High Energy Observations of Gamma-ray Bursts with Fermi

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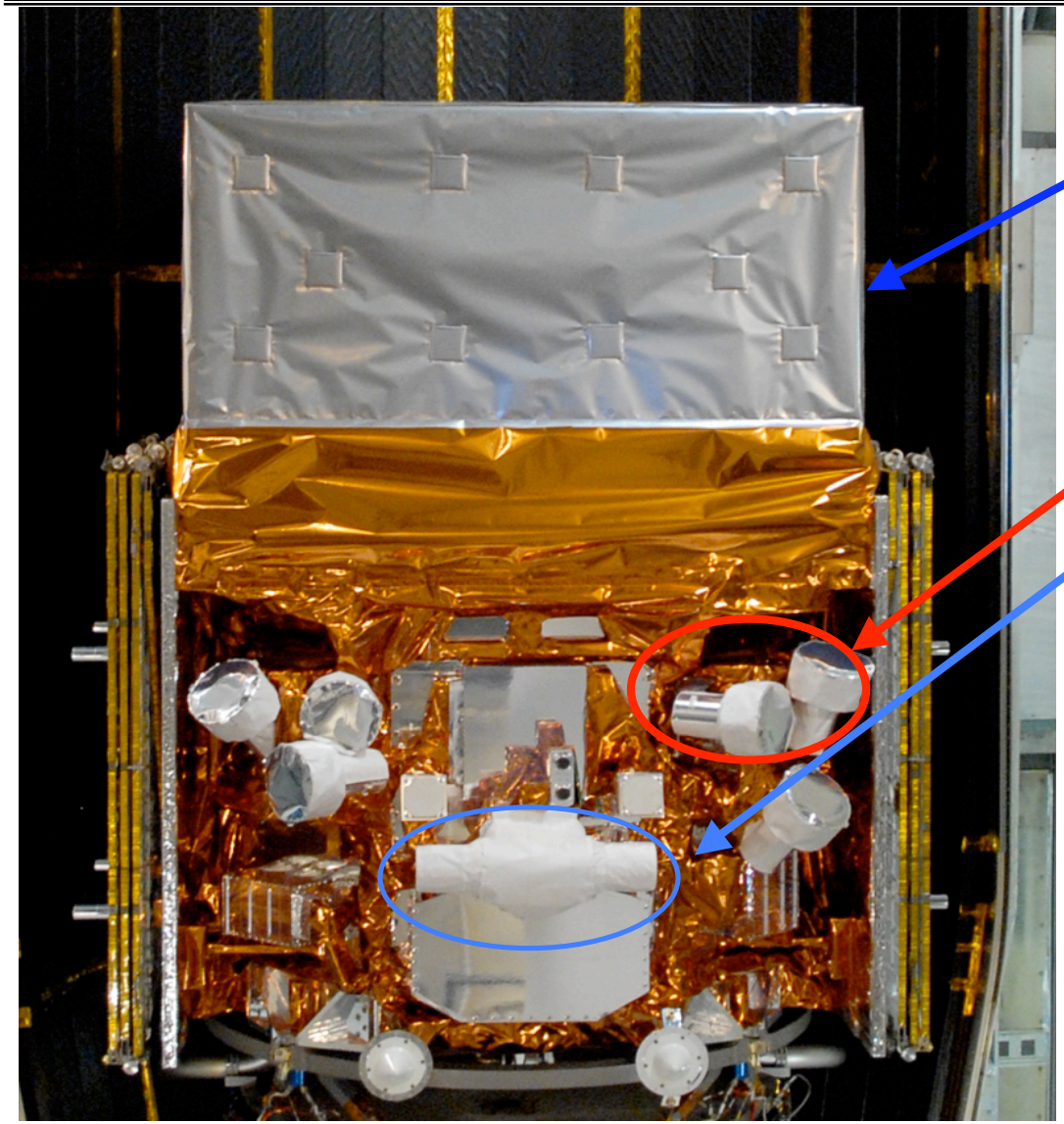
on behalf of the Fermi LAT and GBM Collaborations

The Fermi Observatory



Large Area Telescope (LAT)
Larger FOV (>2.4 sr): more GRBs
Larger effective area: better statistics
Less dead time: detailed lightcurve, time-resolved analysis
Wider energy coverage: up to > 300 GeV

Gamma-ray burst Monitor
12 NaI Detector
2 BGO Detectors
Onboard localization over the entire unocculted sky.
Covered energy range 8keV-40MeV

Huge field of view:

- LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours.
- GBM: whole unocculted sky at any time

Huge energy range:

Including the unexplored band: 10GeV-100GeV

Both LAT and GBM can independently trigger

Fermi and GRBs

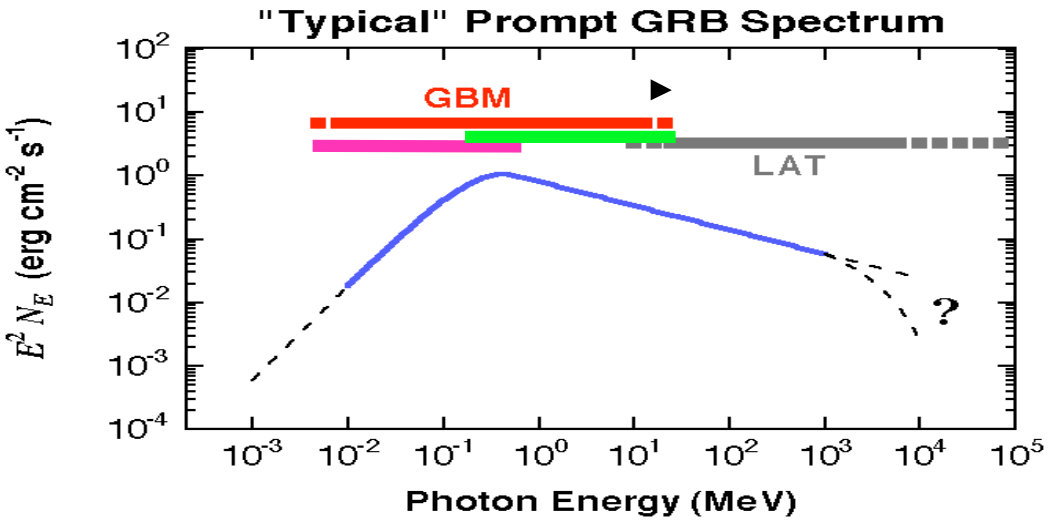
GBM-LAT synergy for GRB studies

✓Spectral coverage of more than 7 decades (8keV->300GeV)

- -Bright burst: study of the cut-off,if any.

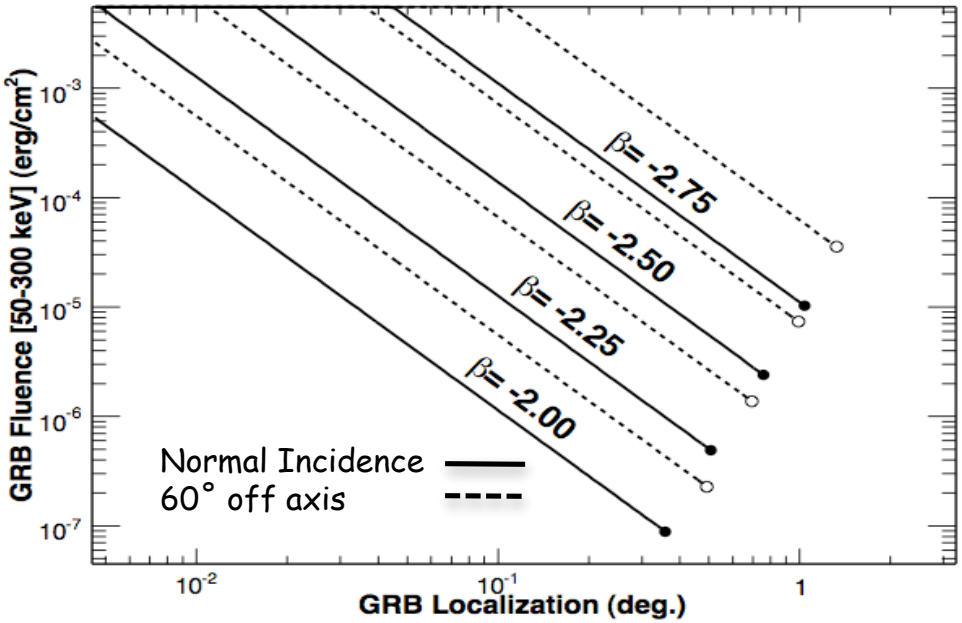
✓Detailed temporal/spectral resolution:

- -Is there any "extra component"?
- -How common is the extended/delayed GeV emission?
- -Time Lag in pulses as a function of energy
- -Intrinsic lag vs cosmological effects (QG)
- -Constrain the LF of the expanding shells.

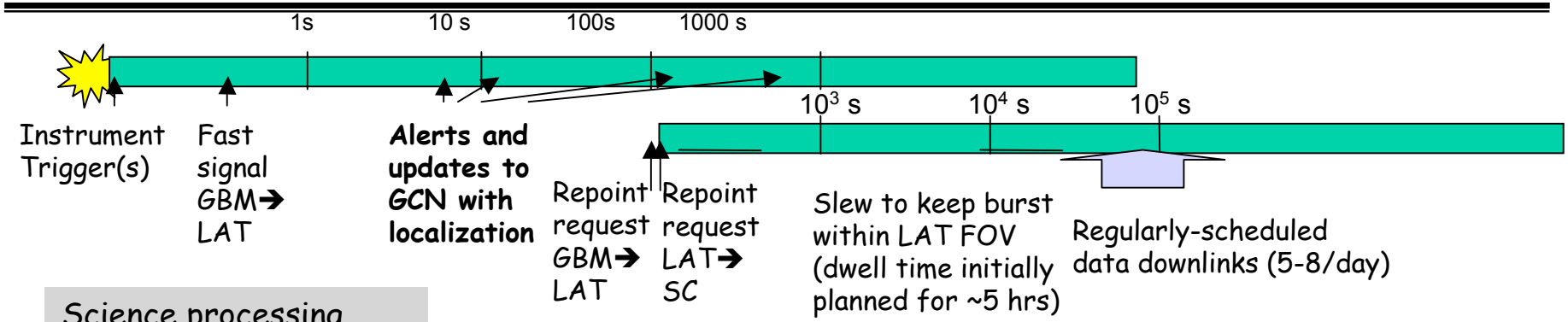


Connection with the other wavelength

- This scenario gets even more exciting if other observatories are involved thanks to the good LAT burst localization
  - X-ray- GeV connection:
    - Simultaneous detection of X-Optical afterglow with Swift➔ better determination of the localization and redshift determination
    - X-Ray flares – GeV emission at late time (Galli et al. 2007)
  - TeV connection:
    - Few GRB/yr have LAT location <0.1 degrees, suitable for TeV observation
    - Very-High-Energy delayed emission?? (Galli et al. 2008)



Alerts and Data Flow

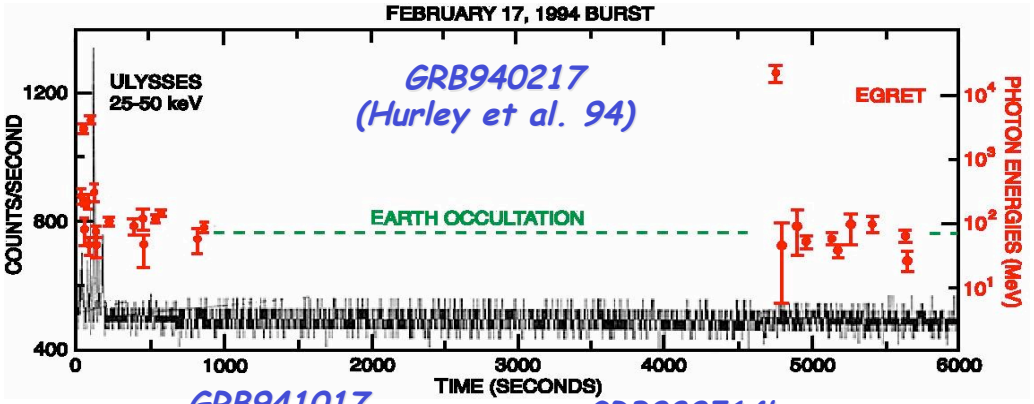


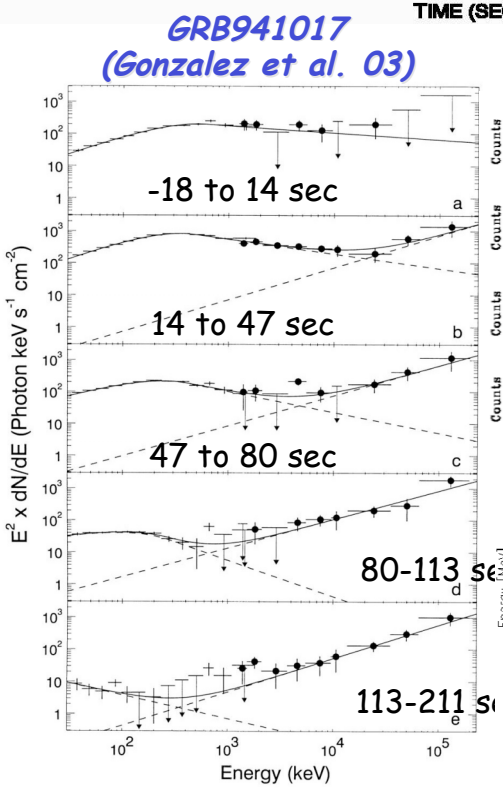
Science processing parameters reviewed by Users Committee

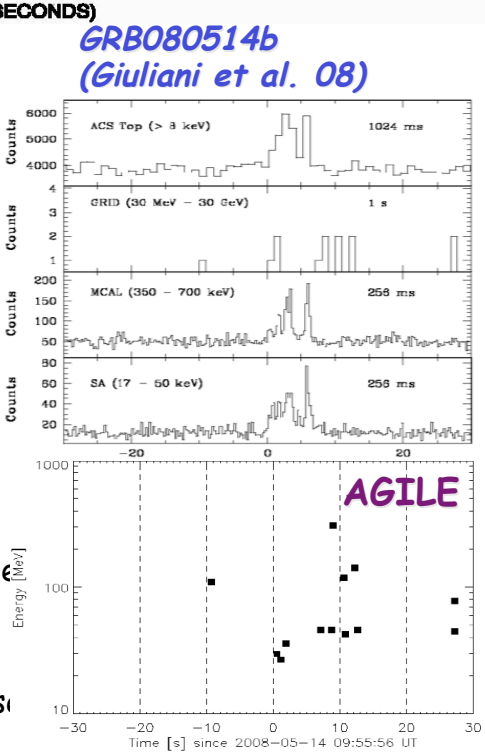
Planned repoint frequency (adjustable):
- bursts starting within LAT FOV ~1/week
- bursts starting outside LAT FOV ~1/month

- **Onboard processing (both LAT and GBM) - GCN alerts:** location, intensity (cnts), hardness ratio, trigger classification etc
- **GBM ground processing of prompt data (few minutes):**
  Updated GBM position, preliminary light curve
- **LAT ground processing (5-12 hours):** updated location, high energy spectrum, flux (or upper limit), afterglow search results
- **Final ground processing (24-48 hours):** GBM model fit (spectral parameters, flux, fluence), joint LAT-GBM model fit.

High Energy Emission from GRB: Before Fermi







Limited knowledge about GRB emission above ~100 MeV

Few GRB detected by EGRET:

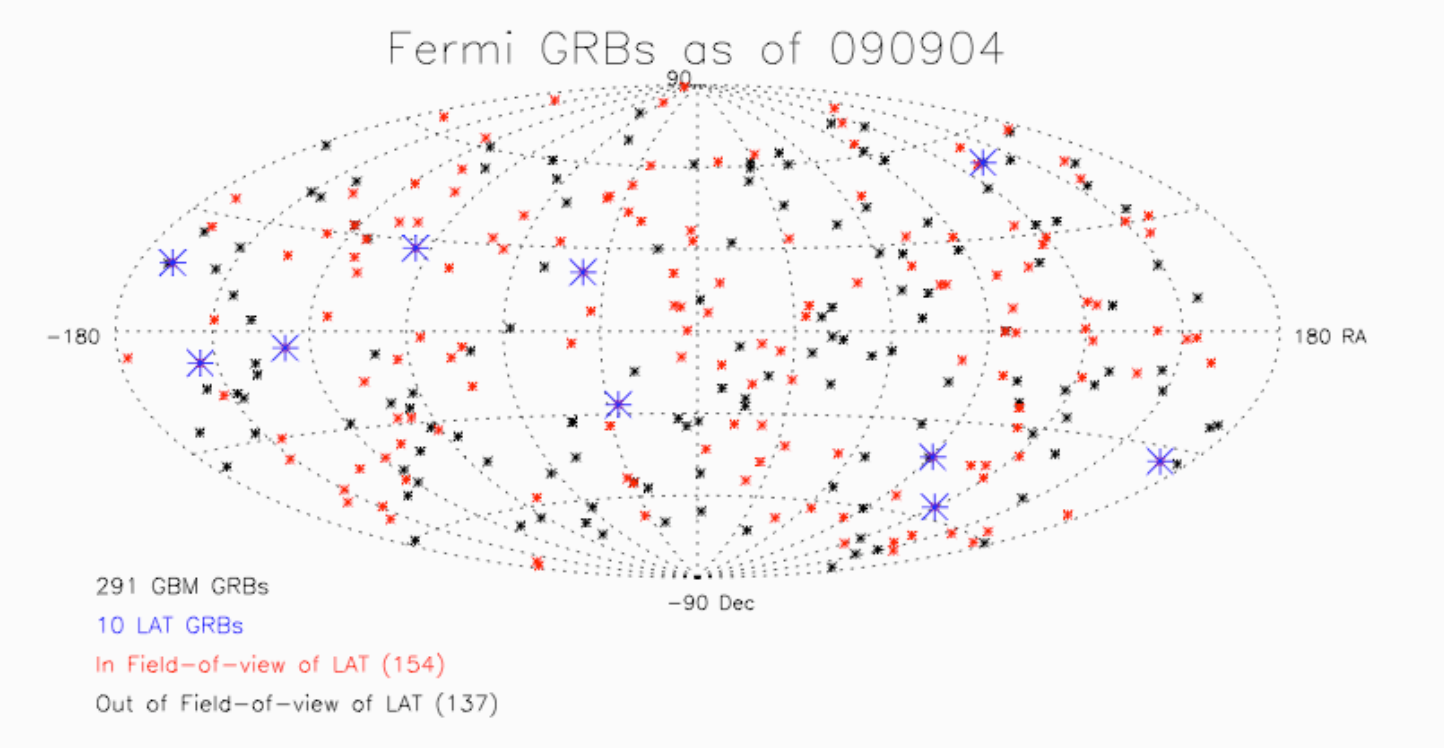
GRB940217:
18 GeV photon were detected up to 90 minutes after the GRB trigger

GRB941017:
distinct high-energy spectral component (up to 200 MeV), with a different temporal evolution

AGILE recently detected:

GRB080514B:
detected photons up to a few 100 MeV lasting somewhat longer than the soft gamma-rays

Fermi-LAT GRB detections

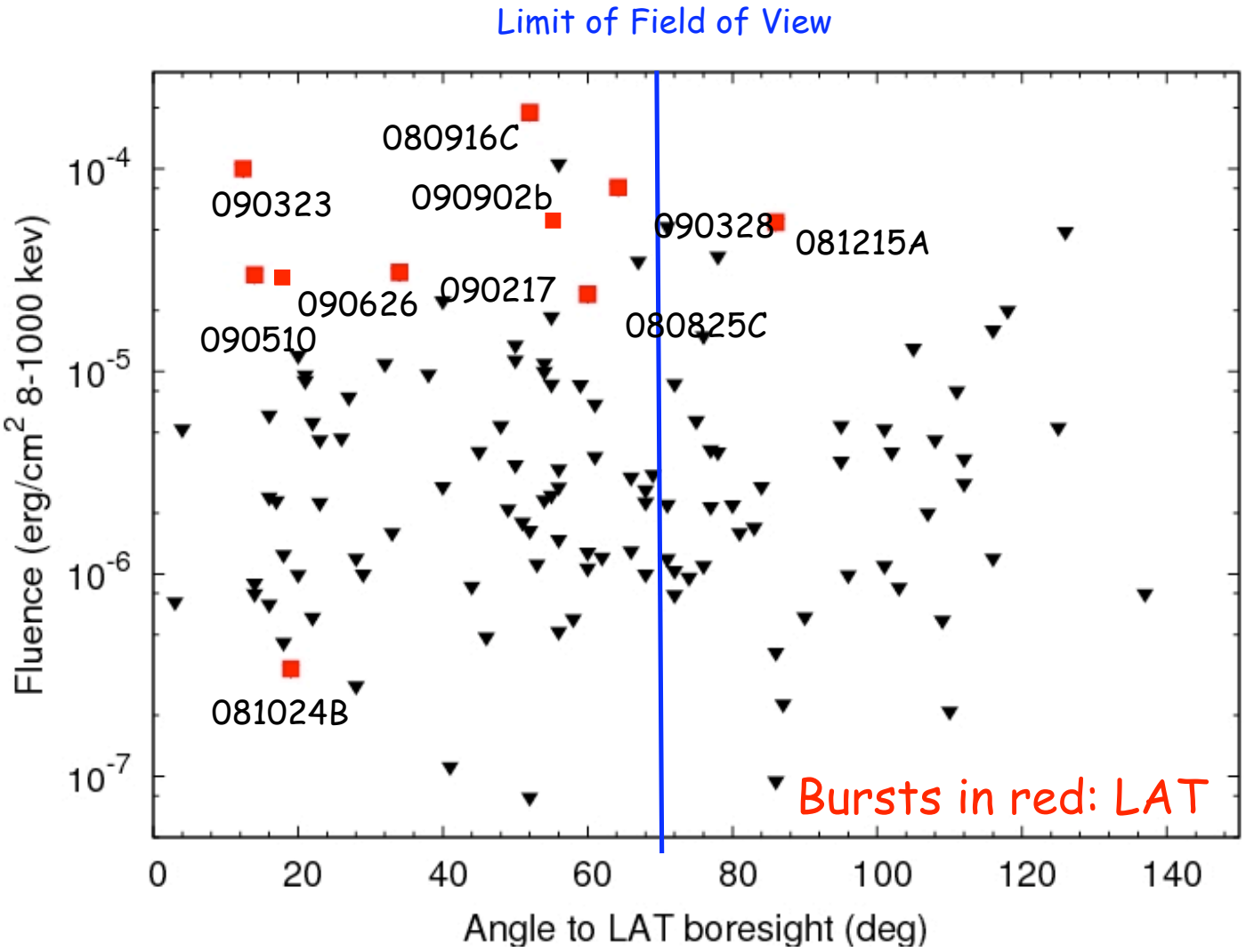


- ✓1 year from GBM turn on: 252 GRBs, 138 in the LAT FoV
- ✓11 GRB detection at high energy so far (9 in the first year)

  9 long bursts (080825C, 080916C, 081215a, 090323, 090328, 090626, 090902b & 090926) &

  2 short bursts (081024b & 090510)

Fluence of LAT bursts



Temporal profile

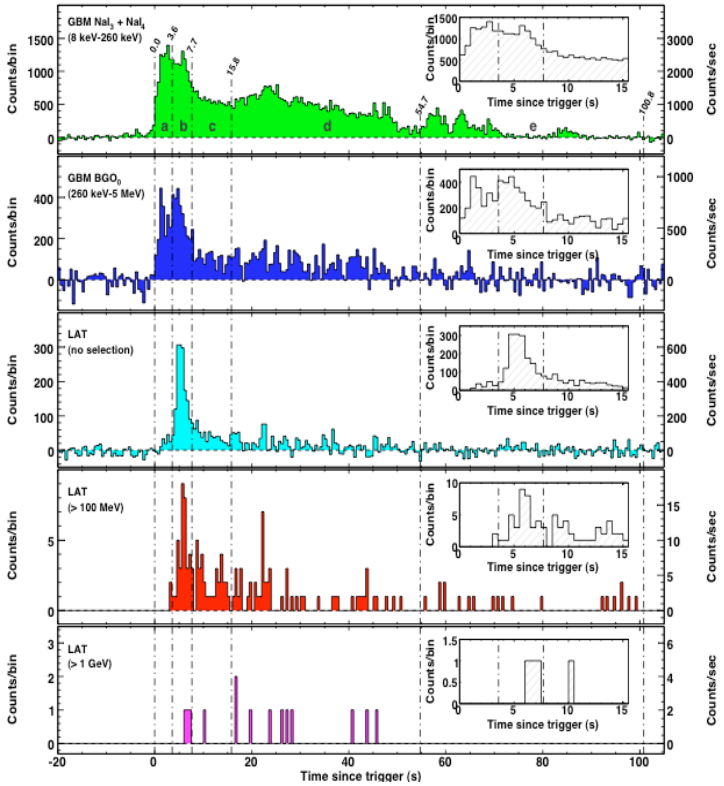
✓Delayed HE emission ➔ long (080916C, 090902b & weak possiblity in 080825c)

and short GRBs (081024b & 090510)

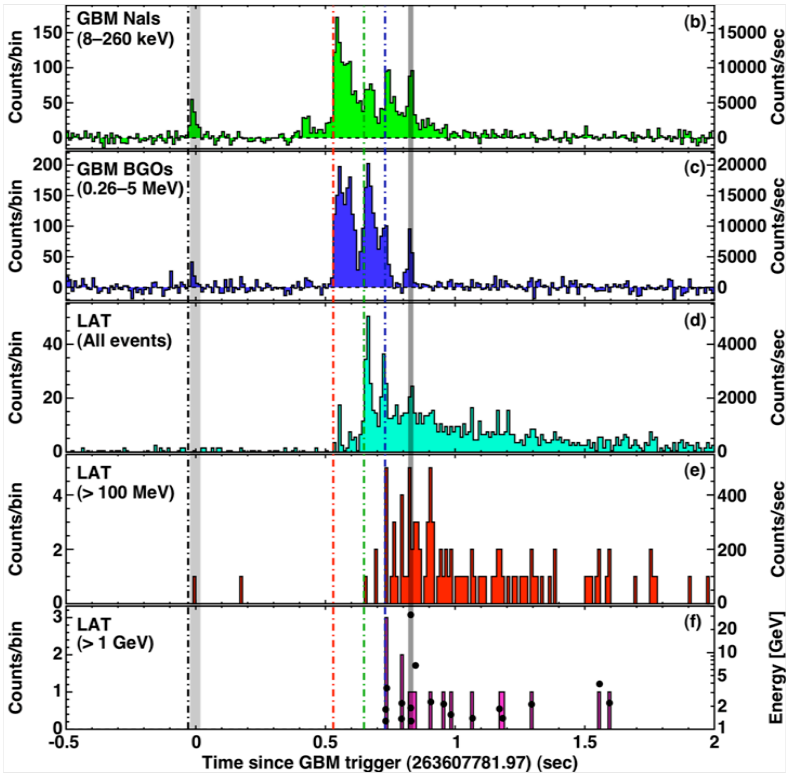
-080916C-> proton synchrotron radiation in the prompt phase (Razzaque et al 09)

-090510-> electron synchrotron radiation in the early afterglow phase (Ghirlanda et al 09)

GRB080916C (long)

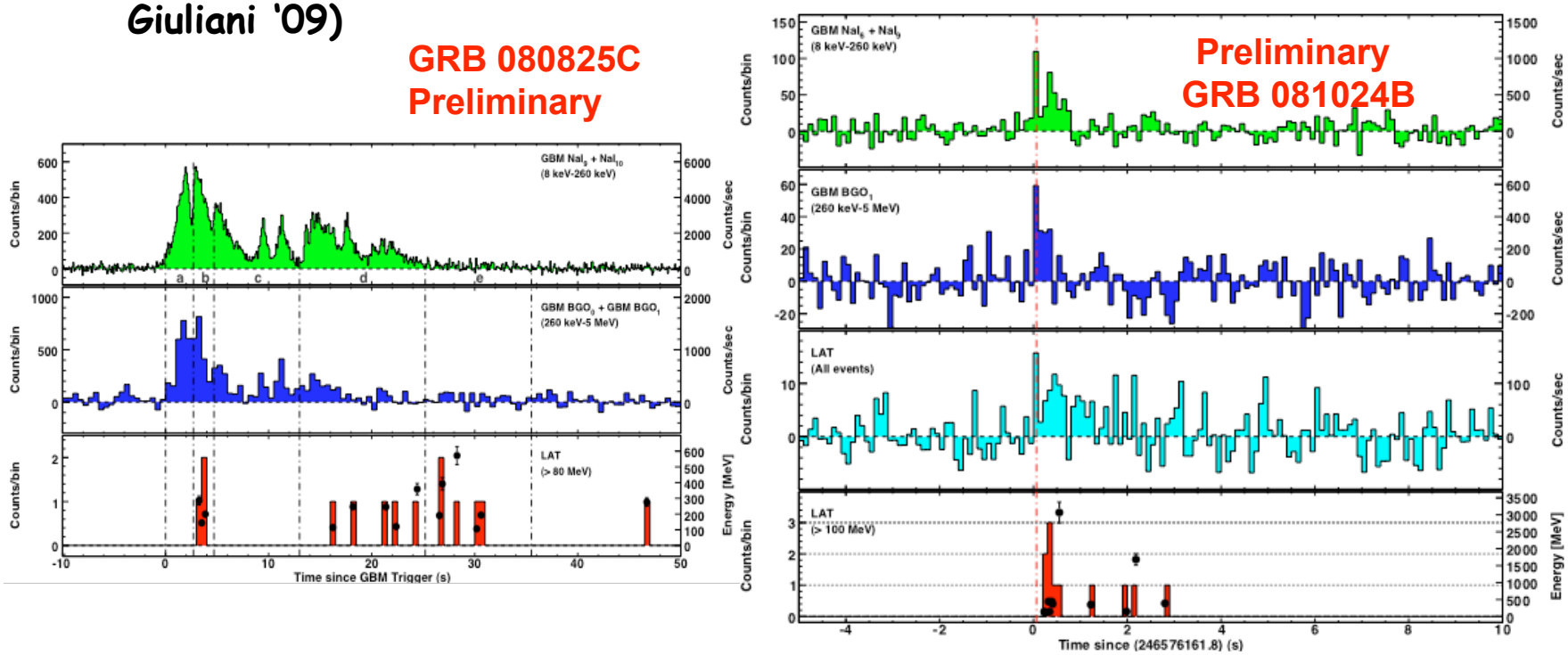


GRB090510 (short)



Temporal profile

- Apparent temporal onset of high-energy emissions (coincident with 2nd GBM pulse)-> 080825c: Monte Carlo simulation confirms that there is a weak evidence of the delay but evidence of temporally extended emission
  - Separate region from initial GBM emission
- Highest energy is very late
- Similar template seen in short bursts
- Delayed emission also detected by Agile (080514B, Giuliani '08, 090510, Giuliani '09)

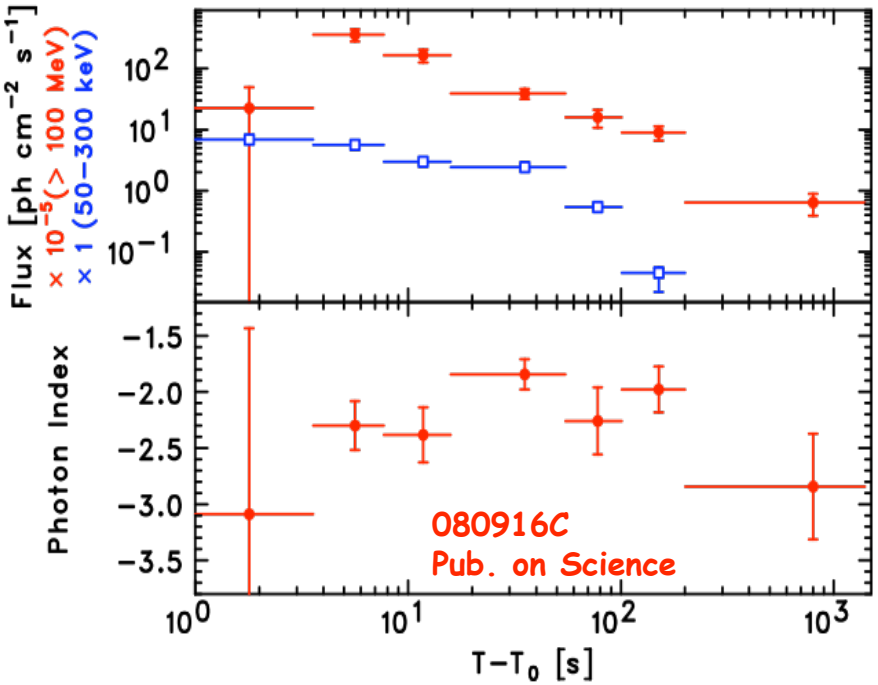


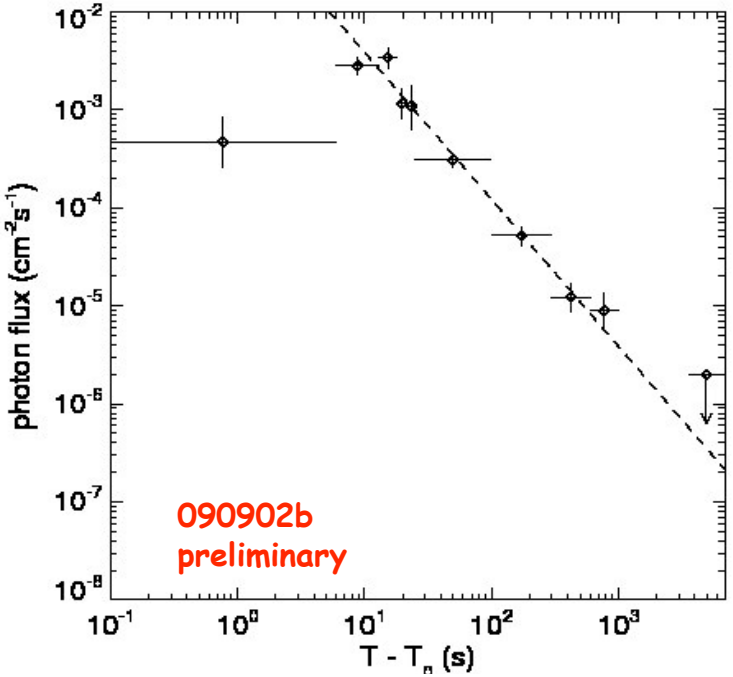
Temporal profile

✓Afterglow HE Emission ➔ Long (080825c, 080916C, 090323, 090328, 090626 & 090902B) and short GRB (090510 & 081024b)

·HE (>100 MeV) emission shows different temporal behavior

-Temporal break in LE emission while no break in HE emission





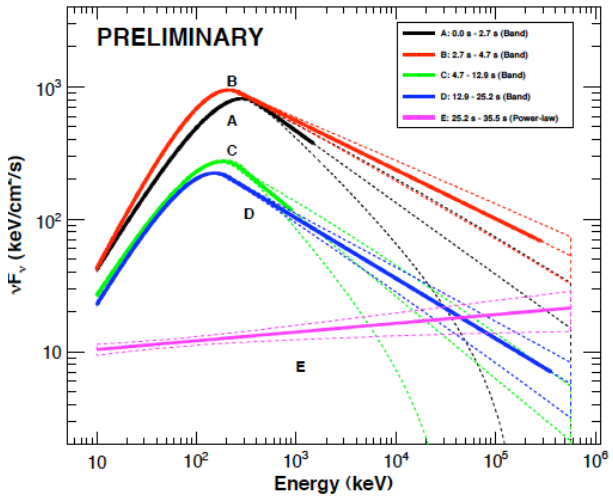
Spectral Evolution

Strong spectral evolution ➔long bursts (080825C, 080916C & 090902b)
short bursts (081024b & 090510)

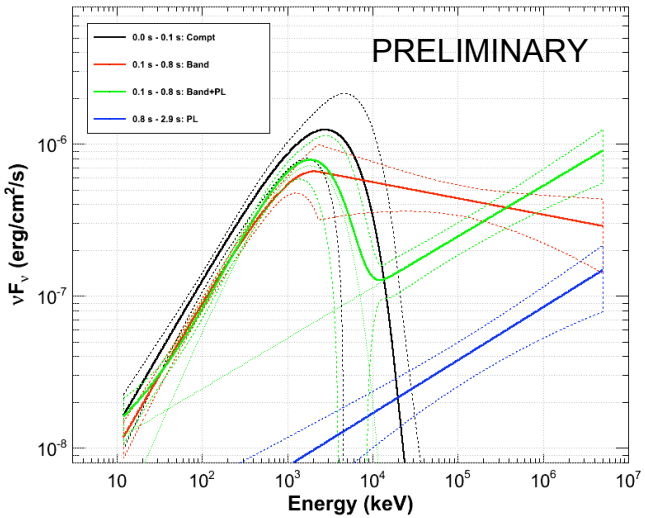
✓**Some trends**

- **Soft to hard evolution**
- **"Extra component" @ HE**
  - **Few events in GRB081024B, not possible to discriminate models**
  - **Evidence in GRB090510, GRB090902**

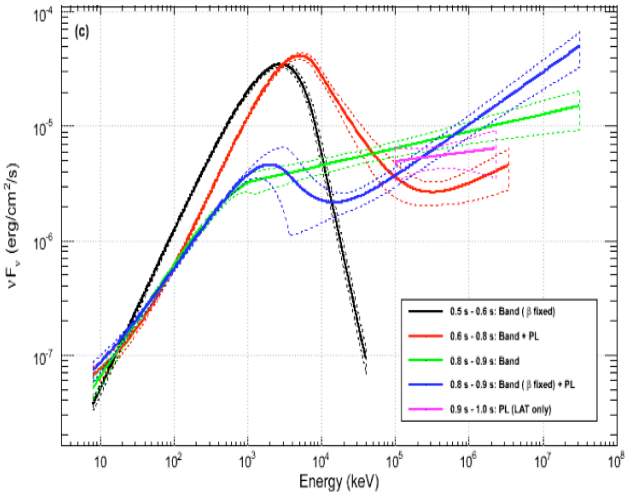
GRB080825C



GRB081024b



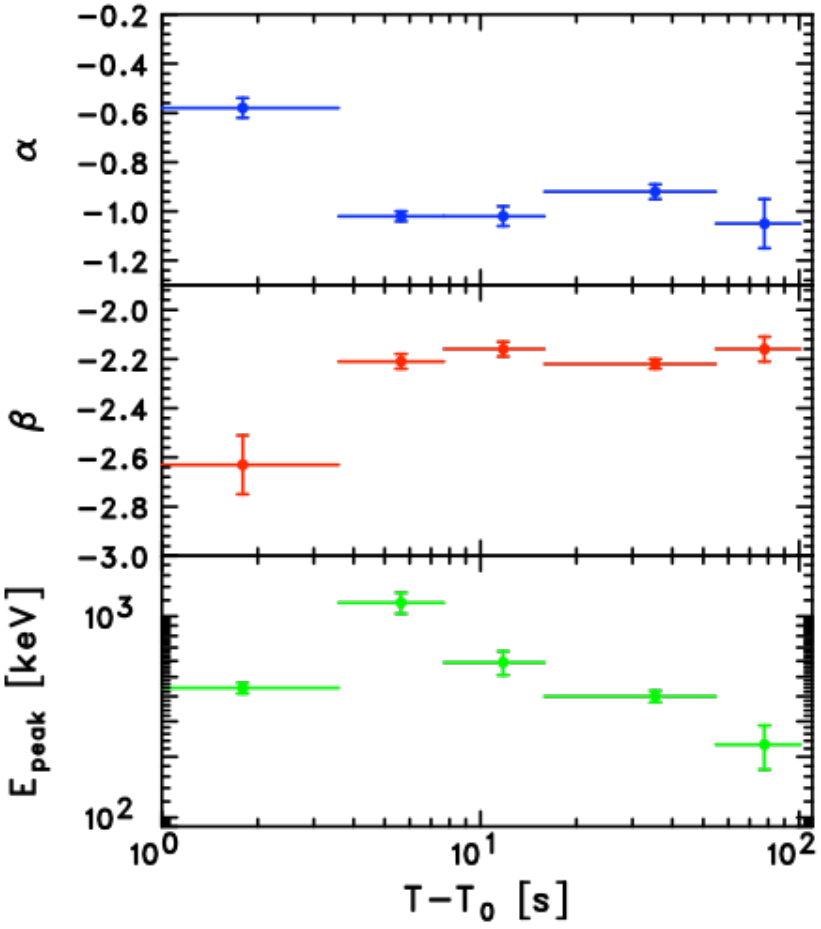
GRB090510

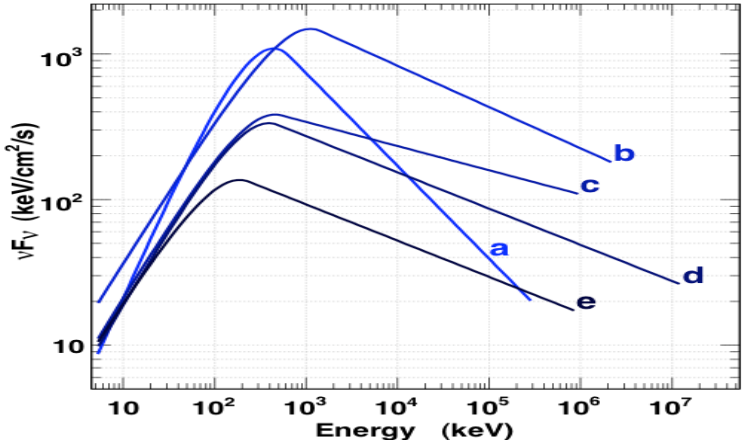


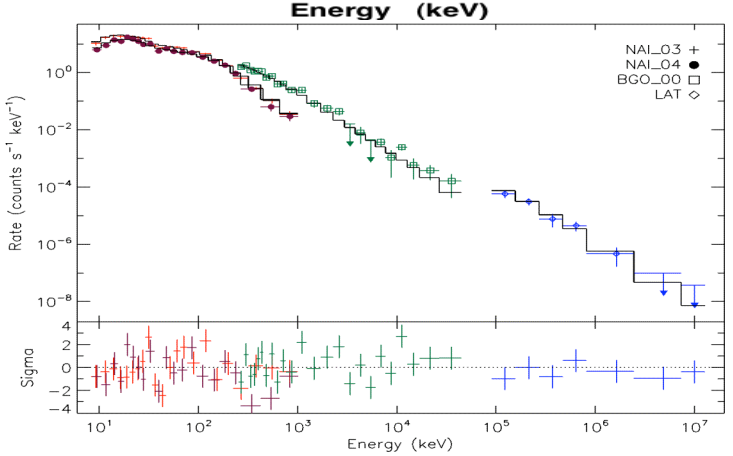
Time resolved spectral analysis: 080916C

- -Rapid soft to hard evolution, then hard to soft.
- -Gradual decrease of Epeak
- -No evidence of extra-component

GRB 080916C

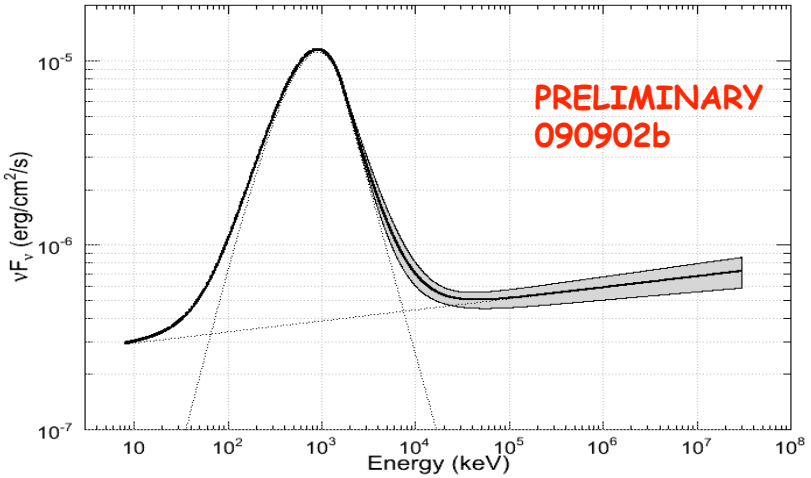


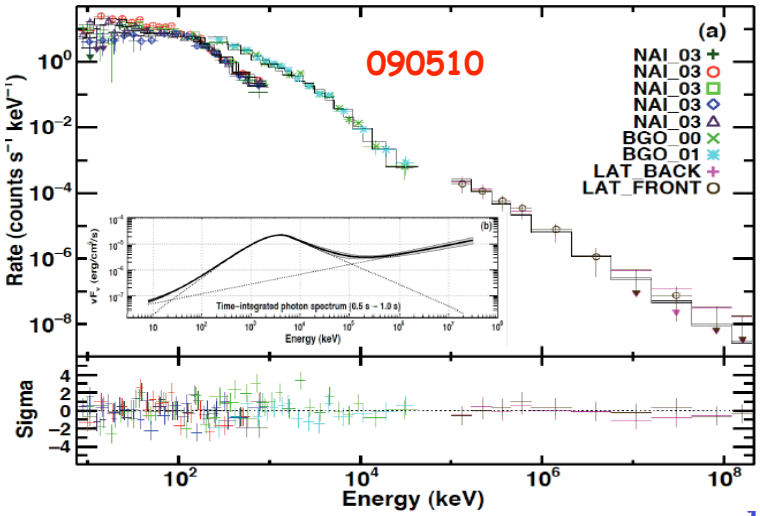




High Energy Extra Component

-Two bursts show a clear (>5σ) evidence of extra component: GRB090902b (long burst) & GRB090510 (short burst)



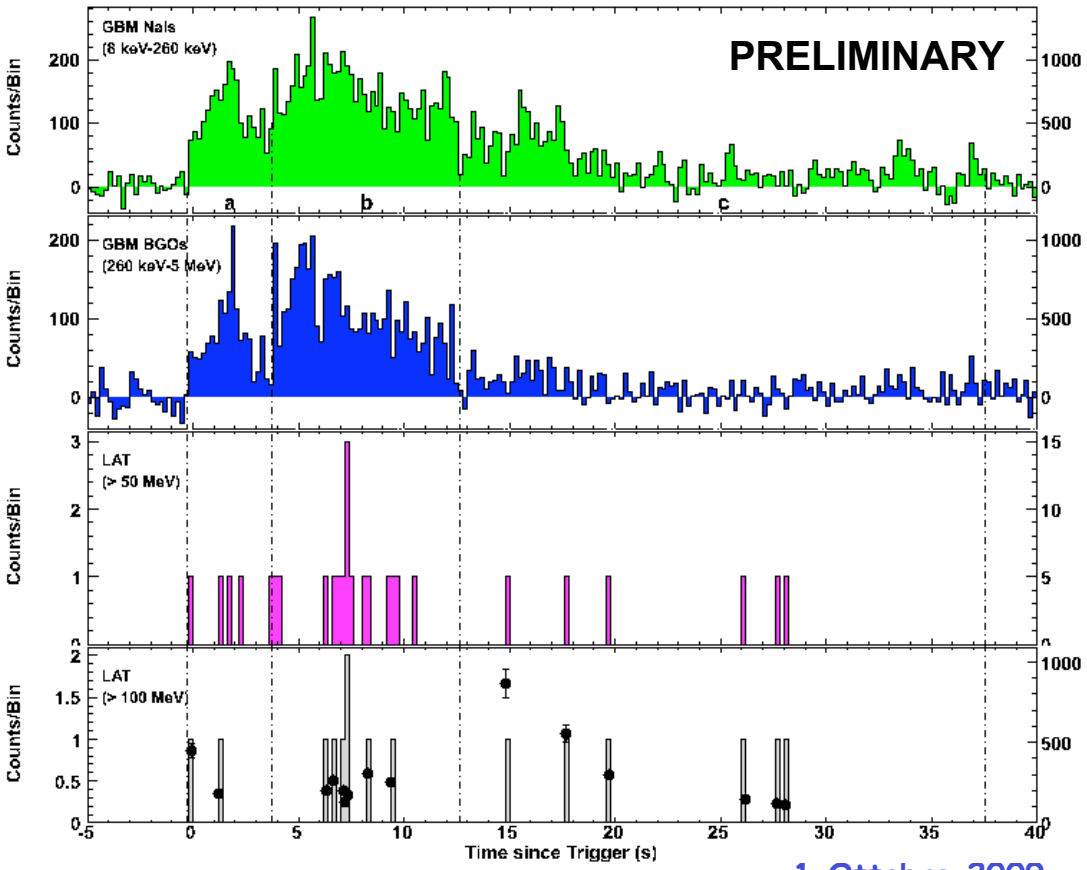


Significant deviation from Band function➔ PL component
(low energy <50keV & high energy >100MeV)
-Hadronic model, proton synchrotron radiation (Razzaque et al. 2009)?
-photohadronic interactions (Asano et al. 2009)?

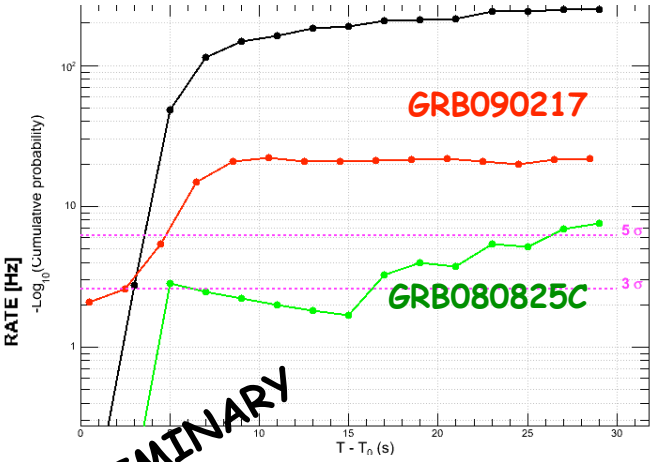
Best modeled by a Band function + PL component
Leptonic Model:
Synchrotron- synchrotron self Compton
Hadronic Model:
Emission from ultra-relativistic protons and ions (photo-meson or synchrotron processes)

The featureless burst: 090217

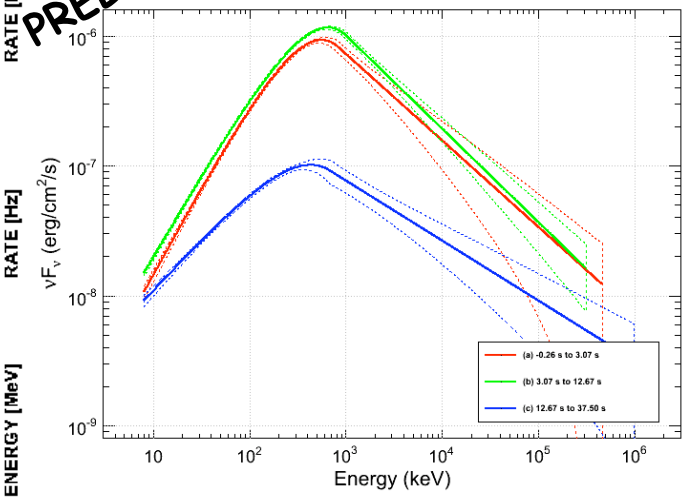
- No delay in HE emission, and different event accumulation
- Band model with no spectral evolution
- No extended emission



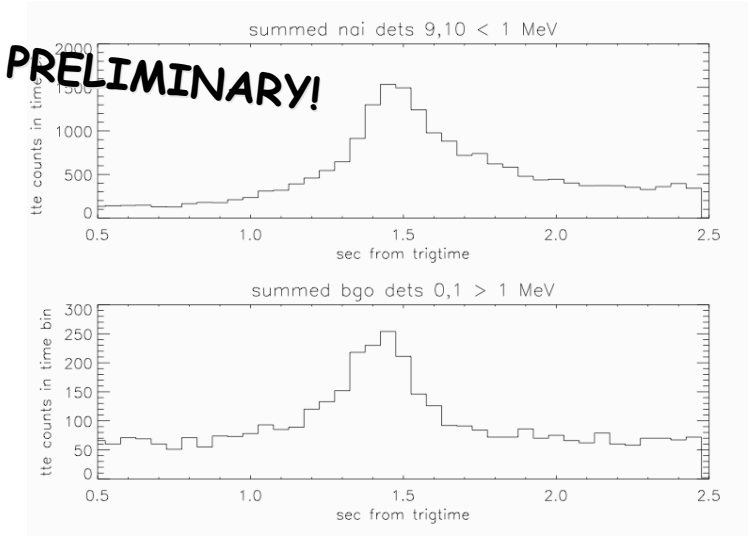
GRB080916C



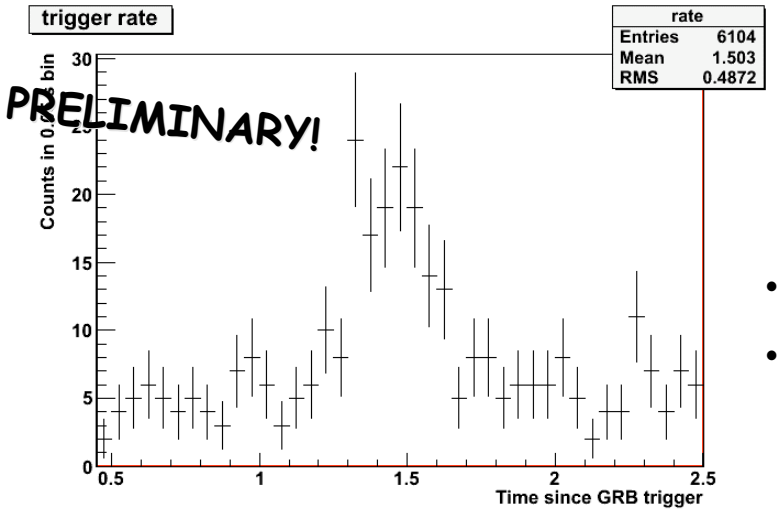
PRELIMINARY



An interesting case...081215a



- ✓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



- •Did not last longer than GBM pulse
- •Not delayed with respect to GBM pulse

Summary of LAT detected bursts

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

Summary

that's just the beginning!!!

- Fermi is performing extremely well, the LAT already doubled the number of GRBs detected above 100 MeV
- Some observed properties
  - High energy emission (>100 MeV) observed in both long and short bursts
  - Delayed onset between LAT and GBM ("the missing peak") in many cases
    - Characteristic Spectral evolution
    - Separate region from initial GBM emission (Internal Shocks?)
    - Not seen in 090217
    - Both in long and short bursts
- Single Band-function dominates 6 decades of energy band
  - 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)