Fermi view of Gamma-ray bursts

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On behalf of the Fermi LAT/GBM collaboration
• Introduction – GRBs and high energy gamma-rays
• GRB observations by Fermi
  - Fermi Gamma-ray Space Telescope
  - onboard trigger and autonomous repoint observation
  - Fermi GRB detection statistics
• Fermi recent results
  - highlights of Fermi-GBM (GBM 2nd Catalog)
  - highlights of Fermi-LAT (LAT 1st Catalog)
    - temporally extended emission
    - delayed onset of high energy emission
    - highest energy photon and bulk Lorentz factor of GRB jet
• Future GRB observation by Fermi
• Summary
Intense hard X-ray to gamma-ray emission discovered at the 60’s

- Event rate: 1-2 per day
- Wide diversity in light curve (0.1-1000s duration)
- Cosmological distance (z~0.1-9)
- Bimodal duration distribution (short/long GRB)
- Non-thermal spectrum

Photon/s/cm$^2$/MeV

0.01    0.1       1        10         100

MeV

E$^2$N$_E$ erg/cm$^2$/s

J. T. Bonnel (NASA)
After the spiky prompt emission, there is long-lived (~day) afterglow from radio to X-rays

Late phase afterglow shows smooth light curve
• Still many unknown, unclear… emission mechanism of gamma-ray, jet formation, .. Etc

key observation: high-energy gamma-ray emission

Piran 2003
High energy emission from GRB: Pre Fermi Era

GRB940217 (Hurley et al. 94)
- 18 to 14 sec
- 14 to 47 sec
- 47 to 80 sec
- 80-113 sec
- 113-211 sec

GRB941017 (Gonzalez et al. 03)
Temporary distinct HE spectral component
EGRET detected > 100 MeV photons from a few GRBs
Different behavior from <100 MeV photons
- Long-lived emission
- Extra spectral component
- Constrain on emission mechanism
- Highest energy photon
- Bulk Lorentz factor of jet
- Cosmology, fundamental physics
- Extra galactic background light
- Lorentz invariance violation
Need large FoV, high sensitivity
Silicon-Strip detectors
- Identification & direction measurement of γ-rays

CsI calorimeter
- Energy measurement

ACD (plastic scintillators)
- background rejection

Fermi Gamma-ray Space Telescope

**Gamma-ray Burst Monitor (GBM)**
- 12 NaI detectors (8keV-1MeV)
- onboard trigger, localization
- spectroscopy
- 2 BGO detectors (150keV-40MeV)
- spectroscopy (overlapping LAT band)

- Efficient observing mode
- Wide FoV
- Low deadtime
- Large effective area
- Good angular resolution
- Energy coverage

2013.09.04
GRB observation by Fermi

• > 7 decades of energy range
• Large FoV (GBM: \( \approx 4\pi \), LAT: \( \approx 65 \text{deg} \) (90deg for LLE))
• > 10 times sensitivity of EGRET

Example for bright GRB 080916C (Abdo+09)
GBM/LAT on-board processing (10—15 s):
GCN alert within 10—15 s from the trigger time through TDRSS (alert, location).
Now 2 s~ 150s windows are also used for on-board search
We have few onboard triggers ( GRB 090510, GRB 131108A )

LAT ground processing (a few hours after data downlink)
Final location, spectrum (1st circular).
Final location, high-energy flux and spectrum, afterglow search results (2nd circular).
Data downlink may take > a half of day once ARR is triggered
GBM FSW triggers Autonomous Repoint Request (ARR)
S/C slew to the GBM position up to 2.5 hours subject to earth-limb constraint

ARR triggered for almost a half of LAT events ➔ helpful for extended emission search
• GBM detections: ~250 GRBs / year (1700), ~half in the LAT FoV
• LAT detections: ~15/year (102), ~8% of GBM detections
The second Fermi-GBM Gamma-ray Burst CATALOG: (von Kielin+14)

Differences can be seen between long/short GRBs
Fermi-GBM highlights 2) spectra

The second Fermi-GBM Gamma-ray Burst SPECTRAL CATALOG (Gruber+14)

Systematic studies with large sample of Fermi-GBM detected GRBs
Non-thermal component gives an universal (e.g. short/long GRBs) $E_{\text{peak}} - L_{\text{iso}}$ correlation (Guiriec+ 15)

$$L_i^{NT} = (9.6 \pm 1.1) \times 10^{52} \left( \frac{E_{\text{rest, NT}, \text{peak}, i}}{100 \text{ keV}} \right)^{1.38 \pm 0.04} \text{ erg s}^{-1}.$$
The FIRST Fermi-LAT Gamma-ray Burst CATALOG: (Ackermann+13)

35 LAT-detected GRBs are listed and systematically studied.
• The FIRST Fermi-LAT Gamma-ray Burst CATALOG: (Ackermann+13)
• 35 LAT-detected GRBs are listed and systematically studied

LAT-detected GRBs are typically brightest GBM bursts
Fermi-LAT highlights 2) delayed onset and extended emission

**GRB 080916C (long)**
Abdo et al. 2009, Science 323, 1688

Delay in HE onset: ~4-5 s

**GRB 090510 (short)**

LAT emission until 200 s
No spectral evolution
(photon index \(-2.1 \pm 0.1\))
More than half of LAT GRBs show delayed-onset and extended emission.
Delayed and extended high-energy emission disfavors IC and SSC origin. But external shock origin is more likely (Kumar & Barniol Duran 2009).

**GRB 110731A**

Swift-XRT and many optical observations (Swift-UVOT, GROND, and MOA) are available.

Broadband spectrum is well fit by a single power-law spanning 10 orders of magnitude in energy.

**GRB 130427A**

Broadband spectrum is well fit by a broken power-law, still consistent with FS synchrotron emission (Granot & Sari 02, Perley +13).

95 GeV photon at T0+244s is problematic for modeling.
Delayed and extended high-energy emission disfavors IC and SSC origin. But external shock origin is more likely (Kumar & Barniol Duran 2009).

GRB 130427A

Broadband spectrum is well fit by a broken power-law, still consistent with FS synchrotron emission (Granot & Sari 02, Perley +13).

95 GeV photon at T0+244s is problematic for modeling.

95 GeV photon at T0+244s is problematic for modeling.
Some bright LAT GRBs show deviations from typical Band function in high energy band.
Fermi-LAT catalog – the Band crisis?

- Some bright LAT GRBs show deviations from typical Band function in high energy band
- LAT high-energy photon is dominated by single PL component of extended emission phase

<table>
<thead>
<tr>
<th>GRB Name</th>
<th>Fluence</th>
<th>Best Model</th>
<th>$\theta$ (deg)</th>
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<td>100724B</td>
<td>4665 $\pm$ 76</td>
<td>Band with exponential cutoff</td>
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<td>090907B</td>
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<td>2225 $\pm$ 48</td>
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<td>1795 $\pm$ 43</td>
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<td>090323</td>
<td>1528 $\pm$ 44</td>
<td>Logarithmic parabola</td>
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Several-tens-of-GeV photons in GRB frame

Possible correlation between $E_{\text{iso}}$ and highest photon energy

Short GRB is outlier? Need more sample!

Highest photon energy is useful for
- Limit on bulk Lorentz factor
- Constraint on synchrotron model
- EBL model
- Lorentz invariance violation (LIV)
Due to large luminosity and small emitting region, optical depth for the $\gamma-\gamma \rightarrow e^+e^-$ pair production is too large to observe the non-thermal emission from GRB \( \rightarrow \) compactness problem.

Relativistic motion ($\Gamma \gg 1$) could avoid this compactness problem

\( \Gamma_{\text{min}} \) can be derived using observed highest energy photon

Gehrels et al. arXiv1301.0840
• In the context of the early afterglow model, the delayed LAT onset is due to the transition between the coasting fireball and the self similar phase (Blandford & McKee 1976, Rees & Meszaros 1994)

• Peak-flux time of the LAT is of the order of the fireball deceleration time

\[
\Gamma_0 = \left( \frac{3E_{k,\text{iso}}(1+z)^3}{32\pi n_{\text{m,p}}c^5 t_{\text{peak}}^3} \right)^{1/8} \begin{cases} a^{-1/8}; & a = 4 \quad \text{(adiabatic)} \\ a^{-5/32}; & a = 7 \quad \text{(radiative)} \end{cases}
\]

Similar result to $\gamma$-$\gamma$ opacity limit
• Several GRBs also show the evidence of an extra component at low energy (>3σ for GRB120323A, >5σ for GRB110721A)
• Signature of photospheric emission?
• Artifact due to spectral evolution of single spectrum? (Burgess & Ryde 2015)
• Further emission mechanism in addition to the BB is required? (Burgess, Ryde & Yu 2015)
The future of Fermi GRB observations

Towards to the Fermi-GBM 3rd Catalog

Will be completed within a few months.
Towards to the Fermi-GBM 3rd Catalog

Fermi GBM GRBs in first six years of operation

1404 GBM GRBs
+ 1175 Long
* 229 Short
☐ 64 also triggered Swift-BAT

Will be completed within a few months.
Towards to the Fermi-LAT 2\textsuperscript{nd} Catalog

\textit{Pass8} : A new low-level analysis and event reconstruction was developed during the past years. Data are available since June 24\textsuperscript{th}

- improved effective area (100 \% improvement below 100 MeV, 25\% above 1GeV)
- better PSF and localization accuracy
- better background rejection
- reduction in systematic effect

Fermi-LAT 2\textsuperscript{nd} Catalog will contain more than 100 LAT-detected GRBs (We have already >100 LAT bursts ! : Vianello & Omodei arXiv:1502.03122)

• Fermi satellite is now observing GRBs normally
• Fermi-GBM detects more than 1000 GRBs
  - many statistical properties of GRBs have been studied
• Fermi-LAT detects more than 100 GRBs
• Discussed statistical properties of LAT GRBs in catalog paper
  - delayed onset/extended high-energy emission
  - additional spectral component
  - highest energy photons..etc
• Next catalog papers (GBM:3rd/LAT:2nd) is under production
  - large sample number of GBM-detected GRBs
  - >100 LAT-detected GRBs will be contained
  - new analysis result with PASS8 will be summarized