High-energy emission from Gamma-Ray Bursts

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Prompt emission: dominated by gamma rays. Short-lived. Variability reflects central engine activity.

Afterglow emission: low energies. Long-lived. Smooth(ish) decay.

From Chuck Dermer
Fermi provides an unprecedented view of high-energy emission from GRBs: (i) Broad-band spectra from both GBM and LAT
Fermi provides an unprecedented view of high-energy emission from GRBs: (ii) Sky coverage + sensitivity => Statistics!

- 1722 GBM GRBs
- 103 LAT GRBs
- In Field-of-view of LAT (894)
- Out of Field-of-view of LAT (828)
GBM fluence as a function of angle to LAT at GBM trigger time: LAT detects the GRBs that are brighter (more fluent) at low energies and sees dimmer GRBs where it is most sensitive.

These were well outside the LAT's vision at GBM trigger time.
Emission detected by the LAT > 100 MeV is extended in time relative to lower energies, behaving like afterglow radiation, decaying as a flat power-law in time, (most) favoring adiabatic expansion into the surrounding material.

LAT GRB Catalog
Ackermann et al. 2013

How common is extended high-energy emission?
Is high-energy emission related to the afterglow?
Sensitivity of LAT to prompt emission is determined by angle to GRB position at GBM trigger time. Sensitivity to extended emission depends on which direction LAT boresight is headed after trigger time...

An Automatic Repoint Request (ARR) from the GBM Flight Software places the GBM on-board position for BRIGHT (peak flux or fluence) GRBs close to the LAT boresight for 2.5 hours (subject to constraints).

Over 140 times since enabling in 2009

Nearly 50% of LAT detections come from GRBs for which GBM issues ARRs.

In survey mode the LAT rocks (now) 50 deg off the zenith north or south on alternate orbits. GRB placement in drifting of FoV affects sensitivity to GRB -> chance.
Repointing the LAT to bright GBM GRBs enables the LAT detection of extended emission for GRBs outside its view at trigger time and/or over a longer period.

- ARR allows capture of extended emission.
- No ARR for these: too dim to meet out-of-field criteria.
- This GRB was bright but occulted by the Earth to Fermi for the main emission period.
- This GRB is intrinsically dim but very close - iPTF detected an OT in the GBM error box, and a supernova was found associated with the GRB.
LAT flux and upper limits as a function of XRT flux extrapolated into the LAT energy range for 386 GRBs with exposure during XRT observations (1156 time intervals).

![Graph showing LAT flux and upper limits as a function of XRT flux](image)

- **Line where LAT flux = Extrapolation of XRT flux**
- **Some XRT extrapolations are constraining: breaks in afterglow spectrum?**
- **Most extrapolations fall below LAT sensitivity.**

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Comparing expected vs measured LAT flux may provide probe of interstellar medium: wind versus homogeneous.

Along line of equality: LAT flux matches expectations.

To the right of line: LAT flux is less than expected, implying cooling break between XRT and LAT.

XRT photon index vs expected LAT flux: XRT spectra of GRBs LAT detected fall here (hard spectra: photon index <2)
One in ~7.5 GBM GRBs also triggers the Swift BAT - broad spectral coverage from Fermi and redshifts/energetics from Swift follow-ups.

In addition to those GRBs triggering the BAT, Swift detects Fermi GRBs by observing LAT-detected GRBs with the X-Ray Telescope - hours after the GBM trigger.
The overlapping sample of GBM-Swift BAT triggers and LAT detections contains GRBs observed contemporaneously over the prompt and early afterglow phase from keV -> GeV.
GRB 090510 shows variable, spiky “prompt” emission and smoothly decaying “afterglow” emission.

Delayed onset of $>100$ MeV emission: signature of proton synchrotron? Proton-induced cascades?
GRB 110731A was observed long enough and over a broad enough energy range to test consistency of LAT with afterglow at lower energies.

But prompt high-energy emission is really spiky!

Broadband spectrum over 10 decades of energy consistent with a single power-law compatible with external-shock synchrotron.
GRB 130427: the “ordinary monster” shows variable prompt emission and extended emission out to 70 ks later.
GRB 130427A provides 70 ks of HE data to explore afterglow models: standard afterglow models challenged by GeV photons 100s s after trigger.

Even with extreme conditions, observations of these HE photons challenge afterglow models.

Extreme acceleration conditions

Wind medium

Homogeneous ISM

Lorentz factors (500 - 2000)

Solid: Adiabatic
Red: Radiative
Dot-dashed: bracketing

Ackermann et al. 2013
NuStar observations and VERITAS upper limits provide additional evidence against SSC nature of extended HE emission

UL to synchrotron PL compatible with extension of LAT PL in time.

These observations are not contemporaneous with the final detected LAT data point.
Spectral shapes $> 100$ MeV exhibit varied relationships to the spectral shapes inferred from GBM observations.

GRB 080916C
Abdo et al. 2009

GRB 090902B
Abdo et al. 2009

Extra power law at low and high energies.

GRB 090510
Ackermann et al. 2010
The Band function may not represent some GRB spectra over the energy range sampled by GBM - extrapolations to LAT energies may not be reliable.

In addition, pure Band functions are broader than photospheric and narrower than synchrotron predictions e.g., Axelsson et al. 2014, Yu et al. 2015. Physical modeling (synchrotron, photospheric, combinations) is moderately successful e.g., Ryde et al. 2010, Burgess et al. 2013, Zhang et al., 2015.
Prompt emission: LAT component scales with GBM fluence but often with delayed onset. Temporal and spectral relationship complex.

Afterglow emission: LAT component is common and scales with X-ray afterglow brightness/hardness.

20 km

1-6 AU

1000-2000 AU

INTERNAL SHOCK or magnetic energy dissipation

EXTERNAL SHOCK

Bulk Lorentz factors of >100s implied by escape of GeV photons & variability timescales. Lorentz invariance.

Bulk Lorentz factors of 100s implied if peak LAT emission represents start of coasting phase.

Mostly adiabatic expansion. Wind medium favored.
New LAT catalog will have many new detections over 4 years of old catalog + 2 extra years

Second LAT catalog: the fluence gap is being filled

First LAT catalog: LAT saw only the brightest GBM GRBs

- Pass 8: A new low-level analysis and event reconstruction was developed during the past years. Data are available since June 24th, giving
  - improved effective area (100% improvement below 100 MeV, 25% above 1 GeV)
  - better PSF and localization accuracy
  - better background rejection
  - reduction in systematic effects

8th Huntsville GRB symposium

- Huntsville, Alabama. 24 - 28 October 2016.