Gamma-Ray Bursts and Fermi: What We Have Seen

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On behalf of the Fermi LAT and GBM Collaborations

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Gamma-Ray Bursts

- Gamma-Ray Bursts are violent explosion happening at cosmological distances (up to $z=8.2$)
- The “Prompt phase”: Intense flashes of gamma-rays lasting from few millisecond to hundreds of seconds.
- The “afterglow phase”: longer lasting emission, discovered in X-rays and found in optical, radio

High statistic was collected at keV-MeV energies by BATSE. The prompt spectrum at these energy is typically described by a smoothly broken power law, first introduced by David Band, in 1993, and known as the Band function. Only little was known at GeV energies before the Fermi era.
**GRB Observations by Fermi**

- **Improved performance of Fermi LAT (Large Area Telescope)**
  - Larger FOV (>2.4 sr): more GRB samples
  - Larger effective area: better statistics
  - Less dead time: detailed lightcurve, time-resolved analysis
  - Wider energy coverage: up to > 300 GeV

**Fermi GBM-LAT covers >7 decades of energy band (8 keV to > 300 GeV)**

Both LAT and GBM can independently trigger

**“Typical” Prompt GRB Spectrum**

- **GBM**
- **LAT**

Fermi Gamma-ray Burst Monitor
Views entire unocculted sky

- **NaI**: 8 keV - 1 MeV
- **BGO**: 200 keV - 40 MeV

12/10/09  N. Omodei - Fermi Symposium 2009
How do we observe?

- Burst Advocates (BGM and LAT) on shift every day
  - Look at every GBM and LAT alert, and search in the data
  - In case of LAT detection, LAT sent notices via GCN
- GBM and LAT team work together in analyzing and interpreting LAT Fermi data
  - Circulars are sent via GCN in case something is found
- LAT “full statistic”, what does this mean?
  - We can select events that trigger the detector, and passed the onboard-gamma filter (~400 Hz)
  - Good only for time analysis.
- Joint fitting with the GBM the Prompt emission
  - RMFIT, LAT “transient” events >100 MeV
- Long lived emission studies
  - “Diffuse” events for long integration time
  - Likelihood fit, standard LAT software
Fermi GRBs

327 GBM GRBs
12 LAT GRBs
In Field-of-view of LAT (166)
Out of Field-of-view of LAT (161)

• GBM: 252 GRB/yr
• LAT: 9 GRB/yr
What we have seen:

- The Onset between Low-Energy and High-Energy emission
- Temporal Extended High Energy Emission
- Deviation from a pure Band function: the extra component
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The Onset between Low-Energy and High-Energy emission

- First long bright LAT GRB
- The “lack of the first peak”: that was a surprise!
- Absorption?
  - You would expect a cut off in the spectrum...

12/10/09

13.2 GeV photon
Spectral Evolution of GRB 080916C

- Rapid soft to hard evolution in (a) to (b)
- Gradual decrease of $E_{\text{peak}}$ from (b) to (d)
- Spectrum consistent with a Band function, no roll-off!
What we have seen:

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Long-Lived HE Emission in 080916C

- HE (>100 MeV) emission shows different temporal behavior
  - Temporal break in LE emission while no break in HE emission
  - Indication of cascades induced by ultra-relativistic ions?
  - or angle-dependent scattering effects?

The “March bursts” (090323/090328) show a ~1 ks long lived emission in the LAT, see Piron’s talk on Wednesday.
• Temporal onset of high-energy emissions (coincident with 2nd GBM pulse)
  – Common origin for this emission in low and high energies (Not statistically significant, here)
• Highest energy is very late (GRB 080825C)
  – No detectable low energy emission
• For the first time, temporal extended emission seen also in short burst!
• Delayed emission also detected by Agile (080514B, Giuliani ‘08, 090510, Giuliani ‘09)
Significant emission (TS>25) up to T0+200s

No evidence of a spectral evolution

LAT lightcurve best fit by a power-law: $a = -1.38 \pm 0.07$

Black : LAT
White : LAT (prompt)
Blue : GBM (prompt)
Green : BAT (triggered on prompt)
Red : XRT (after T0+100s)
Violet : UVOT (after T0+100s)
And another Bright GRB, 090926

- Onset in interval “a”
  - Emission >100 MeV starts few second after the emission at low energies

- Extended high energy emission
  - Highest energy event

- Emission above 100 MeV is “spiky”
  - Very narrow spike (0.1 s) from few keV to >100 MeV energies
What we have seen:

- The Onset between Low-Energy and High-Energy emission
- Temporal Extended High Energy Emission
- Deviation from a pure Band function: the extra component
Finally, clear detection of an extra component

Clear detection of an extra component, non consistent with the Band function.
Are we seeing an early afterglow?
Also Synchrotron/SSC seems to work!
(See Chuck Dermer’s Poster)

-1.62 +0.03 -0.03
Best fit spectrum is a band function (smoothly broken power-law) + power-law component. **Challenge for theoretical models:**

- Can the **SSC** model reproduce the excess <50keV?
- **Hadronic** models providing hard component with excess at low and high energies?
- Can **Early afterglow** models produce a >10 GeV emission?
- Two non-thermal power-law + thermal component?
But Nature is bizarre:
GRB 090217: a featureless burst

- >100 MeV events detected from the trigger time
- No delay in HE emission, and different event accumulation
- Band model with no spectral evolution
- No extended emission
The GBM light curve consists of a very hard narrow pulse on top of a broader emission episode, with a duration (T90) of about 7.7s (8-1000 keV).

GRB occurred outside LAT FoV
- (86 deg to boresight)

Significant increase of raw TKR rates coincident with GBM trigger
- Only low energy events can trigger the instrument (thanks to the multiple scattering) with energies below ~140 MeV (selection effect)

Not delayed wrt GBM pulse

Did not last longer than GBM pulse
## Summary of LAT Bursts

<table>
<thead>
<tr>
<th>GRB</th>
<th>duration</th>
<th># of events $&gt; 100$ MeV</th>
<th># of events $&gt; 1$ GeV</th>
<th>delayed HE onset</th>
<th>Long-lived HE emission</th>
<th>Extra Component</th>
<th>Highest Energy</th>
<th>Redshift</th>
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<td>080825C</td>
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<td>x</td>
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<td>✓</td>
<td>✓</td>
<td>~20 GeV</td>
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</table>
• Delay Onset?
  – Not expected, this is really new stuff

• Deviation from the Band function?
  – 941017 (Gonzalez, Nature 2003 424, 749)
  – The extension below 50 keV is new!

• Extended GeV emission?
  – some clues from Egret (940215 Hurley at al) and Agile (Giuliani et al. 2008).
    But now we have the statistic needed to make a detail study of GeV afterglows. Also crucial to have Swift in orbit!

• How about the number of GRBs?
  – Consistent within fluctuation with what we predicted (considering BATSE burst beta<-2).

See Dan Kocevski’s talk on “Fermi-LAT Upper Limits for Fermi GBM-detected Gamma-ray Bursts”
Constraining physics

- Relativistic motion of the emitting shell:
  - A relativistic motion of the shell allows higher energy events in dense region to escape.
  - Observing high-energy events correlated with the fast variability allows to constrain to the speed ($G_{\text{min}}$) of the emitting shell.
  - Assuming high-energy emission is spatially consistent with the low energy emission: GRB060916C, GRB090510, GRB090902B both have consistently $G_{\text{min}} \approx 1000$ (See Soeb Razzaque poster)

- Lorentz Invariance Violation
  - Constrain the dispersion of the speed of light:
    - 090510, better limit so far.
  - See V. Vasileiou’s Talk

- Constraining EBL models
  - See next…
• GRB can be used as a probe for testing the transparency of the Universe, and constraining models!
• Statistic is needed!

See Soeb Razzaque’s Poster
Fermi is performing extremely well in GRB observation, the LAT already doubled the number of GRBs detected above 100 MeV.

- High energy emission (at GeV) observed in both long and short bursts

Some observed properties:
- Delayed onset between LAT and GBM (“the missing peak”)
  - Characteristic Spectral evolution
  - Separate region from initial GBM emission (Internal Shocks?)
  - Not seen in 090217
  - Both in long and short bursts
- Deviation from the ordinary Band-function
  - Extra component dominates in few cases (both in long and shorts)
- Long lived high-energy emission detected both in Long and Short bursts
- Fundamental physics tested (LIV, Gamma-min, EBL)
YELLOW SLIDE MEANS BACKUP