Gamma-Ray Bursts and Fermi: What We Have Seen

Nicola Omodei
INFN Pisa

On behalf of the Fermi LAT and GBM Collaborations

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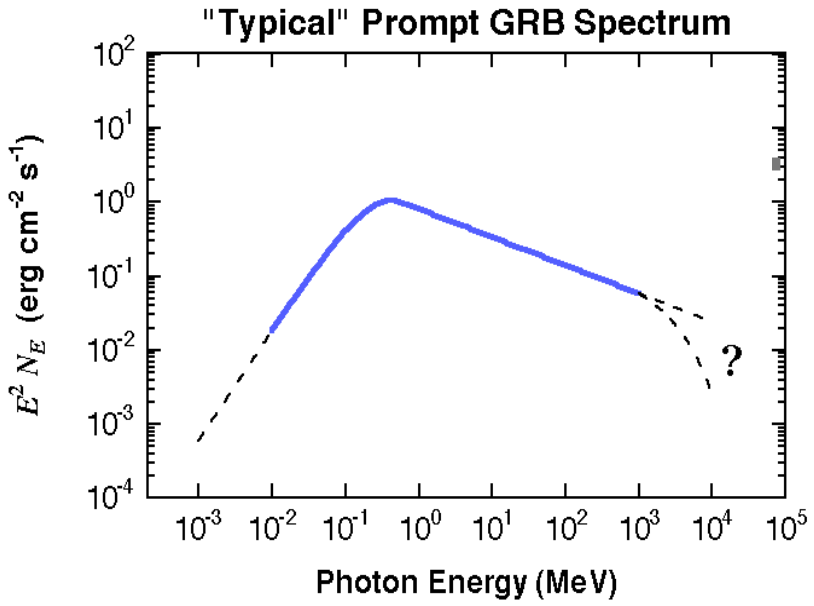
Gamma-Ray Bursts

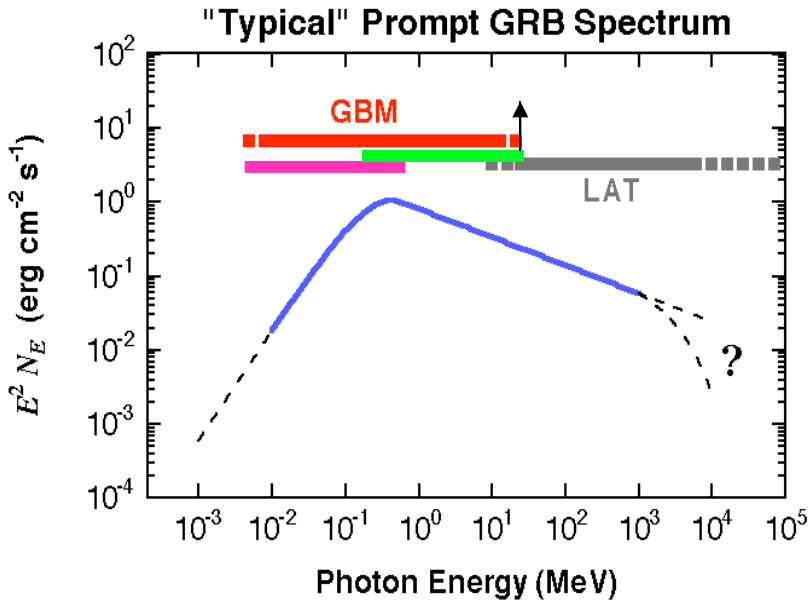
- **Gamma-Ray Bursts are violent explosion happening at cosmological distances (up to z=8.2)**
- **The "Prompt phase": Intense flashes of gamma-rays lasting from few millisecond to hundreds of seconds.**
- **The "afterglow phase": longer lasting emission, discovered in X-rays and found in optical, radio**



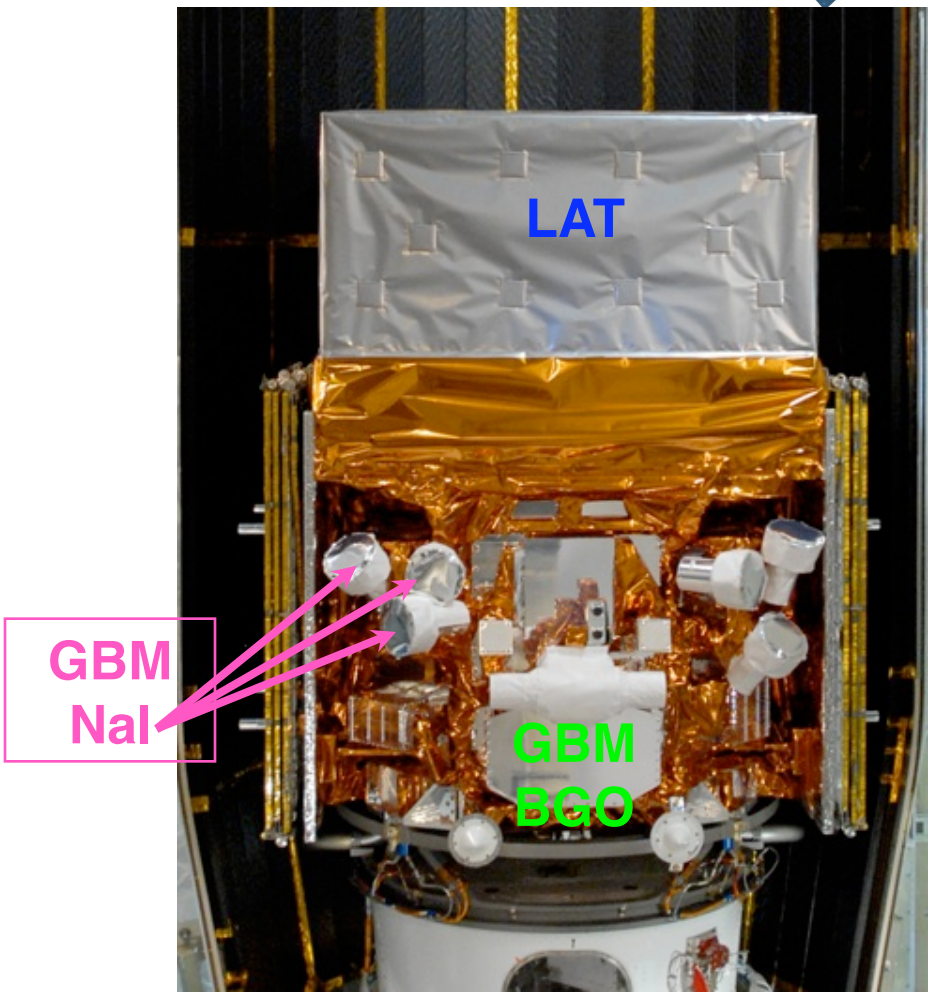
High statistic was collected at keV-MeV energies by BATSE
The prompt spectrum at these energy is typically described by a smoothly broken power law, first introduced by **David Band**, in 1993, and known as the **Band function**
Only little was known at GeV energies before the Fermi era

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**



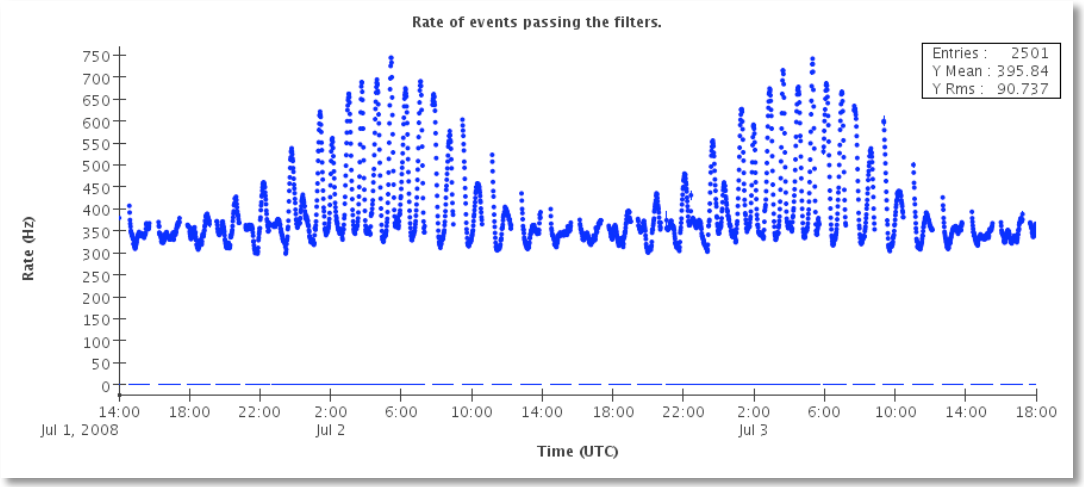
Fermi GBM-LAT covers >7 decades of energy band (8 keV to > 300 GeV)
Both LAT and GBM can independently trigger



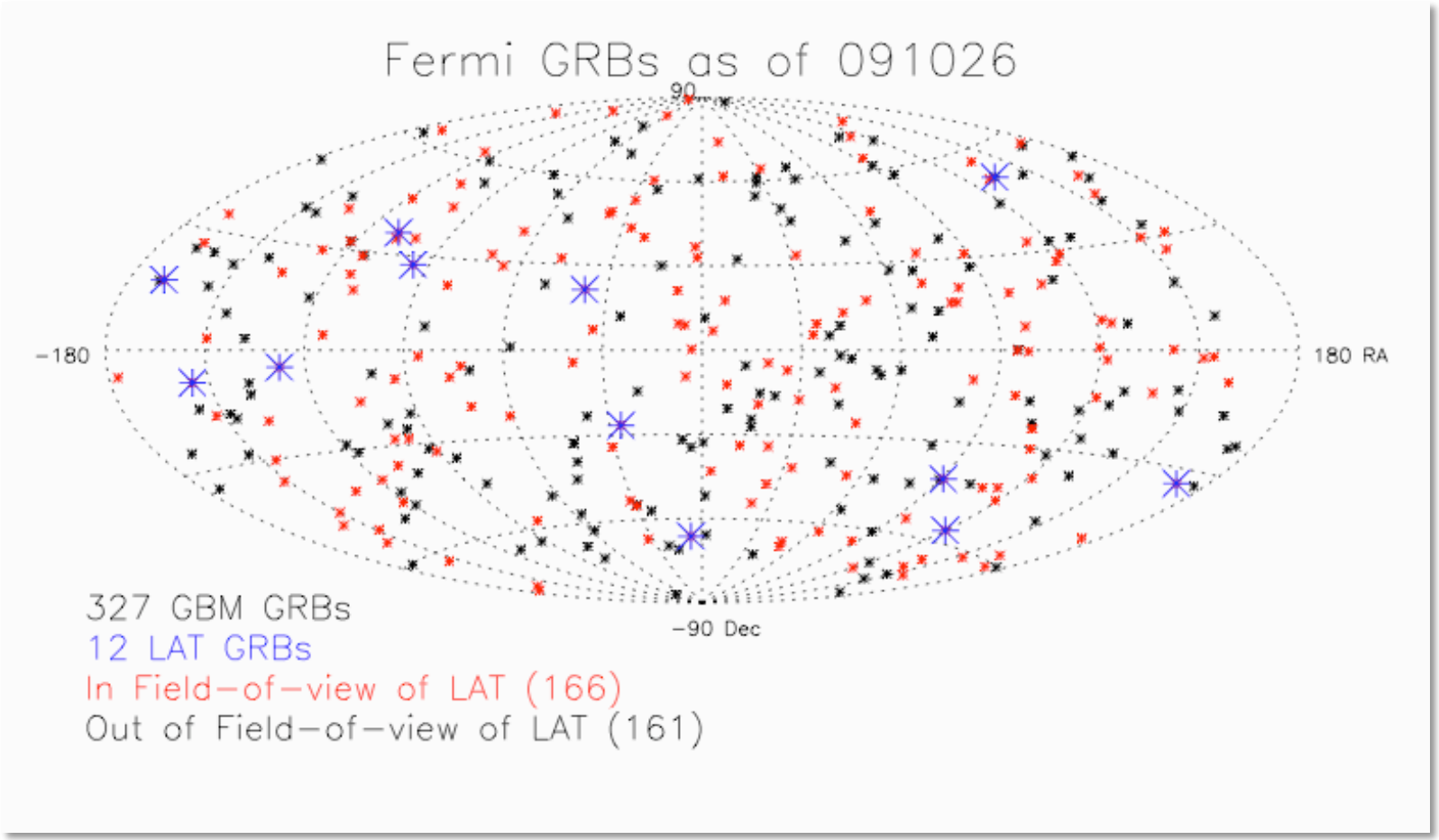
Fermi Gamma-ray Burst Monitor
Views entire unocculted sky
NaI: 8 keV - 1 MeV
BGO: 200 keV - 40 MeV

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



- **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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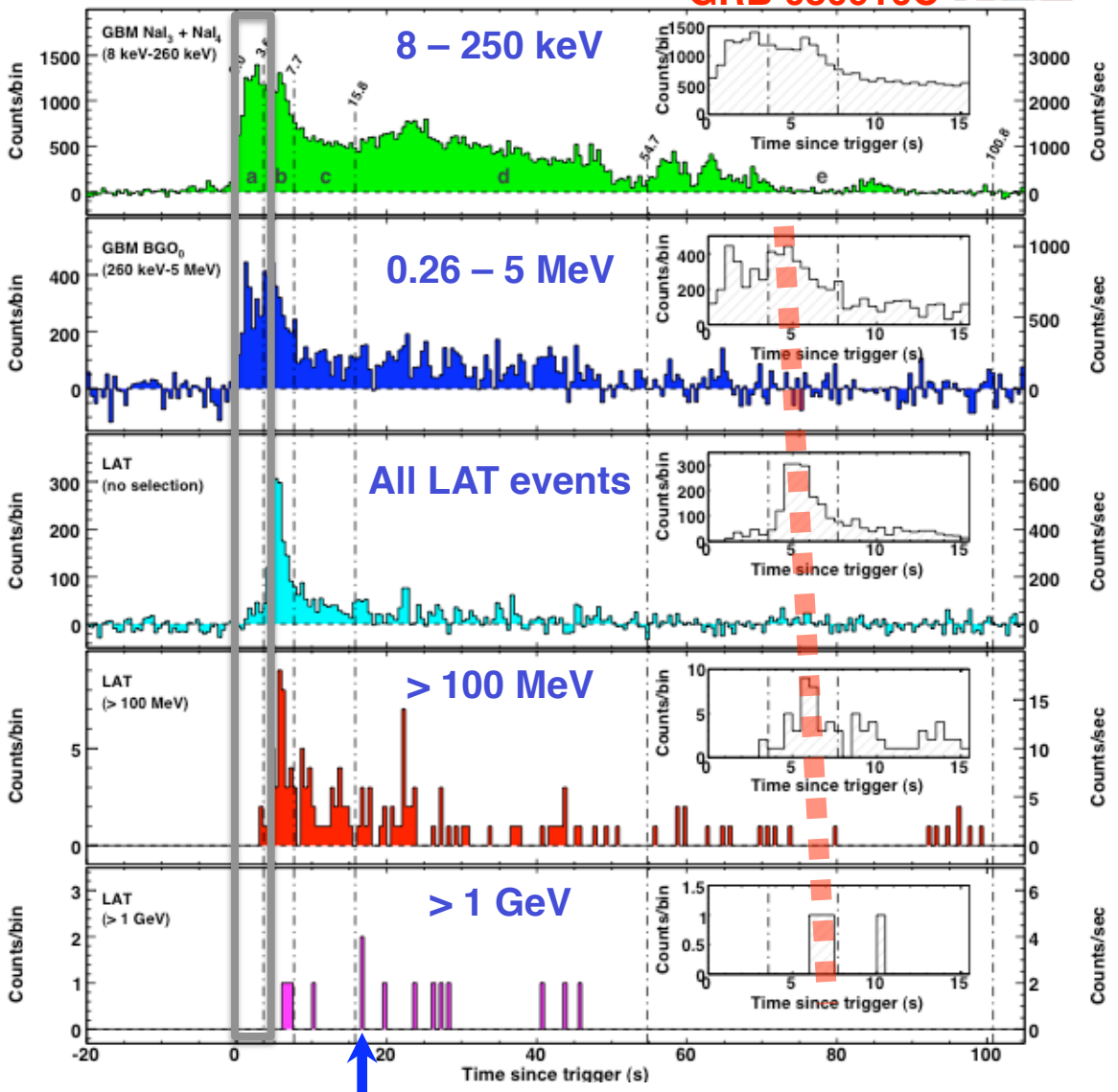
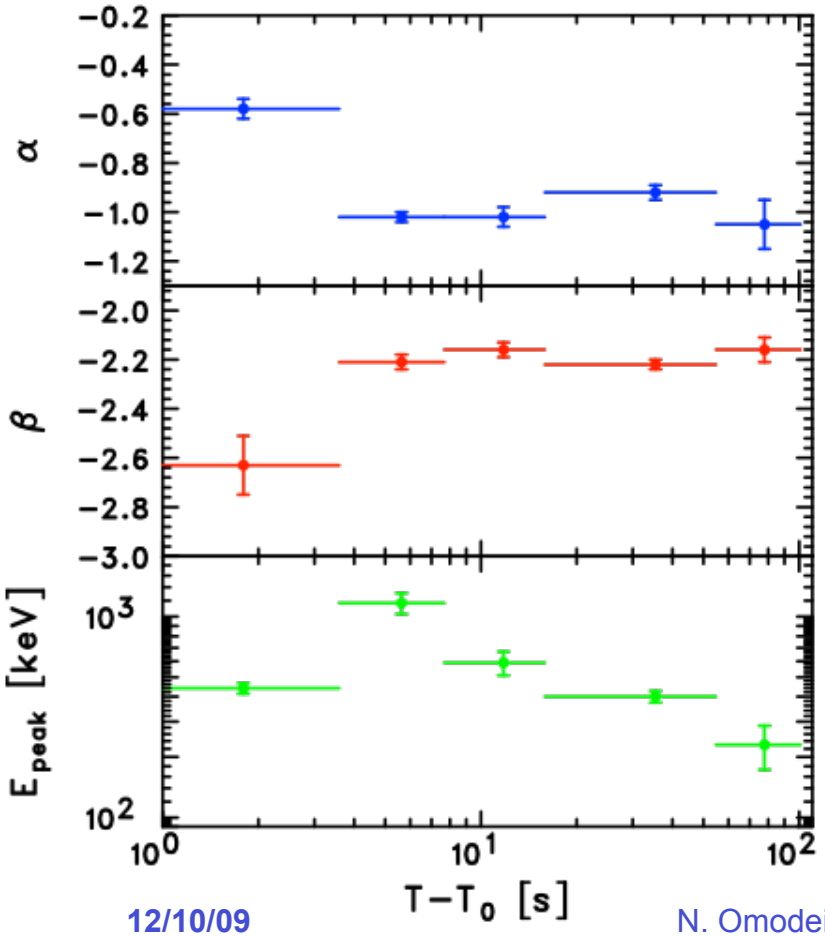
The Onset between Low-Energy and High-Energy emission

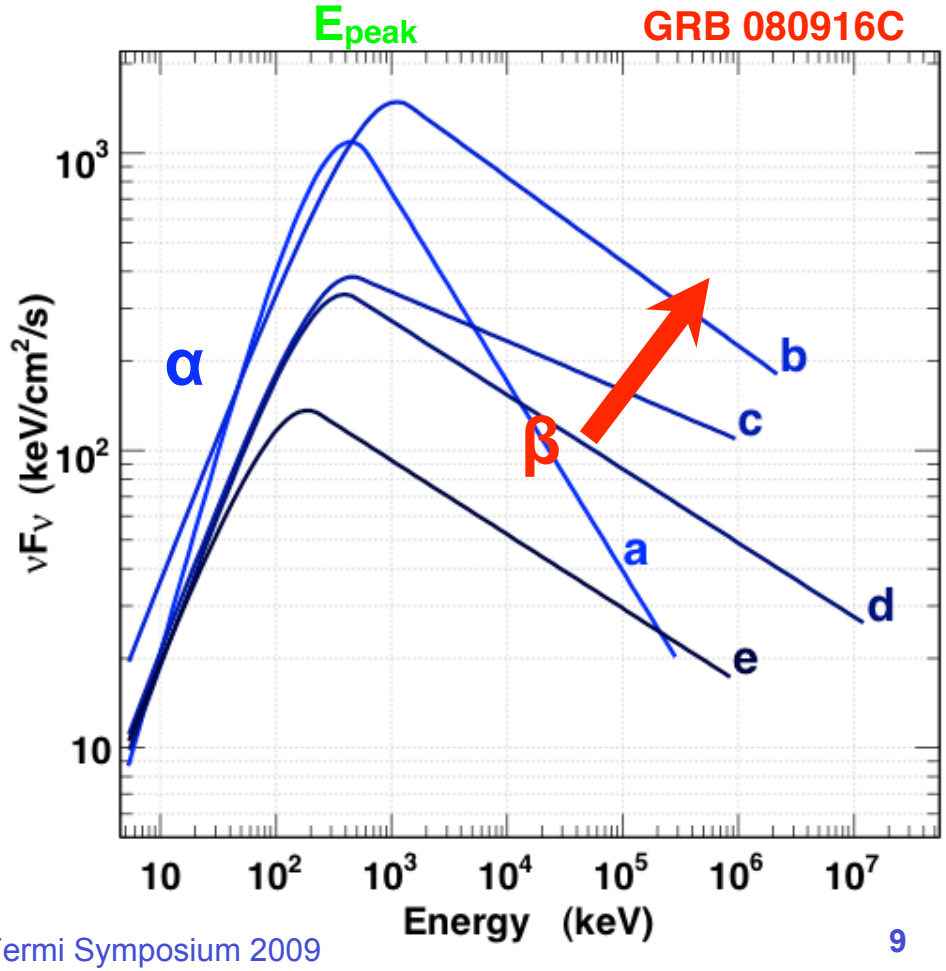
- First long bright LAT GRB
- The “lack of the first peak”: that was a surprise!
- Absorption?
  - You would expect a cut off in the spectrum…



Spectral Evolution of GRB 080916C

- Rapid soft to hard evolution in (a) to (b)
- Gradual decrease of E_{peak} from (b) to (d)
- Spectrum consistent with a Band function, no roll-off!





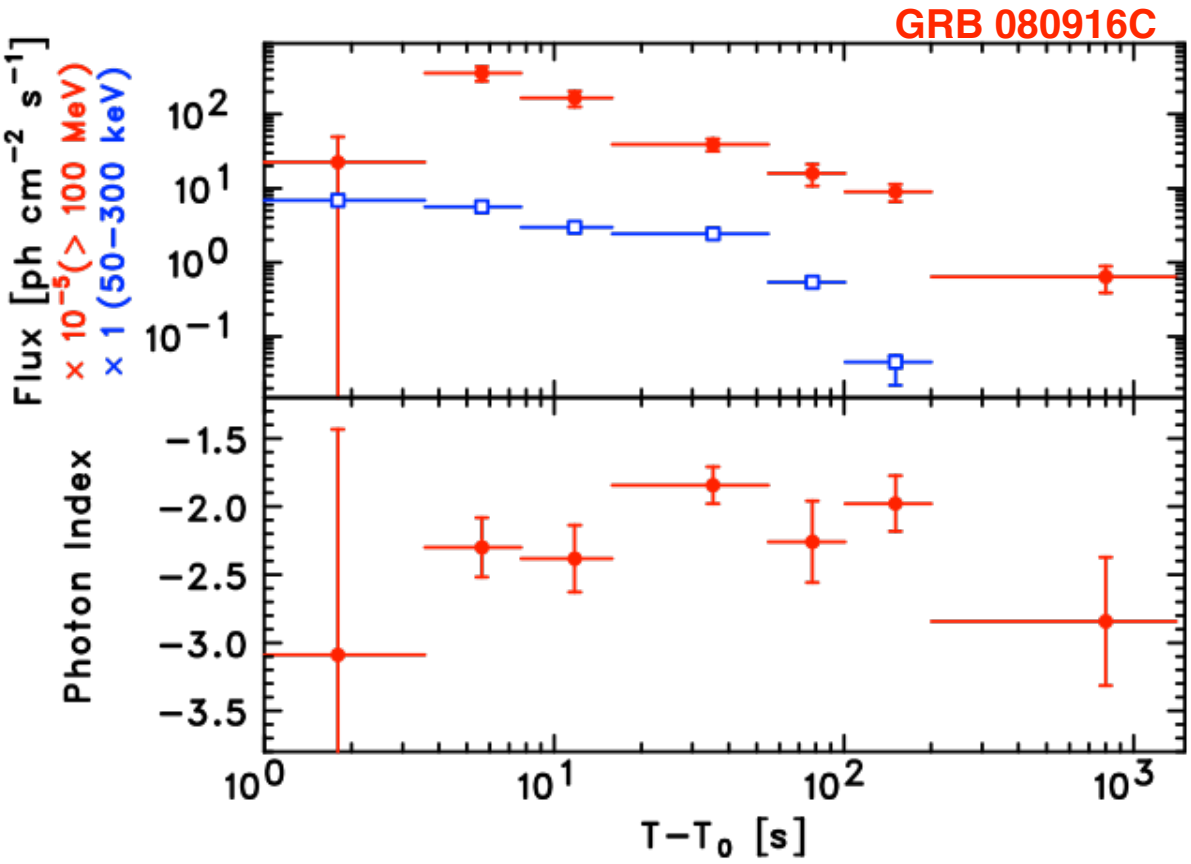
What we have seen:

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

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?**

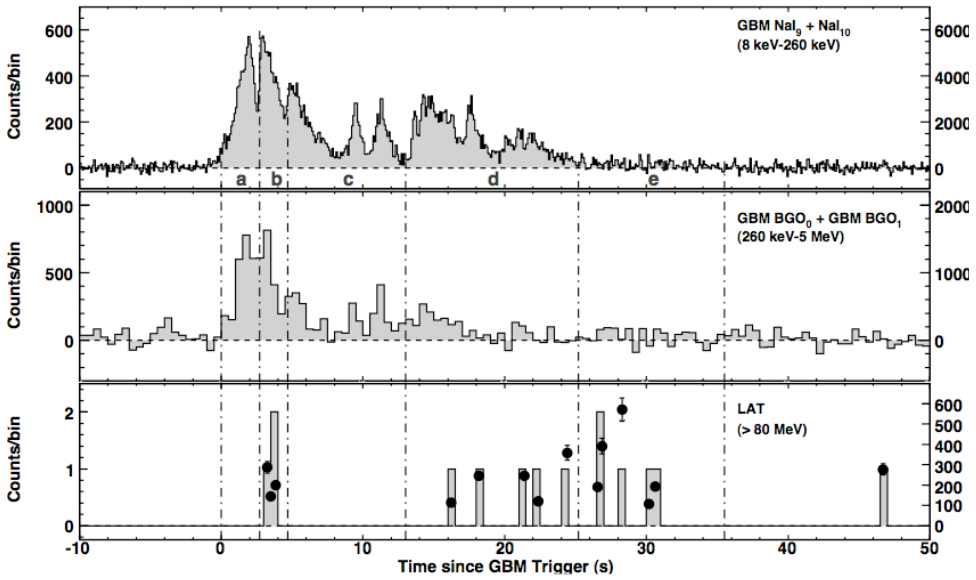
The "March bursts" (090323/090328) show a ~ ks long lived emission in the LAT, see Piron's talk on Wednesday



Delayed HE Emission from Other LAT GRBs

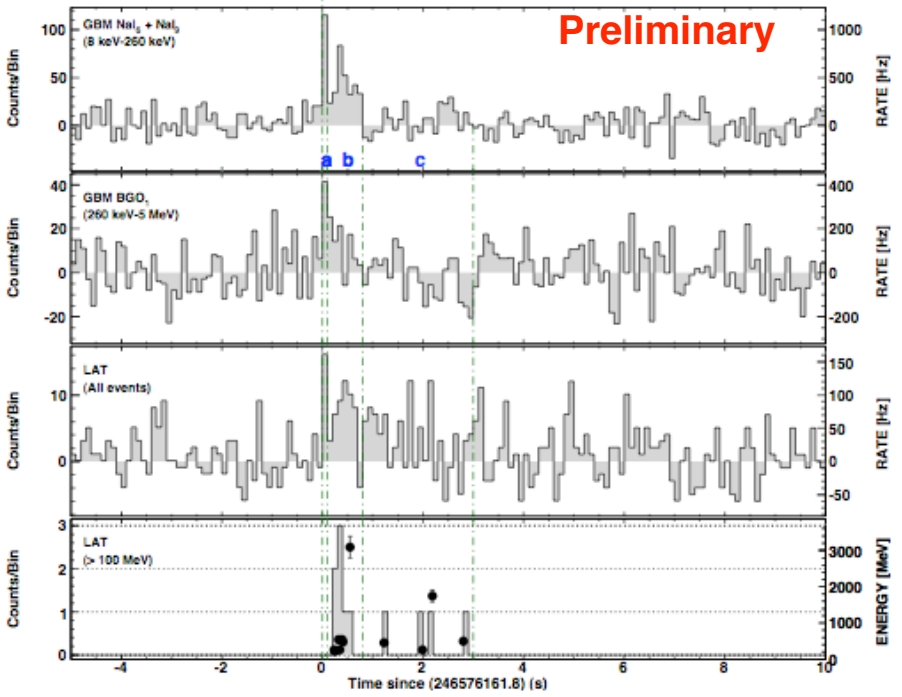
- Temporal onset of high-energy emissions (coincident with 2nd GBM pulse)
  - Common origin for this emission in low and high energies (Not statistically significance, here)
- Highest energy is very late (GRB 080825C)
  - No detectable low energy emission
- For the first time, temporal extended emission seen also in short burst!
- Delayed emission also detected by Agile (080514B, Giuliani '08, 090510, Giuliani '09)

GRB 080825C

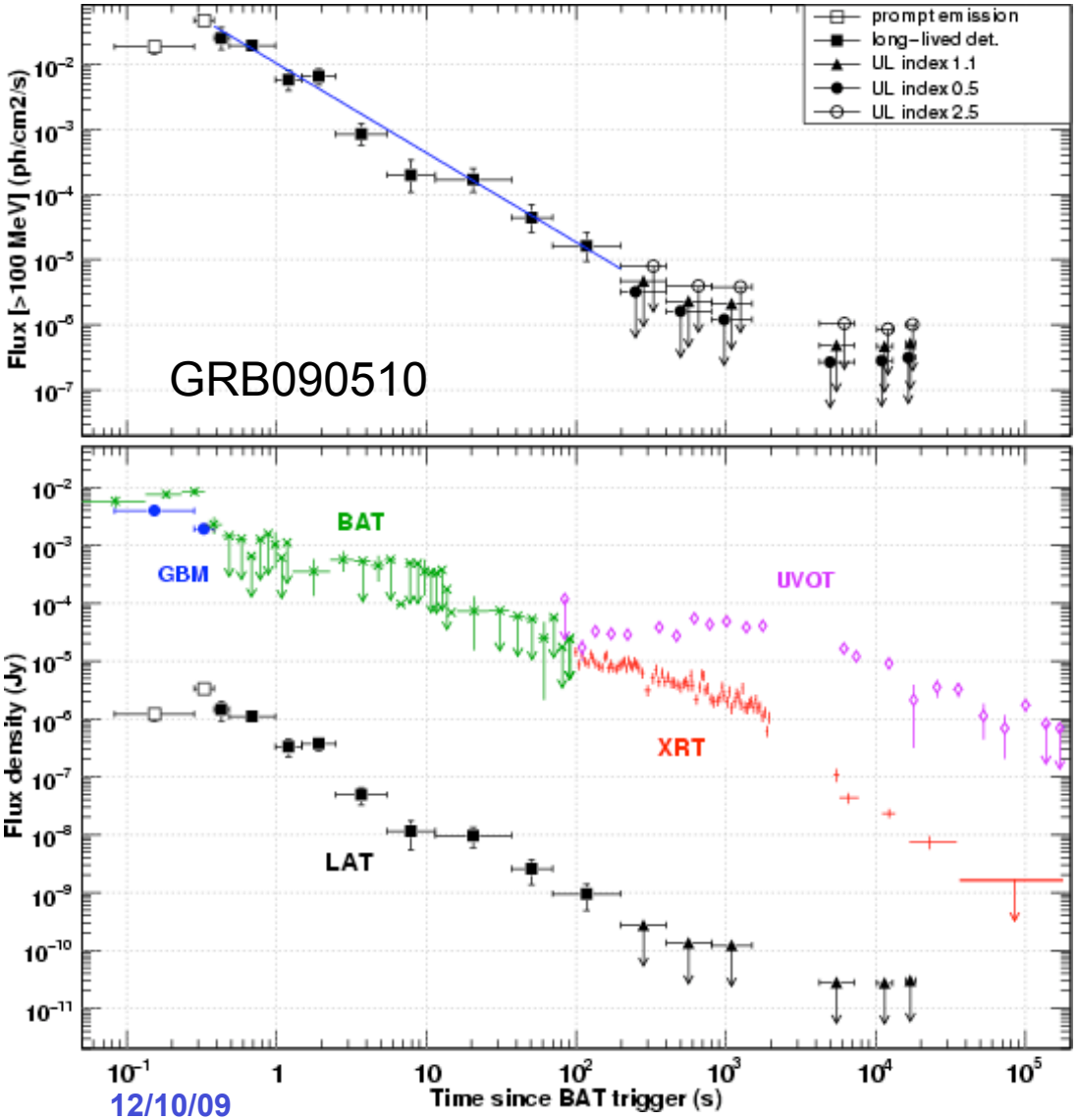


GRB 081024B

Preliminary



The Fermi-Swift era of the high-energy afterglows



Significant emission (TS>25) up to T0+200s

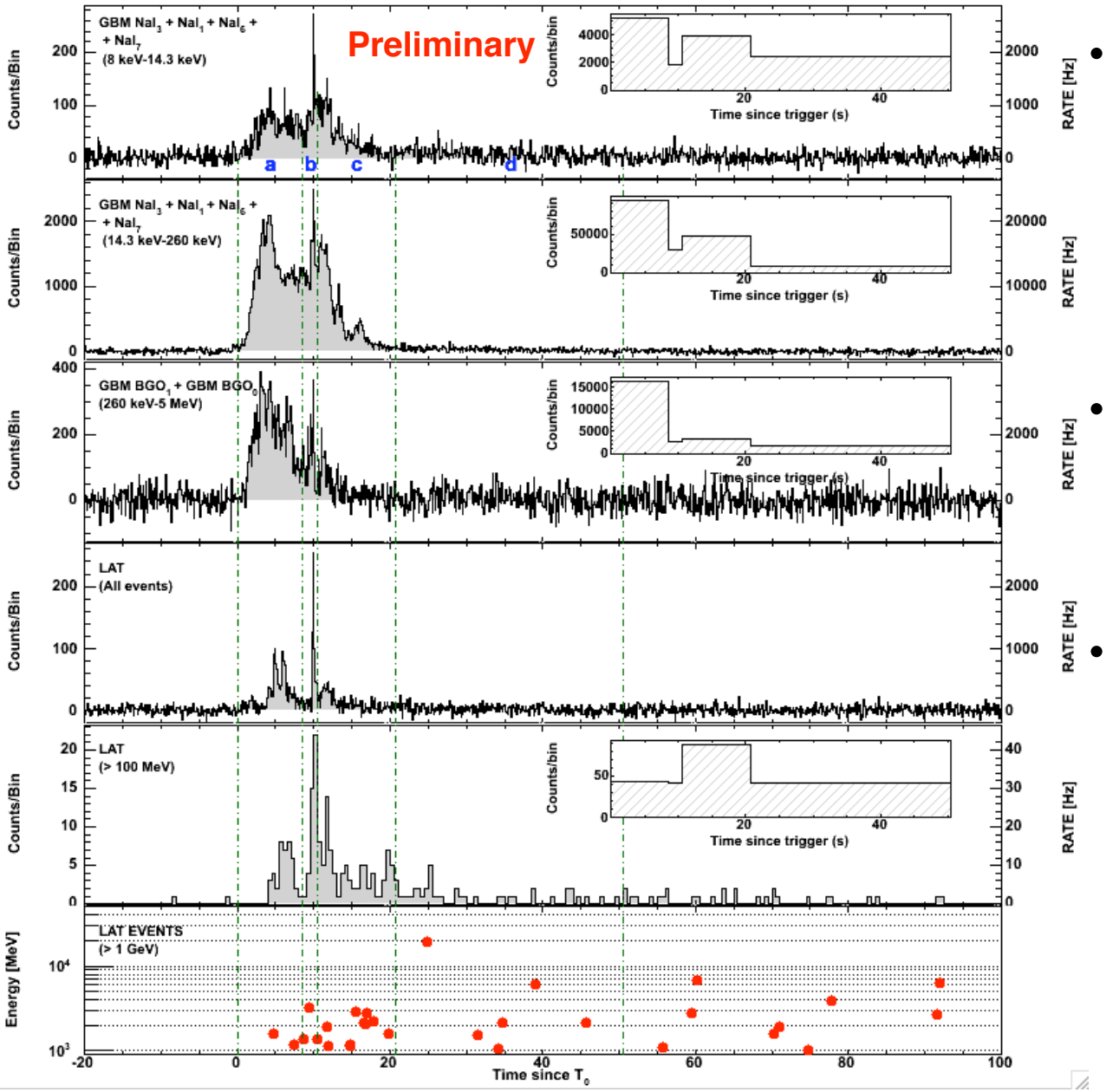
No evidence of a spectral evolution

LAT lightcurve best fit by a power-law: a = -1.38 +/- 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

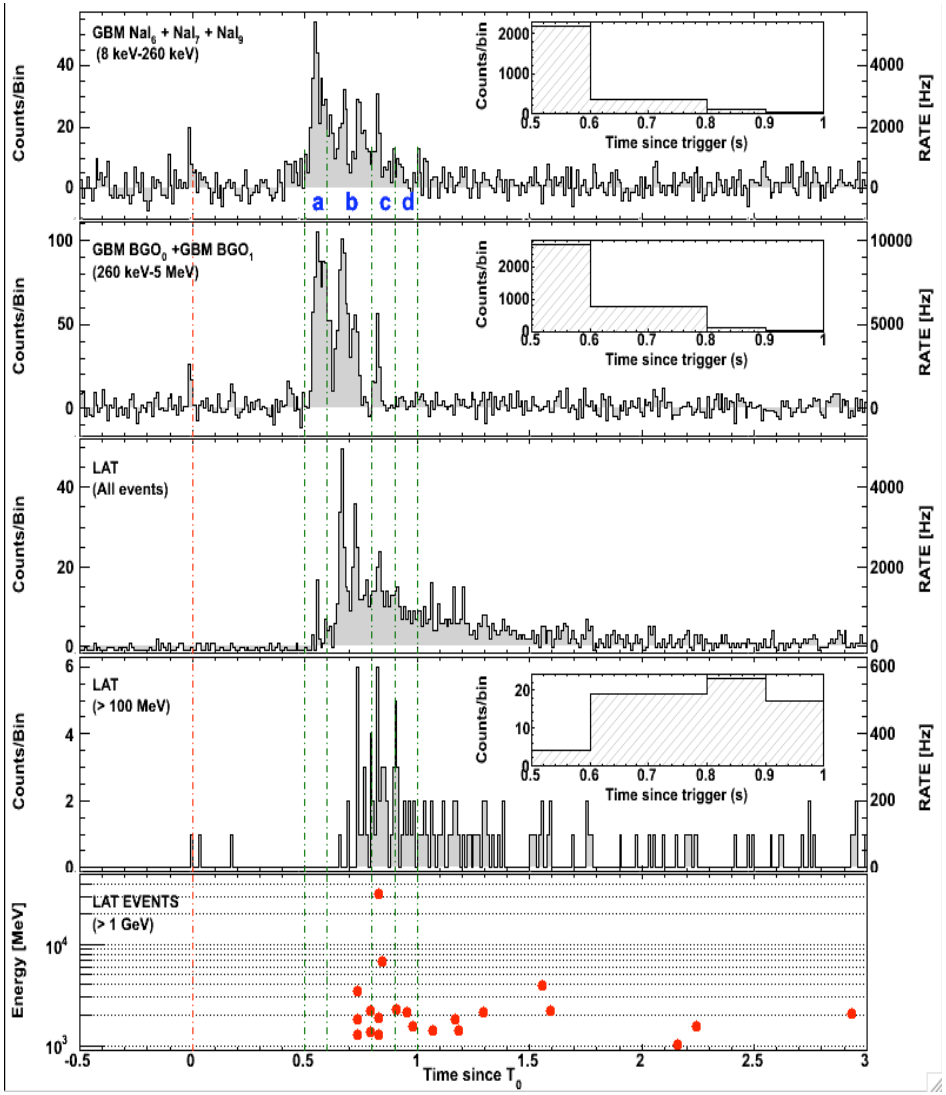


- Onset in interval "a"
  - Emission >100 MeV starts few second after the emission at low energies
- Extended high energy emission
  - Highest energy event
- Emission above 100 MeV is "spiky"
  - Very narrow spike (0.1 s) from few keV to >100 MeV energies

What we have seen:

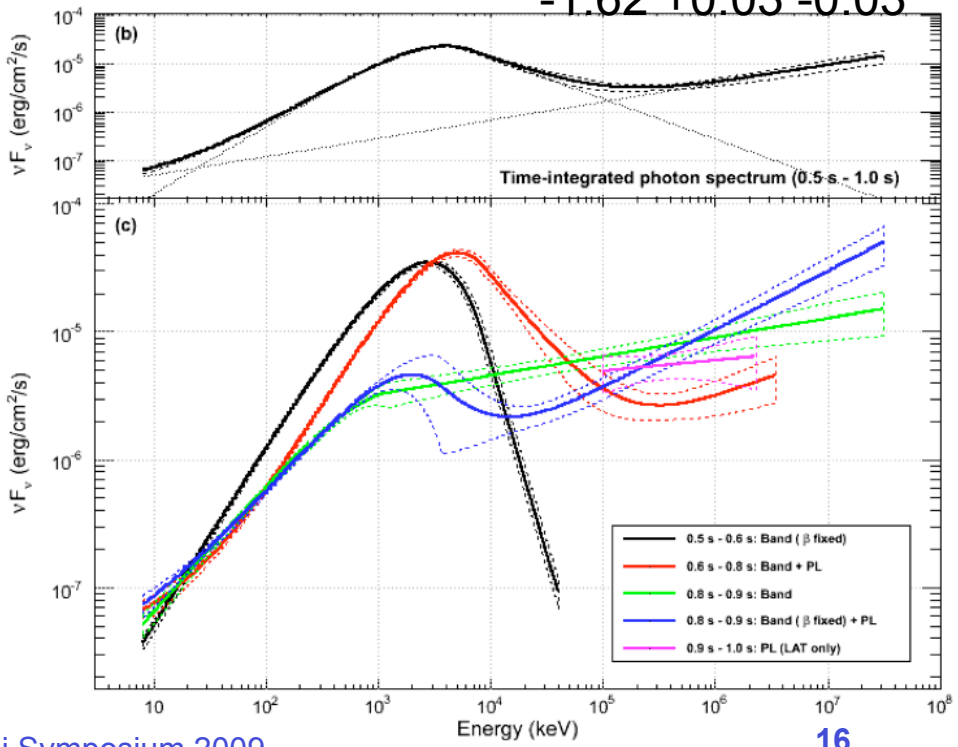
- The Onset between Low-Energy and High-Energy emission
- Temporal Extended High Energy Emission
- **Deviation from a pure Band function: the extra component**

Finally, clear detection of an extra component

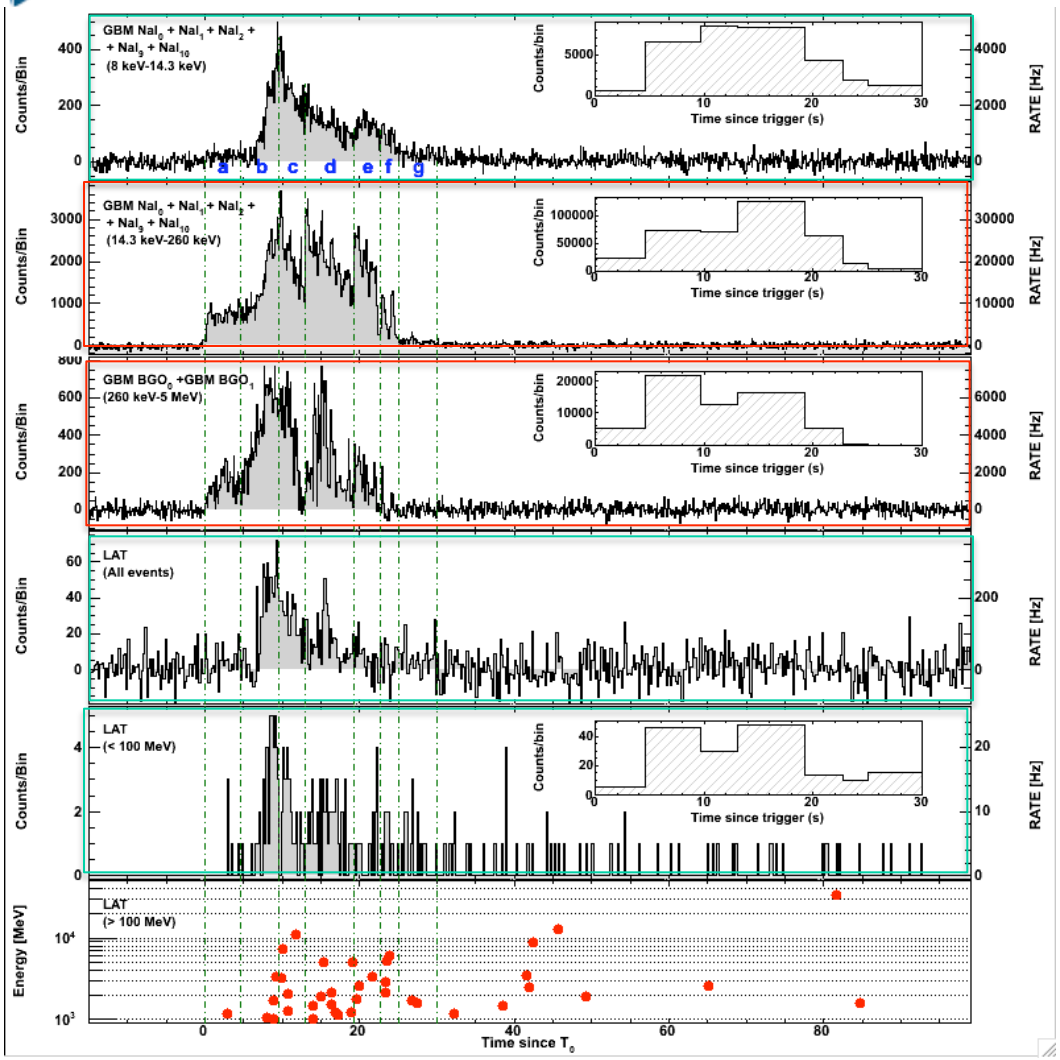


GRB090510. First bright short GRB (Abdo et al., Nature, 2009)
Clear detection of an extra component, non consistent with the Band function.
Are we seeing an early afterglow?
Also **Synchrotron/SSC** seems to work!
(See Chuck Dermer's Poster)

-1.62 +0.03 -0.03

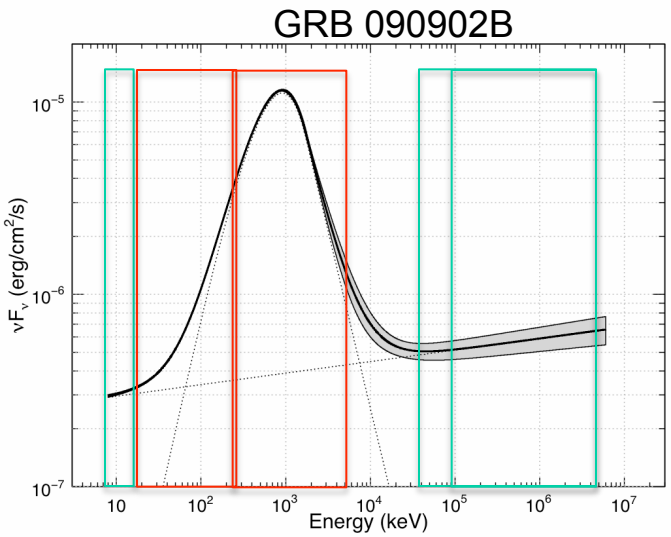


Also in long GRB



(arXiv:0909.2470)

See Jim Chiang Talk and Soeb Razzaque poster!



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?

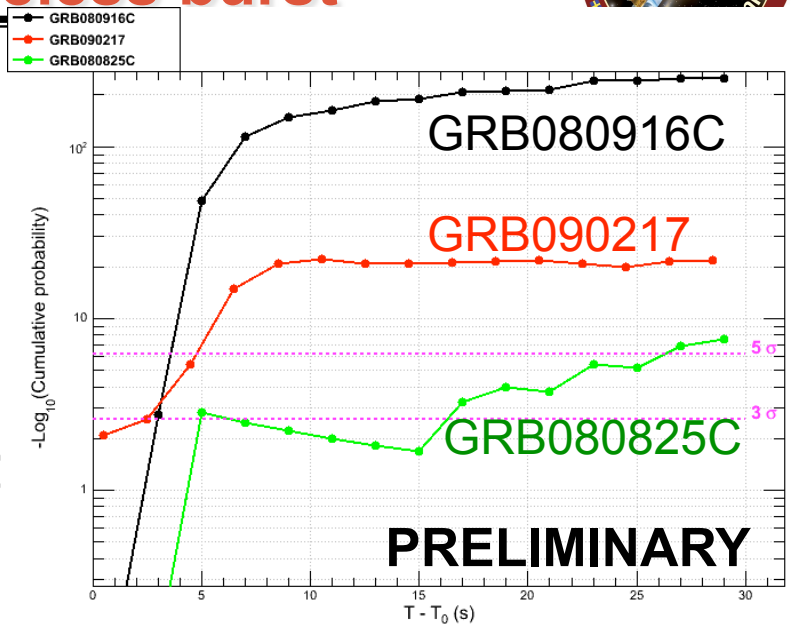
-**Hadronic** models providing hard component with excess at low and high energies?

-Can **Early afterglow** models produce a >10 GeV emission?

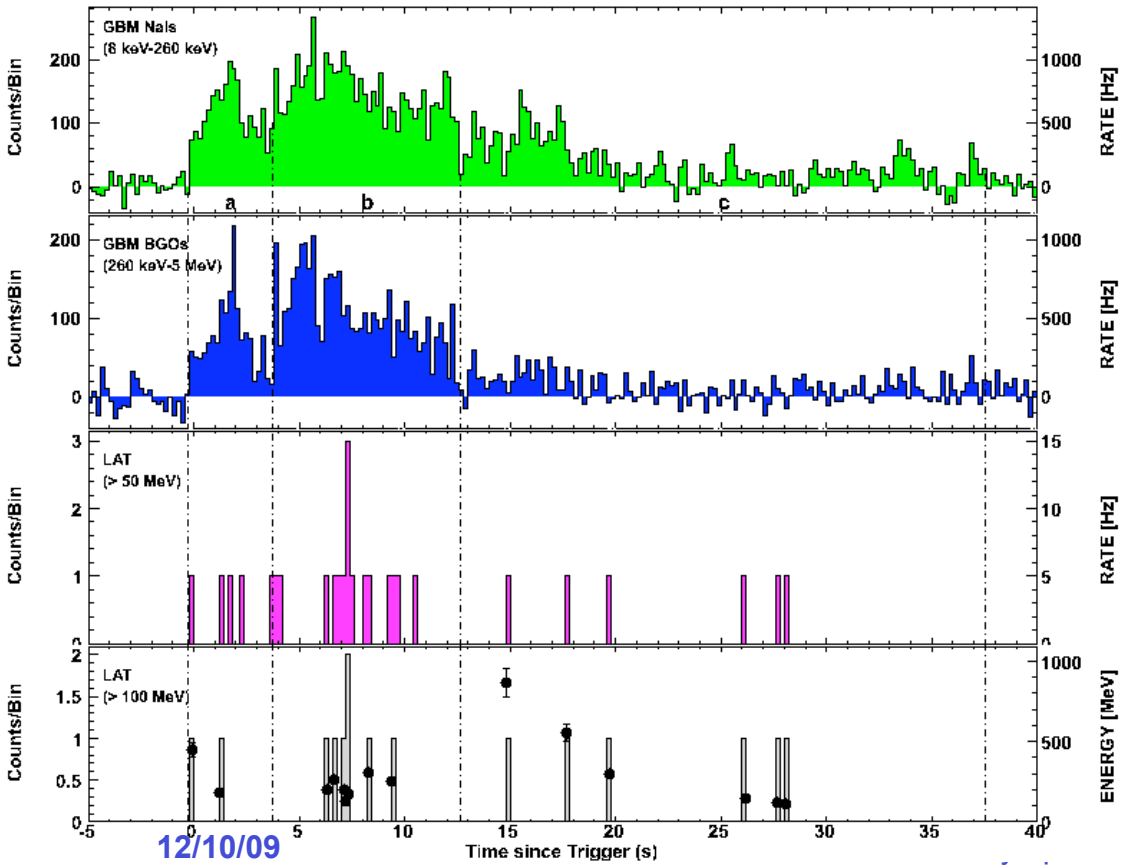
-Two non-thermal power-law + thermal component?

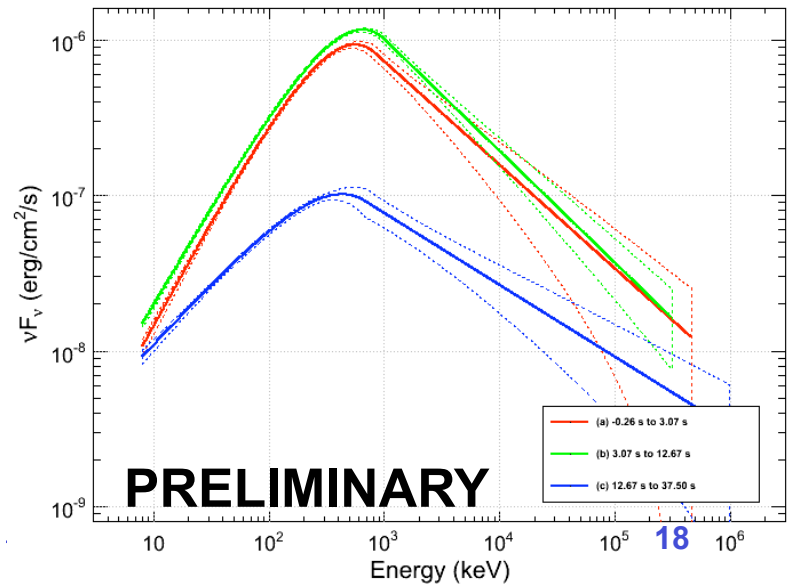
But Nature is bizarre: GRB 090217: a featureless burst

- >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

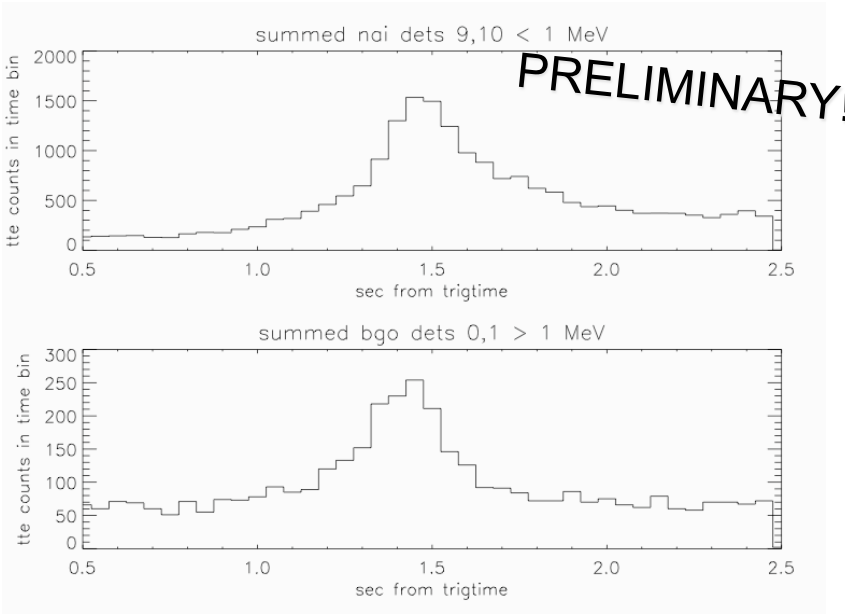


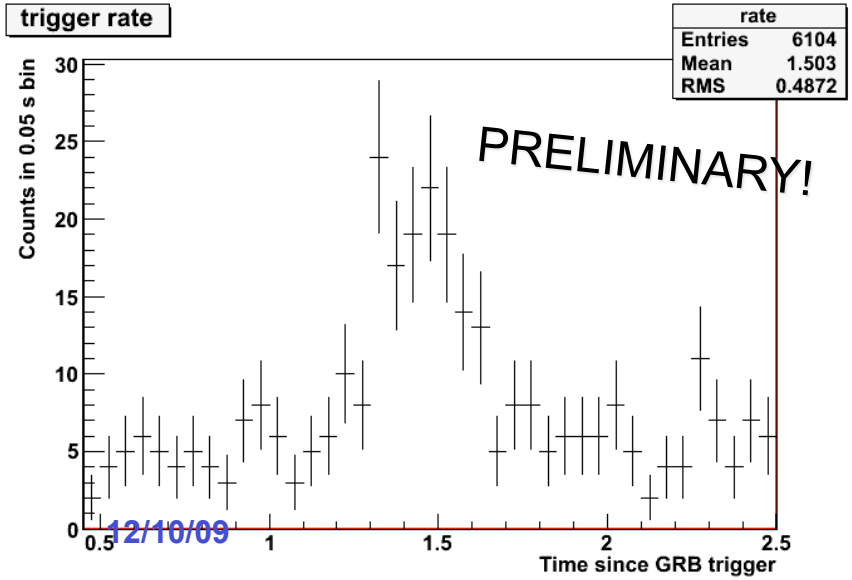
PRELIMINARY





GRB081215A - An interesting case...





- **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**

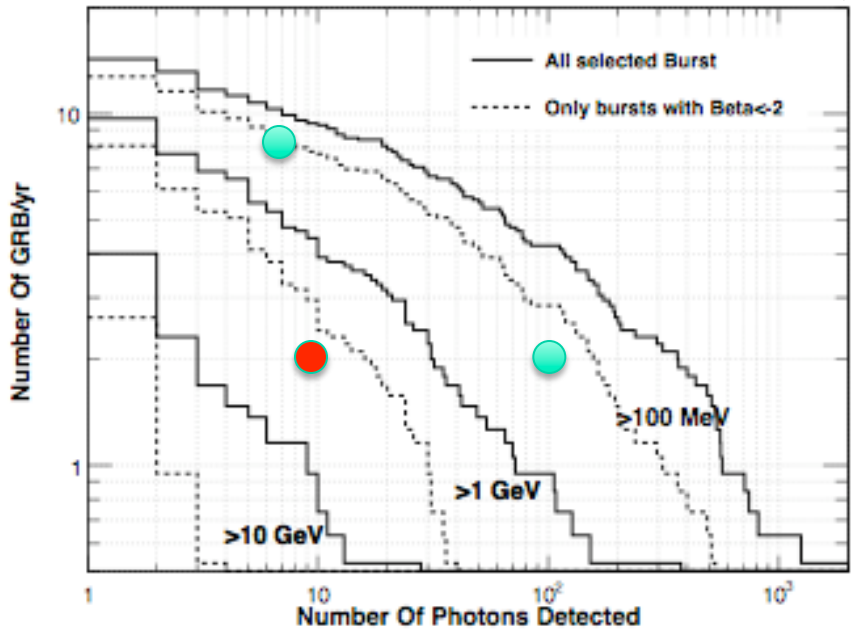
Summary of LAT Bursts

GRB	duration	# of events > 100 MeV	# of events > 1 GeV	delayed HE onset	Long-lived HE emission	Extra Component	Highest Energy	Redshift
080825C	long	~10	0	?	✔	x	~600 MeV	
080916C	long	>100	>10	✔	✔	?	~ 13.2 GeV	4.35
081024B	short	~10	2	✔	✔	?	3 GeV	
081215A	long	—	—	—	—	--	—	
090217	long	~10	0	x	x	x	~1 GeV	
090323	long	~20	>0	?	✔	?	?	3.57
090328	long	~20	>0	?	✔	?	?	0.736
090510	short	>150	>20	✔	✔	✔	~31 GeV	0.903
090626	long	~20	>0	?	✔	?	?	
090902B	long	>200	>30	✔	✔	✔	~ 33 GeV	1.822
090926	long	>150	>50	✔	✔	✔	~20 GeV	2.1062

Have we seen what we expected to see?

- **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).**

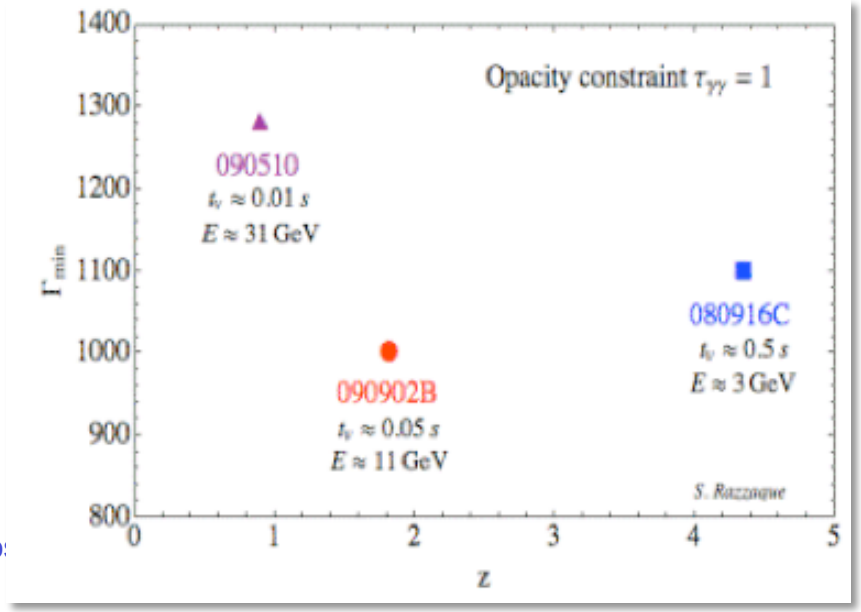
Band, D. L. et al. 2009, ApJ



See Dan Kocevski's talk on "Fermi-LAT Upper Limits for Fermi GBM-detected Gamma-ray Bursts"

Constraining physics

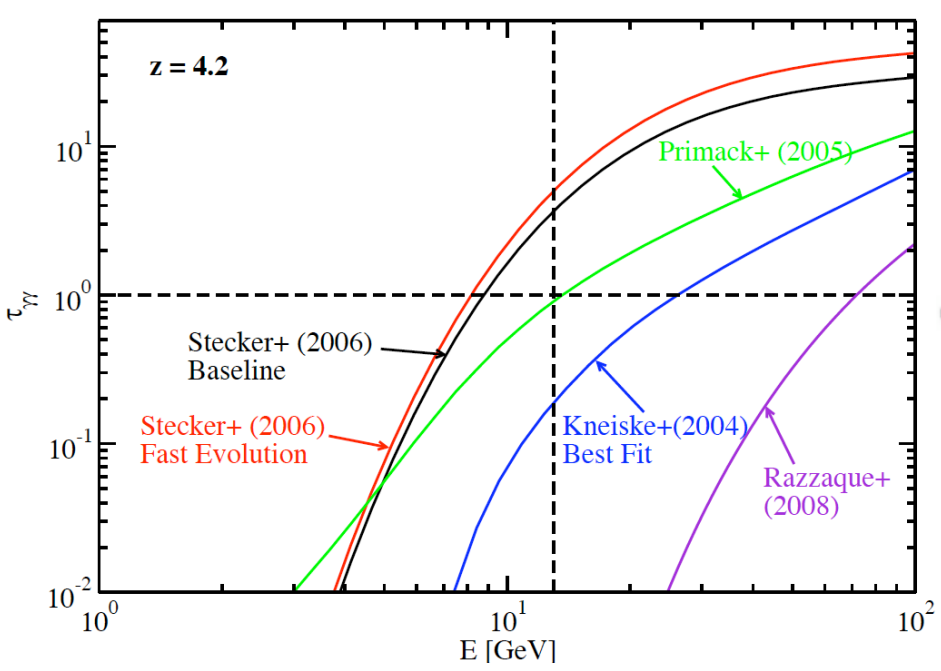
- **Relativistic motion of the emitting shell:**
  - **A relativistic motion of the shell allows higher energy events in dense region to escape.**
  - **Observing high-energy events correlated with the fast variability allows to constrain to the speed (G_{min}) of the emitting shell.**
  - **Assuming high-energy emission is spatially consistent with the low energy emission: GRB060916C, GRB090510, GRB090902B both have consistently G_{min} ~ 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…**

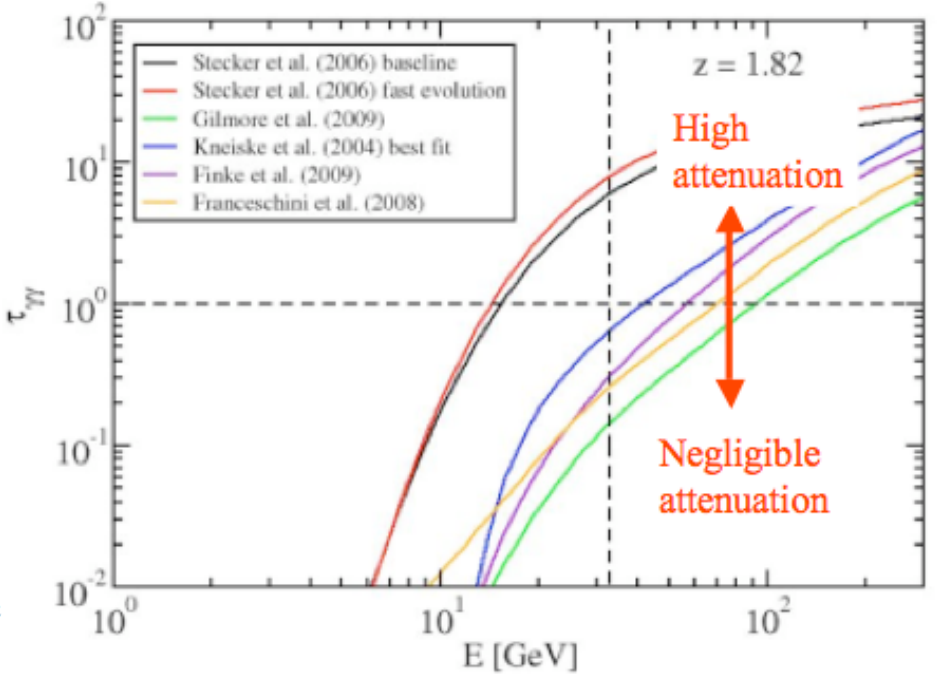


Constraining the EBL

- **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





Summary

- **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