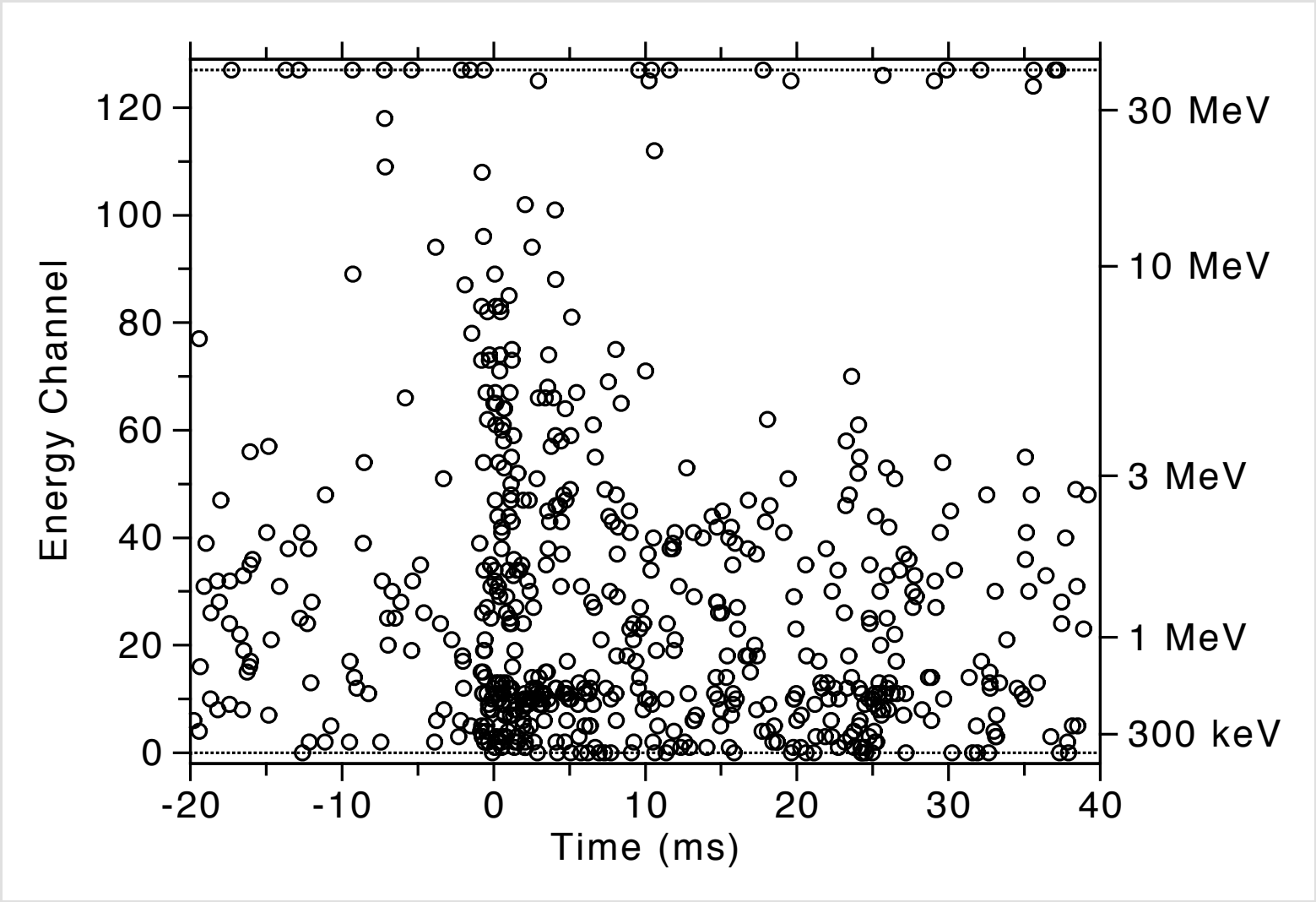
Simulation: J. Dwyer





Briggs, et al, GRL, 2011

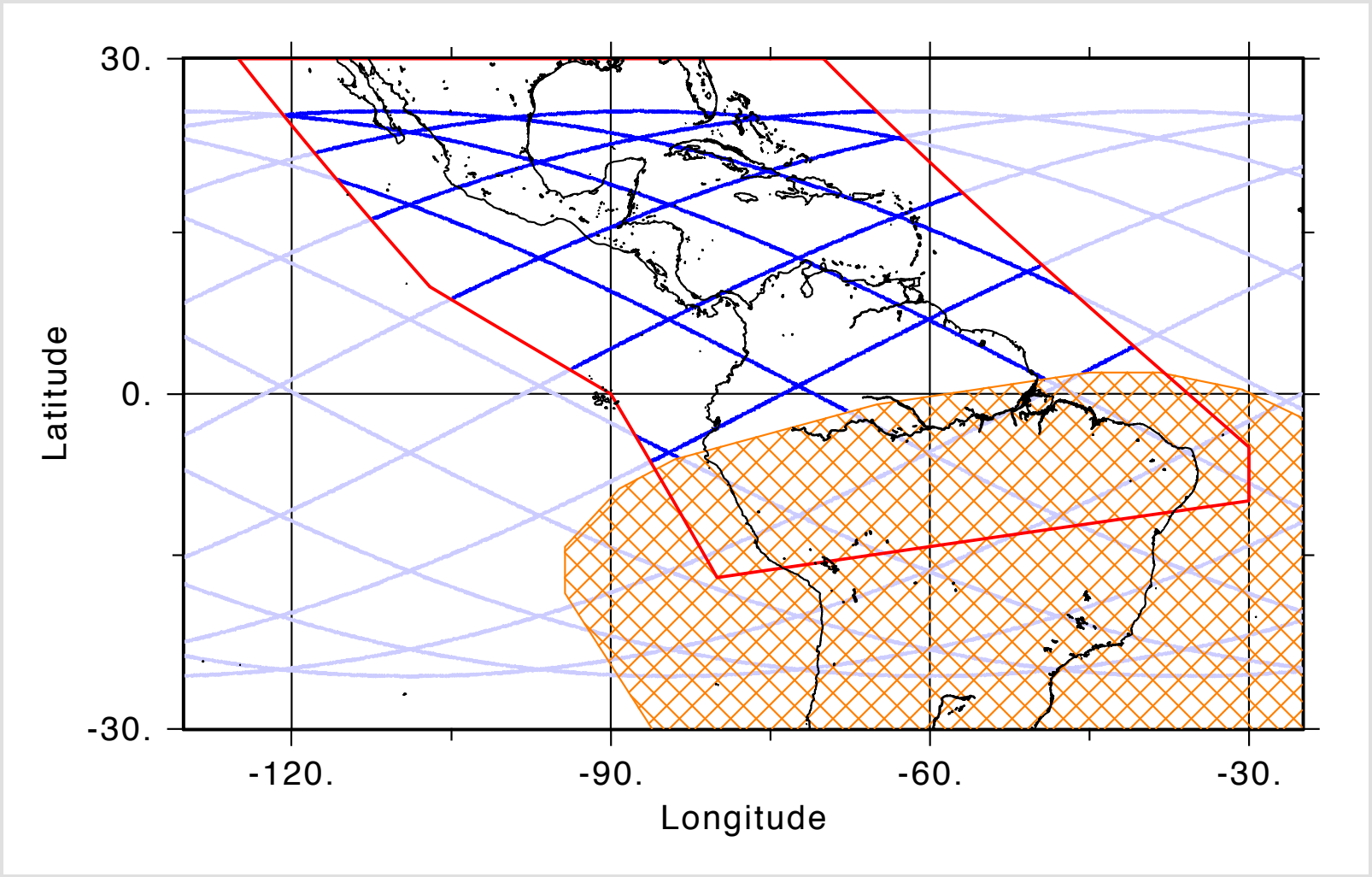

positron
electron
photon
Pair Production
Bremsstrahlung
atom
electron
$\vec{E}$

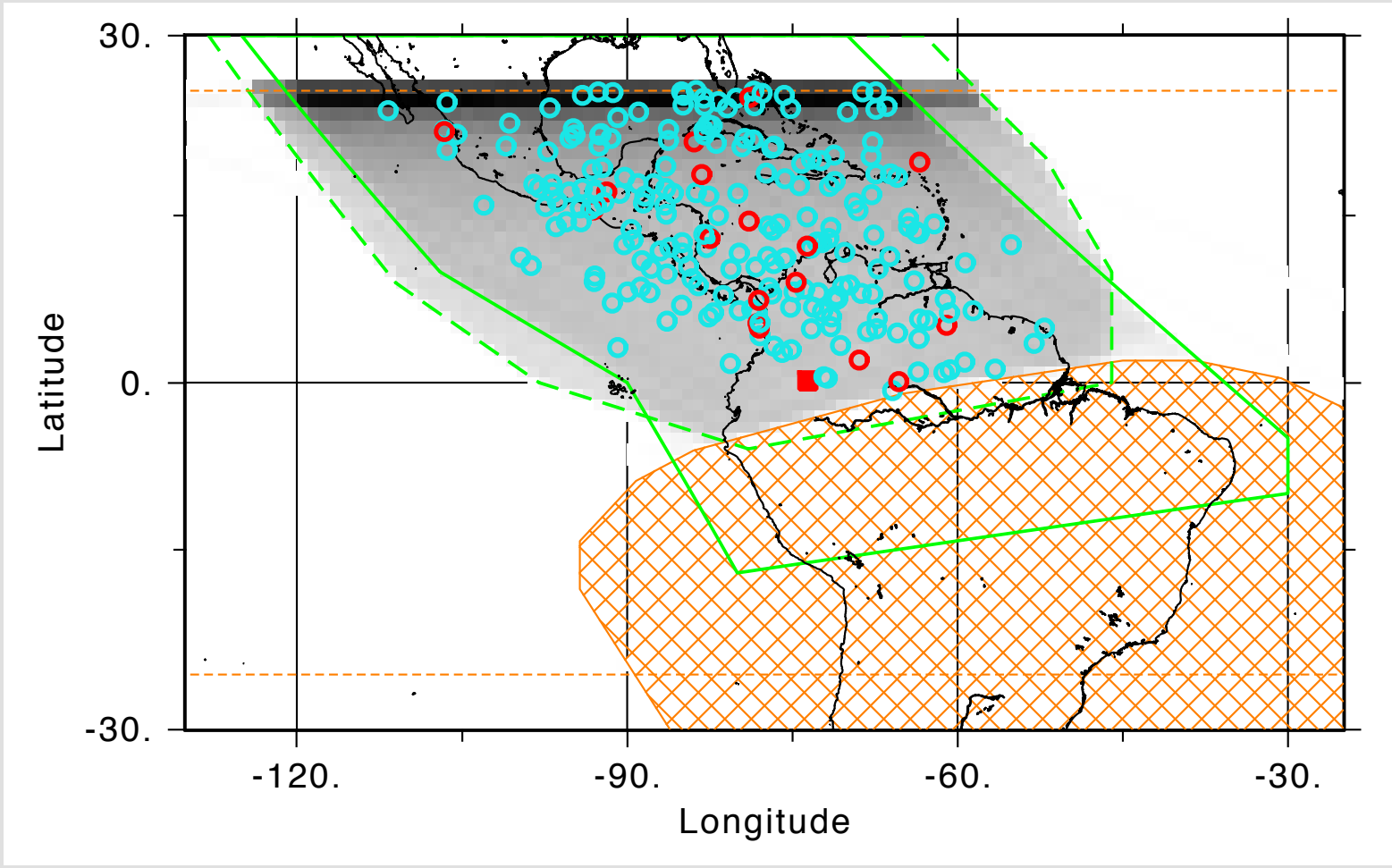

Energy Channel
120
100
80
60
40
20
0
-20
-10
0
10
20
30
40
Time (ms)
30 MeV
10 MeV
3 MeV
1 MeV
300 keV

Currently 250 (triggered) TGFs

The TGF rate since the Flight Software was improved (2009 Nov 10): one per 4.0 days.

But as Oliver Twist said, “Please sir, I want some more.”


30.
0.
-30.
Latitude
-120.
-90.
-60.
-30.
Longitude


30.
0.
-30.
Latitude
-120.
-90.
-60.
-30.
Longitude

Currently ~700 TGFs.

“Please sir, I want some more.”

Fermi and GBM have permission to produce GBM TTE data all the time!
We predict ≈850 TGFs per year.

http://gammaray.nsstc.nasa.gov/publications/tgf_journal.html