Fermi Gamma-ray Space Telescope

GRB with the Fermi Large Area Telescope

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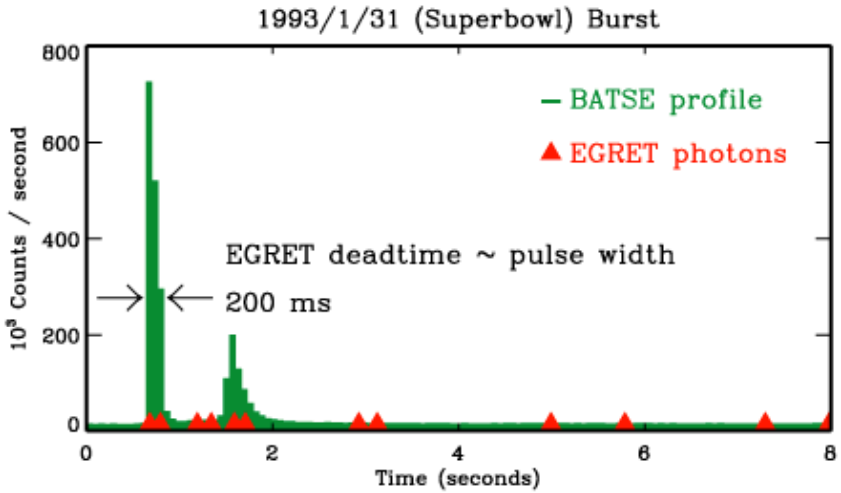
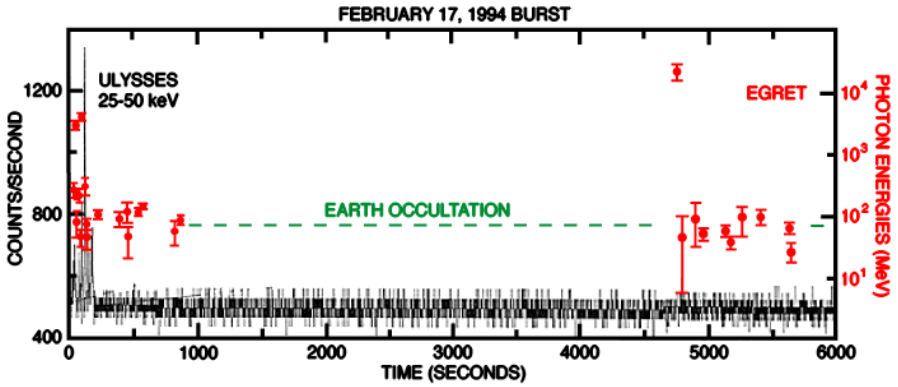
On behalf of the Fermi/LAT collaboration

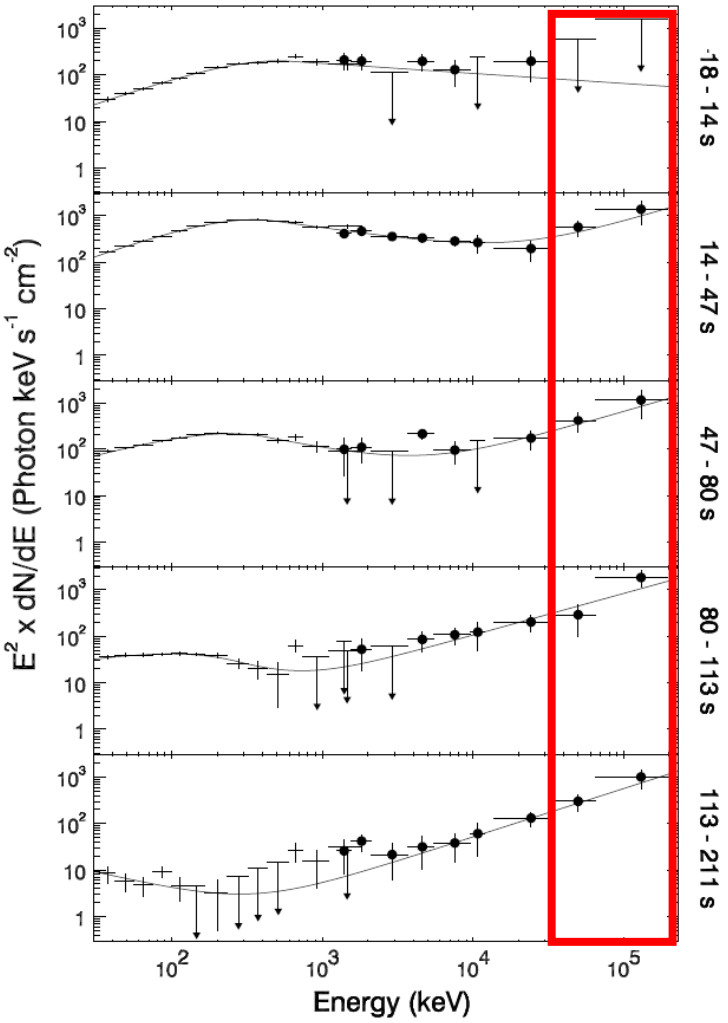
The EGRET heritage on GRBs

Prompt Emission (GRB 930131)



Delayed Emission (GRB 940217)





Spectral extra components (GRB 941017)

The Fermi Observatory

- Large Area Telescope (LAT)
  - Large field of view (2.4 sr @ 1 GeV)
  - Sees the entire sky every 3 hours
  - 20 MeV to >300 GeV
  - Onboard and ground burst triggers
  - Localization, spectroscopy

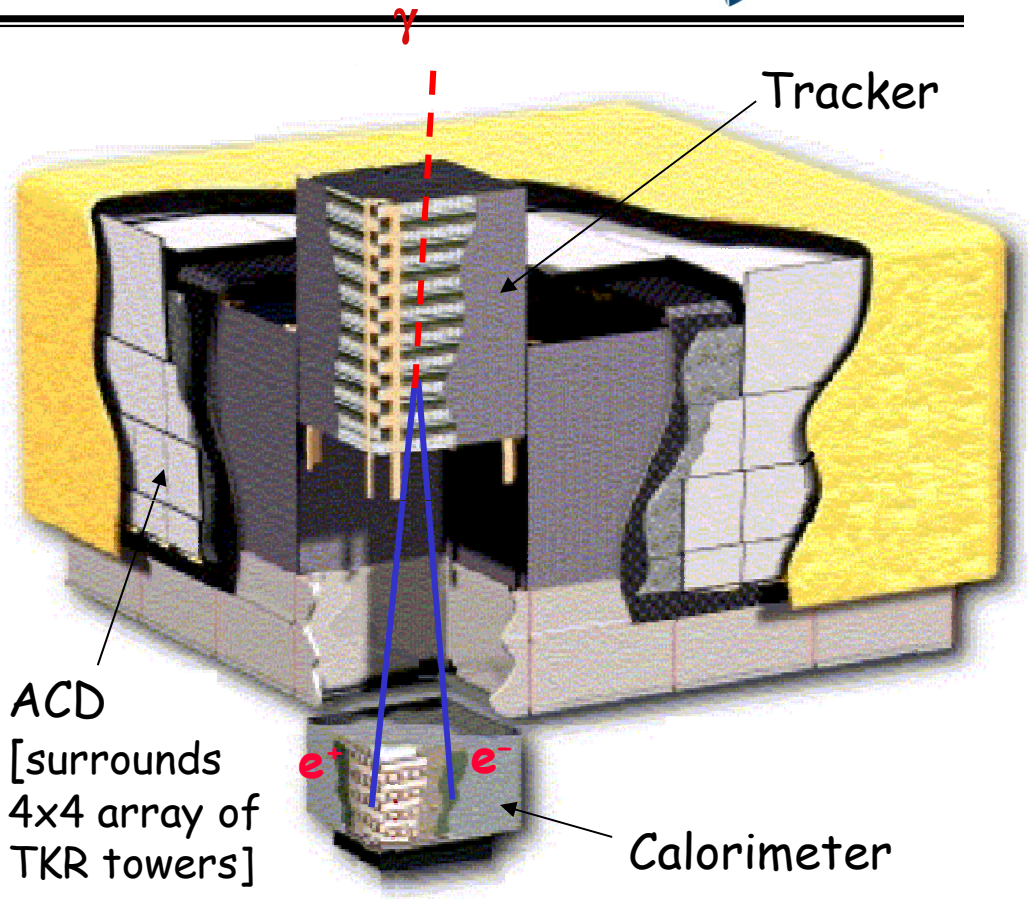
Atwood et al. 2009, ApJ 697, 1071

- Gamma-ray Burst Monitor (GBM)
  - Sees the entire unocculted sky (>9.5 sr)
  - 8 keV to 40 MeV
  - 12 NaI detectors (8 keV to 1 MeV)
    - Onboard trigger, onboard and ground localizations, spectroscopy
  - 2 BGO detectors (150 keV to 40 MeV)
    - Spectroscopy

Meegan et al. 2009, ApJ 702, 791

Overview of LAT

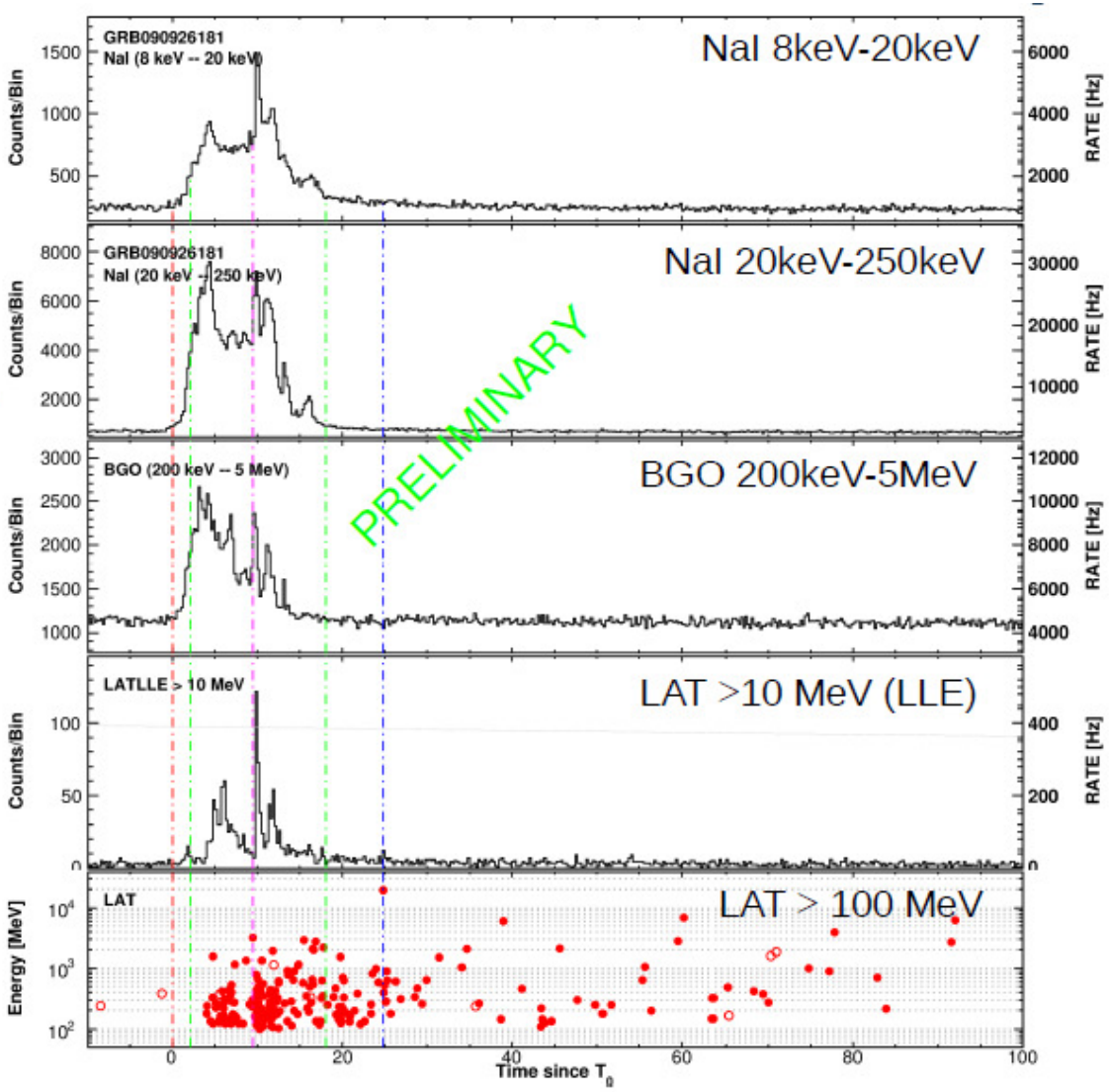
- **Precision Si-strip Tracker (TKR)** 18 XY tracking planes. Single-sided silicon strip detectors (228 μm pitch) Measure the photon direction; gamma ID.
- **Hodoscopic CsI Calorimeter(CAL)** Array of 1536 CsI(Tl) crystals in 8 layers. Measure the photon energy; image the shower.
- **Segmented Anticoincidence Detector (ACD)** 89 plastic scintillator tiles. Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- **Electronics System** Includes flexible, robust hardware trigger and software filters.



Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

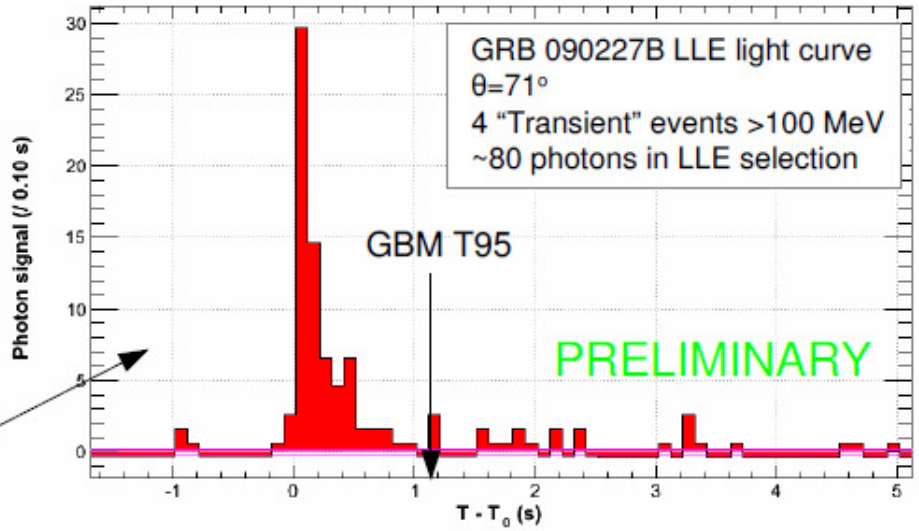
A "typical" bright GRB in Fermi

- Ackerman+11: correlated variability in various bands, with a sharp spike at T_0+10 s
  - All energy ranges synchronized (<50 ms)
  - Low and high energies are co-located or even causally correlated
- LAT >100 MeV emission is delayed (~4 s)
  - Delay > spike widths
- LAT >100 MeV emission is temporally extended, well after the GBM prompt phase
  - 19.6 GeV photon detected at T_0+24.8 s

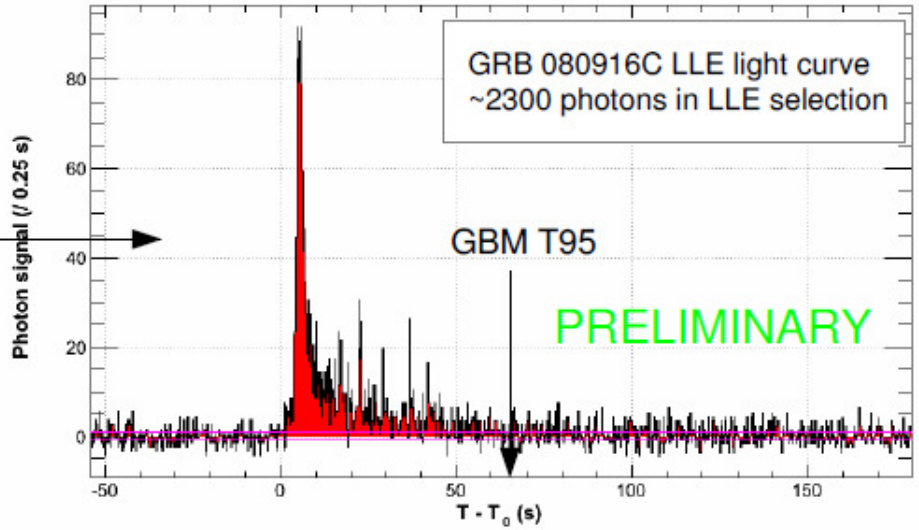


The LAT Low Energy (LLE) event class

- Most GRBs are detected using the standard event selection (Pass6_V3 "Transient") and analysis technique (unbinned maximum likelihood >100 MeV)
  - **Current "default" is Pass7. "Transient" selection for < 100 s. "Source" selection for > 100 s**
- Some other bursts are too weak, too soft, or at a too high off-axis angle to be significantly detected



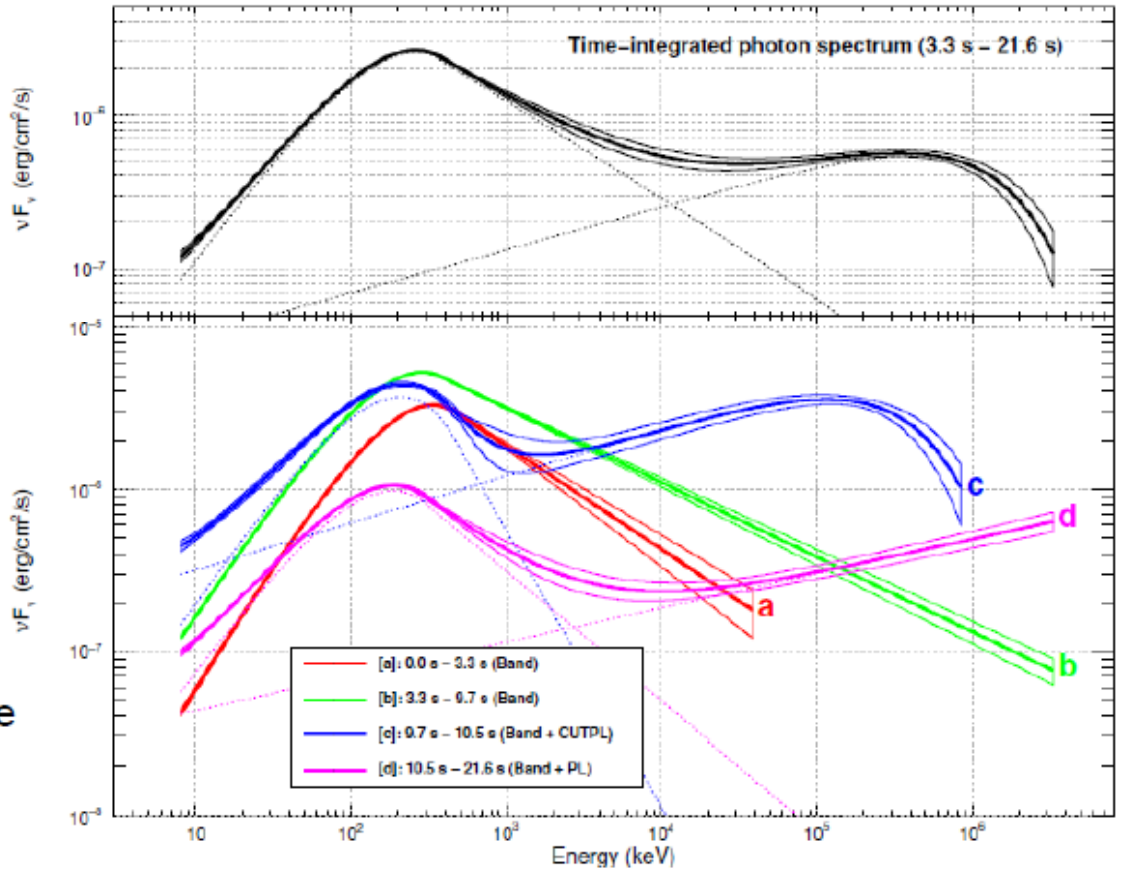
- We introduced the LLE event class
  - Relaxed selection criteria → higher background, significantly higher effective area in the 10-100 MeV range and at larger off-axis angles
  - Worse PSF than transient class (no localization possible)



A "typical" bright GRB in Fermi

- Fluence = 2.2 x 10^{-4} erg cm^{-2} (10 keV - 10 GeV)
- E_{iso} = 2.2 x 10^{54} erg
- Extra component (power law)
  - Starts delayed (~9 s)
  - Persists at longer times
  - Dominates > 10 MeV
- Spectral cutoff
  - Significant in bin c, marginally in bin d
  - Shape not constrained
- First direct measurement of the jet Lorentz factor: Γ ~ 200-700
  - If cutoff due to $\gamma\gamma$ absorption
  - Model dependent

Ackermann et al. 2011, ApJ 729, 114

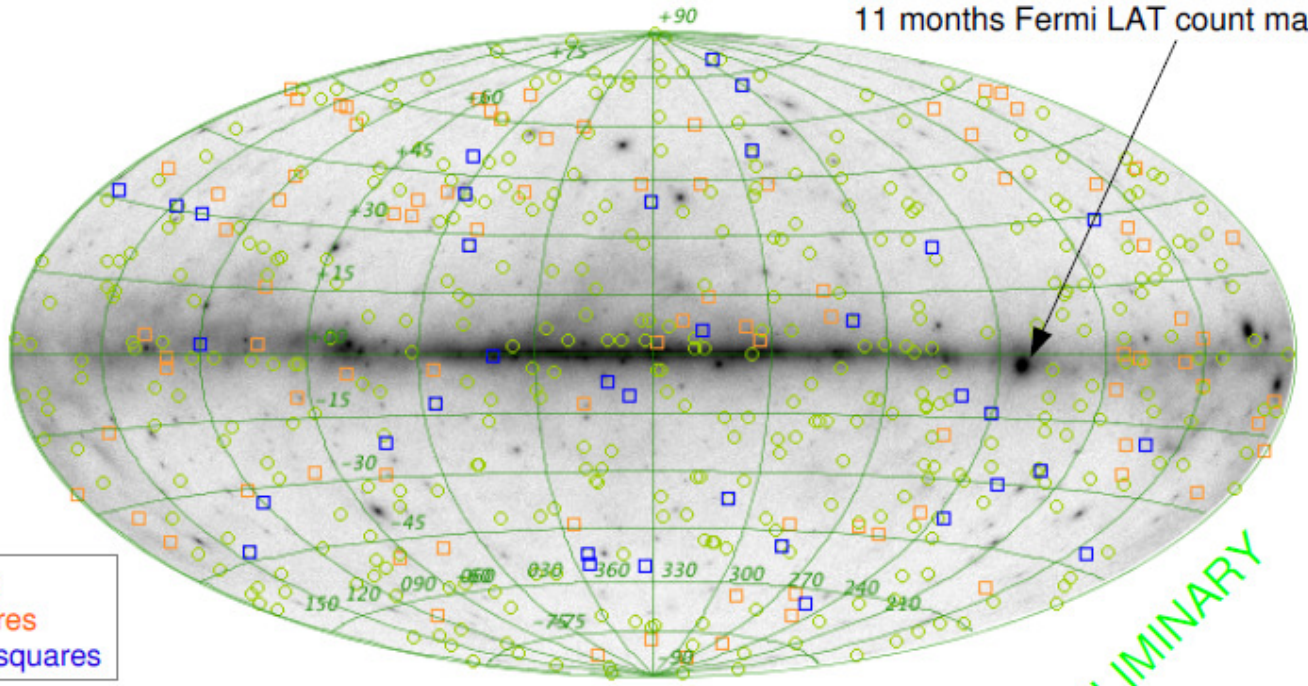


The Fermi/LAT GRB catalog

- **Systematic study of GRB properties at high energies (>10 MeV)**
- **Covers a 3-year period starting from August 2008, including:**
  - **Tabulated GRB parameters**
    - **Start / end times, duration, fluence, energetics, average and peak fluxes, time of the peak flux, temporal decay slope, spectral evolution**
    - **Spectral analysis results (from GBM+LAT joint fits)**
  - **Discussions on the unique properties of individual bursts (presence of extra spectral components and of high-energy spectral cutoffs)**
  - **Details on the analysis: methodology, tools, methods and caveats**
- **Paper submitted to ApJS, arXiv:1303.2908**

The GRB catalog

GBM 2-year catalog
LAT 3-year catalog

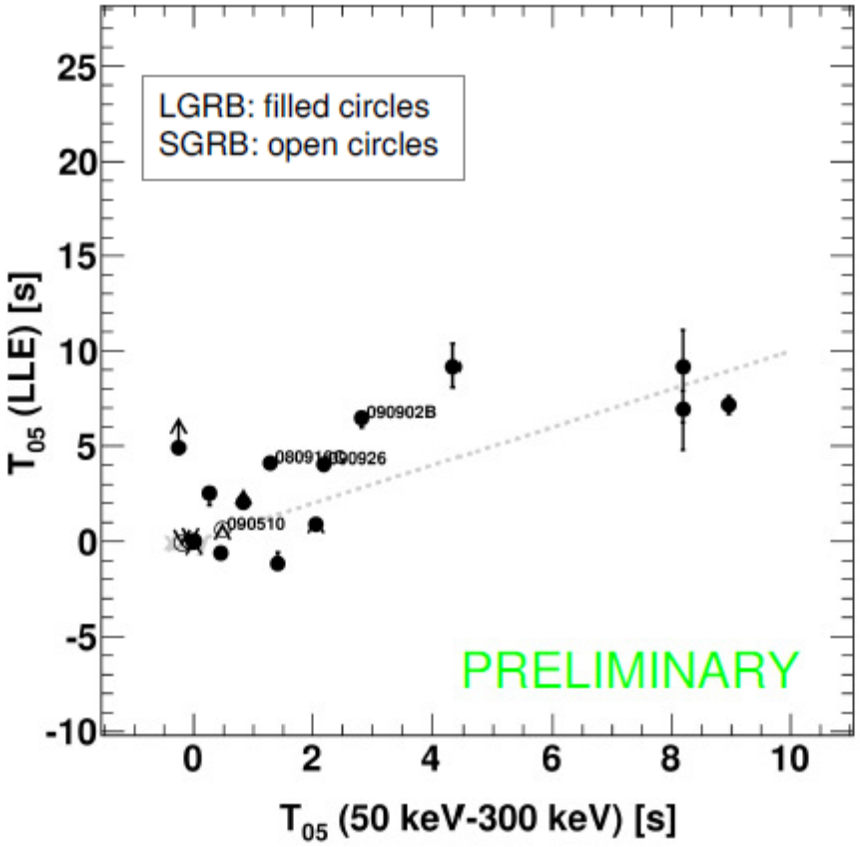


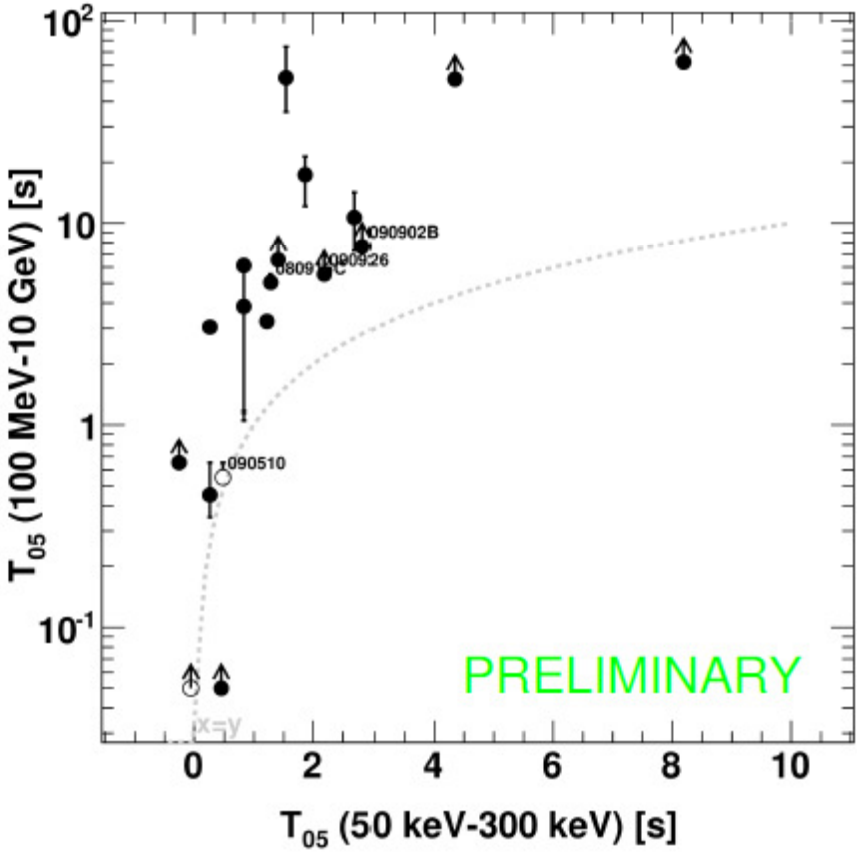
GBM LGRB: green circles
GBM SGRB: orange squares
LAT detections (35): blue squares

- The GBM detects ~250 GRBs / year, ~half in the LAT FoV
  Paciesas et al. 2012, ApJS 199, 18; Goldstein et al. 2012, ApJS 199, 19
- The LAT detected 35 GRBs in 3 years (30 long, 5 short), including 7 "LLE-only" GRBs
  - Bright LAT bursts with good localizations are all followed-up by Swift
  - 10 redshift measurements, from z=0.74 (GRB 090328) to z=4.35 (GRB 080916C)
  - 4 joint BAT-GBM-LAT detections: GRBs 090510, 100728A, 110625A, 110731A

Delayed onset of >100 MeV photons

- GBM T_{05} vs. LLE T_{05}: onset of LLE emission is compatible with GBM
- GBM T_{05} vs. LAT T_{05}: LAT >100 MeV emission is systematically delayed

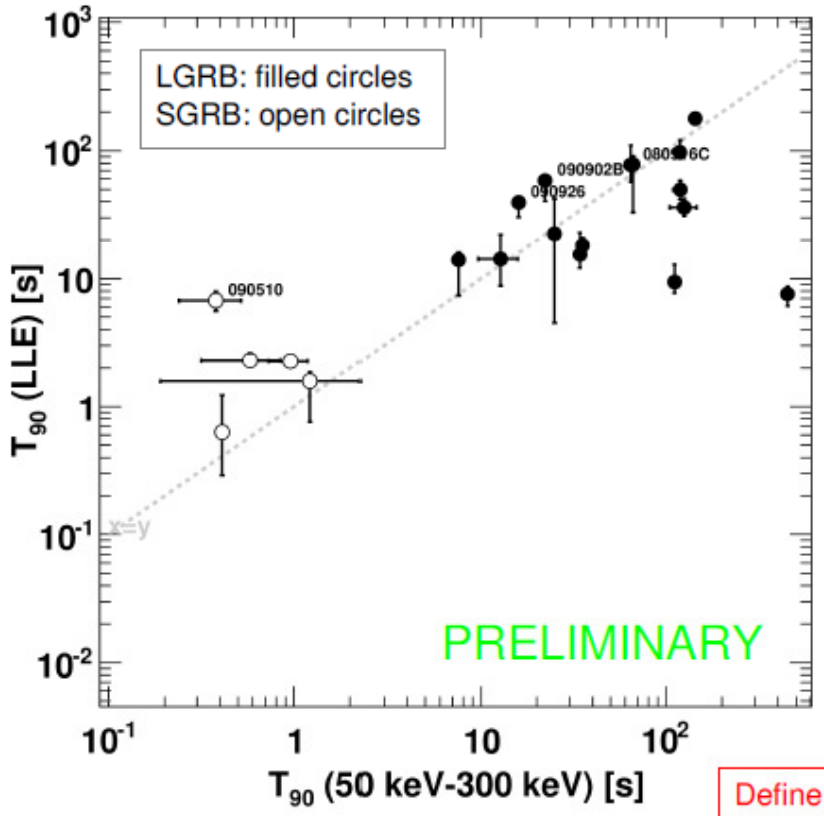


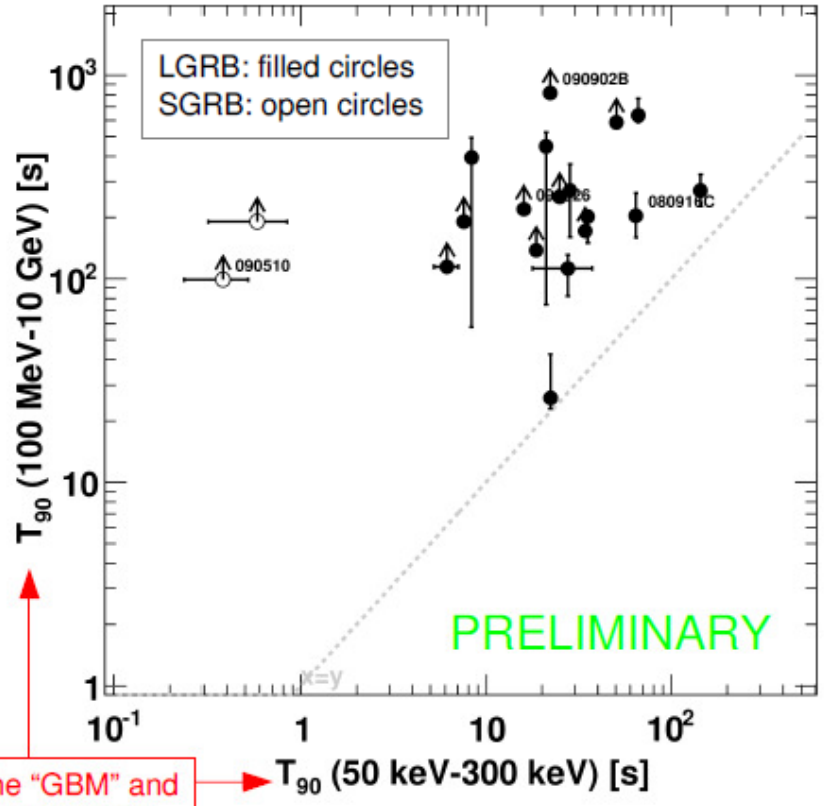


Temporally extended emission of > 100 MeV component

- GBM T_{90} vs. LLE T_{90}: duration of LLE emission is compatible with GBM
- GBM T_{90} vs. LAT T_{90}: LAT >100 MeV emission lasts systematically longer

Different components? Caveat: different sensitivities and S/N ratios between GBM, LLE and LAT >100 MeV





Define the "GBM" and "LAT" time windows

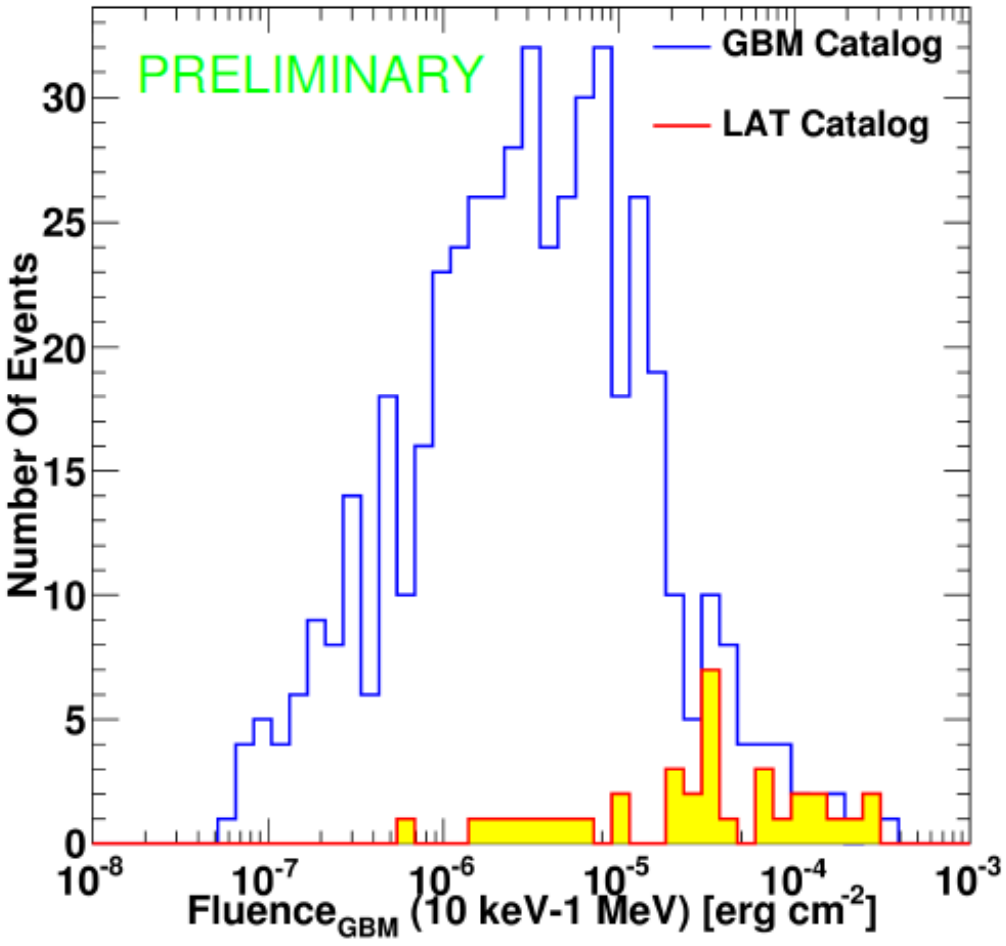
Band model "crisis"

- GBM+LAT joint spectral fits during "GBM" time window
  - Photospheric emission component (seen in a couple of *Fermi* bursts so far) not included in the catalog spectral fits
- The (phenomenological) Band function does not capture all features in the data
  - Note: extra PL detected in GRB 080916C spectrum (better bkg estimation and response matrices than in the 1st paper)
- Broad-band physical models are needed

Fluence 10 keV - 10 GeV (10^{-7} erg/cm^2)	Best model
4665^{-76}_{+78}	Band with exponential cutoff
4058^{-24}_{+25}	Comptonized + Power law
2225^{-48}_{+50}	Band + Power law with exponential cutoff
1795^{-39}_{+41}	Band + Power law
1528^{-44}_{+44}	Band
1293^{-27}_{+28}	Comptonized
1098^{-27}_{+35}	Comptonized + Power law
927^{-16}_{+17}	Logarithmic parabola
876^{-28}_{+28}	Logarithmic parabola
817^{-33}_{+34}	Band
638^{-25}_{+26}	Band
518^{-27}_{+28}	Band
517^{-20}_{+21}	Band
512^{-15}_{+16}	Band
461^{-14}_{+15}	Band
422^{-22}_{+23}	Band
417^{-37}_{+47}	Comptonized
379^{-21}_{+20}	Band + Power law
360^{-16}_{+18}	Band + Power law

PRELIMINARY

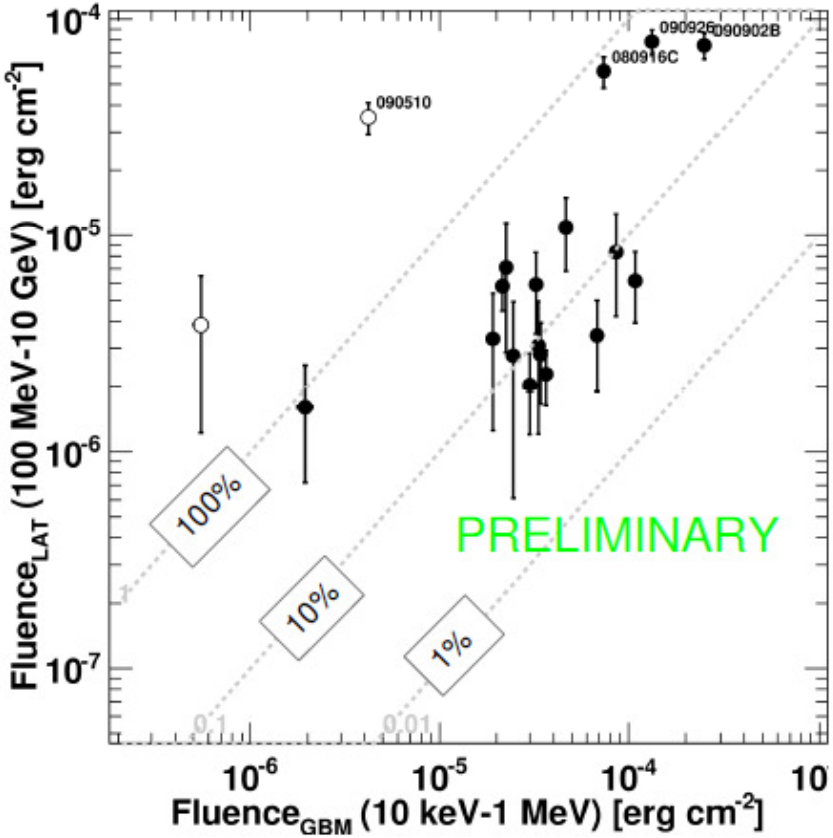
< 1 MeV of LAT GRB

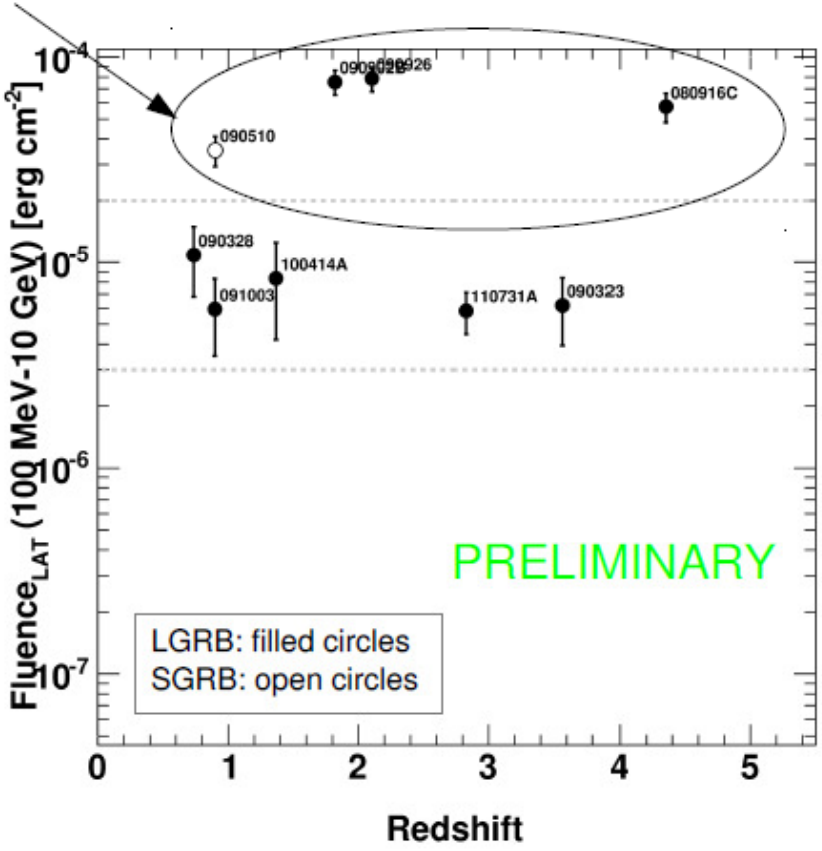


- Fluence in GBM energy range and "GBM" time window
  - LAT bursts vs. entire sample in GBM spectral catalog (Goldstein et al. 2012)
- Not surprisingly, LAT bursts are among the brightest GBM bursts
  - Selection effects (autonomous repointings) are possible though

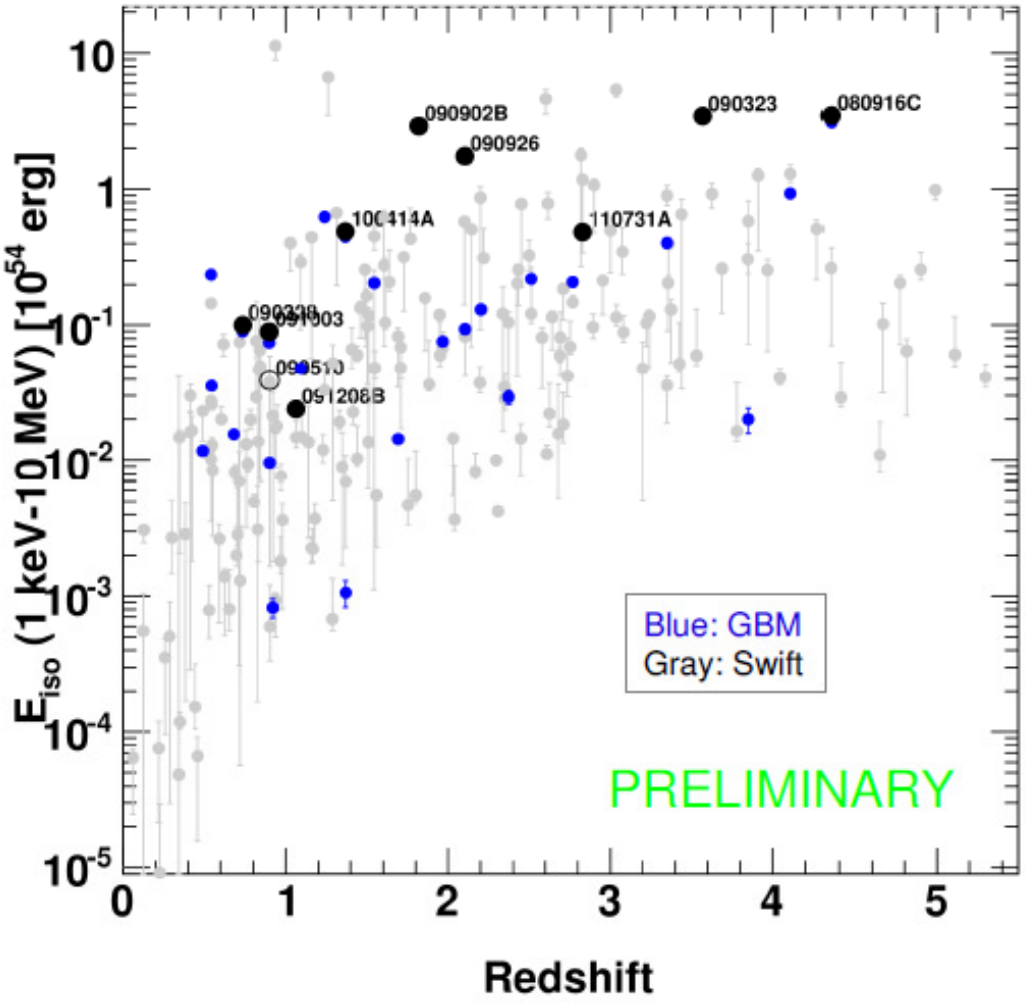
GBM and LAT fluence

- GBM and LAT fluences computed in "GBM" and "LAT" time windows, respectively
  - Short GRBs (LAT fluence > GBM fluence) are harder than long GRBs (LAT/GBM fluence ~10%)
- A hyper-energetic class of long bursts? GRBs 080916C, 090902B, 090926A are exceptionally bright
  - They do not appear bright because they are systematically closer to us





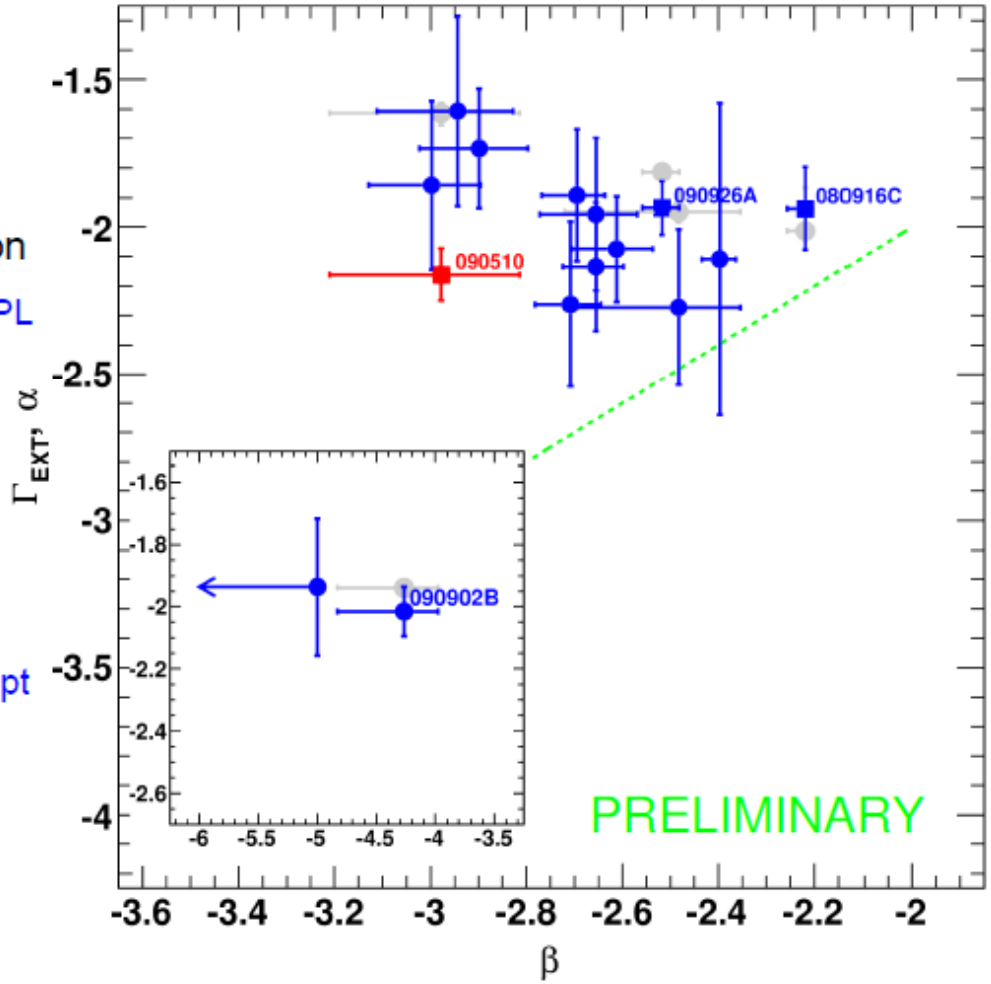
Energetics



- E_{iso} (1 keV - 10 MeV) in "GBM" time window vs. redshift
  - LAT bursts vs. GBM (Goldstein et al. 2012) and Swift (Butler et al. 2007) samples
- LAT bursts are among the most energetic bursts
  - Intrinsically and observationally
- GRB 090510 is also one of the most energetic short bursts
- No particular trend in redshift (small sample)

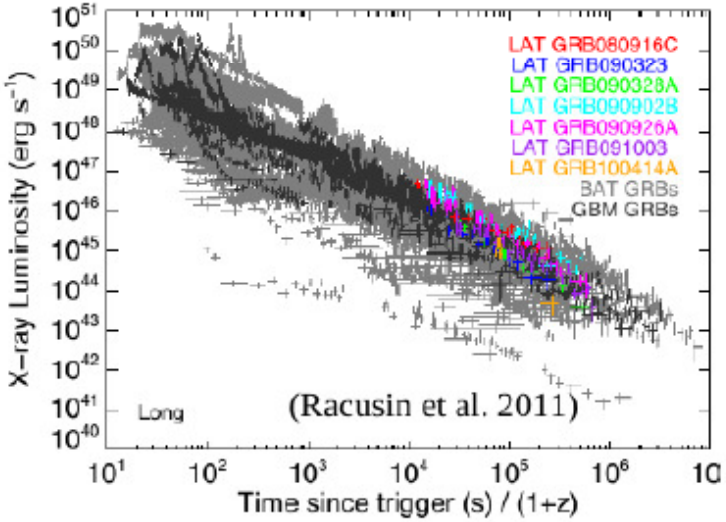
Extended and Prompt Spectra

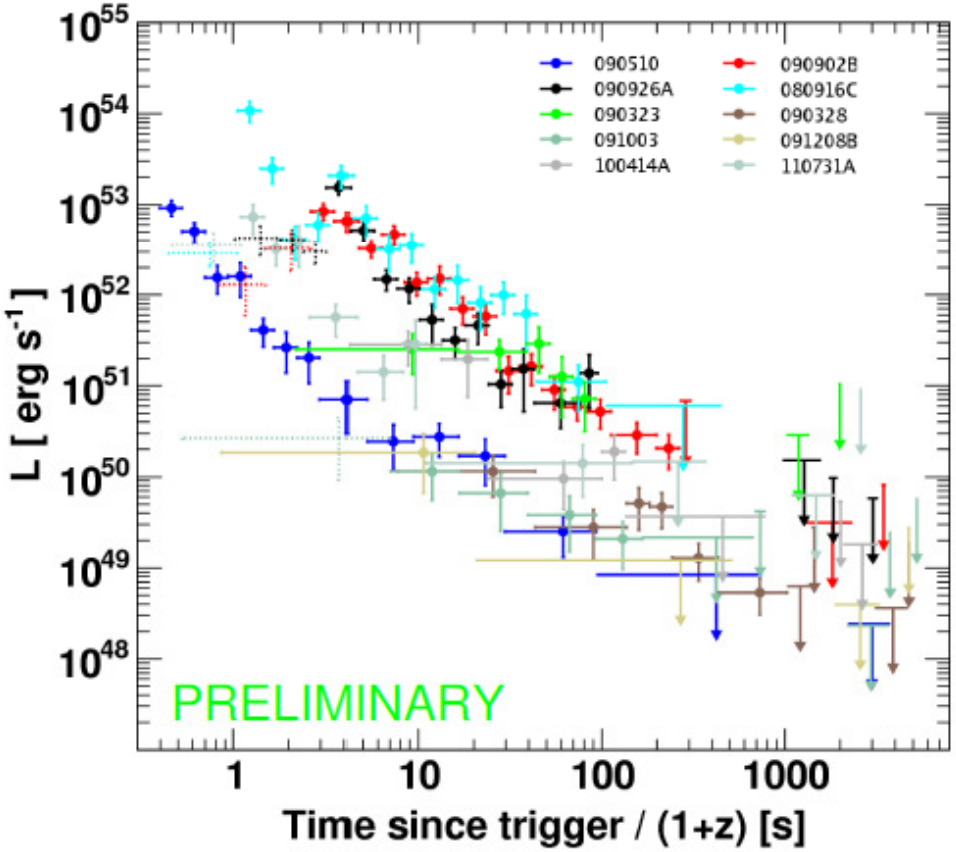
- $\beta=\beta_{BAND}$ here: spectral index of Band function in the prompt phase
- Γ_{EXT} : spectral index of extended emission
  - α (grey points): spectral index of extra PL from GBM-LAT joint fit in the prompt phase
- Prompt and extended phase spectra not correlated
  - Stronger spectral variability in the prompt phase



Afterglow of LAT GRB

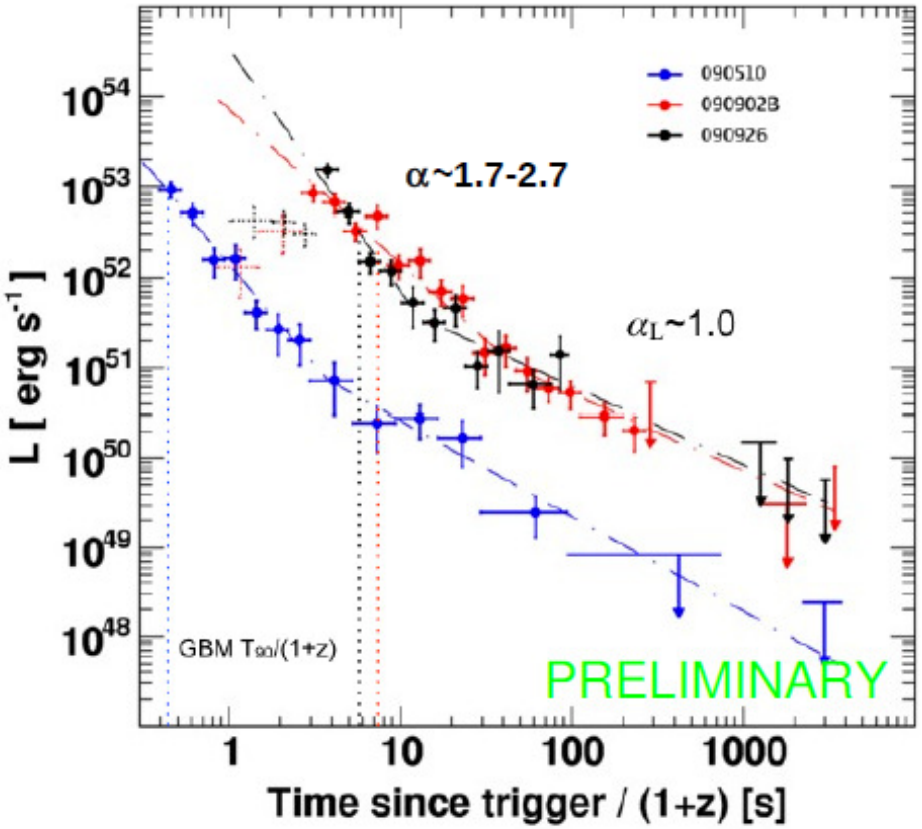
- Photon spectral index is constant and typically averages around $\Gamma_{EXT} \sim -2$ (previous slide)
- Rest-frame luminosity (100 MeV – 10 GeV) in the afterglow phase: $L(E,t) \sim t^{-\alpha}E^{-\beta}$
  $\beta=-\Gamma_{EXT}-1=1$, $\alpha=1$ for an adiabatic fireball in a constant density environment (10/7 if radiative)

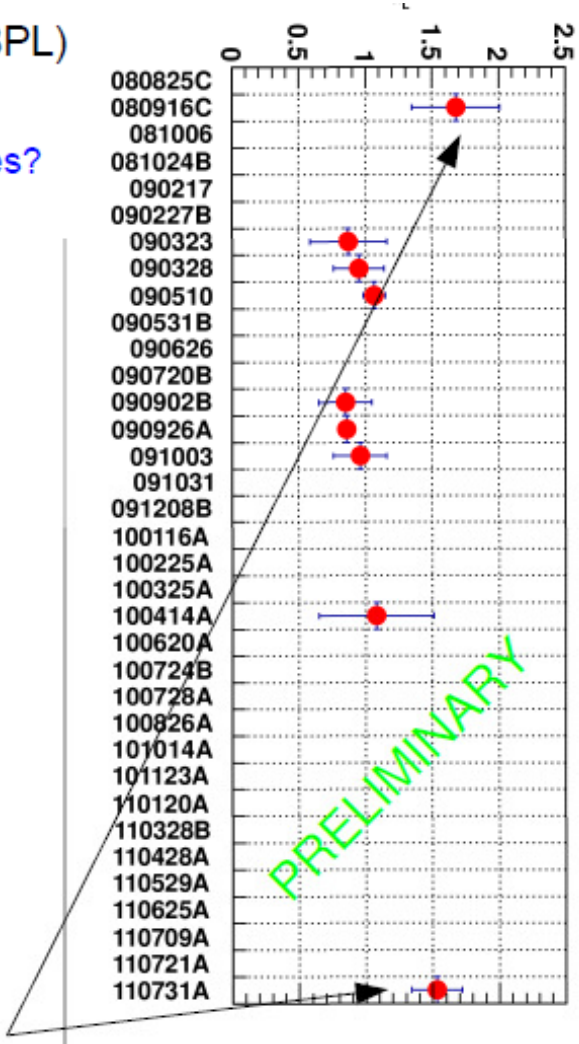




Decay of High energy flux

- Light curves fitted with a simple or a broken power law (BPL)
- BPL significant in 3 cases (chance probability < 10^{-3})
  - Transition between prompt- and afterglow-dominated phases?
- α_L ~ 1 at late times → adiabatic fireball

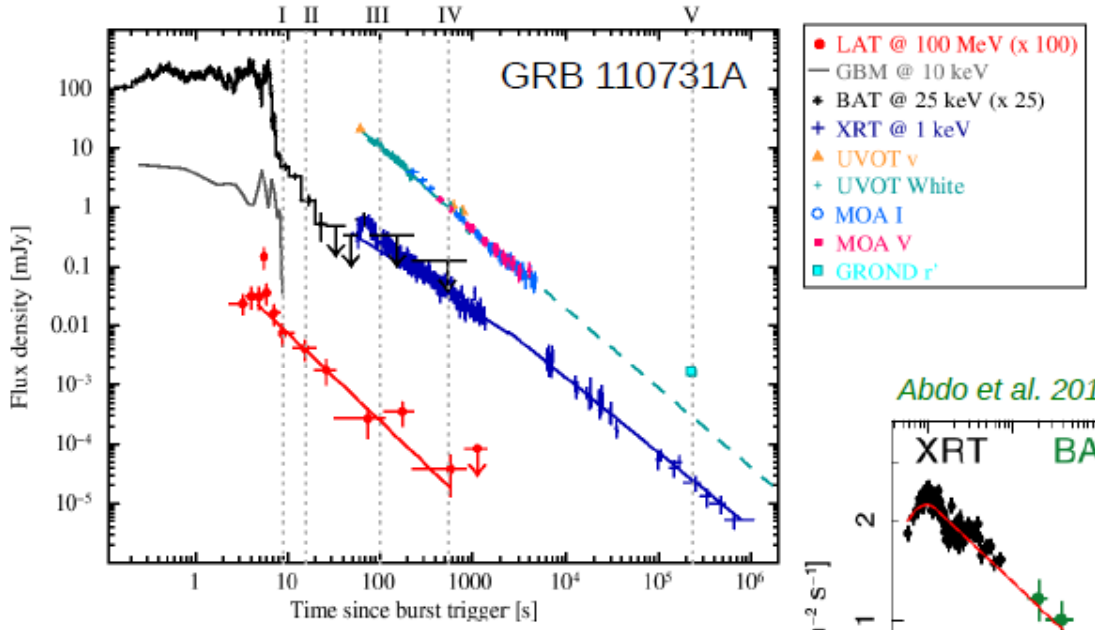




- 2 outliers: break not detected? (Both have the shortest detected emission in the rest frame)

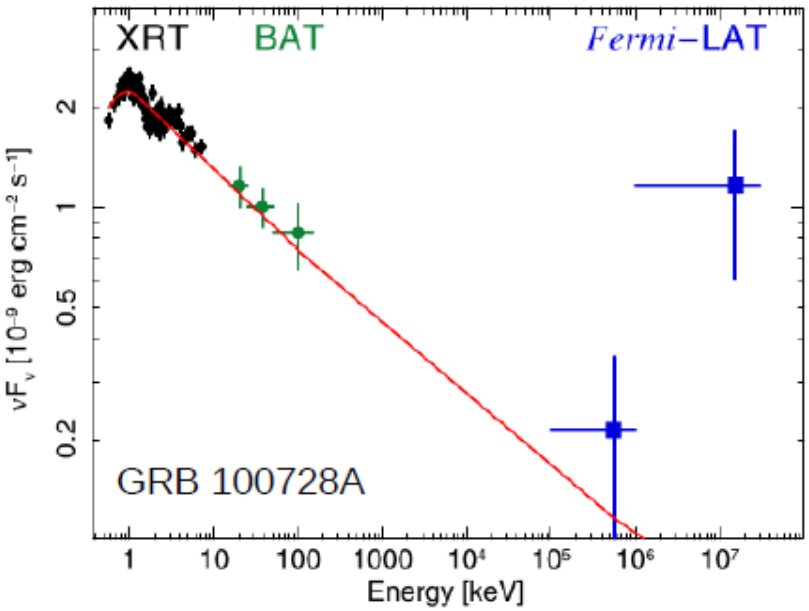
Swift and Fermi GRB

Ackermann et al. 2013, ApJ 763, 71



- GRB 110731A long-lived GeV emission from forward shock
  - Onset time $<T_0+8$ s (possible contamination from IS)
  - $\Gamma\sim500$ compatible with the value derived from the cutoff seen in the prompt emission spectrum ($P\sim3\times10^{-4}$)

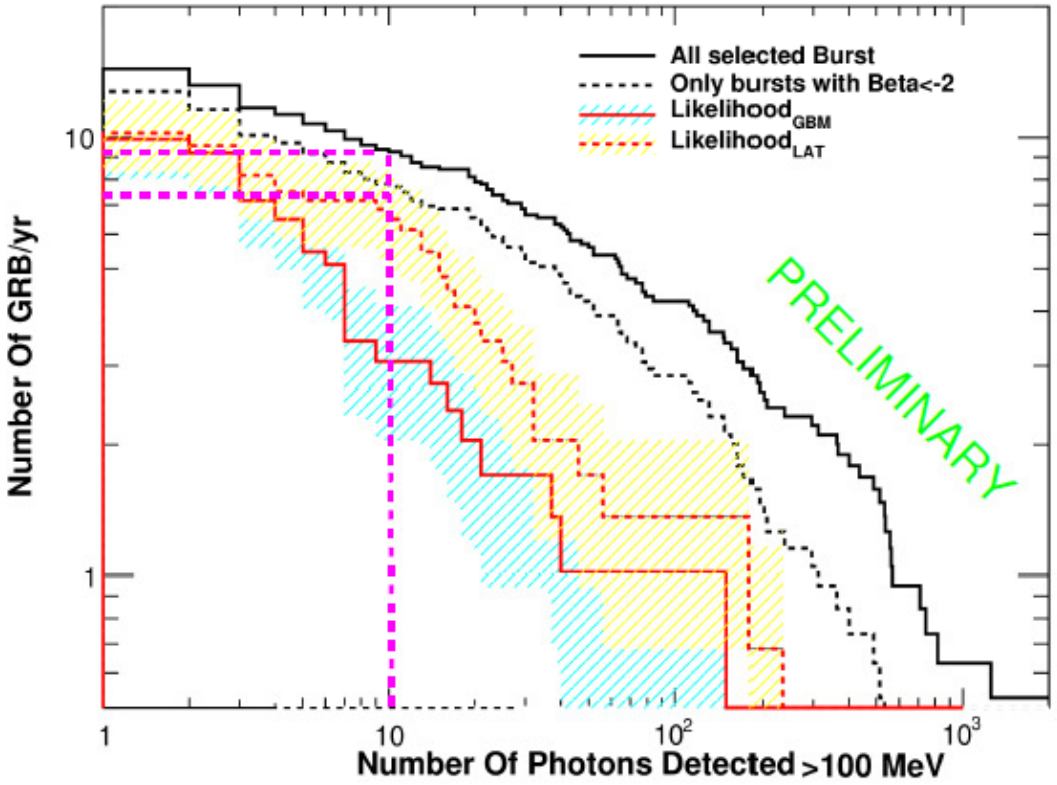
Abdo et al. 2011, ApJ 734, L27



- GRB 100728A was detected during X-ray flaring activity only
  - Spectrum compatible with same PL from X rays to gamma rays, modeled with internal shocks

GRB rate at High Energy

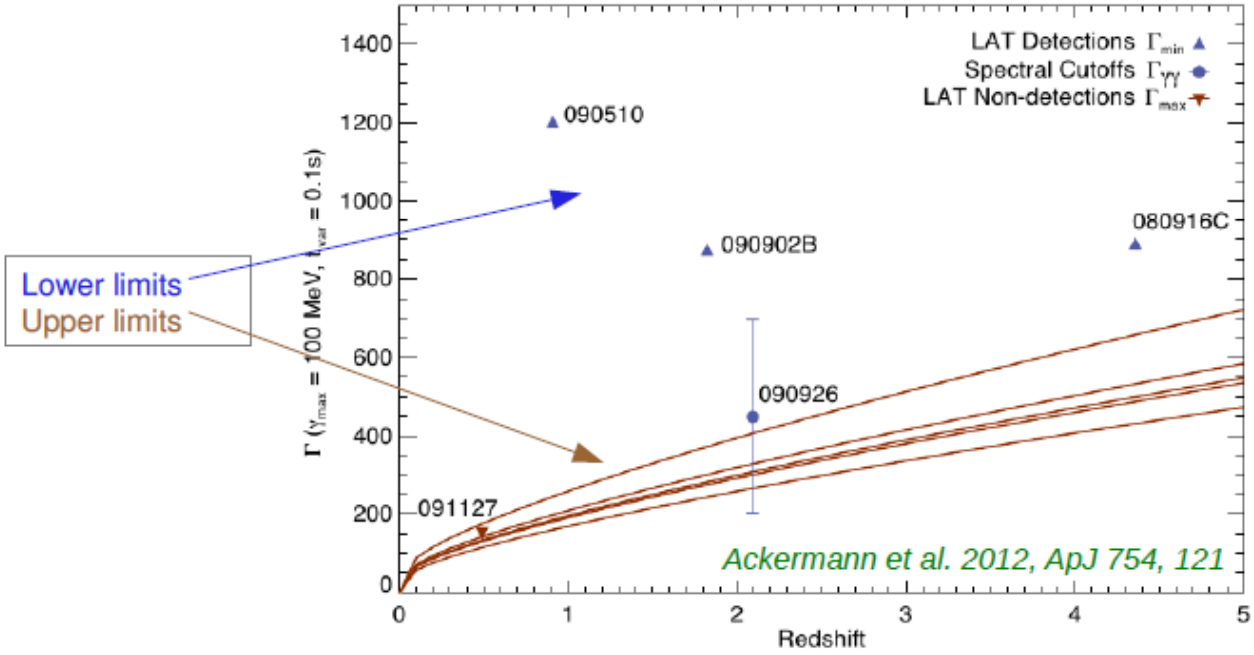
- Pre-launch estimates (Band et al. 2009):
  - 9.3 GRBs expected / year >100 MeV with >10 photons
- Number of "predicted" photons from likelihood fit ("GBM" and "LAT" time windows)
  - 6.3 GRBs observed / year >100 MeV with >10 photons



- Fewer GRBs than anticipated
  - Although both analyses have their own systematic uncertainties
- Extra PL components must be rare
- Is the high-energy emission suppressed?
  - Like for GRB 090926A

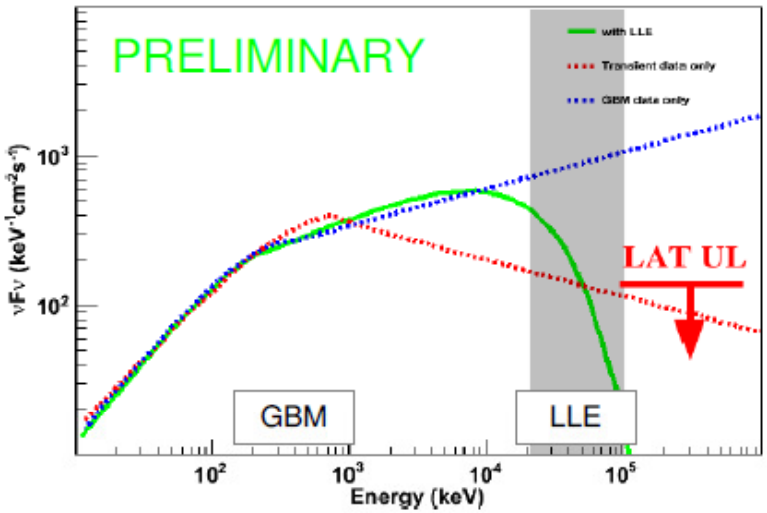
Spectral cutoff and pair attenuation

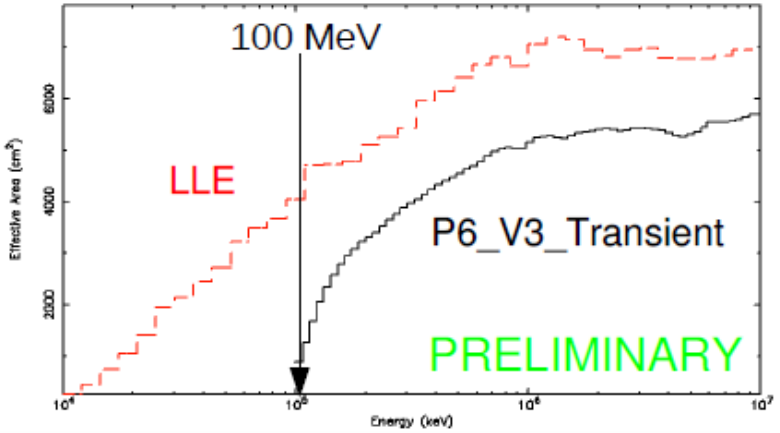
- 3 of the 4 brightest LAT bursts show an extra PL component with no attenuation → high Γ_{min}~1000
- 6 GBM bright bursts not detected by the LAT show some form spectral softening at tens of MeV → Γ_{max}~150-650 assuming 100 ms variability and 1<z<5 (we only know the redshift for GRB 091127)

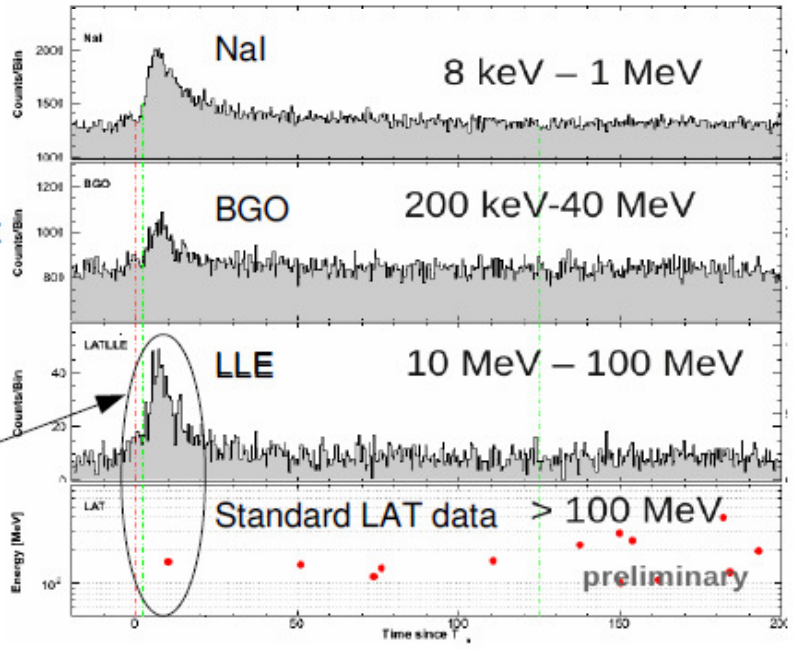


- Target photon field for γγ absorption assumed uniform, isotropic and time-independent
  - Error bar for GRB 090926A accounts for different models
  - Granot 2008, Hascoët & Daigne 2011 give significantly (~3 times) lower Γ values

Spectral cutoffs at LE?







- Standard LAT "Transient" selection runs out of effective area below 100 MeV
- The LLE event selection provides plenty of statistics to probe GRB spectral cutoffs in the 10-100 MeV energy range

http://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermille.html

Conclusions

- **Interesting patterns and emergent groups**
  - **LAT >100 MeV emission is delayed & temporally extended w.r.t. the emission seen in the GBM**
  - **Short & long GRBs seem to have similar HE properties – short GRBs may be harder**
  - **LAT bursts are fluent, bright & energetic**
  - **Hint for a class of hyper-energetic GRBs → needs more observations**
  - **The distribution of GRB jet Lorentz factors might be broad → needs better spectral coverage in the 10-100 MeV range (LLE, Pass 8)**
- **Prompt emission phase**
  - **Band model crisis → need detailed physical models**
  - **Origin of the delayed onset of the LAT >100 MeV emission?**
  - **Origin of the high-energy emission? From internal and/or external shocks? Leptonic and/or hadronic?**
  - **Transition from prompt emission phase to early afterglow: how does the extra PL component relate to the long-lived GeV emission?**
- **Long-lived GeV emission**
  - **Decays as t^{-1} at late times, consistent with the canonical afterglow model (adiabatic fireball)**
  - **Afterglow broad-band spectra of e.g. GRB110731A compatible with FS emission**

HE Gamma-ray Data Analysis School

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2013

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Event

Title:	High-energy gamma-ray astrophysics: from solar activity to black holes
When:	22.07.2013 - 26.07.2013
Where:	Sexten Primary School - Via Panorama 6, Sexten
Category:	Conferences 2013

Description

On July 22 - 26, 2013 a school on High energy astrophysics data analysis will be organized in the Sexten Center for Astrophysics in the Dolomites area.

http://www.sexten-cfa.eu/en/conferences/2013/details/27-high-energy-gamma-ray-astrophysics-from-solar-activity-to-black-holes