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Theoretical models of GRB 090227B and GRB 090510

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Summary

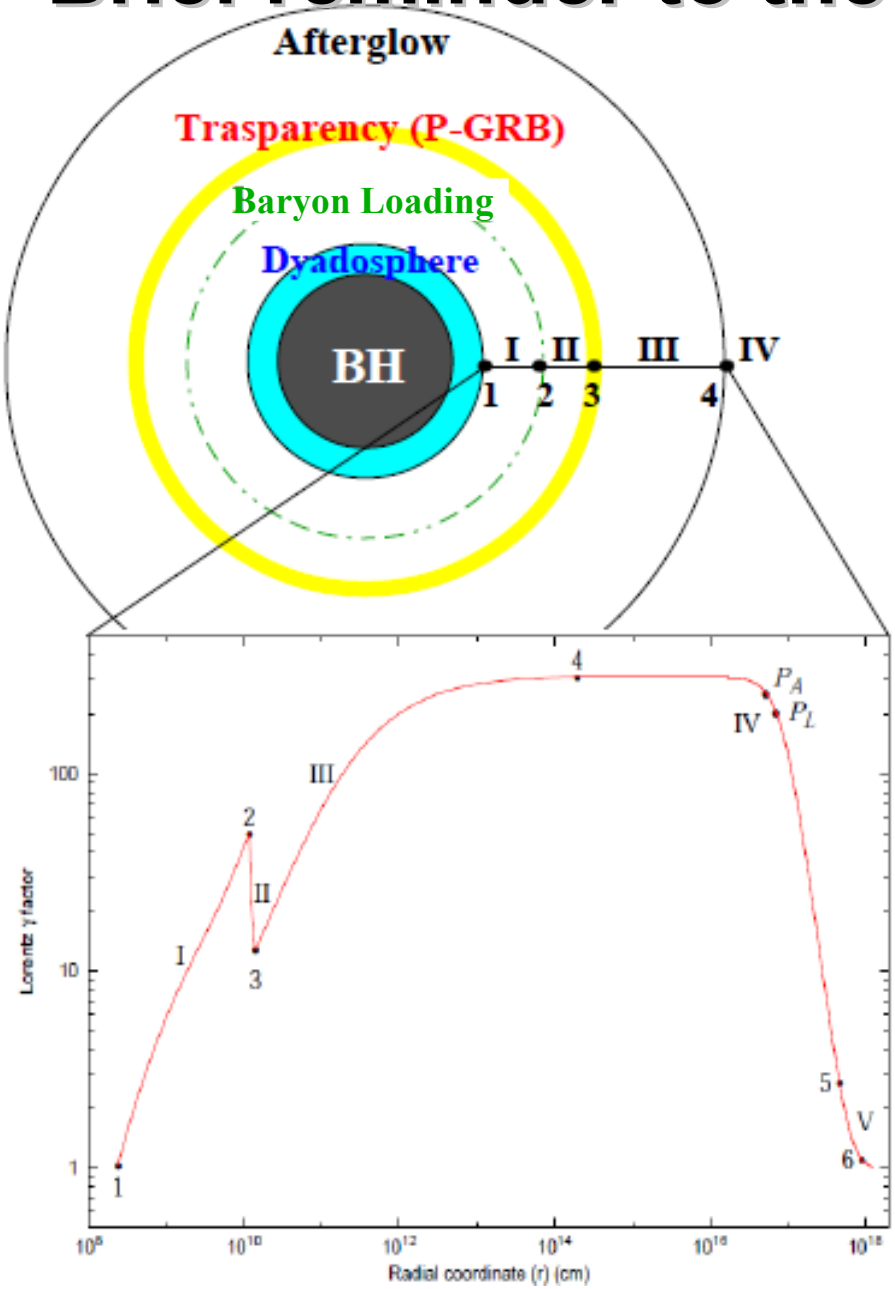
- Brief reminder to the Fireshell model

- GRB 090227B:
  - ⇒ Observations and data analysis
  - ⇒ Theoretical estimate of the redshift
  - ⇒ Interpretation within the Fireshell model

- GRB 090510:
  - ⇒ Observations and data analysis
  - ⇒ Interpretation within the Fireshell model

- Conclusions.

Brief reminder to the Fireshell Model



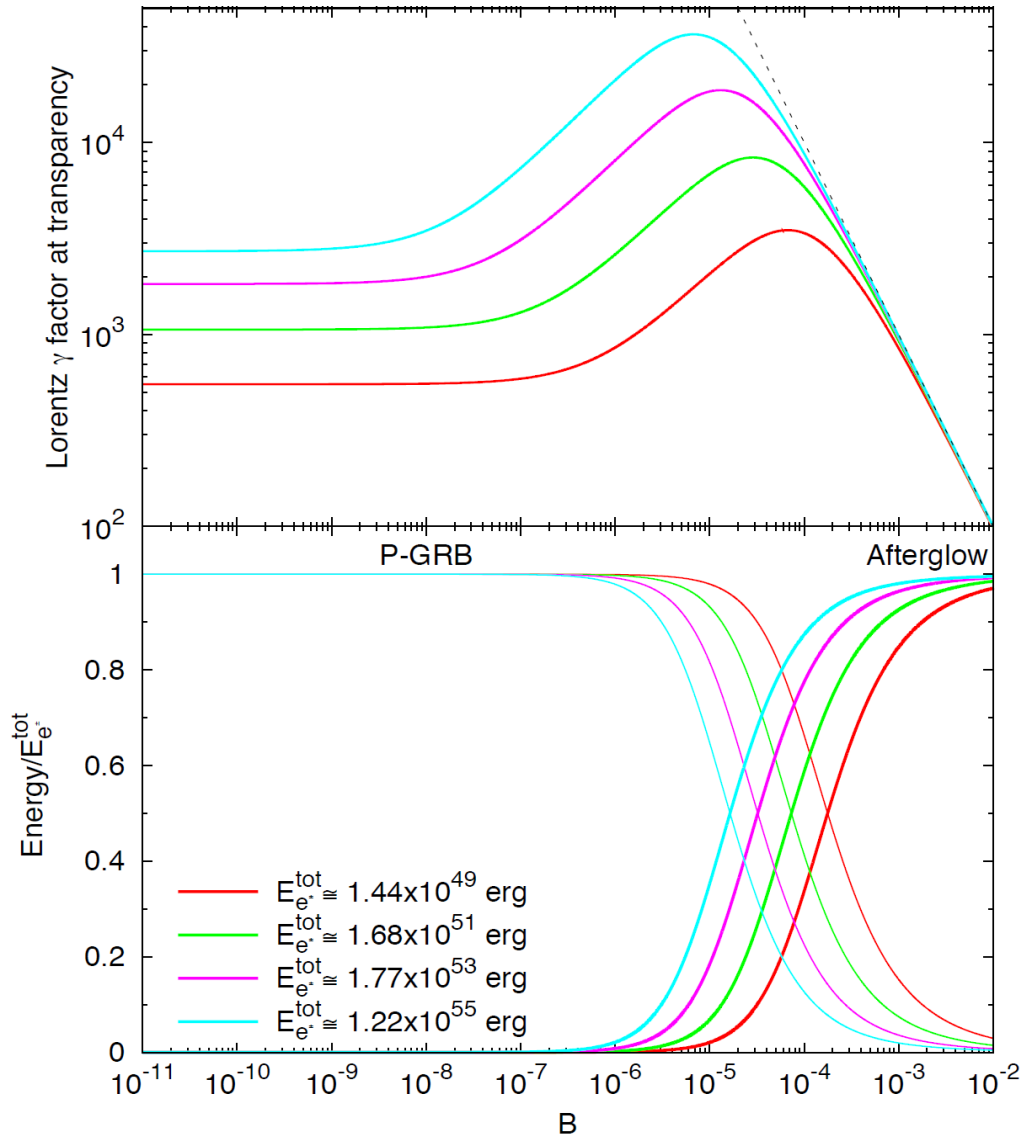
1) GRBs originate from an optically thick $e^{\pm}$ plasma in thermal equilibrium, having total energy $E_{\pm}^{tot}$ and formed in the gravitational collapse to a black hole.

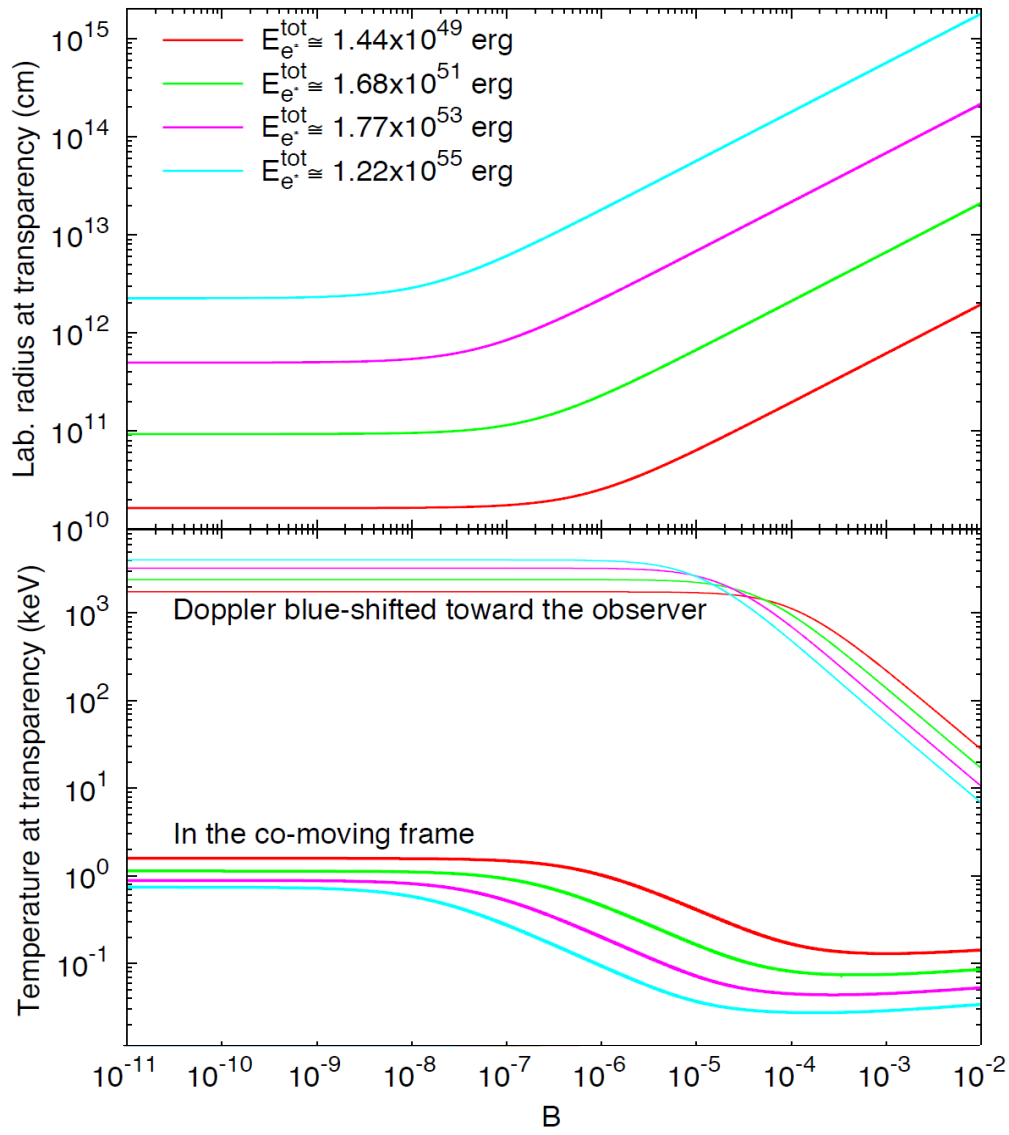
2) The gradual annihilation of the pairs is confined in an expanding shell, the *fireshell*, and engulfs the baryonic matter, described by the Baryon Load $B = M_B c^2 / E_{\pm}^{tot}$, left over in the process of collapse.

3) The shell, in thermal equilibrium among pairs and baryons, self-accelerates to ultra-relativistic velocities until the transparency condition is reached and the Proper-GRB (P-GRB) is emitted.

4) After the transparency, the remaining thin shell composed of baryons still expands ballistically and starts to slow down by collisions with the Circum Burst Medium (CBM) with average density n_{CBM}, giving rise to the extended afterglow.

Brief reminder to the Fireshell Model





GRB 090227B: Observations and data analysis

The bright short-hard GRB 090227B was observed by:

Fermi-GBM (GCN 8921)

The light curve consists of one spike with a duration (T_{90}) of about 0.9 s (10-1000 keV).
The time-integrated spectrum (from T_0-0.1s to T_0+0.4s) is best fitted by a Band function with E_p = (2255 ± 116) keV, α = -0.53 ± 0.02 and β = -3.04 ± 0.23 (reduced-χ^2=1.11).
The fluence (10-1000 keV) in this time interval is (0.87 ± 0.01)x10^{-5} erg/cm^2.

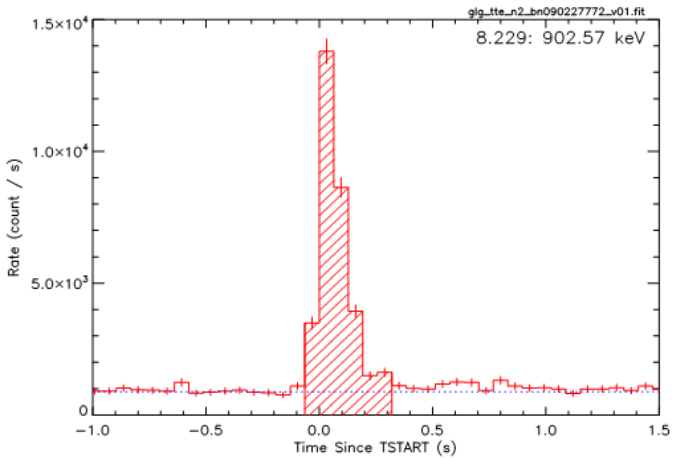
Konus-Wind (GCN 8926)

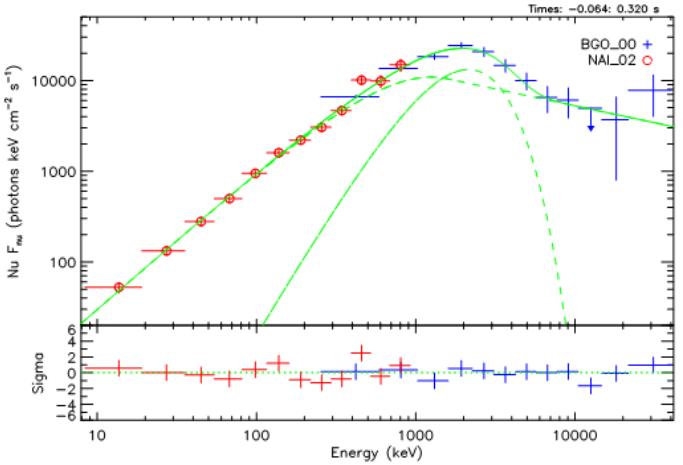
The time-integrated spectrum (from T_0 to T_0+0.192 s) is fitted (in the 20 keV - 10 MeV range) by a Band model with α = -0.41(-0.10, +0.12), β < -2.5 and E_p = 2134 (-326, +332) keV (χ^2 = 28.1/46 dof).
The emission is clearly seen up to 10 MeV.

Time-integrated analysis

T_0-0.064 s $\Rightarrow$ T_0+0.320 s

Spectral Parameter	Value
kT [keV]	545.7 ± 36.8
K_{BB} [ph/(cm^2 s keV)]	$(3.11 \pm 1.46) \times 10^{-8}$
α	-0.46 ± 0.04
β	-2.37 ± 0.21
E_{peak} [keV]	1252 ± 280
K_{Band} [ph/(cm^2 s keV)]	0.104 ± 0.004
C-STAT/DOF	279.59/238
F_{tot} [erg/(cm^2 s)]	$(8.67 \pm 0.28) \times 10^{-5}$
F_{BB} [erg/(cm^2 s)]	$(2.87 \pm 1.35) \times 10^{-5}$



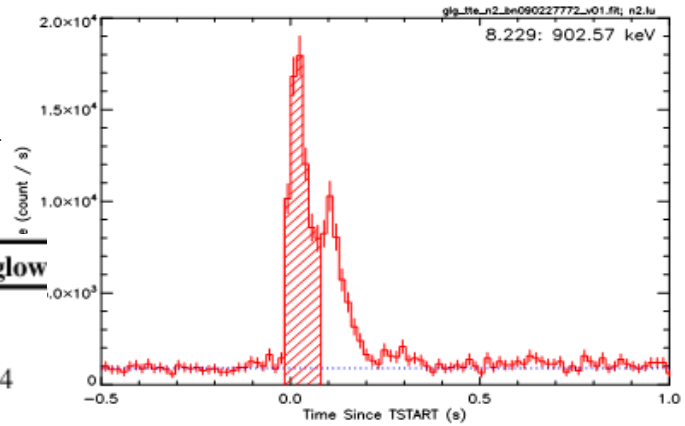


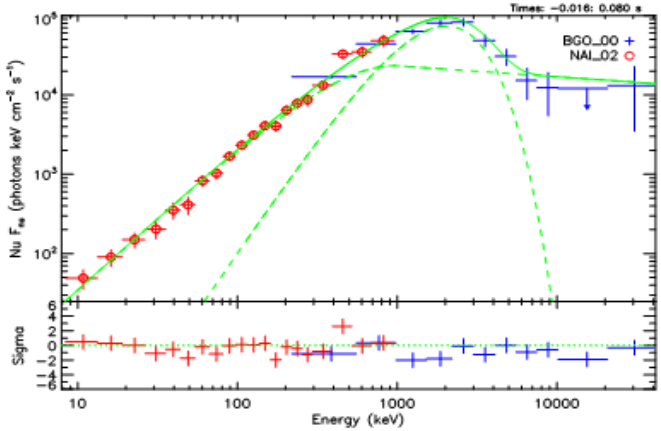
Time-resolved analysis

P-GRB

T_0-0.016 s $\Rightarrow$ T_0+0.080 s

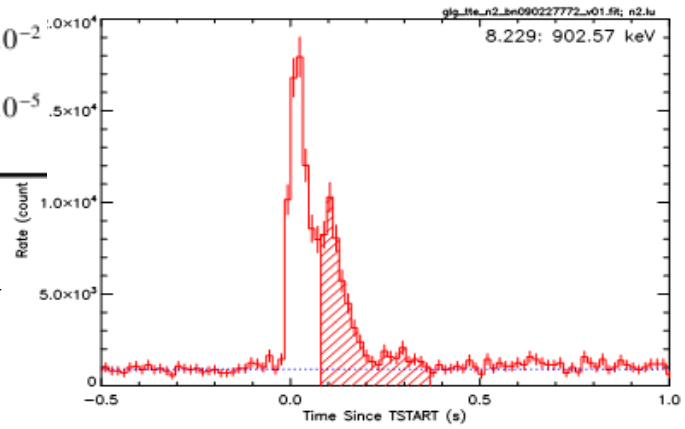
Spectral Parameter	P-GRB	Extended Afterglow
kT [keV]	517 ± 28	...
K_{BB} [ph/(cm^2 s keV)]	$(2.16 \pm 0.63) \times 10^{-7}$	...
α	-0.18 ± 0.11	-0.801 ± 0.054
β	-2.14 ± 0.17	-2.03 ± 0.11
E_{peak} [keV]	952 ± 251	1113 ± 188
K_{Band} [ph/(cm^2 s keV)]	0.237 ± 0.021	$(6.31 \pm 0.33) \times 10^{-2}$
C-STAT/DOF	263.51/239	271.73/242
F_{tot} [erg/(cm^2 s)]	$(3.13 \pm 0.13) \times 10^{-4}$	$(2.68 \pm 0.26) \times 10^{-5}$
F_{BB} [erg/(cm^2 s)]	$(1.61 \pm 0.47) \times 10^{-4}$	...

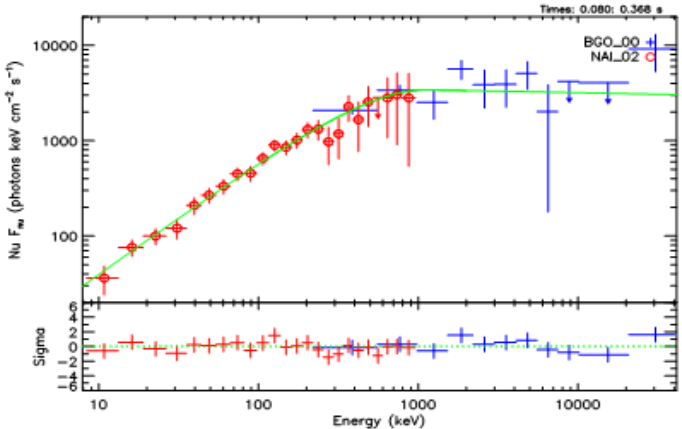




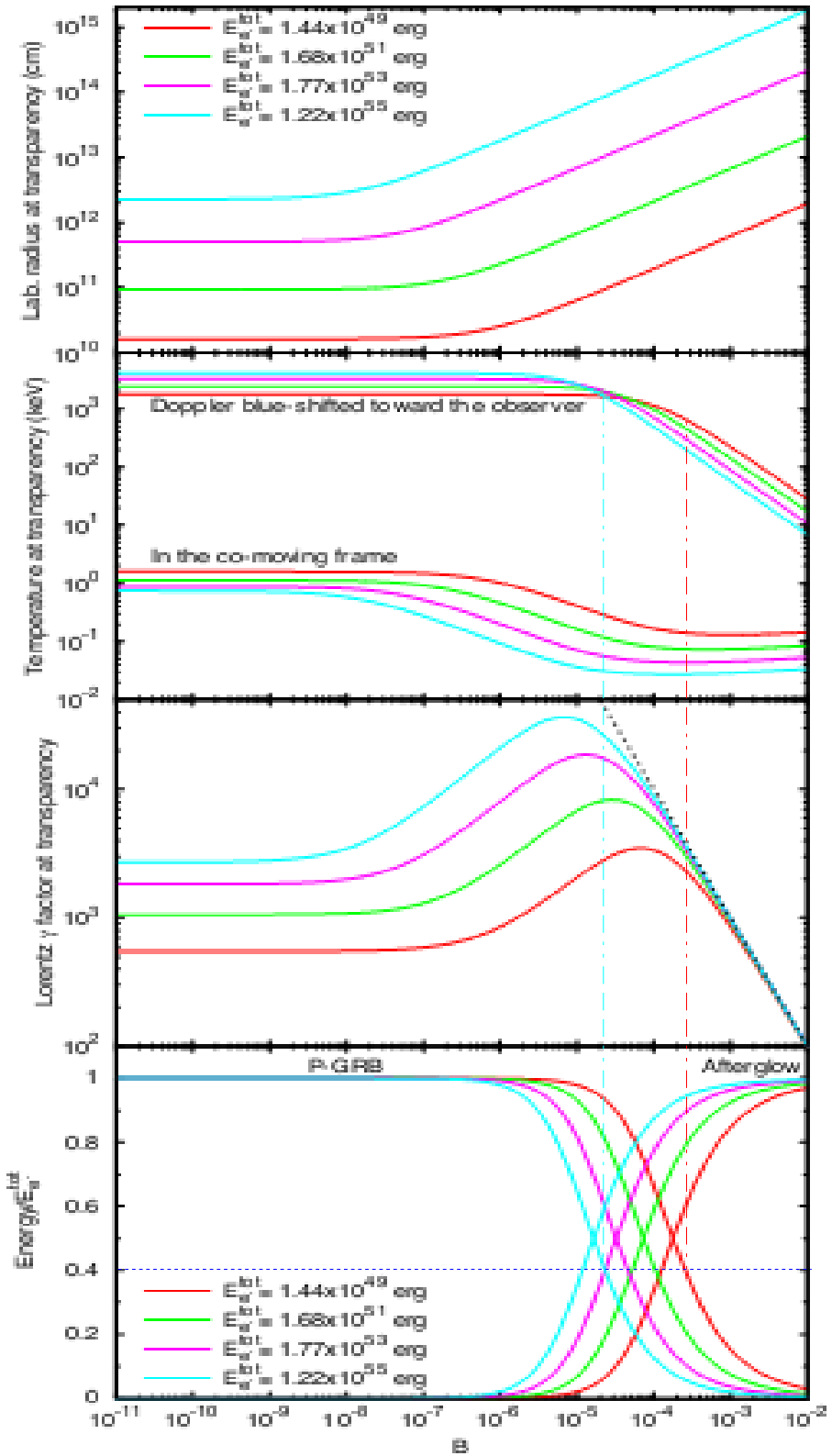
Extended afterglow

T_0+0.080 s $\Rightarrow$ T_0+0.368 s





GRB 090227B: Theoretical estimate of the redshift



No X-ray and optical observations ⇒ no z

From the measured fluences

$$\frac{E_{P-GRB}}{E^{tot}_{e^\pm}} = \frac{4\pi d_l^2 F_{BB}\Delta t_{BB}/(1+z)}{4\pi d_l^2 F_{tot}\Delta t_{tot}/(1+z)} = \frac{S_{BB}}{S_{tot}} = (40.67 \pm 0.12)\%.$$

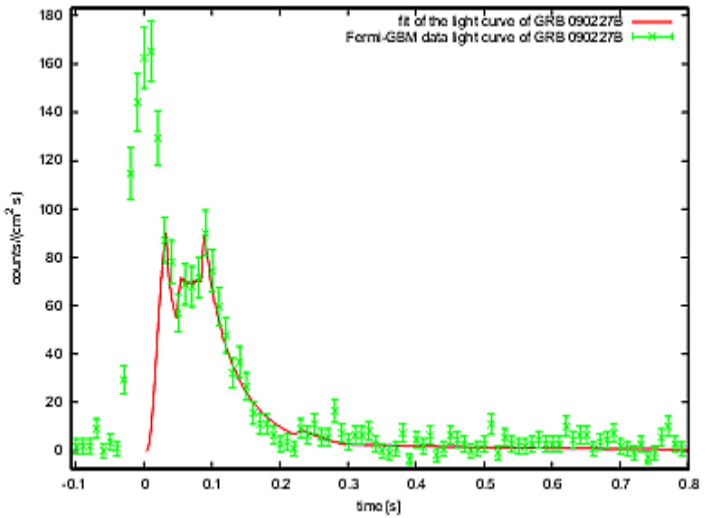
$$\hookrightarrow \boxed{[E^{tot}_{e^\pm}(z), B(z)]} \Rightarrow kT_{obs} = kT_{blue}/(1+z). \Rightarrow \boxed{z}$$

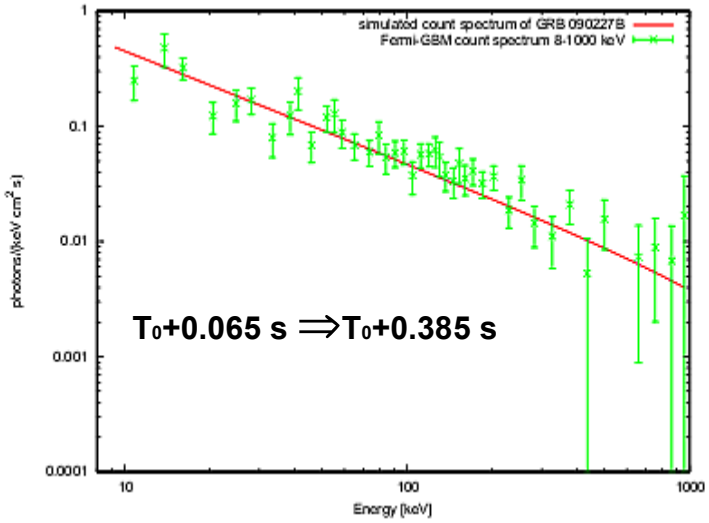
$$E_{iso} = 4\pi d_l^2 \frac{S_{tot}}{(1+z)} \frac{\int_{E_{min}/(1+z)}^{E_{max}/(1+z)} E\,N(E)dE}{\int_8^{40000} E\,N(E)dE} \hookleftarrow$$

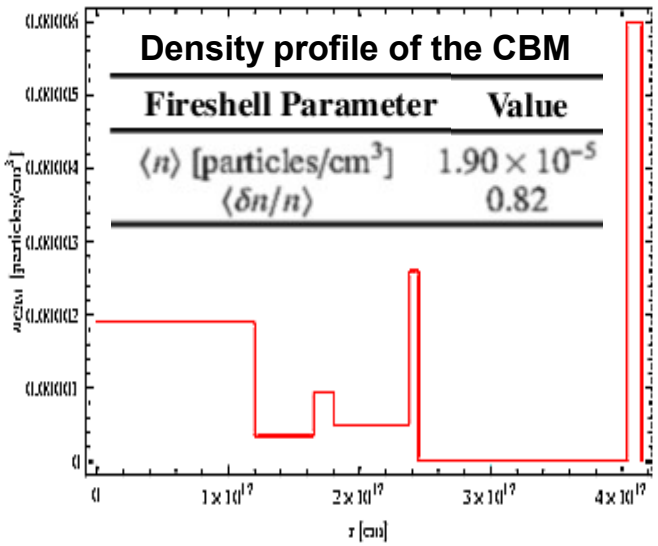
Fireshell Parameter	Value
$E^{tot}_{e^\pm}$ [erg]	$(2.83 \pm 0.15) \times 10^{53}$
B	4.13×10^{-5}
Γ_{tr}	14365
r_{tr} [cm]	1.76×10^{13}
kT_{blue} [keV]	1336
z	1.61 ± 0.14

GRB 090227B: Interpretation within the Fireshell model

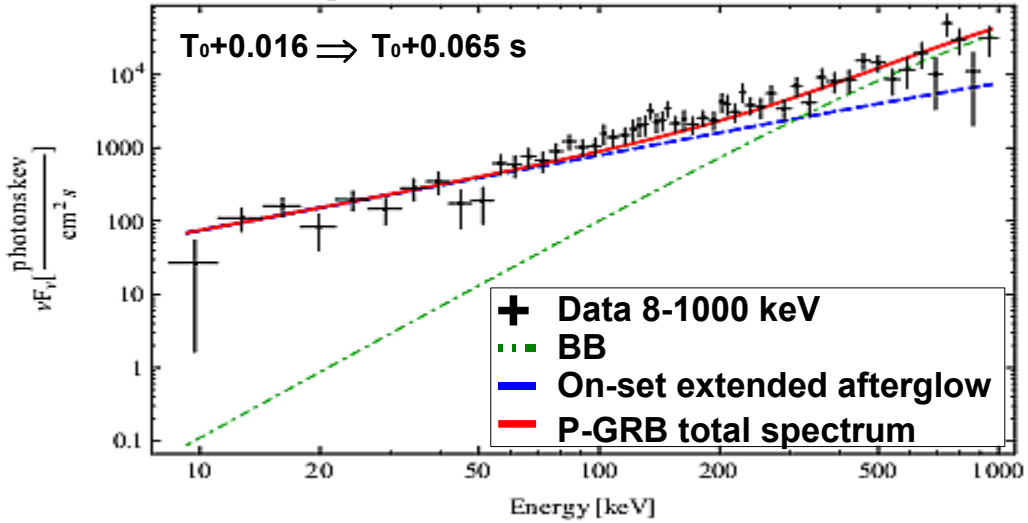
Simulated light curve and spectrum of the extended afterglow

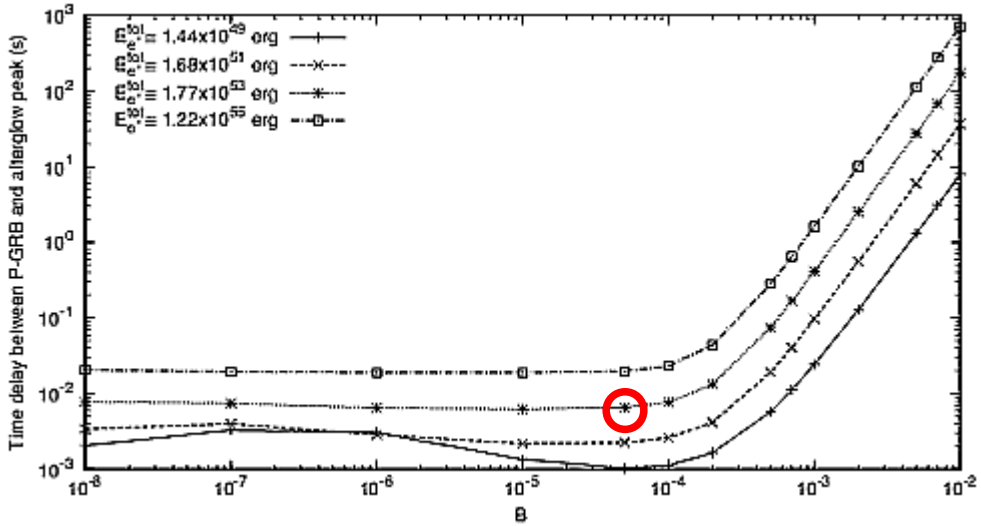






Fit of the spectrum of the P-GRB : BB + on-set of the extended afterglow

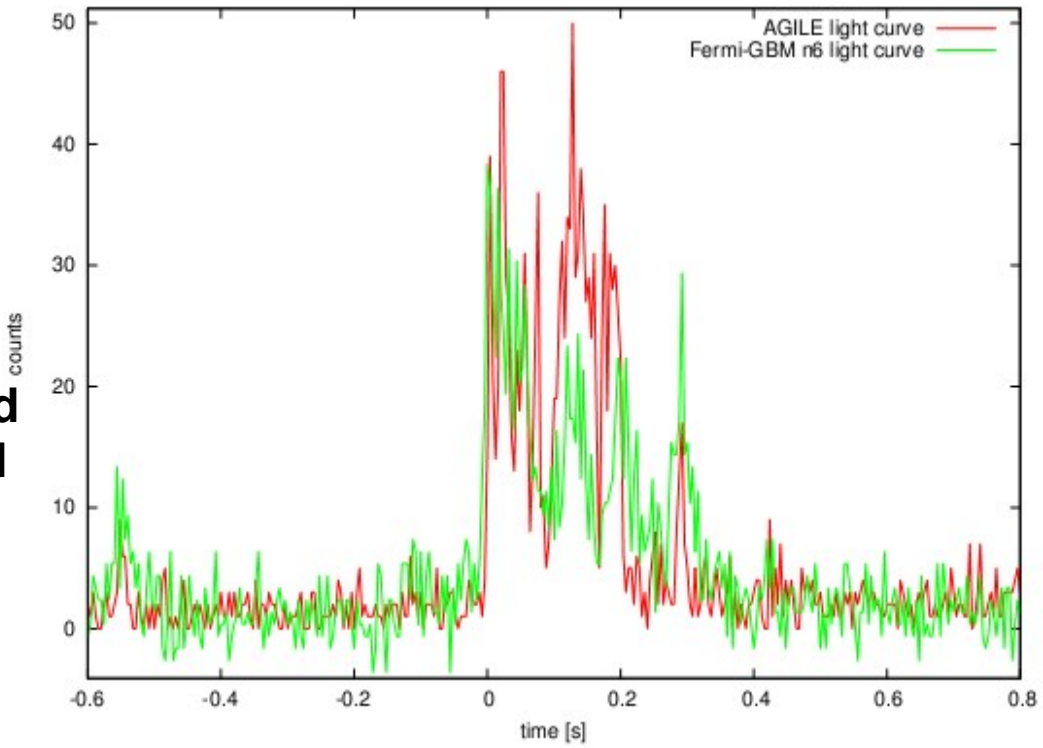




Observations and data analysis of GRB 090510

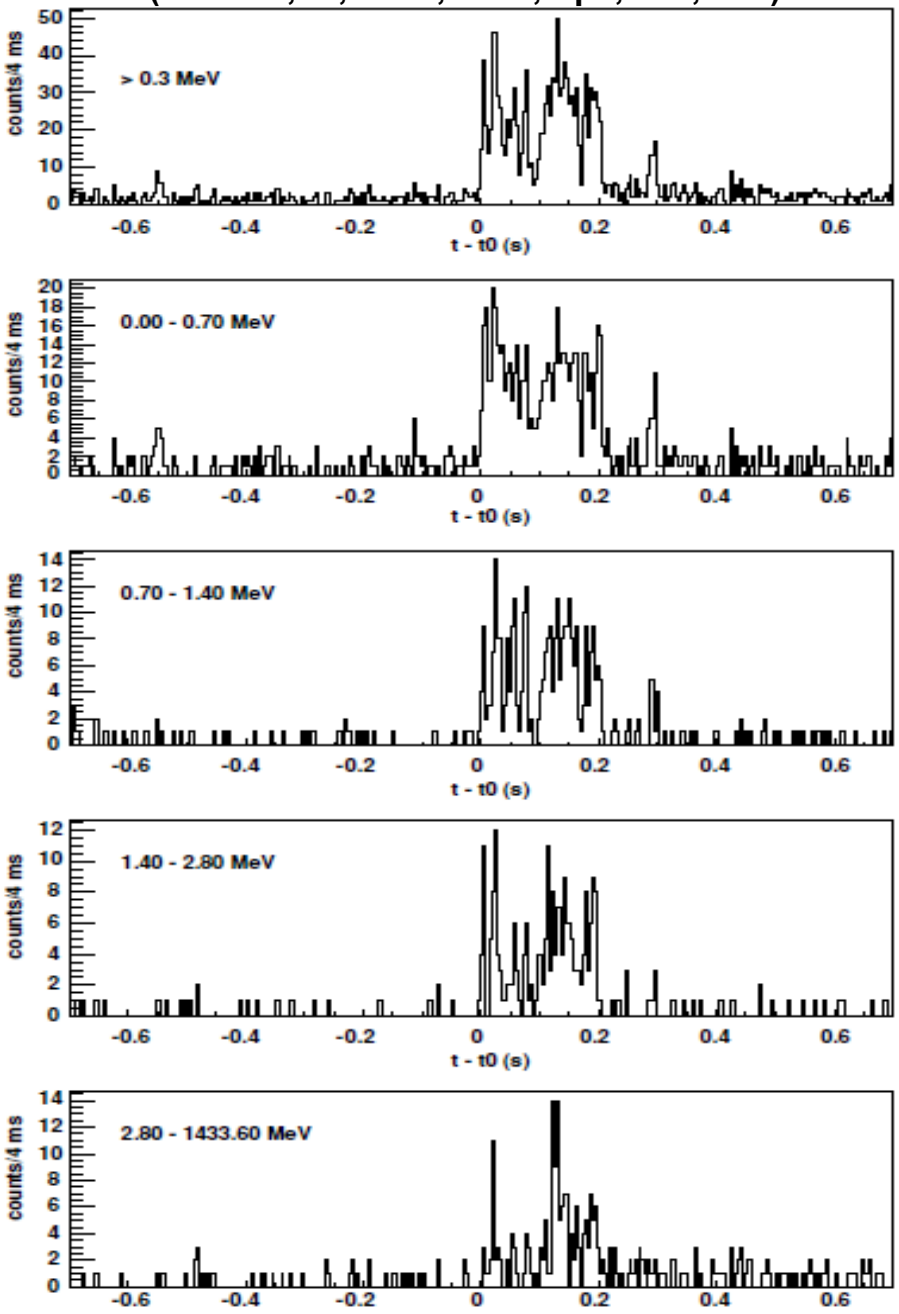
The bright short-hard GRB 090510 was observed by AGILE (Giuliani, A., et al., 2010, ApJ, 708, L84) and Fermi-GBM and LAT (Ackermann,M., et al., 2010, ApJ, 716, 1178).

GRB 090510 shows a deviation from a Band function during the prompt emission phase. The time-integrated spectrum is fit by a Band function with E_p = (3.9 ± 0.3) MeV and a hard power-law component with γ = -1.62 ± 0.03 that dominates the emission below 20 keV and above 100 MeV.
A faint GBM pulse and a LAT photon are detected 0.5 s before the main pulse.

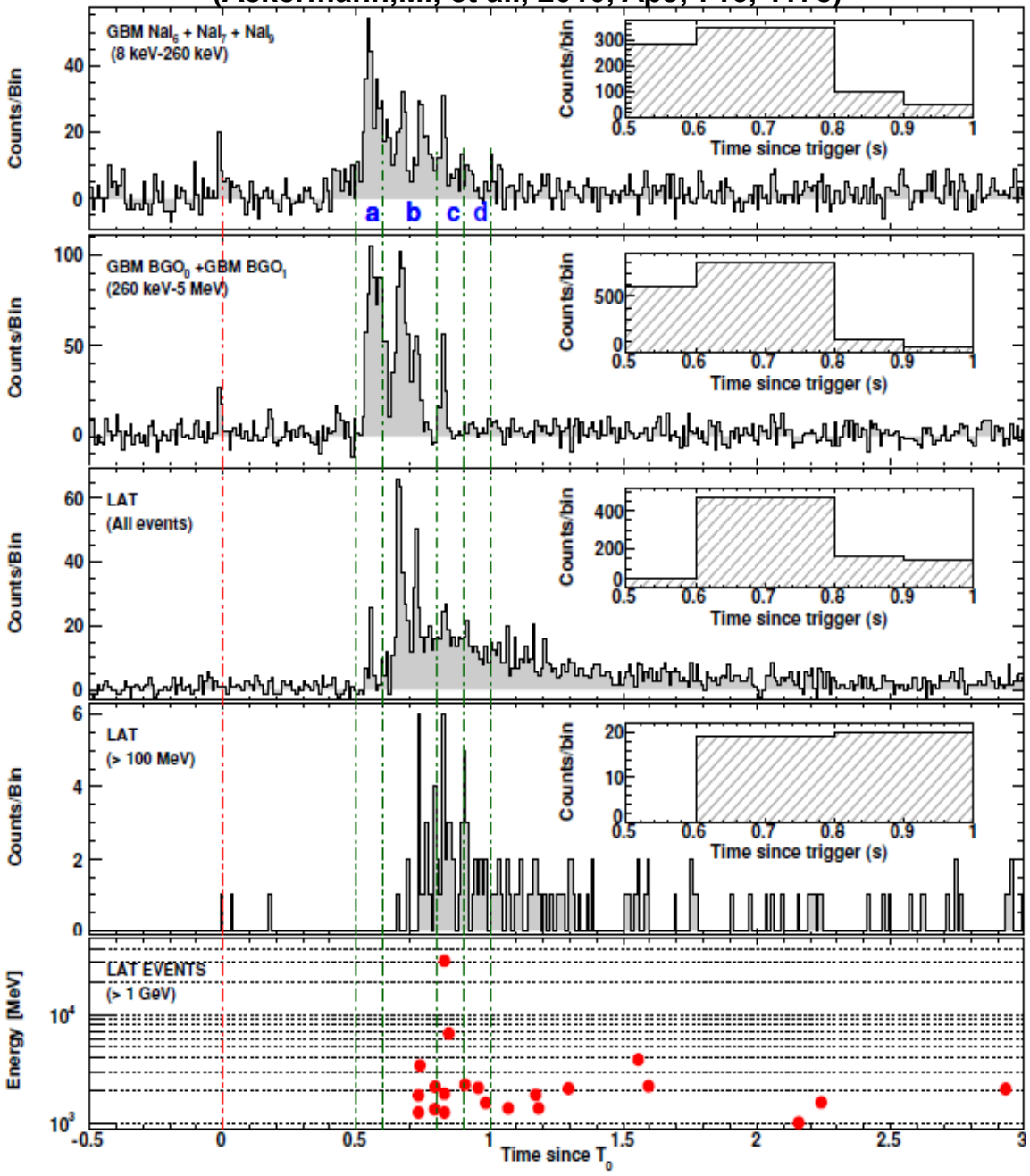


The LAT detected a photon with energy 30.5 (+5.8, -2.6) GeV, the highest ever measured from a short GRB.
Using simple opacity arguments with a variability time scale on the order of tens of ms, and z = 0.903 one can obtain $\Gamma \geq 1000$ (Ackermann,M., et al., 2010, ApJ, 716, 1178).

(Giuliani, A., et al., 2010, ApJ, 708, L84)



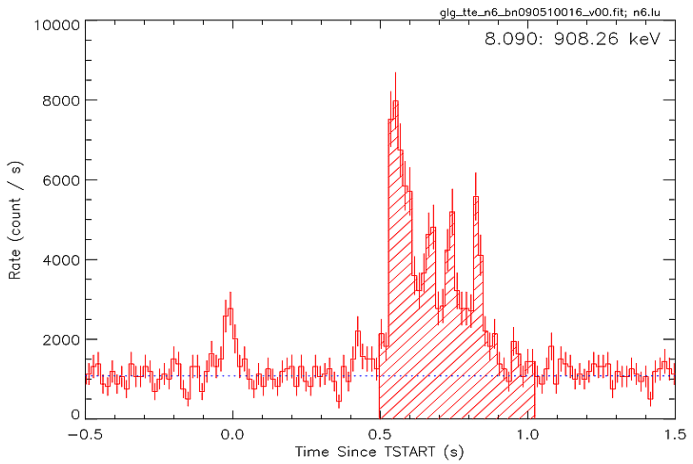
(Ackermann,M., et al., 2010, ApJ, 716, 1178)

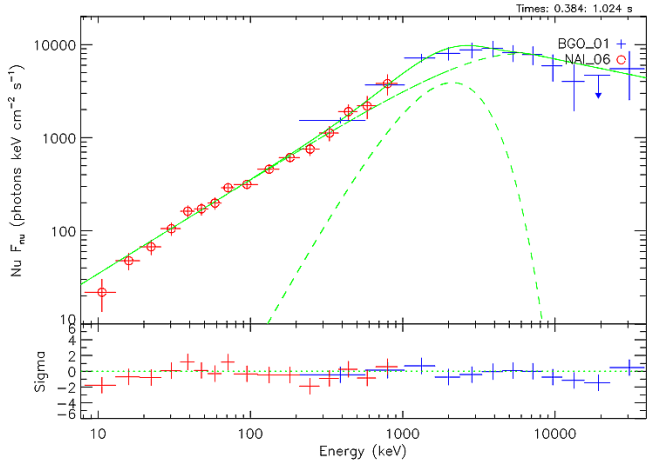


Time-integrated analysis

T_0+0.496 s $\Rightarrow$ T_0+1.024 s

Spectral Parameter	Value
kT [keV]	540.7 ± 82.7
K_{BB} [ph/(cm^2 s keV)]	$(9.7 \pm 5.7) \times 10^{-9}$
α	-0.984 ± 0.059
β	-2.33 ± 0.32
E_{peak} [keV]	5785 ± 1360
K_{Band} [ph/(cm^2 s keV)]	$(3.55 \pm 0.20) \times 10^{-2}$
χ^2_R	0.79
F_{tot} [erg/(cm^2 s)]	$(4.92 \pm 0.30) \times 10^{-5}$
F_{BB} [erg/(cm^2 s)]	$(8.6 \pm 5.1) \times 10^{-6}$

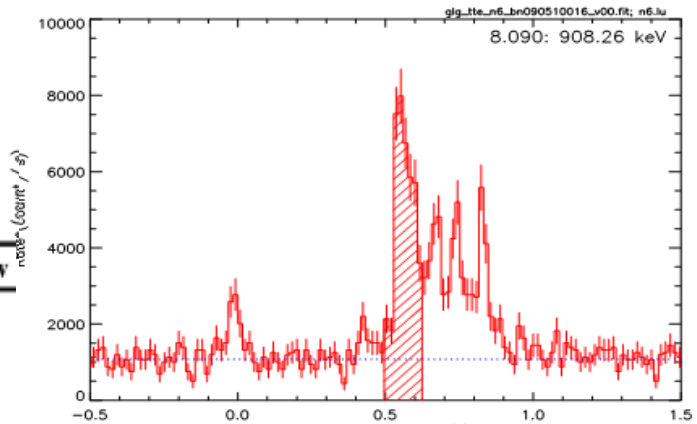


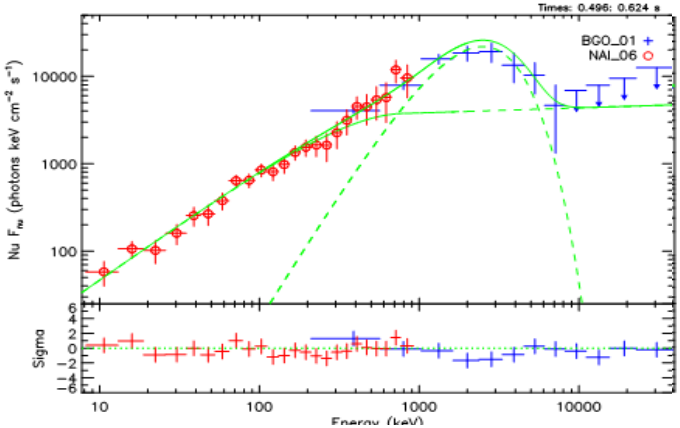


Time-resolved analysis

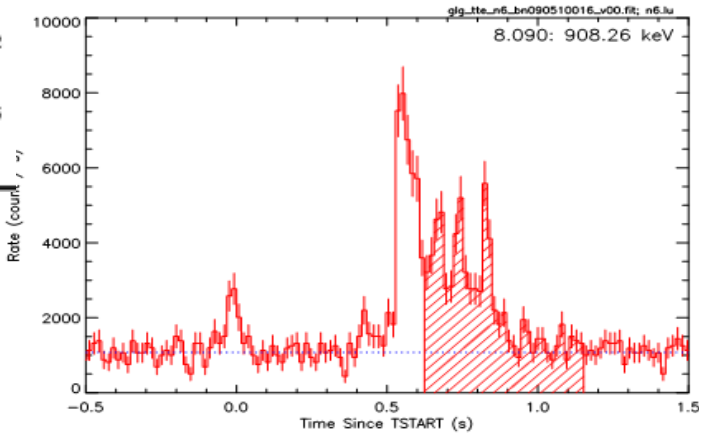
P-GRB
T_0+0.496 s $\Rightarrow$ T_0+0.624 s

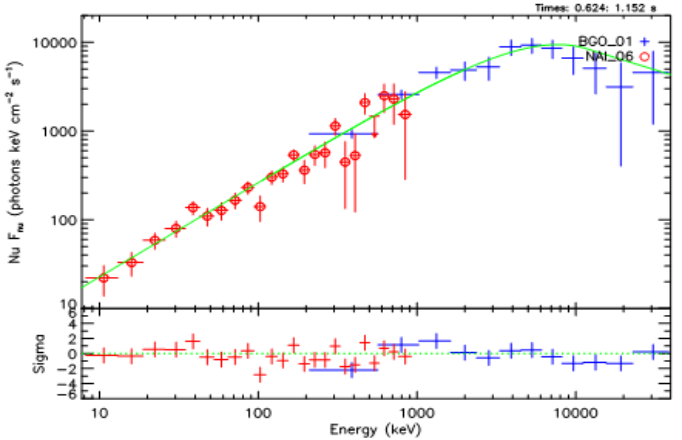
Spectral Parameter	P-GRB	Extended Afterglow
kT [keV]	645 ± 54	...
K_{BB} [ph/(cm^2 s keV)]	$(2.63 \pm 0.88) \times 10^{-8}$	...
α	-0.63 ± 0.17	-0.933 ± 0.039
β	-1.80 ± 0.14	-2.55 ± 0.53
E_{peak} [keV]	630.3 ± 319	7706 ± 1290
K_{Band} [ph/(cm^2 s keV)]	$(9.9 \pm 2.1) \times 10^{-2}$	$(2.65 \pm 0.14) \times 10^{-2}$
χ^2_R	0.74	0.90
F_{tot} [erg/(cm^2 s)]	$(8.70 \pm 0.71) \times 10^{-5}$	$(4.29 \pm 0.33) \times 10^{-5}$
F_{BB} [erg/(cm^2 s)]	$(4.7 \pm 1.6) \times 10^{-5}$	...





Extended afterglow
T_0+0.624 s $\Rightarrow$ T_0+1.152 s



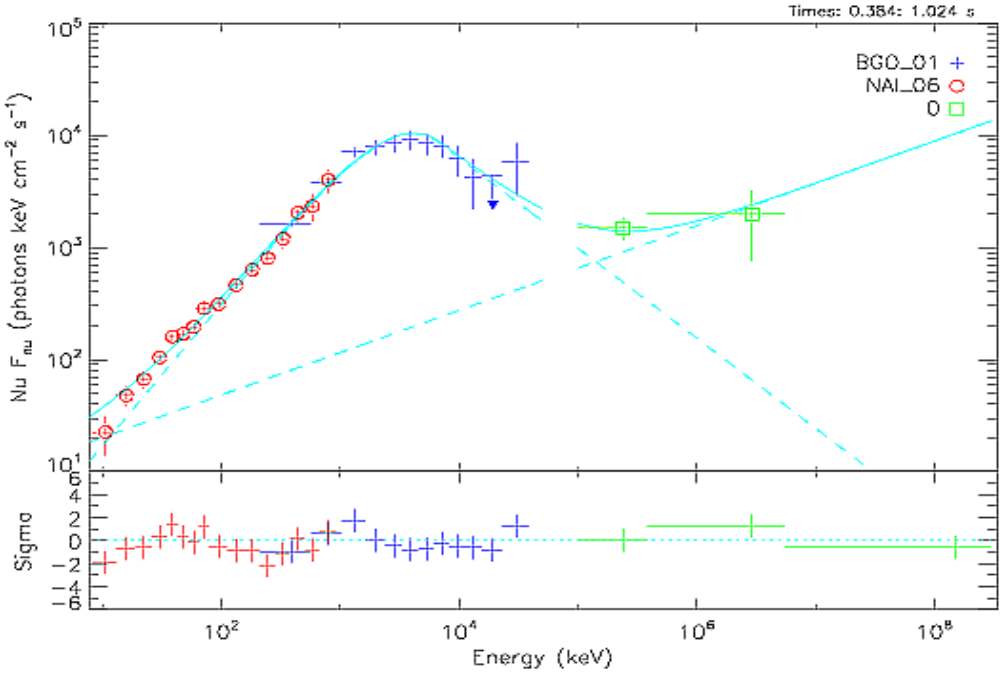


GRB 090510: Interpretation within the Fireshell model

The best fit (GBM+LAT): Band+PL
E_{iso} = (1.08 ± 0.06) x 10^{53} ergs.

The energy detected by LAT
E_{LAT} ≈ 2.94 x 10^{52} ergs = 27.31% E_{iso}

The energy of the BB component
E_{BB} ≈ 1.34 x 10^{52} ergs = 12.42% E_{iso}
and its observed temperature
kT_{obs} ≈ (644.9 ± 53.9) keV.



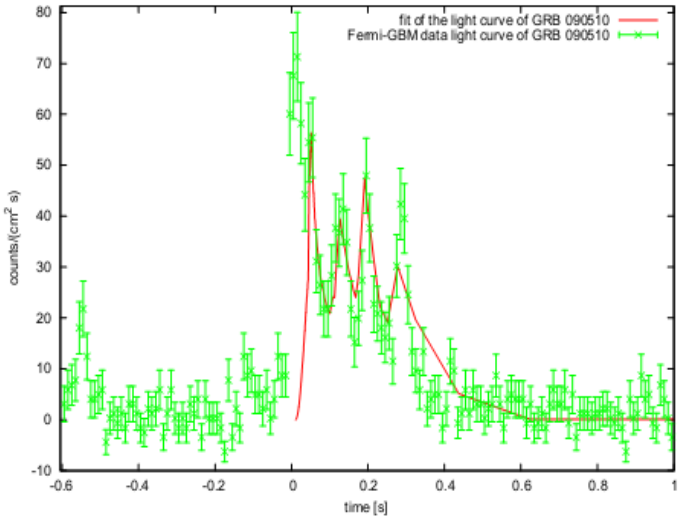
E_{BB} + E_{LAT} ≈ 4.28 x 10^{52} ergs = 39.73% E_{iso}

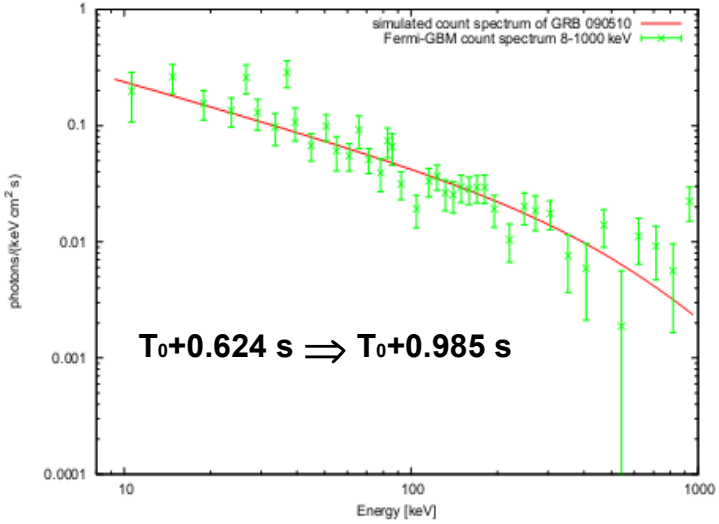
Fireshell Parameter	Value
$E^{tot}_{e^\pm}$ [erg]	$(1.08 \pm 0.06) \times 10^{53}$
B	5.03×10^{-5}
Γ_{tr}	11938
r_{tr} [cm]	1.20×10^{13}
$kT_{blue}/(1+z)$ [keV]	644.2
$E_{P-GRB}/E^{tot}_{e^\pm}$ [%]	39.96

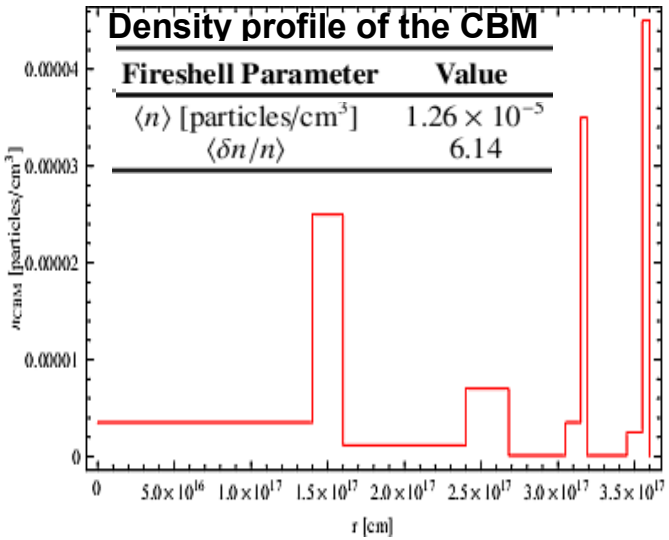
The GeV emission is part of the emission at the transparency

GRB 090510: Interpretation within the Fireshell model

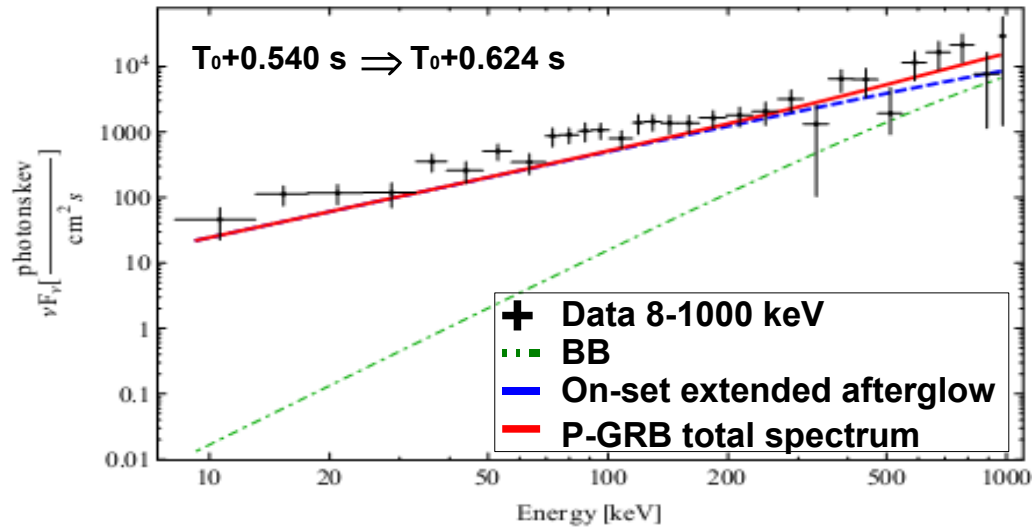
Simulated light curve and spectrum of the extended afterglow

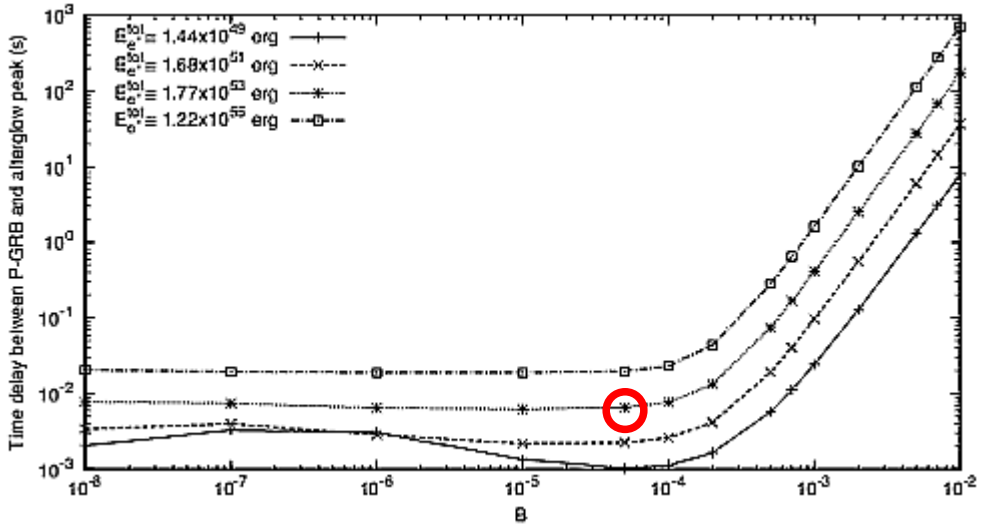






Fit of the spectrum of the P-GRB : BB + on-set of the extended afterglow



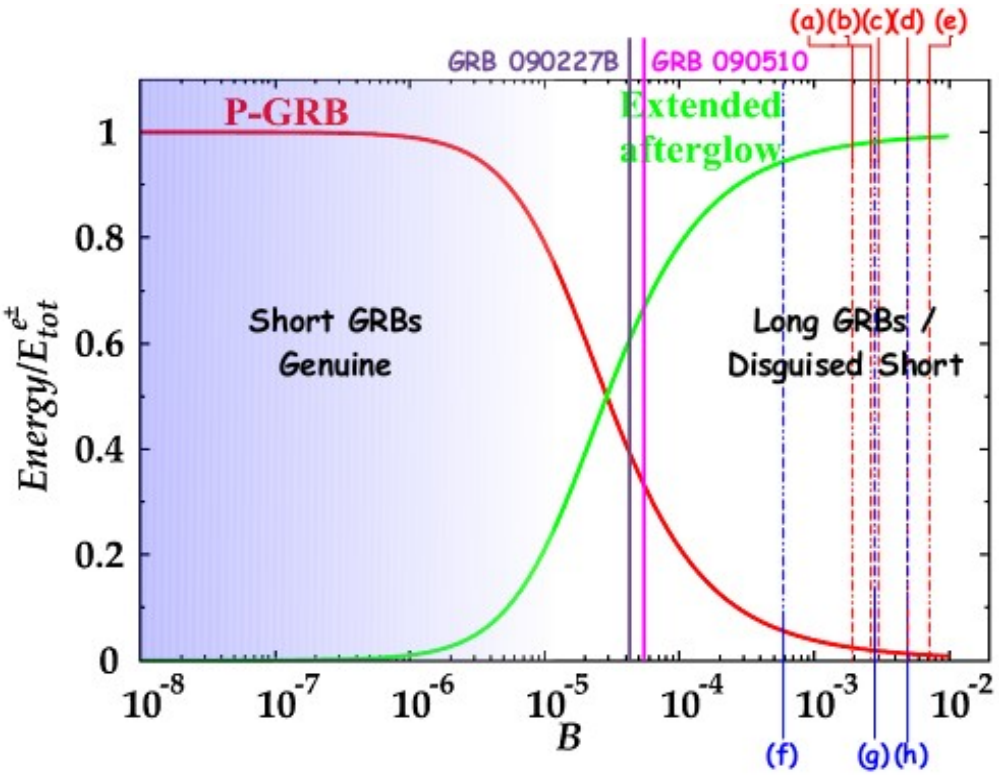


Conclusions (1)

- GRB 090227B and GRB 090510 are characterized by extremely low values of the Baryon load $B \approx 5 \times 10^{-5}$. They are the missing links between the long/disguised short GRBs and the genuine short GRBs class.

- Such sources have $\Gamma > 10000$ and possible GeV-emission like in the case of GRB 090510.

- The GeV-emission is produced in the dyadosphere and as a consequence we have to take into account it in the energy content of the transparency emission.

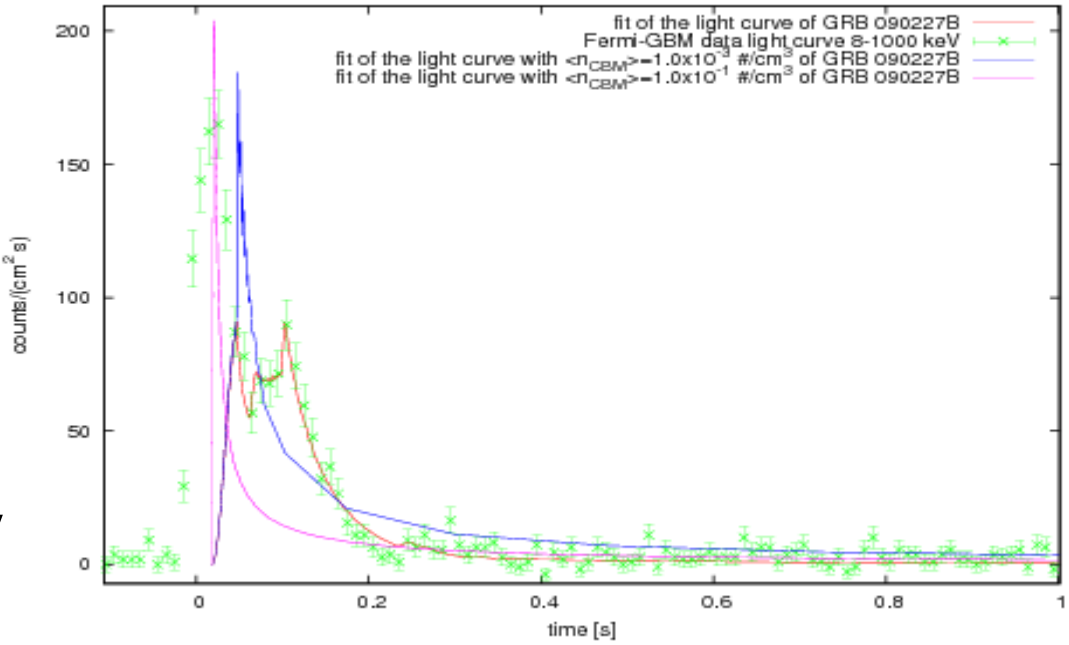


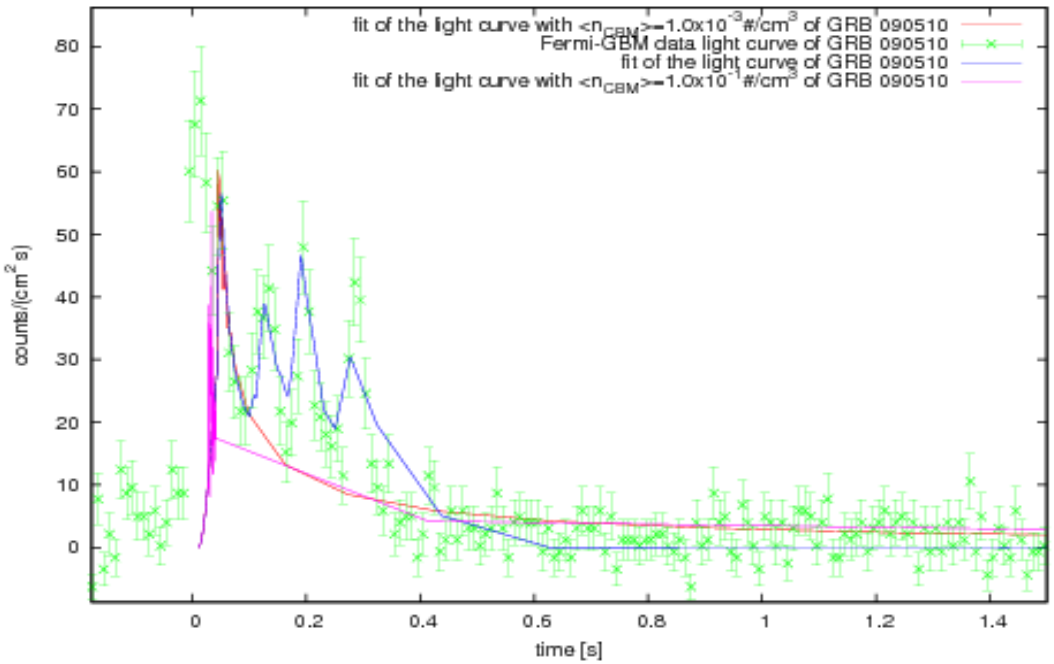
label	GRB	$E_{e^\pm}^{tot}$ [erg]	B	$\langle n_{CBM} \rangle$ [#/cm^3]
(a)	090618	2.49×10^{53}	1.98×10^{-3}	1.0
(b)	080319B	1.32×10^{54}	2.50×10^{-3}	6.0
(c)	991216	4.83×10^{53}	3.00×10^{-3}	1.0
(d)	030329	2.12×10^{52}	4.80×10^{-3}	2.0
(e)	031203	1.85×10^{50}	7.40×10^{-3}	0.3
(f)	050509B	5.52×10^{48}	6.00×10^{-4}	1.0×10^{-3}
(g)	060614	2.94×10^{51}	2.80×10^{-3}	1.0×10^{-3}
(h)	970228	1.45×10^{54}	5.00×10^{-3}	9.5×10^{-4}
	090227B	2.83×10^{53}	4.13×10^{-5}	1.9×10^{-5}
	090510	1.08×10^{53}	5.03×10^{-5}	1.3×10^{-5}

Conclusions (2)

- GRB 090227B and GRB 090510 are peculiar bursts exploded in low density environment of the order of $\langle n_{CBM} \rangle \approx 10^{-5}$ # /cm^3.
  For higher densities the extended afterglow emission results in a spiky emission "squeezed" on the P-GRB and with a prolonged soft tail.

- In these cases, for less energetic and further sources the emission can result in a small spike-like structure that can be easily discarded by the trigger algorithms of the detectors or be under instrumental thresholds.





Thank you