
# GRB090510, a short bright and hard GRB detected by Fermi

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Università and INFN Bari
on behalf of Fermi LAT/GBM collaborations

# Fermi gamma-ray burst GRB 090510 observations limit variation of speed of light with energy

**(Abdo et al. Nature submitted)**

**A paper on the extended emission Swift/Fermi**
**de Pasquale et al. in preparation**

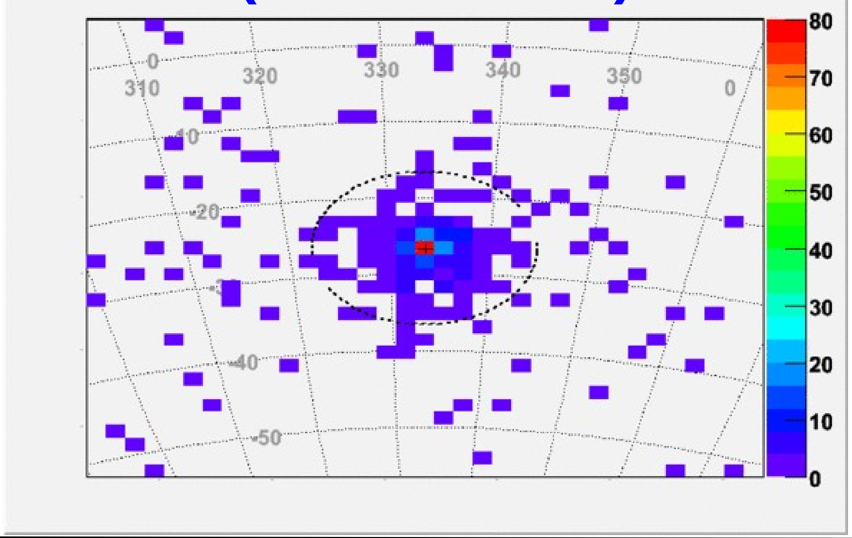
# Outline:

- Multi-wavelength detection
- Duration and t90
- Light curve
- Spectral analysis (time integrated and resolved)
- Possible source of the prompt extracomponent
- Multi-wavelenght analysis of the extended emission
- Constrain on the $\Gamma_{min}$ of the source
- Limit on the LIV
- Conclusions and scientific highlights

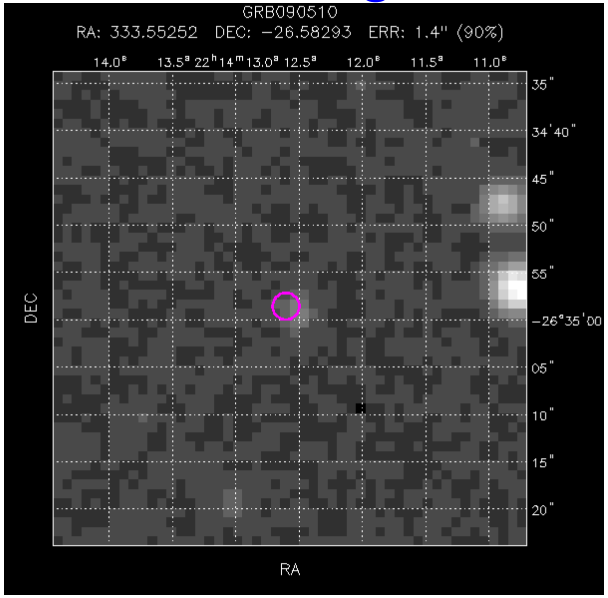
# Multiwavelength detection of GRB090510

- Bright, short GRB090510106 triggered the GBM at 00:22:59.97 UT.
- >5sigma detection by Fermi-LAT (Ohno et al. GCN 9334)
- >10events above 1 GeV (Omodei et al. GCN 9350)
- 1st LAT onboard GCN notices were issued
- Many other satellites as SWIFT, AGILE, Konus-Wind, Suzaku WAM, INTEGRAL/SPI-ACS and ground telescopes as NOT and GROND detected this event.
- Spectroscopic redshift z=0.903(+/-0.003) (VLT:Rau et al.; GCN 9353)

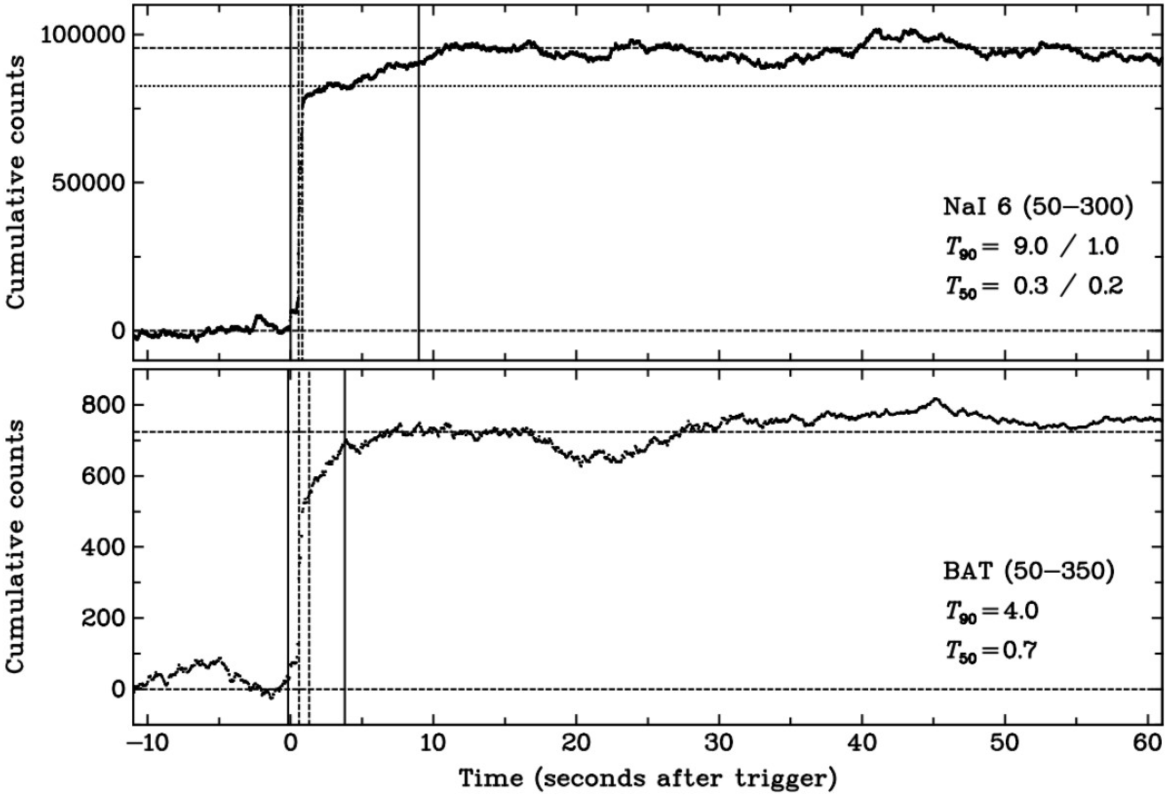
**LAT count map for prompt emission (T0 to T0+50s)**




**Swift XRT afterglow image**



# Multidetector duration study



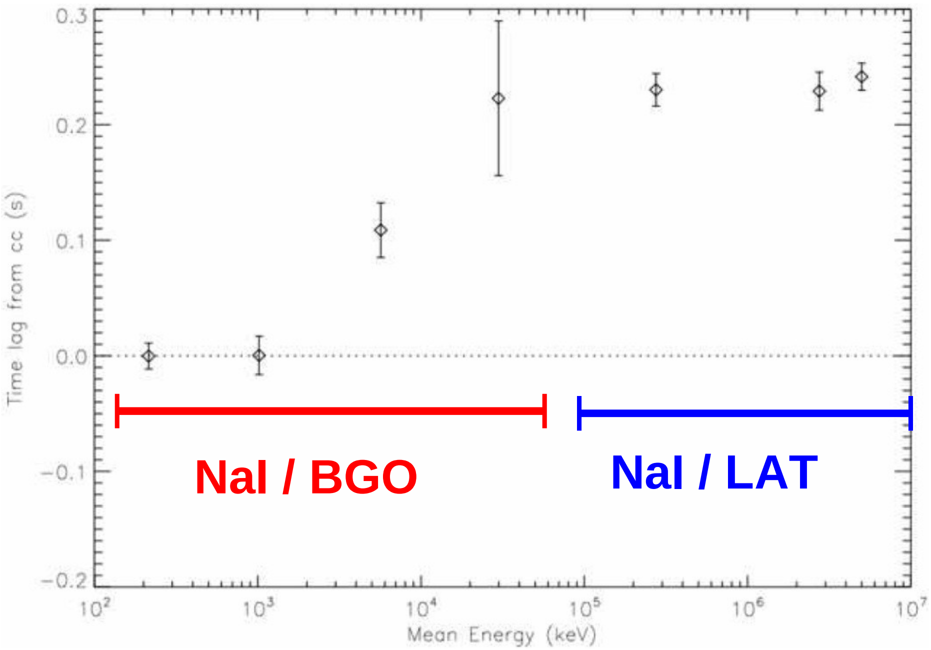

Duration computed in the standard energy range 50-300 keV with NaI detectors

$T_{90}$ (NaI3,6,7) = 2.1s
$T_{50}$ (NaI3,6,7) = 0.2s

$T_{90}$ (NaI6) = 9s
$T_{50}$ (NaI6) = 0.3s

Background fluctuation => not unique plateau selection.

# Spectral lag analysis




Methods : Cross Correlation Function (CCF) and a LAT only spectral lag analysis that use the Shannon Information cost function.

$T - T_0 = 0.5\ s \div 1.45\ s$

Energy intervals for CCF:

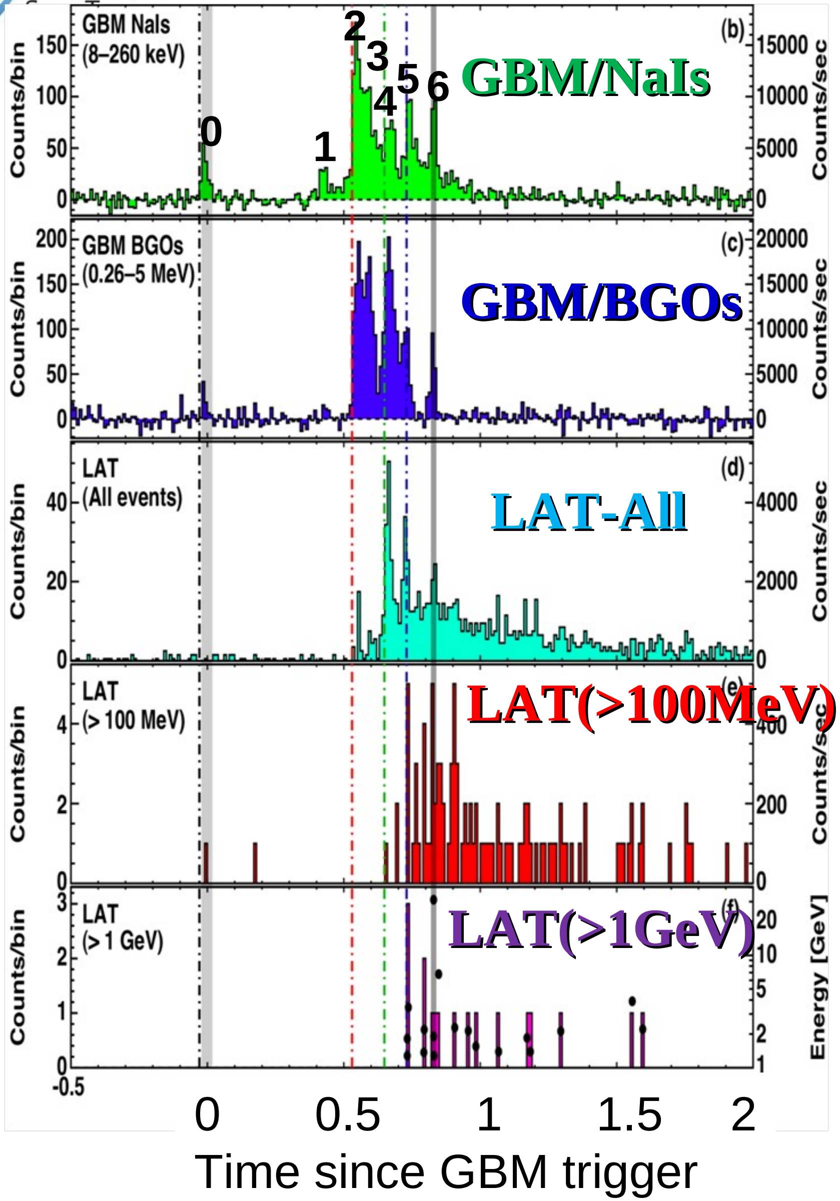
- BGO: from 0.11 to 45.5 MeV
- LAT : 0.1-1 GeV, 1-10 GeV and >10 GeV

Base band-width : NaI 8-40 keV

- Results:
  - Similar results with both methods
  - **<1MeV: spectral lags negligible**
  - Progressive increase up to ~250ms then remain constant after 30 MeV.
  - For the LAT only data the lag at 99% c.l. is <30 ms/GeV

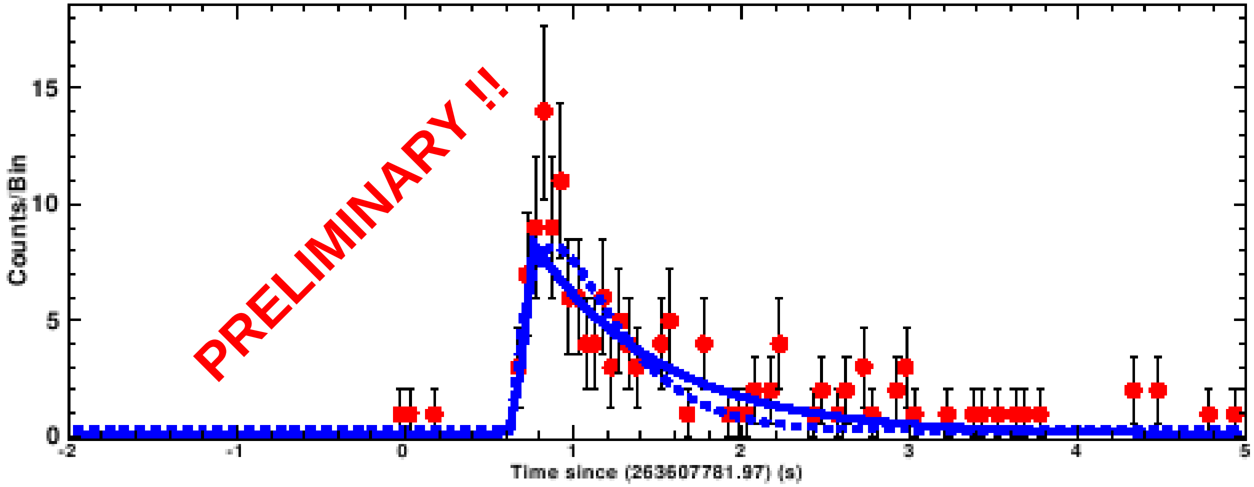
**$T_{90}$=2.1 s**
**No spectral lag**
→ **Short Burst**

# GRB090510: Fermi Lightcurve




- GBM triggered on a weak and soft pulse ($T_0$).
- 6 main peaks in GBM (NaI+BGO) from $T_0$+0.4s to $T_0$+1s
- LAT emission is delayed and starts in coincidence with the brightest NaI peak ($T_0$+0.53s)
- Emission >100MeV begins with the 4$^{th}$ low energy peak ($T_0$+0.63s)
- 31 GeV photon is observed 0.8 s after the trigger
- High energy emission lasts much longer that the low energy (>0.1 GeV detected up to $T_0$+200s)

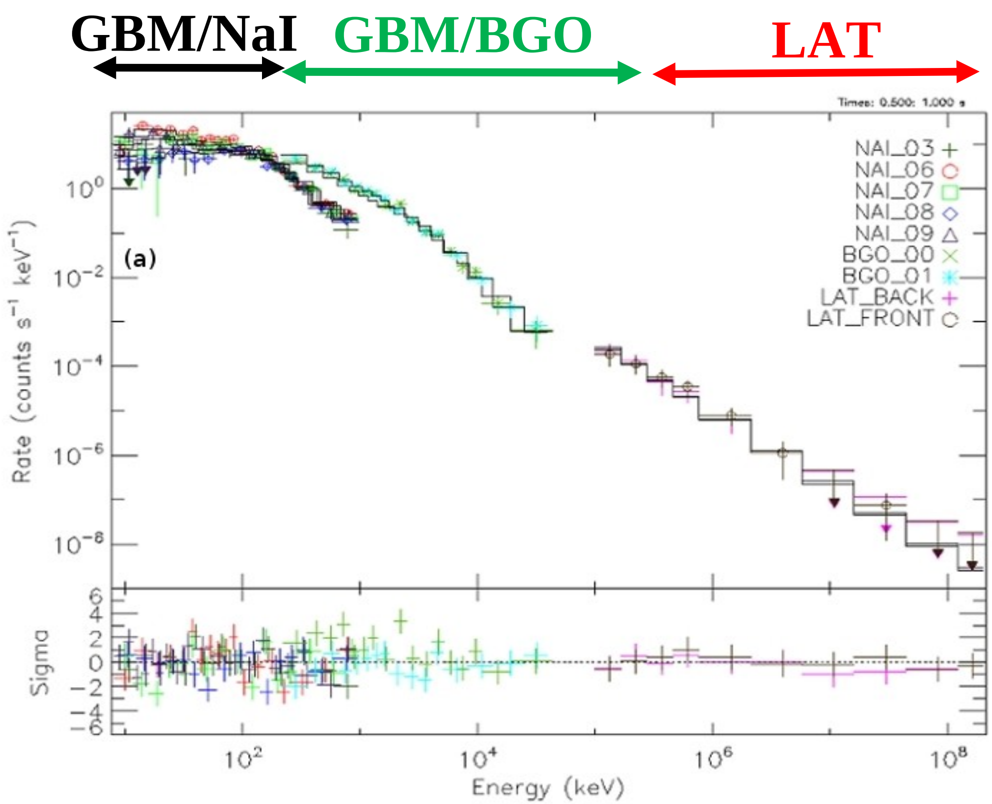
# Onset of LAT emission above 100 MeV




LAT events above 100 MeV with a bin width of 50 ms. The blue dashed line and the blue solid line are the best fit with two different phenomenological pulse shape.

The $t_{05}$ = 0.63 +/- 0.03 s and $t_{01}$ =0.58 +/- 0.05 s

# Prompt emission spectrum:
first clear evidence of an extra component




## Count spectra

-**Significant deviation (>5σ) from the standard Band function above 10 MeV.**
-**Excess adequately fit with an additional powerlaw (PL)**
**->extra-component !!**

- **Lower limit on a possible second break energy: ~4 GeV**

# Prompt emission spectrum:
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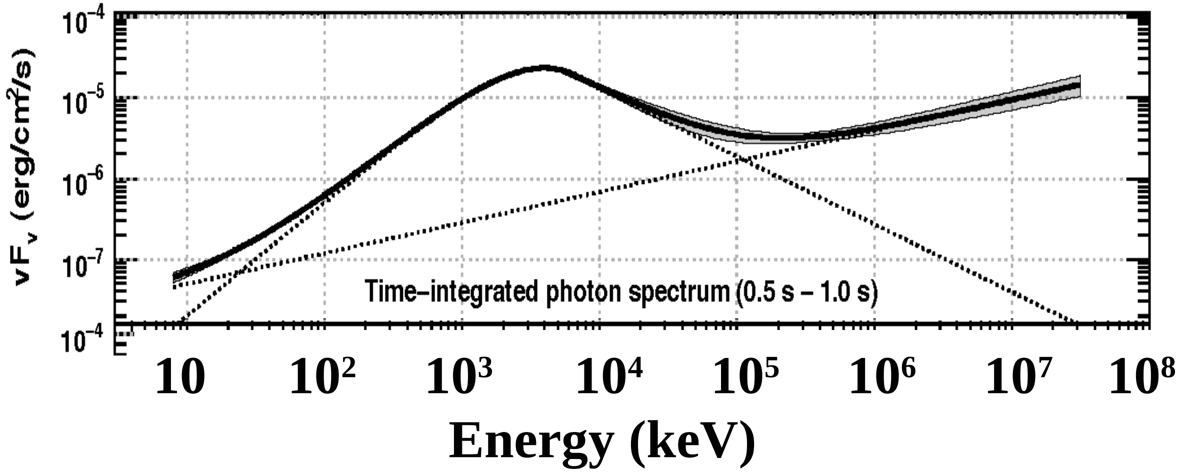



**Spectral parameters:**

**$E_{peak}$ = 3.9 +/- 0.3 MeV**

**α = -0.58 +/- 0.06**

**β = -2.83 +/- 0.20**

**PL Index = -1.62 +/- 0.03**

**Fluence ($_{10keV-30GeV}$)=(5.02+/-0.26)x10$^{-5}$erg cm$^{-2}$**

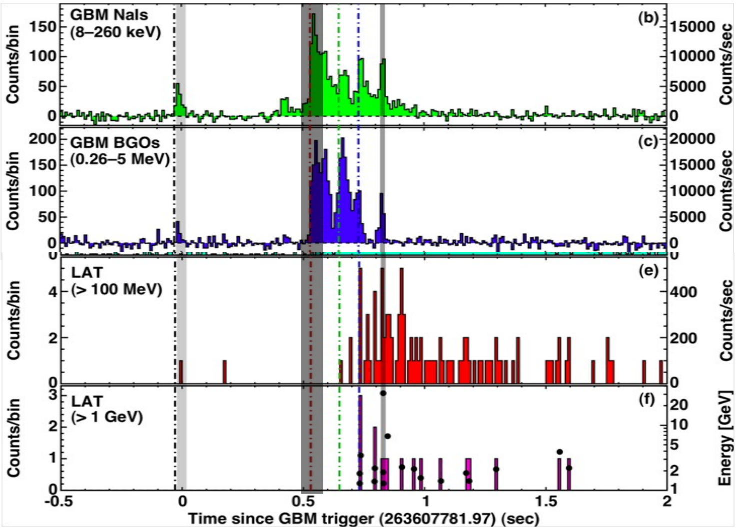
**$E_{iso}$=(1.08+/-0.06)x10$^{53}$ erg**

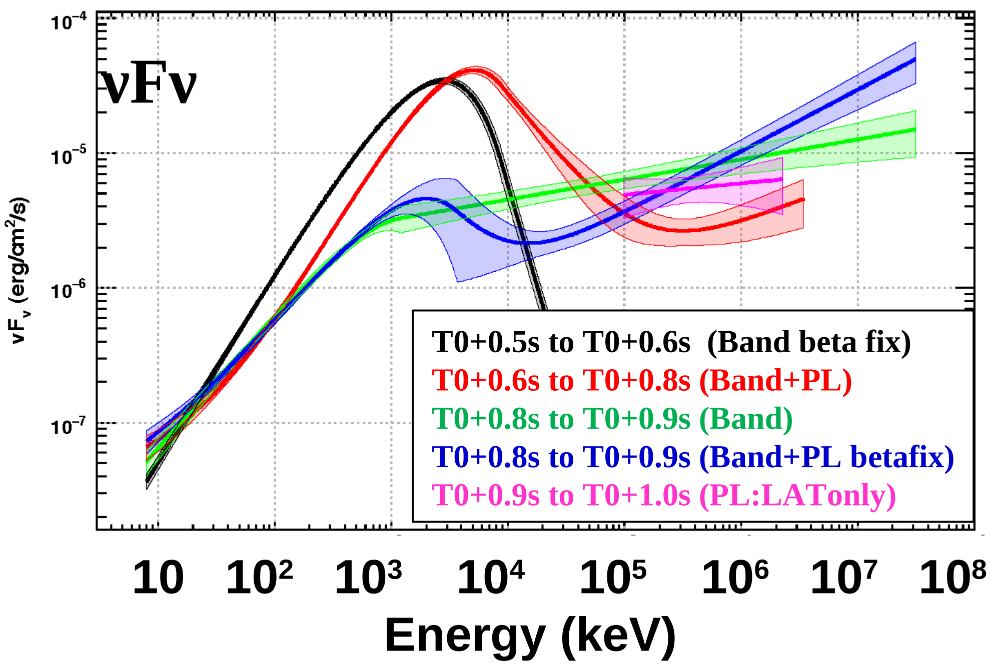
**⇒ ~37% of the fluence from the extra-comp.**

**⇒ EBL affects the total fluence for <1%**

Fermi Gamma-ray Space Telescope

# Time resolved spectra




**(a) T0+0.5s to T0+0.6s :**
Band function with steep beta (<-5.0)
No extra component

**(b)T0+0.6s to T0+0.8s :**
Additional component significant only in this time interval

**(c) T0+0.8s to T0+0.9s :**
Band only fit : harder beta
→ inconsistent with the previous bin.
Band+PL : fix beta to the value from the previous bin; extra comp. can be fit with a similar PL index.
→ Reasonable to adopt the extra component for this time bin

**(d) T0+0.9s to T0+1.0s :**
LAT data is fit by PL with a steeper index of ~-1.9
Extrapolation of at low energy inconsistent with GBM upper limits
→ spectral break ?

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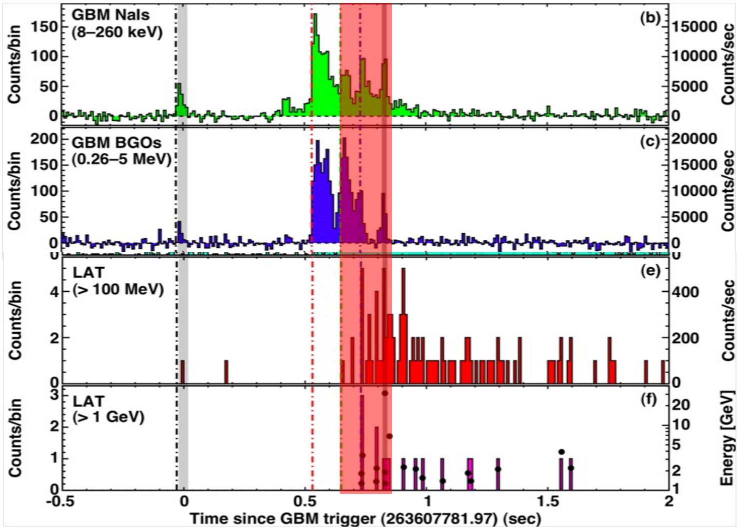


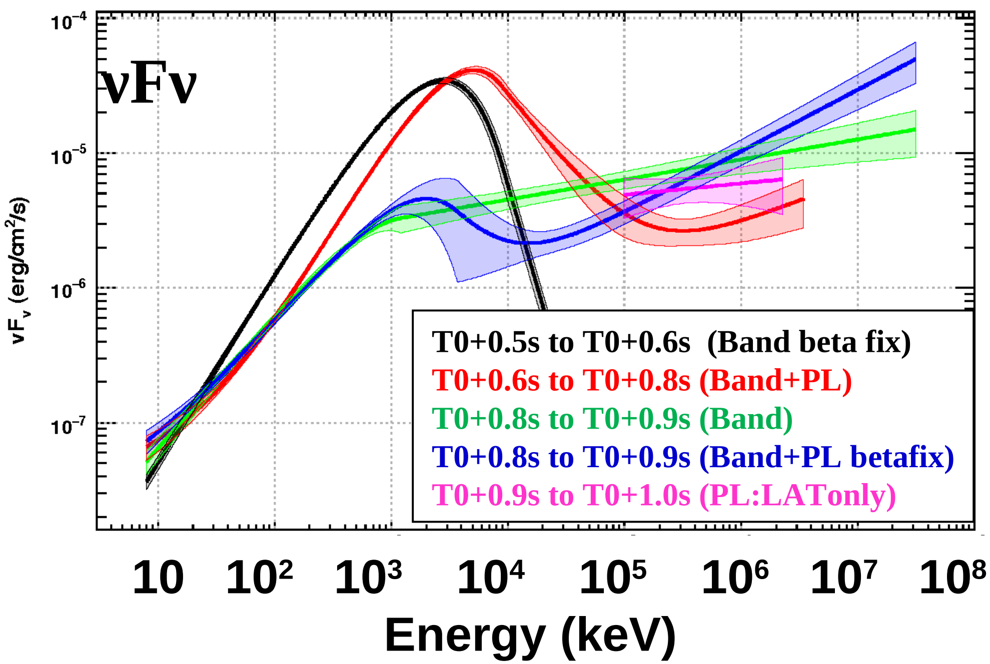


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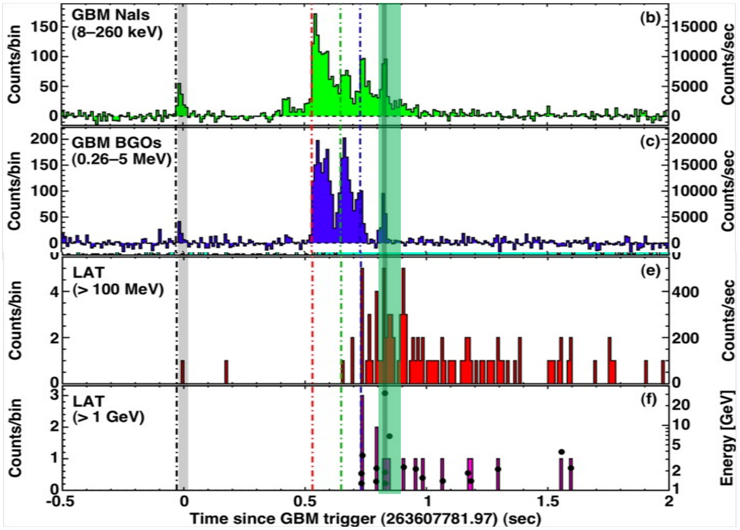


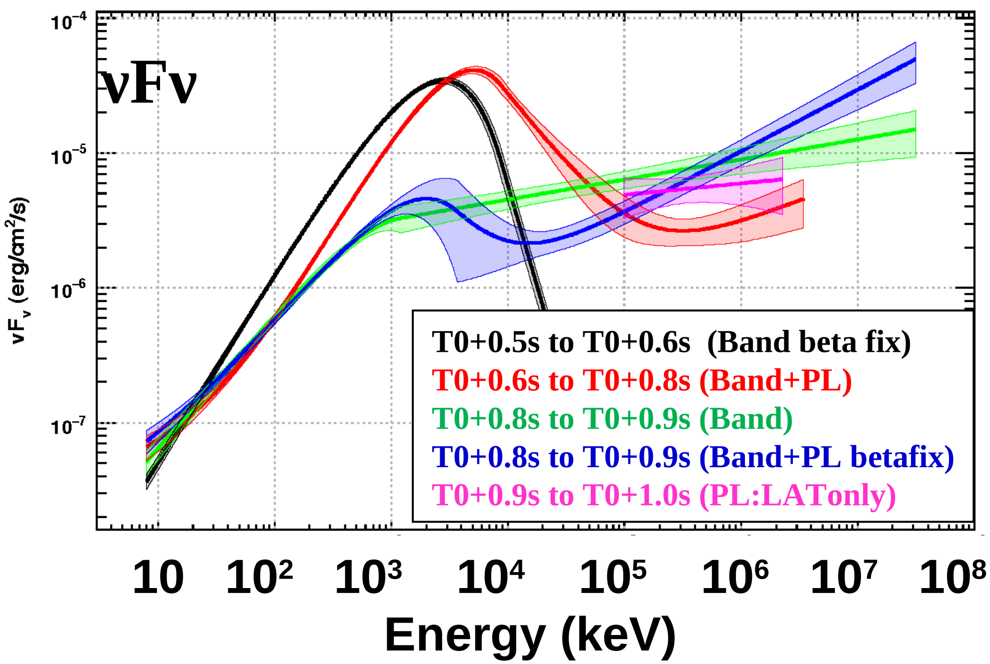


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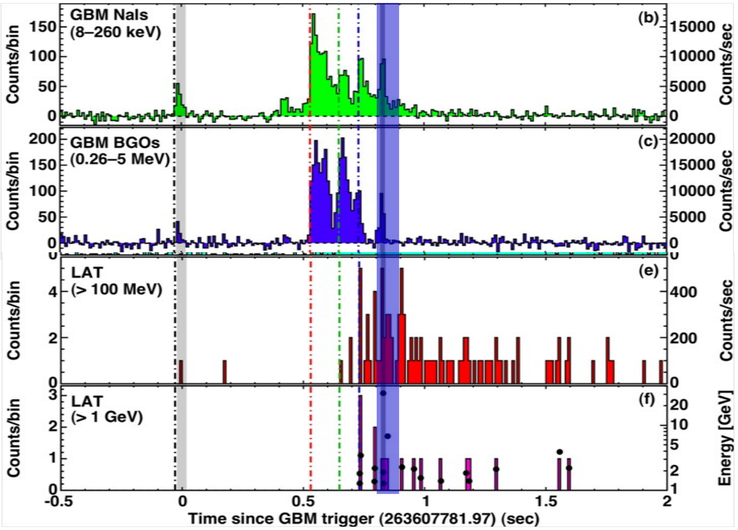


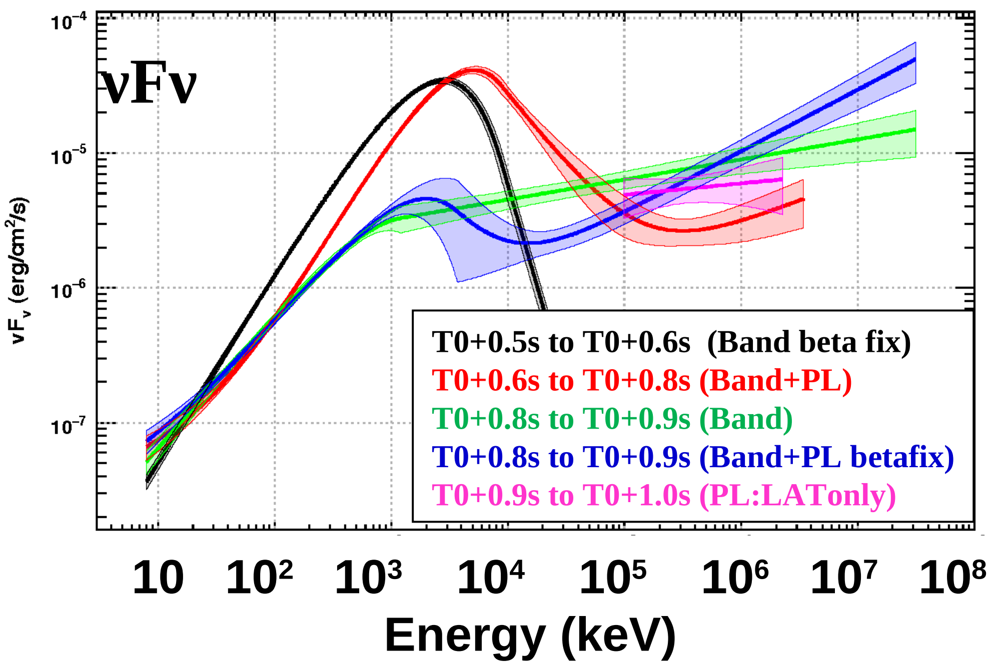


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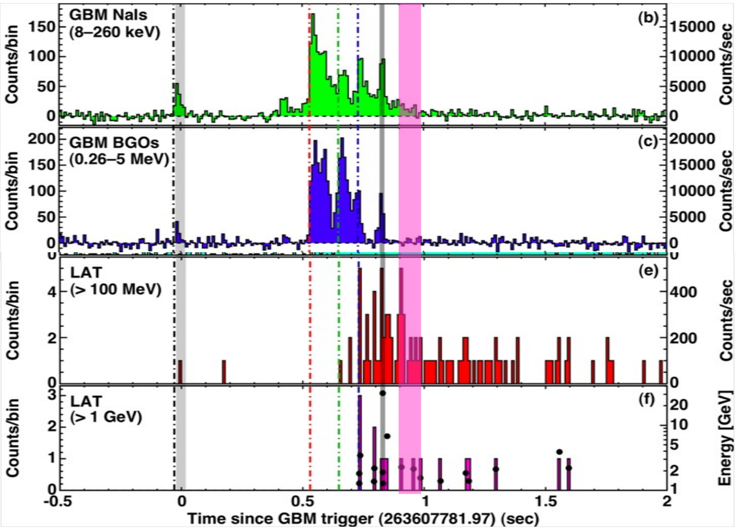


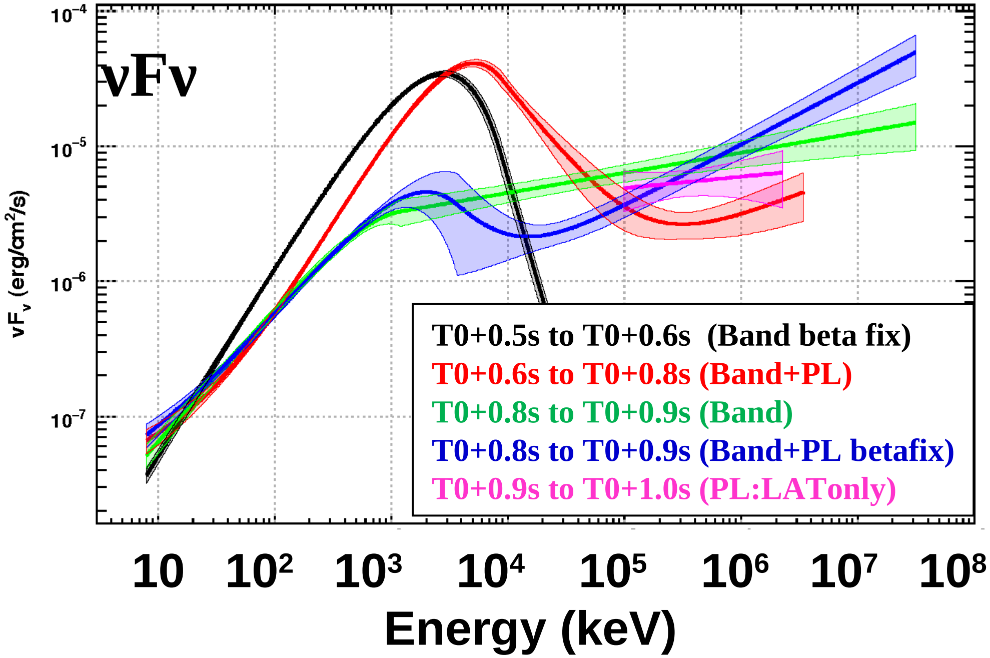


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# Origin of extra component

## A. Leptonic Model

**Low energy component (<10MeV) : synchrotron emission from non thermal electrons**

**Extra component (>10MeV) : synchrotron-self Compton**

✓**Can not explain the delayed onset (0.1-0.2s) of this extra component**
✓**Rapid change of B, Γ, electron energy distribution is needed.**

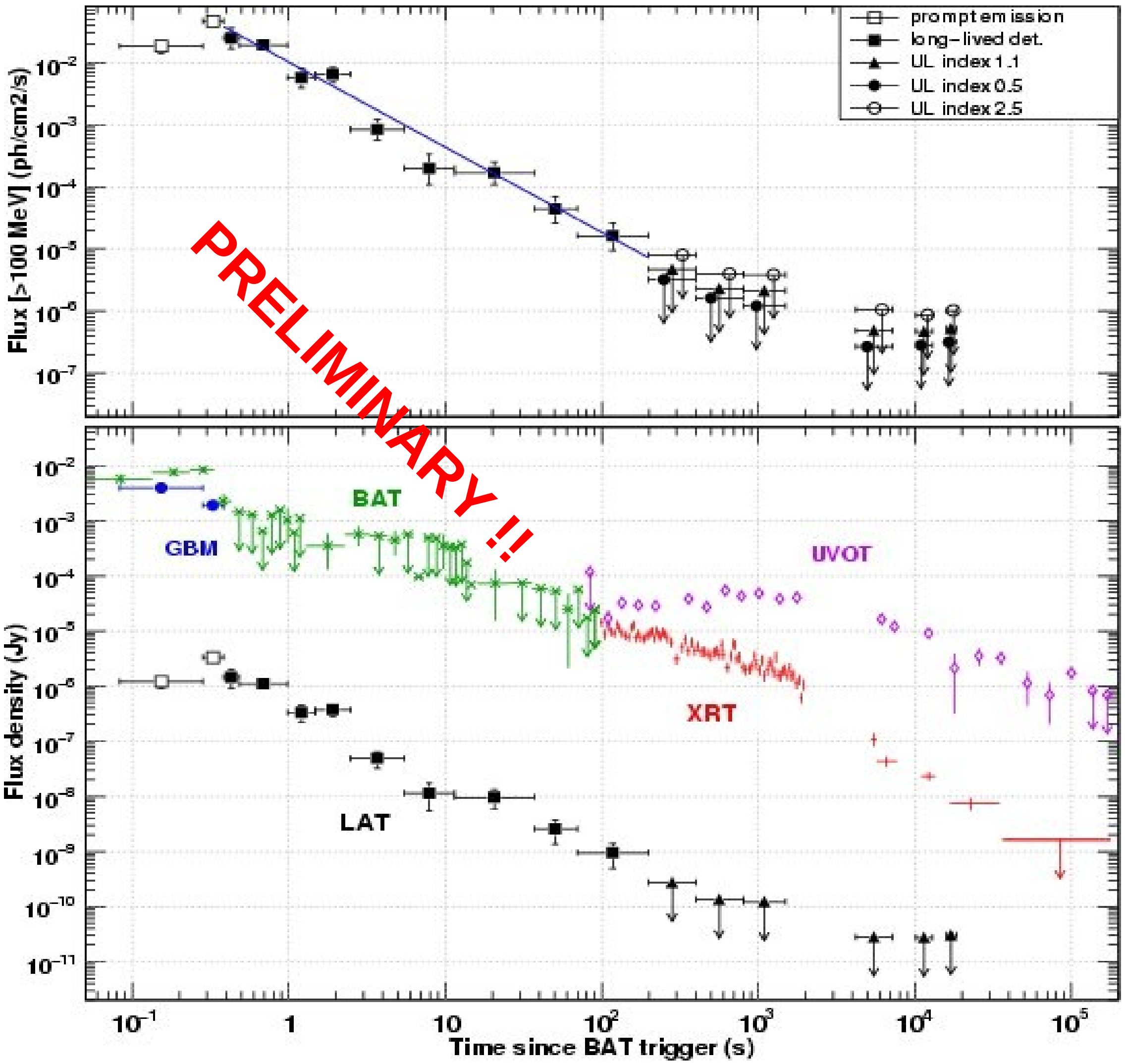
## B. Hadronic model

**Extra component : photo-meson or synchrotron process from ultra-relativistic protons and ions**

- **Short GRBs would be candidate of the origin of UHECRs**
- **Could explain the delayed onset of extra component**

✓**Much larger total energy (>100) is required.**

# GRB 090510 extended emission




Significant (TS>25) HE (>0.1 GeV) emission up to 200 s after the trigger.

LAT lightcurve best fitted by a power-law with index = -1.38 +/-0.07 ($T_0$+0.38 s -$T_0$+200 s)

# GRB 090510 extended emission

Fit results of joint spectra LAT- XRT- UVOT in the **Forward Shock model**:

$\beta_1$ = -1/3 (fixed for the FS model) -> UV range

$\beta_2$ = 1.78 ± 0.04 -> Xray

$\beta_3 = \beta_2$ + 0.5 (imposed by the FS model)

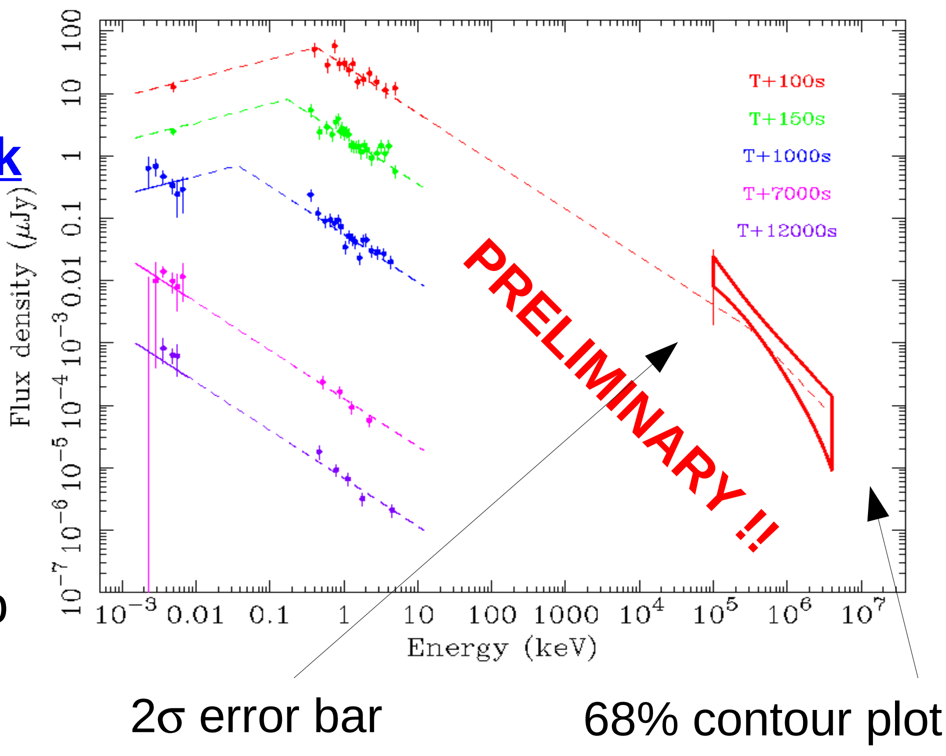
$E_{b1}$ = decreases over time from 0.43 keV to less than 0.001 keV

$E_{b2} \in$ [10 ÷ 133] MeV [for the 100s fits only]

**Model comparison:**

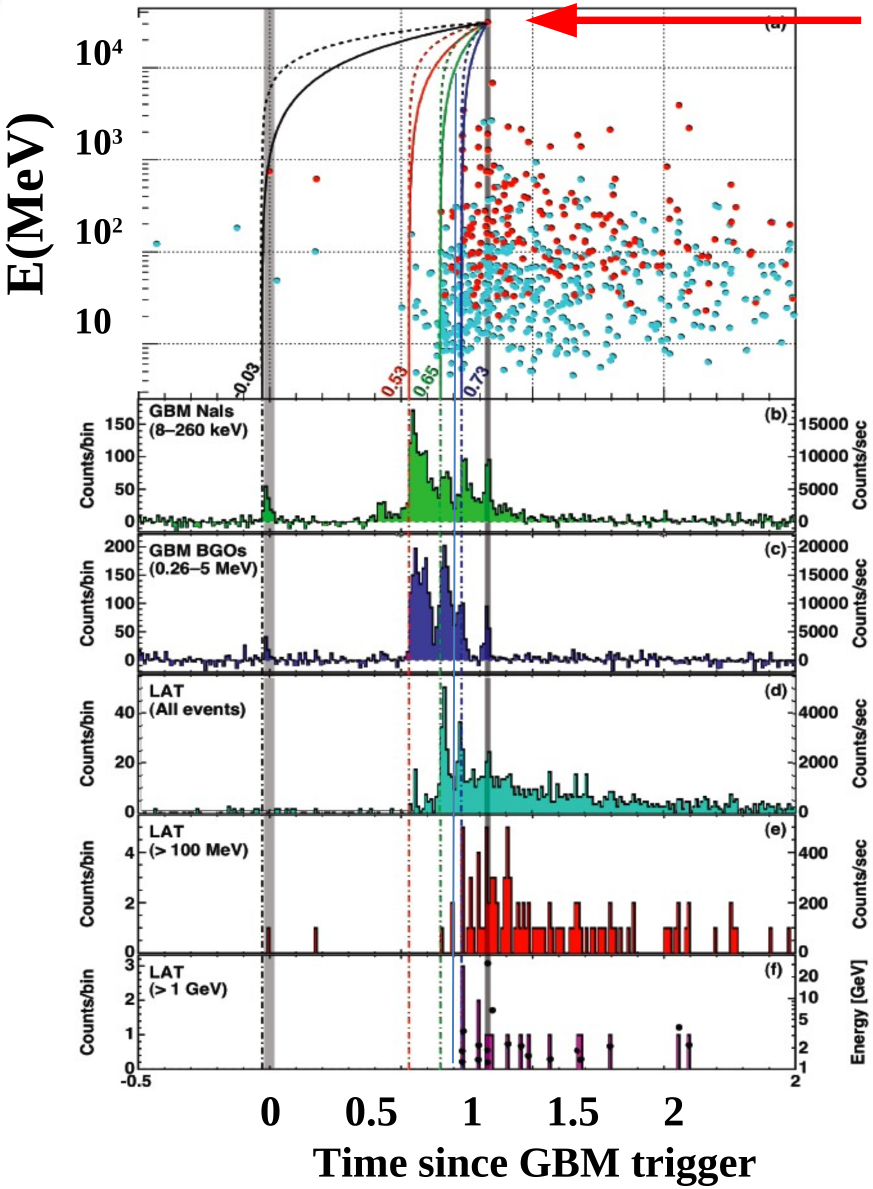
- **X-ray and GeV from Internal Shock, optical from Forward Shock** can reproduce the spectrum at 100s, but needs some fine tunings
- **Optical, X-ray and GeV from Forward Shock** can naturally produce the full broadband spectrum by the simple emission model, but it needs some theoretical extensions to explain overall detailed temporal properties

**UVOT-XRT-LAT SED**



# 31 GeV photon:

## highest energy photon for short GRB




**31 GeV photon : 0.83 s after the trigger**

Association with the GRB:

- 5.8 arcmin from the Swift/UVOT localization well inside 95% psf .
- The significance of this photon is between 4.4 σ and 5.6 σ, with a most likely value close to the upper bound.

**Such high energy photon can be used to constrain the bulk Lorentz factor of relativistic jet and constrain the Lorentz Invariance Violation (LIV)**

# Limit on bulk Lorentz factor

**Due to large luminosity and small emitting region, optical depth for the γ-γ -> e+e- pair production is too large to observe the non-thermal emission from GRB → compactness problem.**

**Relativistic motion (Γ>>1) could avoid this compactness problem, it allows a larger emission radius and a smaller co-moving target photon density. The optical depth for the pair production is :**

$$\tau_{\gamma\gamma}(E) = \frac{3}{4}\frac{\sigma_T d_L^2}{t_v \Gamma}\frac{m_e^4 c^6}{E^2(1+z)^3}\int_{\frac{m_e^2 c^4 \Gamma}{E(1+z)}}^{\infty}\frac{d\epsilon'}{\epsilon'^2}\, n\left(\frac{\epsilon'\Gamma}{1+z}\right)\varphi\left[\frac{\epsilon' E(1+z)}{\Gamma}\right]$$

**$\Gamma_{min}$ can be derived using the condition $\tau_{\gamma\gamma}(E_{max})$=1.**

**If the spectrum is a Band function and the cross section is approximated with a delta function we have:**

$$\Gamma_{\min}(E_{\max}) = \left[\frac{4 d_L^2 A}{c^2 t_v}\frac{m_e^2 c^4}{(1+z)^2 E_{\max}} g\sigma_T\right]^{\frac{1}{2-2\beta}}\left[\frac{(\alpha-\beta)E_{\rm pk}}{(2+\alpha)100\ {\rm keV}}\right]^{\frac{\alpha-\beta}{2-2\beta}} \times \exp\left(\frac{\beta-\alpha}{2-2\beta}\right)\left[\frac{2 m_e^2 c^4}{E_{\max}(1+z)^2 100\ {\rm keV}}\right]^{\frac{\beta}{2-2\beta}};$$

$$\text{for}\quad \Gamma_{\min} > \sqrt{\frac{(1+z)^2 E_{\max} E_{\rm pk}(\alpha-\beta)}{2 m_e^2 c^4 (2+\alpha)}},$$

**The values obtained numerically and with this function agree**

# GRB090510:
## the most powerful outflow for any GRBs

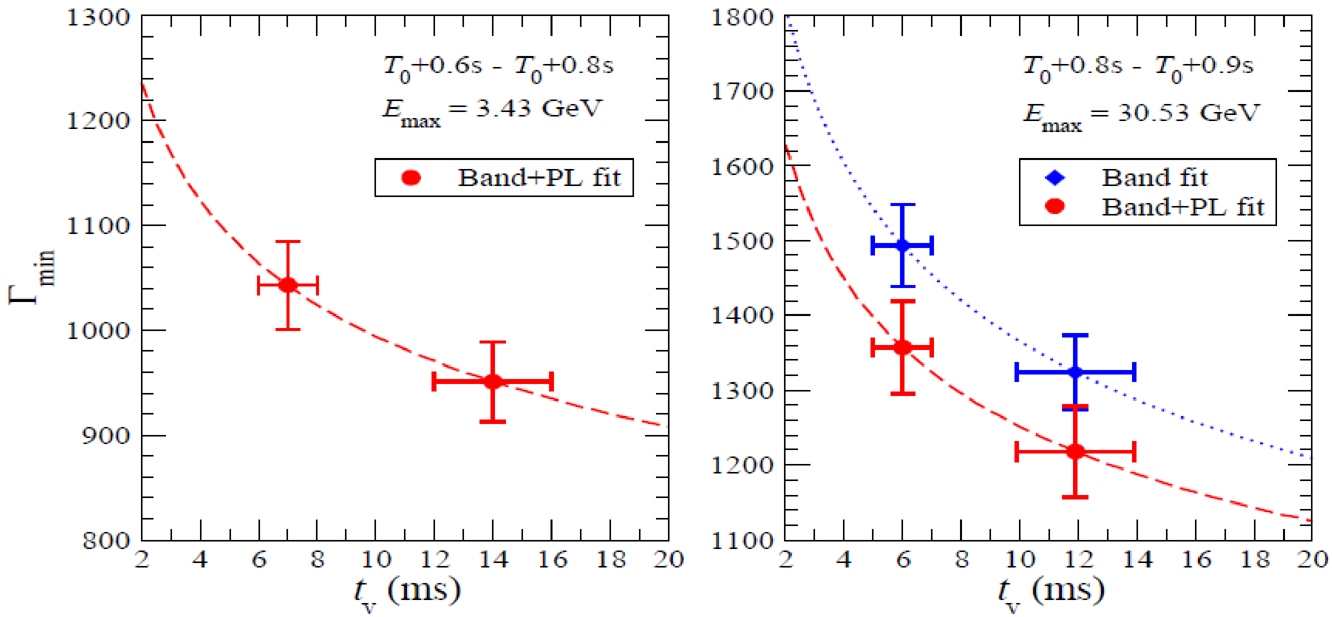
**$\Gamma_{min}$ (T+0.6s – T+0.8s, $E_{max}$=3.43 GeV, $t_v$=14ms) : 950+/-40**

**$\Gamma_{min}$ (T+0.8s – T+0.9s, $E_{max}$=31 GeV, $t_v$=11.9ms) : 1220+/-60**

**First constraint on the bulk Lorentz factor for redshift known short GRB**

**Highest $\Gamma_{min}$ for any GRB, and by far the highest for a short GRB**

**=> short GRBs might have similar power of outflow as long GRB**




- **$t_v$ estimated using the GBM detectors (NaI or BGO)**
- **the error on $\Gamma_{min}$ is estimated propagating the 1-σ limit on the spectral function parameters**

# Limits on Lorentz Invariance Violation (LIV)

**Some quantum gravity models allow violation of Lorentz invariance: $(v_{ph}) \neq c$**

The photon propagation speed is:

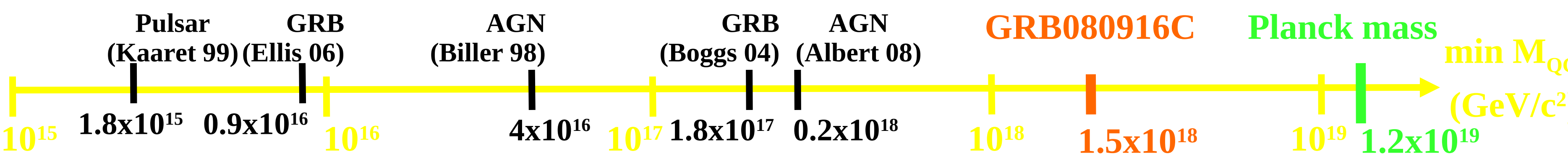
$$v_{ph} = \frac{\partial E_{ph}}{\partial p_{ph}} \approx c \left[ 1 - s_n \frac{1+n}{2} \left( \frac{E_{ph}}{M_{QG,n} c^2} \right)^n \right]$$

$s_n = +/- 1$ respectively sub/super-luminal

**A high-energy photon $E_h$ would arrive after ($s_n$ =+1) or also earlier ($s_n$ =-1) a low-energy photon $E_l$ emitted together.**

**GRB 080916C : the tightest upper limit so far (Abdo et al. 09), for ($s_n$ =+1)**

$$M_{QG,1} > (1.50 \pm 0.20) \times 10^{18}\ \mathrm{GeV/c^2}$$

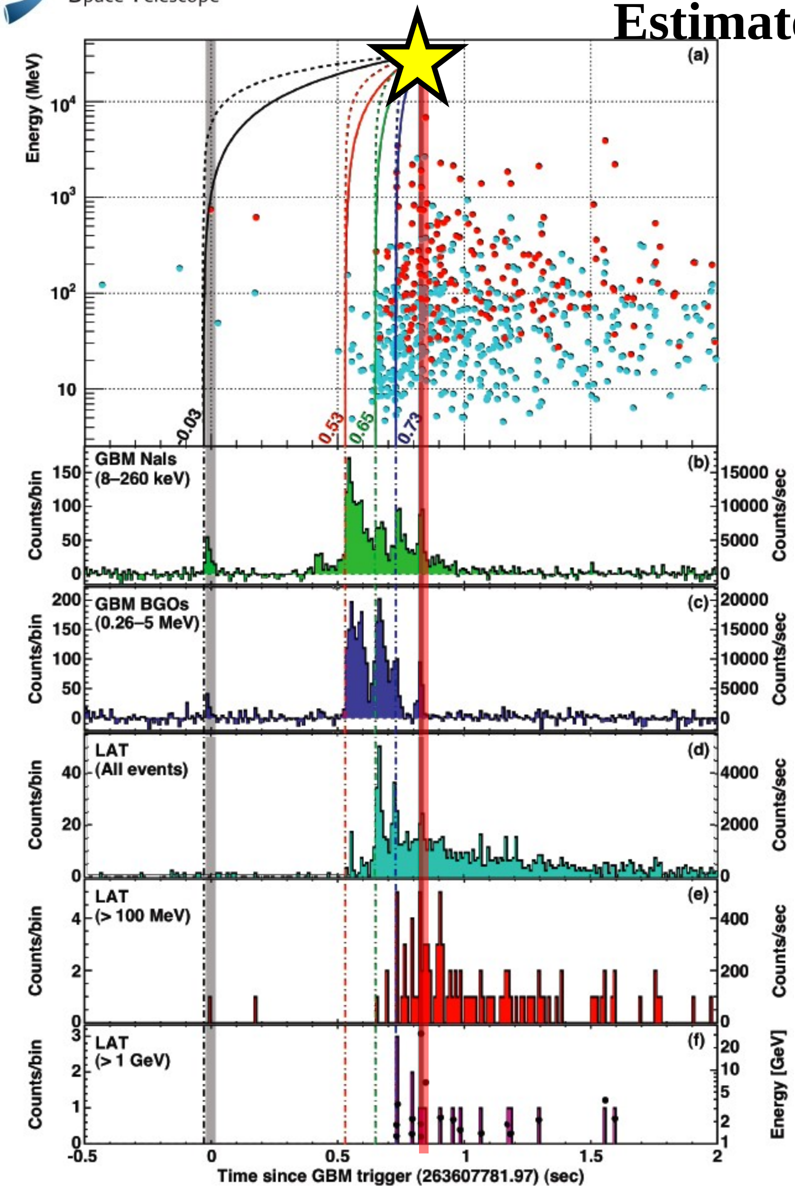



**For ($s_n$ =+1)**

$$\Delta t = \frac{(1+n)}{2H_0} \frac{E_h^n - E_l^n}{(M_{QG,n}c^2)^n} \int_0^z \frac{(1+z')^n}{\sqrt{\Omega_m (1+z')^3 + \Omega_\Lambda}} dz'$$

**n = 1,2 for linear and quadratic Lorentz invariance violation, respectively**

# LIV : first time $M_{QG} > M_{plank}$




**Estimate lower limit of $M_{QG,1}$ for various Δt, ΔE**

◆ **Most conservative case :**

**31GeV photon starts from any <1MeV Emission so for ($s_n$ =+1)**

Δt < 859 ms, **$M_{QG,1}/M_{plank}$ > 1.19**

◆ **Least conservative case:**

**31 GeV photon associates with < 1 MeV spike for ($s_n$ =+/-1)**

Δt< 10ms, **$M_{QG,1}/M_{plank}$ > 102**

**Our new limit : $M_{QG,1}/M_{plank}$ > several is much stronger than the previous result ($M_{QG,1}/M_{plank}$ > 0.1 : GRB080916C ;Abdo 09)**

**Greatly constrain the quantum gravity model (n=1)**

More details in the **F. Stecker** talk

# Summary

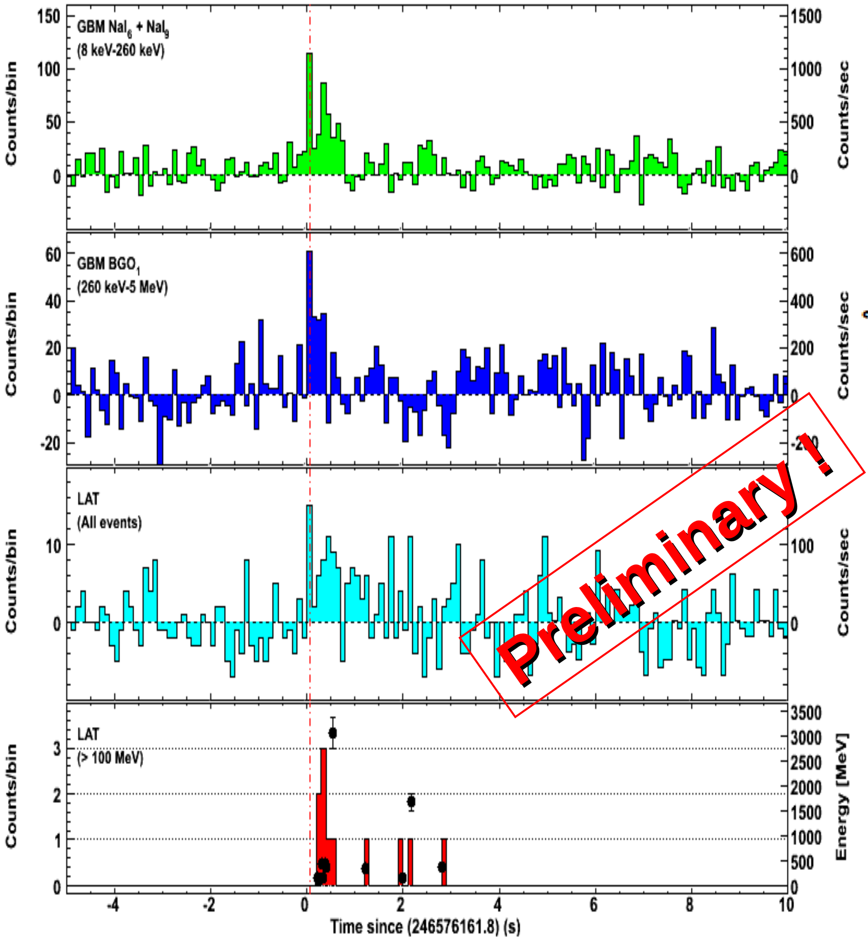
◆ **GRB 090510 : bright short LAT GRB with many interesting results**

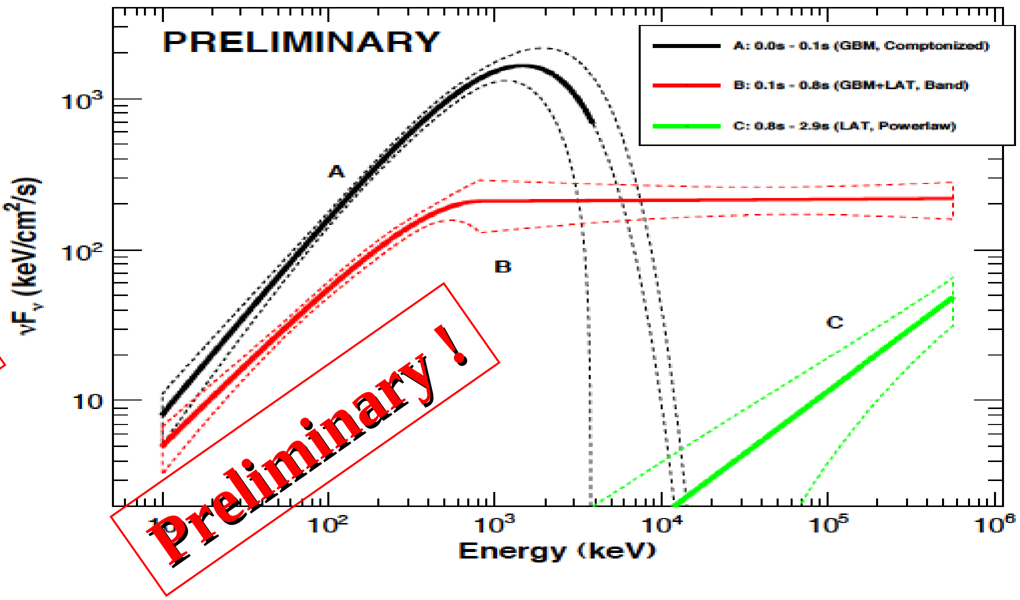
- The first GeV short GRB with known redshift
- First clear (>5σ) evidence of extra component is discovered
- 31 GeV photon is detected: the highest energy photon for short GRB
- Highest bulk Lorentz factor for any GRB ($\Gamma_{min}$>1200)

  ➔ outflow of short GRB might be as powerful as long GRB
- $M_{QG}$>$M_{plank}$ is firstly required: greatly constrain many QG models

# Backup Slides

# GRB 081024B other LAT short GRB



Fermi Gamma-ray Space Telescope

## Table 2 | Limits on Lorentz Invariance Violation

| # | $t_{start} - T_0$ (ms) | Limit on $\lvert\Delta t\rvert$ (ms) | Reasoning for choice of $t_{start}$ or limit on $\Delta t$ or $\lvert\Delta t/\Delta E\rvert$ | $E_l$[†] (MeV) | Valid for $s_n$* | Lower limit on $M_{QG,1}/M_{Planck}$ |
|---|---|---|---|---|---|---|
| (a)[❖] | −30 | < 859 | start of any < 1 MeV emission | 0.1 | 1 | > 1.19 |
| (b)[❖] | 530 | < 299 | start of main < 1 MeV emission | 0.1 | 1 | > 3.42 |
| (c)[❖] | *648* | < 181 | start of main > 0.1 GeV emission | 100 | 1 | > 5.63 |
| (d)[❖] | 730 | < 99 | start of > 1 GeV emission | 1000 | 1 | > 10.0 |
| (e)[♦] | — | < 10 | association with < 1 MeV spike | 0.1 | ±1 | > 102 |
| (f)[♦] | — | < 19 | If 0.75 GeV[‡] γ-ray from 1[st] spike | 0.1 | −1 | > 1.33 |
| (g)[♠] | $\lvert\Delta t/\Delta E\rvert$ < 30 ms/GeV | | lag analysis of > 1 GeV spikes | — | ±1 | > 1.22 |

**Our results disfavor QG models with linear LIV (n = 1)**

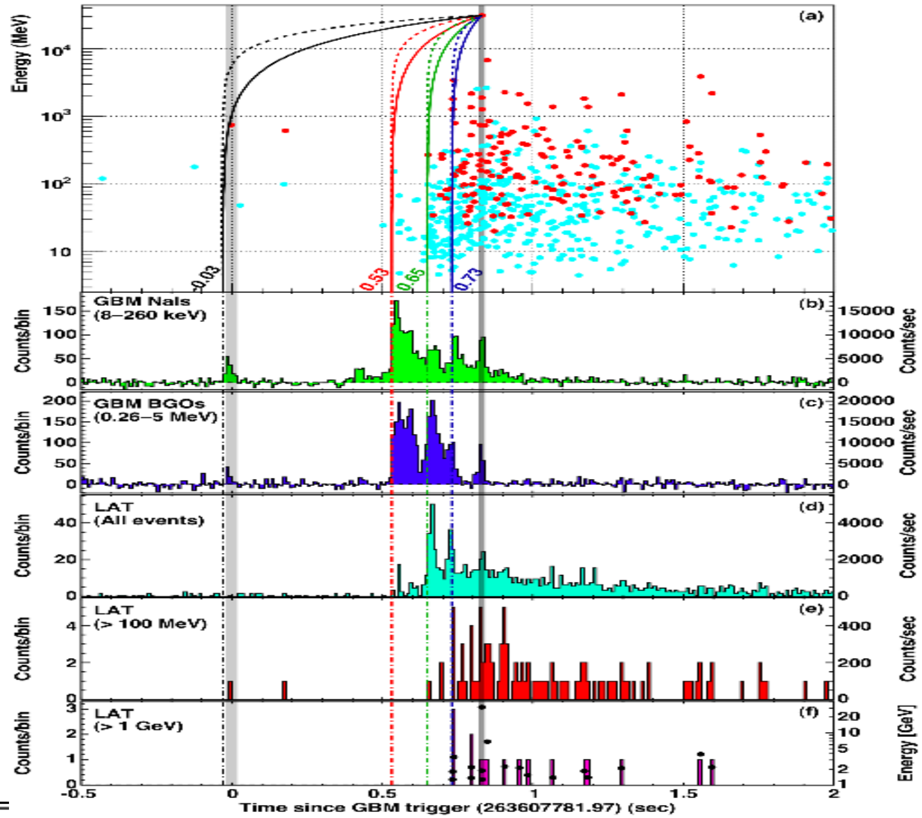
All of our lower limits on $M_{QG,1}$ are above $M_{Planck}$

a-e based on 31 GeV γ-ray

a-d assume that $t_{em} \geq t_{strat}$ $t_{strat}$ = emission onset time

e,f association with a specific low-energy spike

g sharpness of HE



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**Relativistic motion (Γ>>1) could avoid this compactness problem**

**$R \lesssim \Gamma^2 c \Delta t$**

**photon number for γ-γ absorption : $\Gamma^{2(1+\beta)}$**

**$\Gamma_{min}$ can be derived using observed highest energy photon**

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# HE emission from GRBs (2)

What can we get from high energy emission of GRBs?

- Extra component of the prompt emission ?

**Different emission mechanism: Synchrotron self Compton ? Hadronic origin ?**
**Only GRB941017 shows the sign of extra component**

- What is the maximum energy of high energy photon?

**Constrain the bulk Lorentz factor of the relativistic jet**
**No evidence of the cut-off so far.**

- Delayed or long-lived high energy emission ?

**Suggests another emission mechanism**
**Time delay of high energy photon → Limit on the quantum gravity mass :$M_{QG}$**
**A few GRBs show delayed high energy emission (GRB940217, GRB080714)**

**Need more sensitivity and larger FoV**

# Summary for GRB 090510

- First GeV short GRB with known redshift (z=0.9)
- First clear evidence of extra component (>5σ)
- Highest energy photon for short GRB : 31 GeV
- The most powerful outflow for any GRB : Γ>1200
- First time, $M_{QG}>M_{plank}$ is required
- Long-lived emission (?)