The Three Spectral Components of Fermi/LAT GRBs

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http://arxiv.org/abs/1009.3338

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Outline

- Observations
- Three Elemental Spectral Components
- Origin of GeV emission
- Summary
## Highlights on Data Analysis:

Time-Dependent Spectral Evolution in **Finest Time Resolution**

for All The Fermi Bursts

(This work focuses on LAT-only bursts)

<table>
<thead>
<tr>
<th>GRB</th>
<th>z</th>
<th>dur. [sec]</th>
<th>$E_p$ [keV]</th>
<th>$E_{\gamma,iso}$ [erg]</th>
<th>Fluence ($1 - 10^4$ keV)</th>
<th>Spectral Type</th>
<th>Onset Delay</th>
<th>$E_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>080825C</td>
<td>-</td>
<td>22</td>
<td>192 ± 15</td>
<td>-</td>
<td>4.84 ±0.59 × 10^{-5}</td>
<td>BAND</td>
<td>Y</td>
<td>~ 600 MeV</td>
</tr>
<tr>
<td>080916C</td>
<td>4.35</td>
<td>66</td>
<td>1443 +433_303</td>
<td>5.7±0.54 × 10^{54}</td>
<td>1.55±0.15 × 10^{-4}</td>
<td>BAND</td>
<td>Y</td>
<td>~ 13.2 GeV</td>
</tr>
<tr>
<td>081024B</td>
<td>-</td>
<td>0.8</td>
<td>1258 ±2405_522</td>
<td>-</td>
<td>(1.61±3.8) × 10^{-6}</td>
<td>BAND</td>
<td>Y</td>
<td>~ 3 GeV</td>
</tr>
<tr>
<td>081215A</td>
<td>-</td>
<td>7.7</td>
<td>1014 ±140_123</td>
<td>-</td>
<td>8.74±1.21 × 10^{-5}</td>
<td>BAND</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>090217</td>
<td>-</td>
<td>32.8</td>
<td>552 ±85_71</td>
<td>-</td>
<td>4.48±0.69 × 10^{-5}</td>
<td>BAND</td>
<td>N</td>
<td>~ 1 GeV</td>
</tr>
<tr>
<td>090323</td>
<td>3.57</td>
<td>150</td>
<td>812 ±181_143</td>
<td>&gt; 2.89±6.56 × 10^{54}</td>
<td>1.02±0.067 × 10^{-53}</td>
<td>BAND</td>
<td>N</td>
<td>~ 1 GeV</td>
</tr>
<tr>
<td>090328</td>
<td>0.736</td>
<td>80</td>
<td>756 ±48_97</td>
<td>&gt; 1.07±0.24 × 10^{-5}</td>
<td>7.14±0.81 × 10^{-5}</td>
<td>BAND</td>
<td>?</td>
<td>&gt; 100 MeV</td>
</tr>
<tr>
<td>090510</td>
<td>0.903</td>
<td>0.3</td>
<td>6010 ±2524_12690</td>
<td>4.47±4.86 × 10^{52}</td>
<td>2.06±1.88 × 10^{-5}</td>
<td>CPL+PL</td>
<td>Y</td>
<td>~ 31 GeV</td>
</tr>
<tr>
<td>090626</td>
<td>-</td>
<td>70</td>
<td>362 ±47_41</td>
<td>7.81±0.44 × 10^{-5}</td>
<td>BAND</td>
<td>N</td>
<td>~ 30 GeV</td>
<td></td>
</tr>
<tr>
<td>090902B</td>
<td>1.822</td>
<td>21</td>
<td>207 ± 6 [BB]</td>
<td>(1.77±0.01) × 10^{52}</td>
<td>(2.10±0.02) × 10^{-4}</td>
<td>BB+PL</td>
<td>Y</td>
<td>33.4±2.7 _3.5 GeV</td>
</tr>
<tr>
<td>090926A</td>
<td>2.1062</td>
<td>19</td>
<td>412 ± 20</td>
<td>2.10±0.09 × 10^{54}</td>
<td>1.93±0.08 × 10^{-4}</td>
<td>BAND</td>
<td>Y</td>
<td>~20 GeV</td>
</tr>
<tr>
<td>091003</td>
<td>0.8969</td>
<td>21.1</td>
<td>409 ±34_197</td>
<td>7.85±0.73 × 10^{52}</td>
<td>3.68±0.34 × 10^{-5}</td>
<td>BAND</td>
<td>N</td>
<td>&gt; 150 MeV</td>
</tr>
<tr>
<td>091031</td>
<td>-</td>
<td>40</td>
<td>567 ±135_135</td>
<td>-</td>
<td>3.17±0.24 × 10^{-5}</td>
<td>BAND</td>
<td>N</td>
<td>1.2 GeV</td>
</tr>
<tr>
<td>100116A</td>
<td>-</td>
<td>110</td>
<td>1463 ±163_122</td>
<td>-</td>
<td>7.34±1.26 × 10^{-5}</td>
<td>BAND</td>
<td>N</td>
<td>~ 2.2 GeV</td>
</tr>
<tr>
<td>100225A</td>
<td>-</td>
<td>13 ± 3</td>
<td>540 ±381_304</td>
<td>-</td>
<td>1.21±0.67 × 10^{-5}</td>
<td>BAND</td>
<td>Y</td>
<td>~ 300 MeV</td>
</tr>
<tr>
<td>100325A</td>
<td>-</td>
<td>8.3 ± 1.9</td>
<td>198 ±37_44</td>
<td>6.15±1.81 × 10^{-6}</td>
<td>BAND</td>
<td>N</td>
<td>~ 800 MeV</td>
<td></td>
</tr>
<tr>
<td>100414A</td>
<td>1.368</td>
<td>26.4 ± 1.6</td>
<td>520 ±42_39</td>
<td>5.88±0.69 × 10^{53}</td>
<td>1.20±0.12 × 10^{-5}</td>
<td>BAND</td>
<td>N</td>
<td>~ 2.6 GeV</td>
</tr>
</tbody>
</table>
Two distinct types of GRBs
Two distinct types of GRBs
080916C:
Band Function – Does NOT narrow with reducing time bins
080916C

0-20 sec

2-10 sec
Thermal: progressively narrowing with reducing time bins and extra PL
090902B

0-20 sec

8.5-11.5 sec

Energy [keV] vs $N_e$ [photons cm$^{-2}$ s$^{-1}$ keV$^{-1}$] for different models and fits.
Three Elemental Spectral Components (Phenomenally, observationally)

- I : Band-function component (extend up to GeV)
- II: Quasi-thermal Component
- III: extra non-thermal power law component extending to high energies.

Observed spectra are combinations of the three.
• E.g 080916C, 14 out of 17
• 090902B, probably 090510
- X-Ray Excess
- 100724B, 38KeV, Sylvain Guiriec et al 2010
- 081221, 8keV, Shu-Jin Hou, 2010, in prep
Physical Origins of The Three Elemental Spectral Components
Band Function Component

Poynting flux dominated outflow

• 14 out 17 bursts are fitted by Band
• Internal Non-thermal Emission
• Time-dependent Band Function in Finest time resolution
  – NO photosphere thermal component
  – NO second SSC bump
  – NO pair-production cutoff

  – 6-7 orders extension

See Bing Zhang's talk this afternoon.

[most energy carried in B field, not in photons, photosphere emission is suppressed]
  – Compton parameter $Y << 1$ (because $B$ energy density >> photon energy density, $Y = U_{\text{ph}} / U_B << 1$), so SSC suppressed ($L_{\text{ssc}} \sim Y L_{\text{syn}}$)
  - Poynting flux : larger emission radius reduce 2-photon annihilation opacity and increase the pair cutoff energy]
Quasi-Thermal Component

Thermal Emission from Fireball Photosphere

(Paczynski 86, Goodman 86, Pe'er 2006, Pe'er & Ryde 2010, see talks by Pe'er, Lazzati, Beloborodov, Toma)

Photosphere emission when relativistic outflow turn optically thin

- Why “Quasi”: modified by
  1) temporal smear
    multicolor-BB (Ryde et al 2010)
  2) high-latitude emission effect
    gives $\alpha=-1$ (Pe'er & Ryde 2010)
Extra Simple Power law component

Not Straightforward

- Tracking of thermal and non-thermal suggests that they might be from the same origin
- Accompany with BB, or Band
- Extended to GeV, also existed in low energies
- NOT straightforward to expected since theoretically non-thermal GRB spectra should be curved (Pe'er et al 2006, Gupta & Zhang 2007, Asano & Terasawa 2009)
- For 090902B, it might be a combination of Syn emission (low energy dominated) and SSC and Comptonization of thermal photons (Pe'er 2010)
Origin of GeV Emission
A Dilemma

In spectral domain, one single component

In light curve domain, different components

How to solve the dilemma?
Solution 1: Superposition in Spectrum

A Big Issue:

Since observation shows Band function in every time slice. ---> have to assume superpositions of external and internal components in each time slice to “make” a Band function.

Kumar, & Barniol Duran, 2010.
A Dilemma of Superpositions

Superposition in Spectrum

Plus, our simulation shows that the external shock can NOT reproduce a so steep light curve during the prompt emission phase.

(Amanda Maxham, Bin-Bin Zhang And Bing Zhang, 2010, in prep, see Amanda Maxham's Poster 4.03 for details)
Solution 2

Superposition in Light Curve

Alternatively, we propose the Long Term GeV Light Curve is the Superposition effect of internal and external components.
Further Evidence for Internal Origin of Prompt GeV

• Rough Tracking Light Curve btw GBM and LAT
• For 080916C, GeV peak Coincides the Second Peak of GBM light Curve
If Prompt GeV emission is **internal**, how to interpret the onset delay?

**Possibility 1:**

**Change of particle acceleration Mechanism**

Early on, the particle acceleration process may not be so efficient, so the electron energy spectral index is steep
If Prompt GeV emission is internal, how to interpret the onset delay?

**Possibility 1:**

**Change of particle acceleration Mechanism**
Early on, the particle acceleration process may not be so efficient, so the electron energy spectral index is steep.

**Possibility 2:**

**Change of Opacity**
Particle acceleration process is the same, the pair-production opacity changes early on.
(supporting evidence: GBM alone spectra give similar beta with later epochs)
Prompt GeV emission is likely of internal origin

<table>
<thead>
<tr>
<th>Band Extended To GeV</th>
<th>Delay onset of LAT emission</th>
<th>Rough tracking behavior</th>
<th>Long Term Emission in LAT Band</th>
<th>For 080916C, GeV peak Coincides the Second Peak of GBM light Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal</td>
<td>• up-scattered cocoon emission by IS (Toma+09)</td>
<td>• superposition effect of IS and ES Light Curve</td>
<td>• superposition effect of IS and ES Light Curve Slope: require same decay slope at the transition epoch [contrived]</td>
<td>For 080916C, GeV peak Coincides the Second Peak of GBM light Curve</td>
</tr>
<tr>
<td></td>
<td>• protons Sync (Razzaque+09)</td>
<td>• gradual die-off of the central engine activity</td>
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<td>For 080916C, GeV peak Coincides the Second Peak of GBM light Curve</td>
</tr>
<tr>
<td></td>
<td>• up-scattered cocoon emission by residual IS (Li 2009)</td>
<td>• change of Acceleration Condition</td>
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<td>For 080916C, GeV peak Coincides the Second Peak of GBM light Curve</td>
</tr>
<tr>
<td></td>
<td>• change of Opacity</td>
<td>• change of Opacity</td>
<td>• change of Opacity</td>
<td>For 080916C, GeV peak Coincides the Second Peak of GBM light Curve</td>
</tr>
<tr>
<td>External</td>
<td>• Spectrum Slope: require IS and ES spectra mimic a same BAND function in ALL the Time Bins (Kumar &amp; Barniol Buran 2009)</td>
<td>• ES Deceleration time</td>
<td>(but can not be that steep, during PE Amanda Maxham poster 4.03</td>
<td>For 080916C, GeV peak Coincides the Second Peak of GBM light Curve</td>
</tr>
<tr>
<td></td>
<td>[MORE contrived]</td>
<td>= 2nd central engine activity time ← Fine Tuned Bulk Lorentz Factor ← Highly contrived</td>
<td>[MORE contrived]</td>
<td>For 080916C, GeV peak Coincides the Second Peak of GBM light Curve</td>
</tr>
</tbody>
</table>

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**Notes:**
- Internal and External sources are discussed separately.
- The table highlights various factors influencing emission in different bands and the observed peak.
- Internal factors include up-scattered cocoon emission, protons Sync, and changes in opacity.
- External factors focus on spectrum slopes and the evolution of emission across time bins.
Summary

- Three Elemental Spectral Components are observed in Fermi/LAT GRBs
- Prompt GeV emission is likely of internal origin
- Further Co-triggered Bursts by Swift and Fermi will help.
Thanks!
A Judgment Test

- A bright GRB co-triggered by Fermi LAT/GBM and Swift
- External
A Judgment Test

- A bright GRB co-triggered by Fermi LAT/GBM and Swift
- Internal
Backup slides
Band Function Component

- 15 out 17 bursts are fitted by Band
- Time-dependent Band Function in Finest time resolution
- $\beta$: -2.2, high energy PL component:
  - synchrotron
  - SSC (synchrotron self-Compton)
  - Compton up-scattering of a thermal photon source
- $\alpha$: -1, hard to explain
  - syn gives -1.5
  - not simple multi-color BB effect (cf Kenji 2010)
  - high-latitude emission effect: too late
  - may still be synchrotron with bulk heating by ICMART event
Band Function Component

- 15 out 17 bursts are fitted by Band
- Time-dependent Band Function in Finest time resolution

\( \beta = -2.2 \), high energy PL component:
- synchrotron
- SSC (synchrotron self-Compton)
- Compton up-scattering of a thermal photon source

\( \alpha = -1 \), hard to explain
- syn gives -1.5
- not simple multi-color BB effect (cf Kenji 2010)
- high-latitude emission effect: too late
- may still be synchrotron with bulk heating by ICMART event

- 6-7 orders extension

\[ \text{---}> \text{Poynting flux dominated outflow} \]

[most energy carried in B filed, not in photons, photosphere emission is suppressed]
- Compton parameter \( \gamma << 1 \) (because B energy density \( \gg \) photon energy density, \( \gamma = U_{\text{ph}} / U_B \ll 1 \)), so SSC suppressed (\( \text{L}_{\text{ssc}} \sim Y \text{L}_{\text{syn}} \))
- Poynting flux: larger emission radius reduce 2-photon annihilation opacity and increase the pair cutoff energy]