Fermi and Swift observations of the bright short GRB 090510 : prompt emission and afterglow

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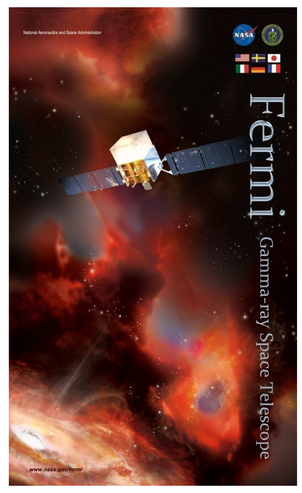
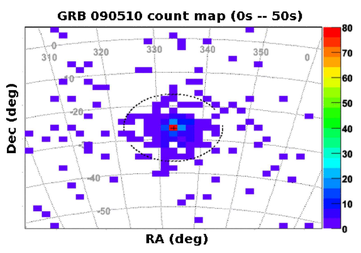
on behalf of the *Fermi* LAT and GBM collaborations



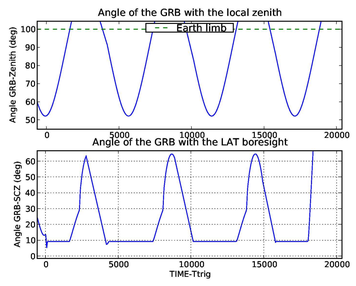
Abstract

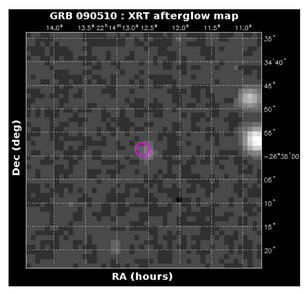
The bright short-hard GRB 090510 was observed by both *Swift* and *Fermi* telescopes. The study of the prompt emission by Fermi revealed an additional high-energy spectral component, the largest lower limit ever on the bulk Lorentz factor in a short GRB jet, and brought the most stringent constraint ever on Lorentz invariance violation models. The fast repoint and follow-up by both telescopes allowed the first multiwavelength study of a GRB afterglow from optical range to several GeV. This long-lived emission has been studied in the framework of the internal shock and external shock models. **Convention :** $F \propto t^{-\alpha}\nu^{-\beta}$



Fermi observation

- GBM trigger : May 10th 2009, 00 : 22 : 59.97 UT
- first LAT onboard detection
- >5σ on-ground LAT detection (Ohno et al. GCN 9334)
- 20 events > 1 GeV (Omodei et al. GCN 9350)
- LAT on-ground : RA = 333.4, Dec = -26.767, err = 7'(stat)
- 5 hour follow-up observation





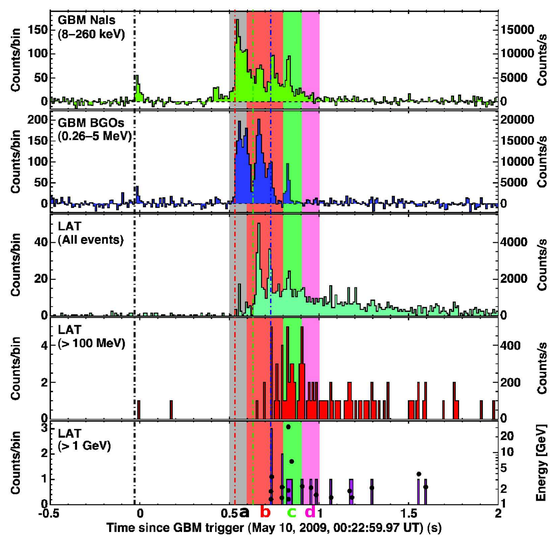
Swift observation

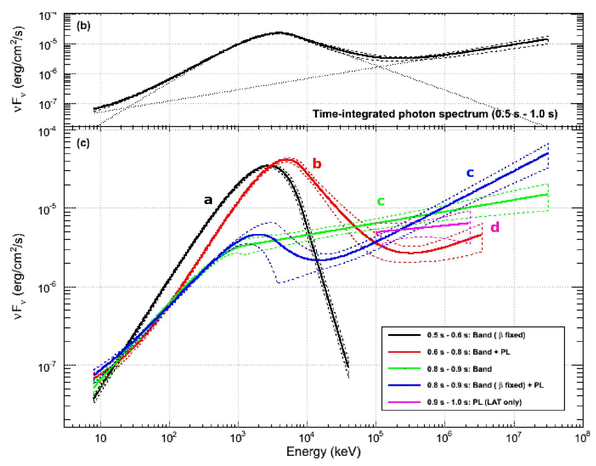
- BAT trigger : May 10th 2009, 00 : 23 : 00.48 UT
- repoint within 100 s, 2 day follow-up
- afterglow detected
- XRT : RA = 333.55227, Dec = -26.58290, err = 0.61"
- z = 0.903 ±0.003 (VLT : Rau et al. ; GCN 9353)

A short hard GRB with an additional high-energy (HE) component

Spectral analysis

- time-integrated spectrum : >5 σ HE component ($\beta_{PL} = 0.62 \pm 0.03$), brings 37% of the total γ-ray fluence
- a (0.5s – 0.6s) : Band function with steep $\beta_{Band} > 4$
- b (0.6s – 0.8s) : significant HE comp, late > 100 MeV emission
- c (0.8s – 0.9s) : HE comp. can be fitted, not significant
- d (0.9s – 1.0s) : LAT data : power-law $\beta_{PL} = 0.9$





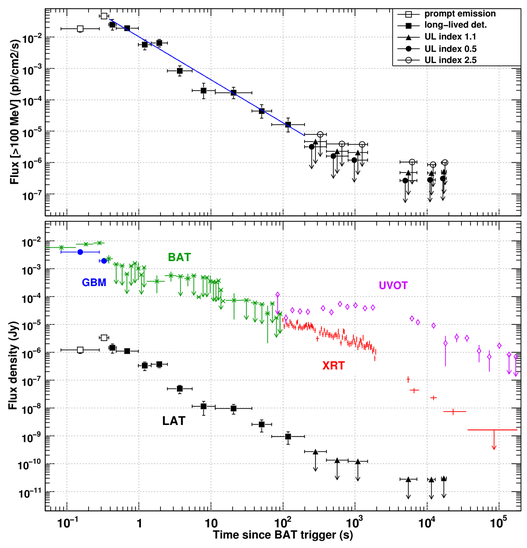
Leptonic model

- e^- synchrotron below 10 MeV, SSC above 10 MeV
- doesn't explain HE component delay (0.1s – 0.2s)
- rapid change of B, Γ or e^- spectrum needed

Hadronic model

- π^0 or synchrotron from p and ions
- can explain the delayed arrival
- large total energy required

eV to GeV afterglow observations



UVOT observations

- initial rise : $\alpha_{Opt,1} = -0.50^{+0.11}_{-0.13}$ (typical of long GRBs !)
- smooth break : $t_{Opt} = 1.58^{+0.46}_{-0.37}$ ks
- late decay : $\alpha_{Opt,2} = 1.13^{+0.11}_{-0.10}$

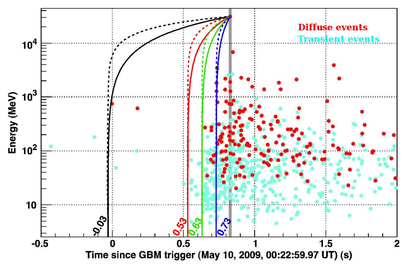
XRT observations

- initial shallow decay : $\alpha_{X,1} = 0.74 \pm 0.03$
- break : $t_X = 1.43^{+0.09}_{-0.15}$ks
- steep late decay : $\alpha_{X,2} = 2.18 \pm 0.10$

LAT observations

- end of GBM prompt emission : GBM trigger + 0.9s = BAT trigger + 0.38s
- unbinned likelihood fits in all time bins
- significant detection (>5σ) up to 200s
- lightcurve shows no feature or break, decay : $\alpha_\gamma = 1.38 \pm 0.07$
- no spectral evolution, average energy index : $\beta_\gamma = 1.1 \pm 0.1$

What about Lorentz Invariance Violation (LIV) ?

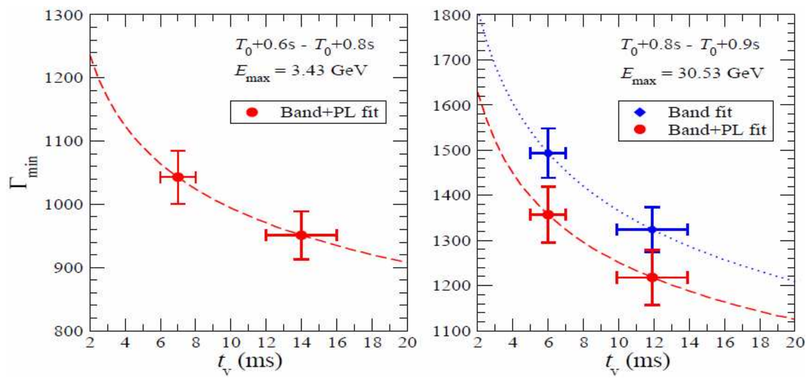


- 31 GeV photon 0.83s after trigger : highest energy photon from a short GRB !
- $v_{ph} \neq c$ allowed by some quantum gravity models : low-energy E_ℓ and high-energy E_h photons emitted together would arrive at different times :

$$\Delta t \propto \frac{(1+n)(E_h^n - E_\ell^n)}{(M_{QG,n}c^2)^n}\ ,\ n = 1, 2$$

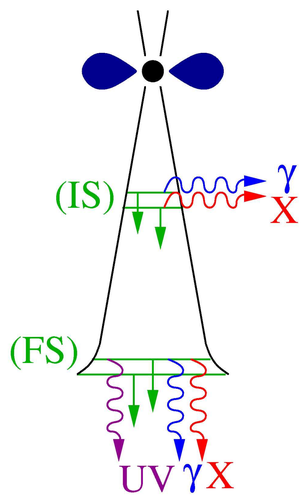
- most conservative limit (gray line) : 31 GeV photon emitted with all <1 MeV $\Rightarrow \Delta t < 859$ ms $\Rightarrow M_{QG,1}/M_{Planck} > 1.19$
- least conservative limit (red line) : 31 GeV photon emitted with <1 MeV spike $\Rightarrow \Delta t < 10$ ms $\Rightarrow M_{QG,1}/M_{Planck} > 102$
  $\Rightarrow$ strong and robust constraint on linear LIV models

A high initial bulk Lorentz factor Γ_0



$\Gamma_{0,min}(E_{max}, t_v)$: $\Gamma_{0,min}(0.6\text{s} - 0.8\text{s}) = 950 \pm 40$; $\Gamma_{0,min}(0.8\text{s} - 0.9\text{s}) = 1220 \pm 60$
$\Rightarrow$ highest $\Gamma_{0,min}$ ever set on a GRB, most rapid ejection measured from a short GRB !

Internal shock or forward shock ?

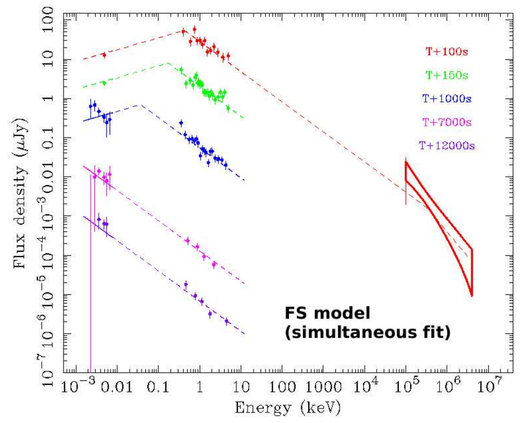


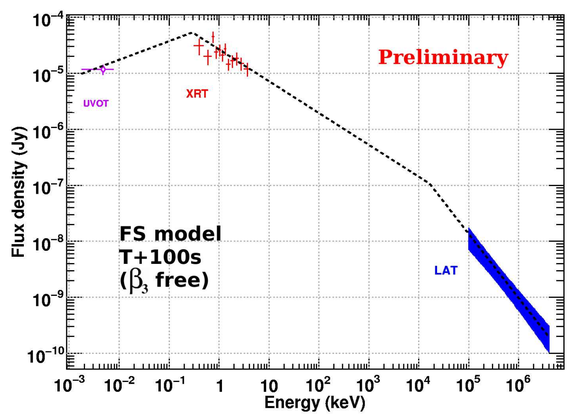
Internal shock (IS) + forward shock (FS)

- X-ray and γ fluxes at 100s consistent with internal shock, with fine tunings
- optical emission from forward shock, initial raise would be the onset of the FS emission
- requires low ambient density : $n \sim 10^{-6} cm^{-3}$
- requires initial bulk Lorentz factor $\Gamma_0 \sim 10^3$, consistent with prompt emission analysis

Forward shock (FS) only

- doubly broken power-law (nicely fits the observed SED over 9 energy decades) :
  $\beta_1 = -1/3$ (UV),
  $\beta_2 = 0.78 \pm 0.04$ (X-ray),
  $\beta_3 = \beta_2 + 1/2$ (γ),
  LE break decrease : 0.43 to <0.01 keV,
  HE break $\in [10 - 130]$ MeV (100s)
- consistent with lightcurves < 1 ks
- early FS onset requires $\Gamma_0 > 5800$
- doesn't explain some temporal properties ($\alpha_{X,1}$ too shallow, $\alpha_{Opt,2} \neq \alpha_{X,2}$)
  $\Rightarrow$ extensions needed : microphysics parameters evolution and/or energy injection





Conclusions

- First GeV short GRB with known redshift (z = 0.903)
- Highest energy photon from a short GRB : 31 GeV
  $\Rightarrow$ The most rapid outflow for any GRB : $\Gamma_{0,min}$ >1200
  $\Rightarrow$ First time, $M_{QG,1} > M_{Planck}$ is required
- First clear evidence of an additional HE component (>5σ)
  $\Rightarrow$ SSC or possible source of UHECRs
- Energetic short GRB with a bright optical and X-ray afterglow and a GeV long-lived emission as well
- IS+FS model reproduces well the fluxes at 100s (fine tuning needed)
- FS model reproduces well the spectrum over 9 energy decades (theoretical extensions needed)
- Joint *Swift-Fermi* observations promising for understanding the origin of long-lived GRB emission !

References

A.A. Abdo, et al. "*Fermi* Gamma-Ray Burst GRB090510 observations limit variation of speed of light with energy", *Nature, submitted* (2009) (arXiv : 0908.1832)
A.A. Abdo, et al. "*Fermi* Observations of GRB 090510 : A Bright, Short Burst with a Hard Power-Law Component above 100 MeV", *ApJL, in prep.*
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