

The Ultra Relativistic GRBs

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2nd Galileo–Xu Guangxi meeting - Ventimiglia

Outlines

- GRBs Observations
- Analysis in the fireshell scenario
- Observed P-GRB emission ?
- The high energy emission
- Conclusions and perspectives

Fermi satellite

Multi-agency space observatory
8 keV - 300 GeV



GBM – GLAST Burst Monitor

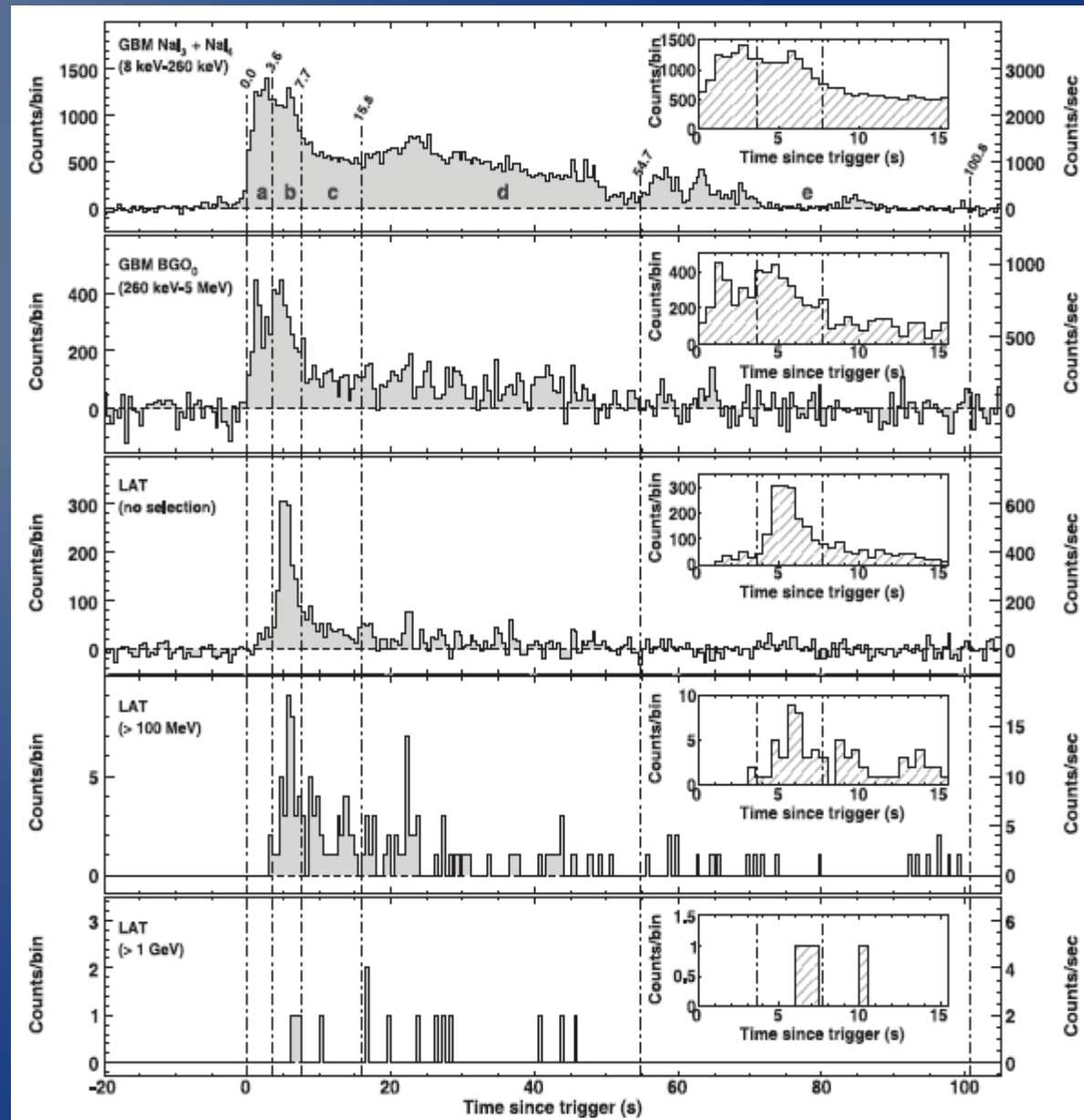
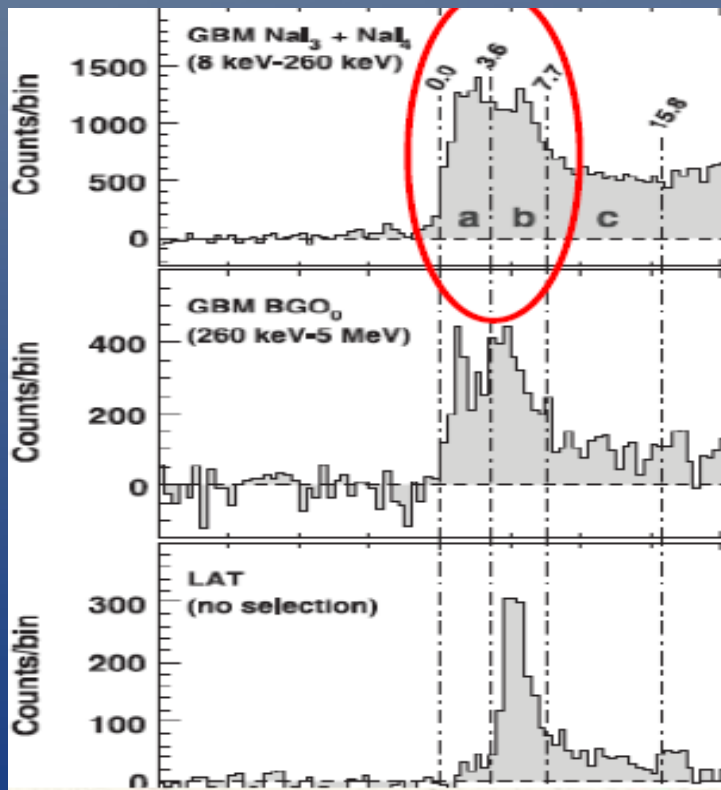
14 scintillation detectors:
12 NaI (8 – 1000 keV)
2 BGO (150 keV – 30 MeV)

LAT – Large Area Telescope

Pair-conversion detector :
100 MeV – 300 GeV
Large field of view (>2 steradians)
Variable resolution (...obvious...)
~ 20 GRBs observed

GRB 080916C

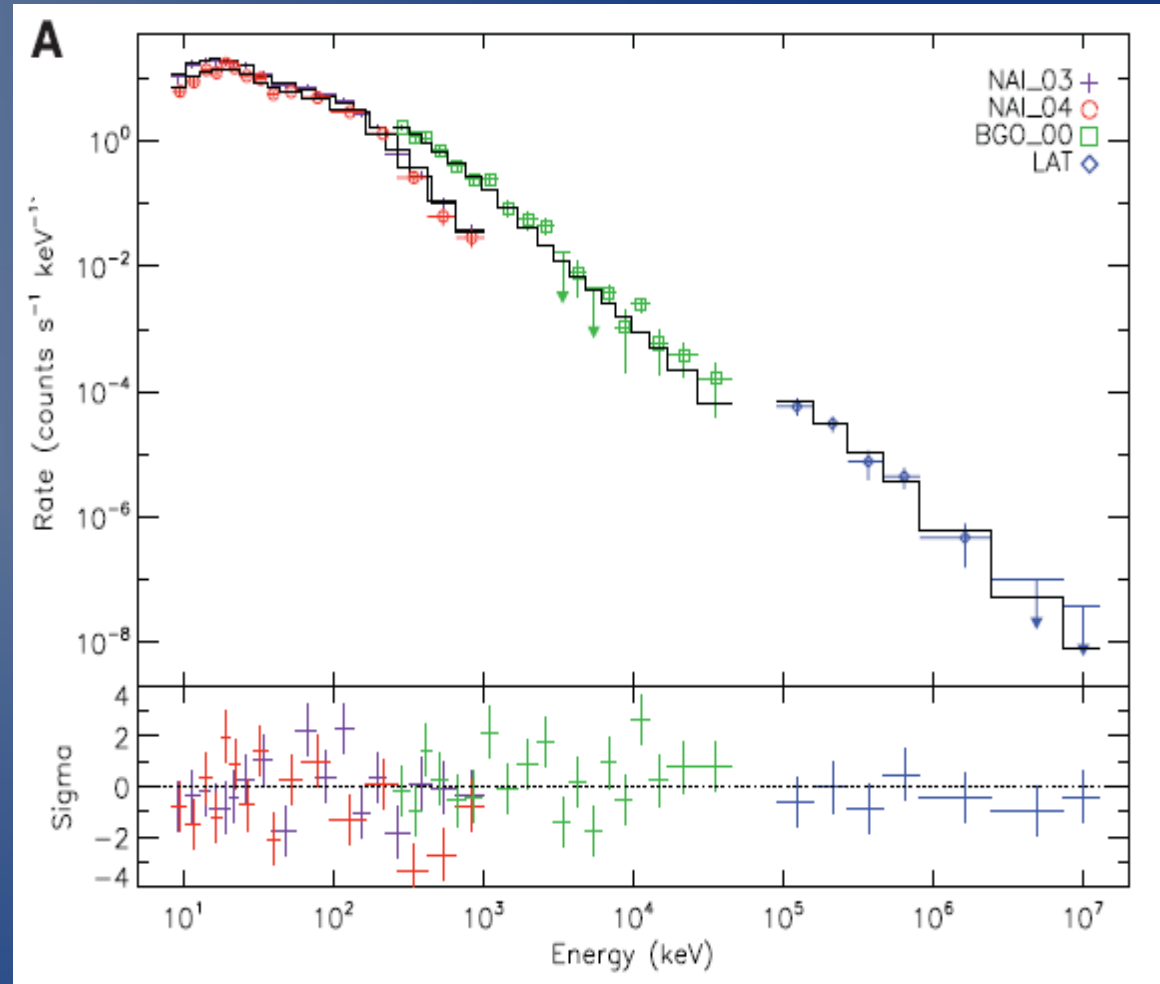
- ✓ Most energetic GRB to date
 $E_{\text{iso}} = 8.8 \times 10^{54}$ ergs
- ✓ T90 = 66 s (8-300 keV)
- ✓ H.E. emission (> 100 MeV) observed in the first 100 s
- ✓ 13.7 GeV photon in d interval
- ✓ $z = 4.35$ (GROND)
- ✓ Delayed onset of H.E. ~4 s



(Abdo et al. Science 2009)

GRB 080916C

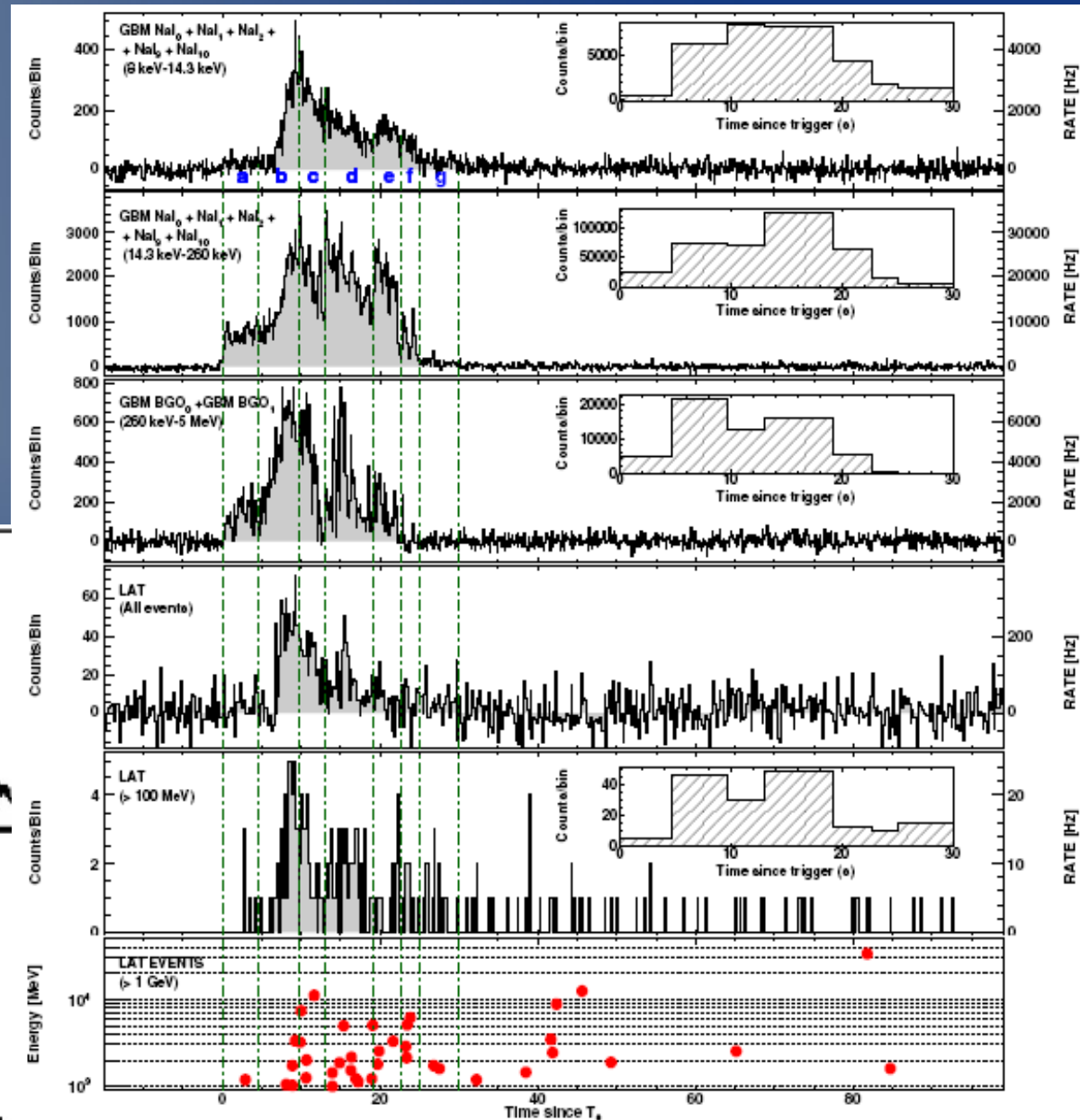
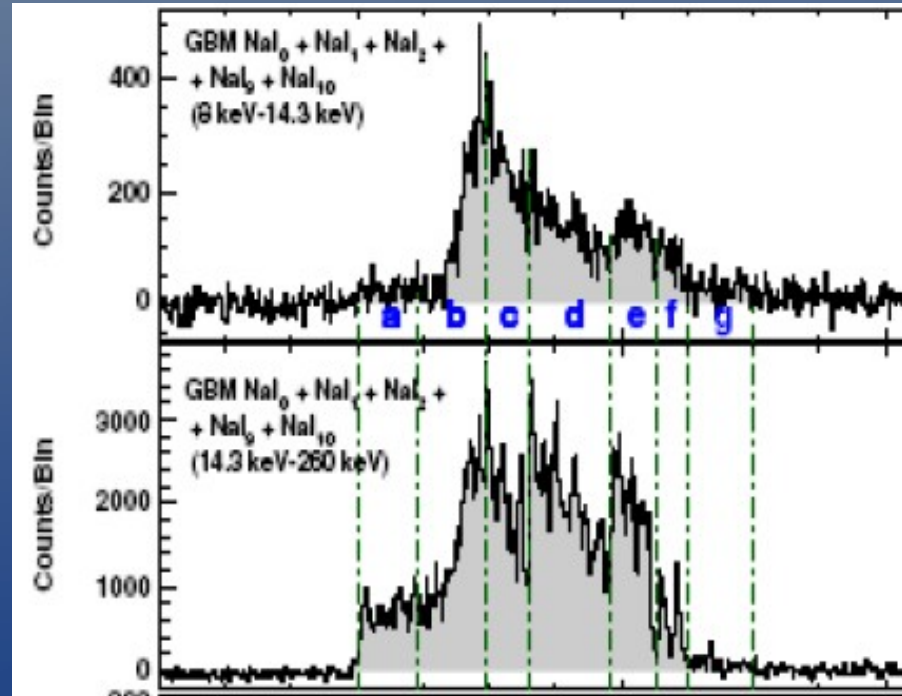
- ✓ Spectrum fitted by a single Band spectral model
- ✓ $E_{p,i} = 2.24 \pm 0.92$ MeV
- ✓ LAT emission fitted by a power-law model :
 $\gamma = -2.14 \pm 0.087$
- ✓ $E_{\text{LAT}} = 2.24 \times 10^{54}$ ergs
- ✓ Strong spectral variation soft-hard-soft



Interval	α	β	E_0 (keV)	$\tilde{\chi}^2$
(0 s, 4 s)	-0.31 ± 0.09	-2.06 ± 0.13	164.4 ± 26.1	1.12
(4 s, 9 s)	-0.89 ± 0.06	-1.78 ± 0.10	413.9 ± 96.5	1.11

GRB 090902B

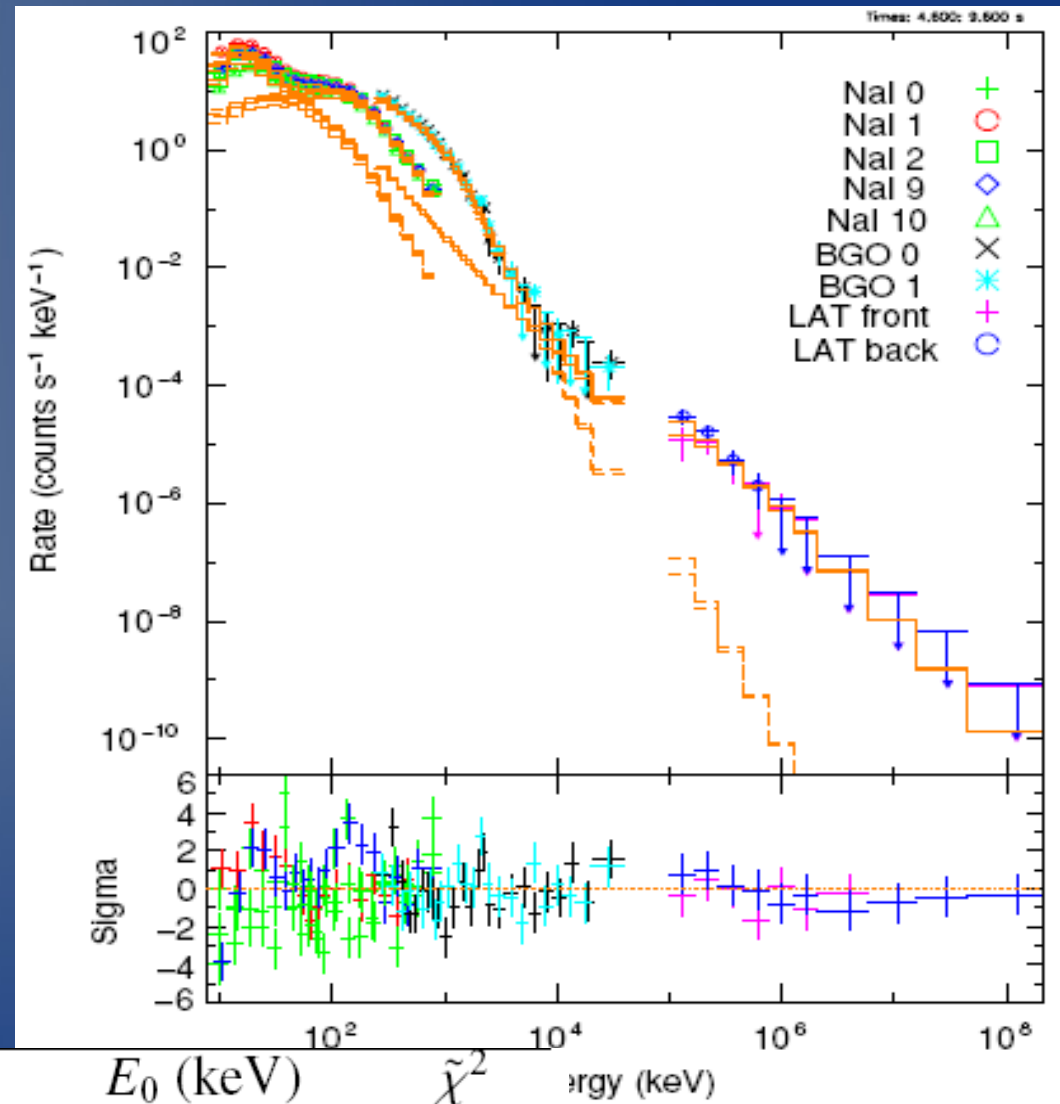
- ✓ $E_{\text{iso}} = 3.57 \times 10^{54}$ ergs
- ✓ $T_{90} = 21.9$ s
- ✓ H.E. emission (> 100 MeV) observed beyond 1 ks
- ✓ Highest photon observed for a GRB : 33.4 GeV after 82 s
- ✓ $z = 1.822$ (Gemini-North)
- ✓ Delayed onset of H.E. ~ 7 s



(Abdo et al. ApJL 2009)

GRB 090902B

- ✓ Spectrum fitted by a Band + power-law spectral model
- ✓ Extra component at low (8 – 50 keV) and high (> 100 MeV) energy
- ✓ $E_{p,i} = 2.07 \pm 0.12$ MeV
- ✓ Spectral variation soft-hard-soft



Interval	α	β	E_0 (keV)	$\tilde{\chi}^2$
(0 s, 4 s)	-0.13 ± 0.09	unconstrained	290.9 ± 30.9	1.13
(6 s, 13 s)	-0.37 ± 0.02	-4.76 ± 1.62	622.1 ± 22.7	1.60

GRB emission in the fireshell scenario

- ✓ Opt thick and spherical sym plasma originated from the formation of a black hole
- ✓ Thermal equilibrium with the engulfed baryonic matter
- ✓ Relativistic expansion until the transparency condition
- ✓ First flash of radiation (*Proper-GRB*) whose SED should be thermal
- ✓ Following observed prompt emission due to collisions of the residual baryonic and leptonic matter shell with the CBM around the burst site (*extended afterglow*)

We need only 2 parameters, the total energy and the baryon loading, and the structure of the circumburst density around the GRB

GRBs simulations - 080916C

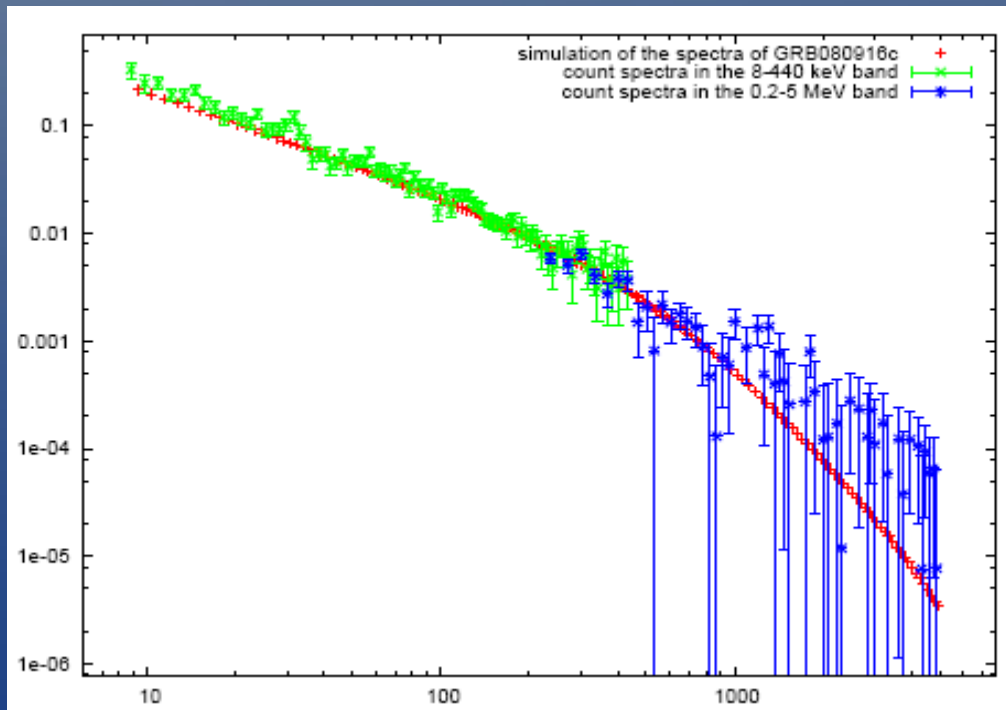
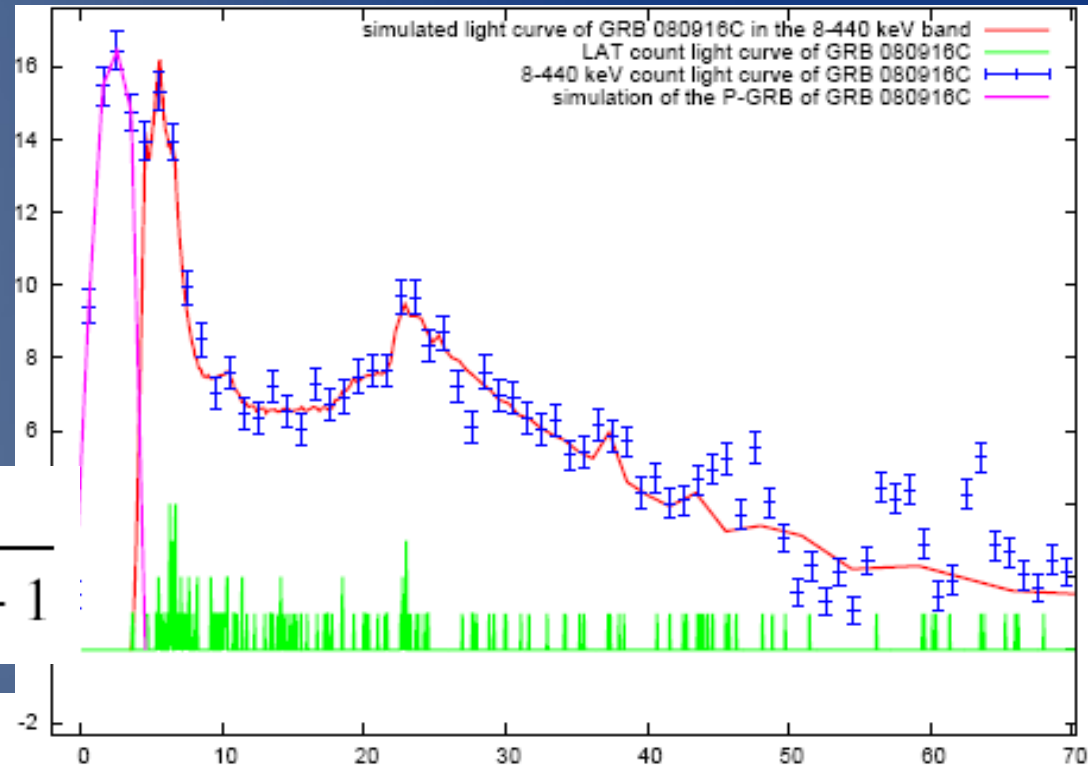
$$E_{\text{dya}} = 8.8 \times 10^{54} \text{ ergs}$$

$$B = 3 \times 10^{-4}$$

$$\langle n \rangle = 2.2 \times 10^{-3} \text{ \#/cm}^3$$

$$E_{\text{PGRB}} = 4.8 \% E_{\text{dya}}$$

$$\frac{dE}{dAd\Omega dv dt} = \frac{2h\nu^3}{c^2} \left(\frac{h\nu}{k_B T} \right)^\alpha \frac{1}{\exp\left(\frac{h\nu}{k_B T}\right) - 1}$$



Results

$$\text{Bulk Lorentz } \Gamma = 3170$$

$$T_{\text{PGRB}} = 34.3 \text{ keV}$$

$$\alpha = -1.92$$

090902B

$$E_{\text{dya}} = 3.63 \times 10^{54} \text{ ergs}$$

$$B = 9 \times 10^{-4}$$

$$\langle n \rangle = 3.15 \times 10^{-2} \text{ \#/cm}^3$$

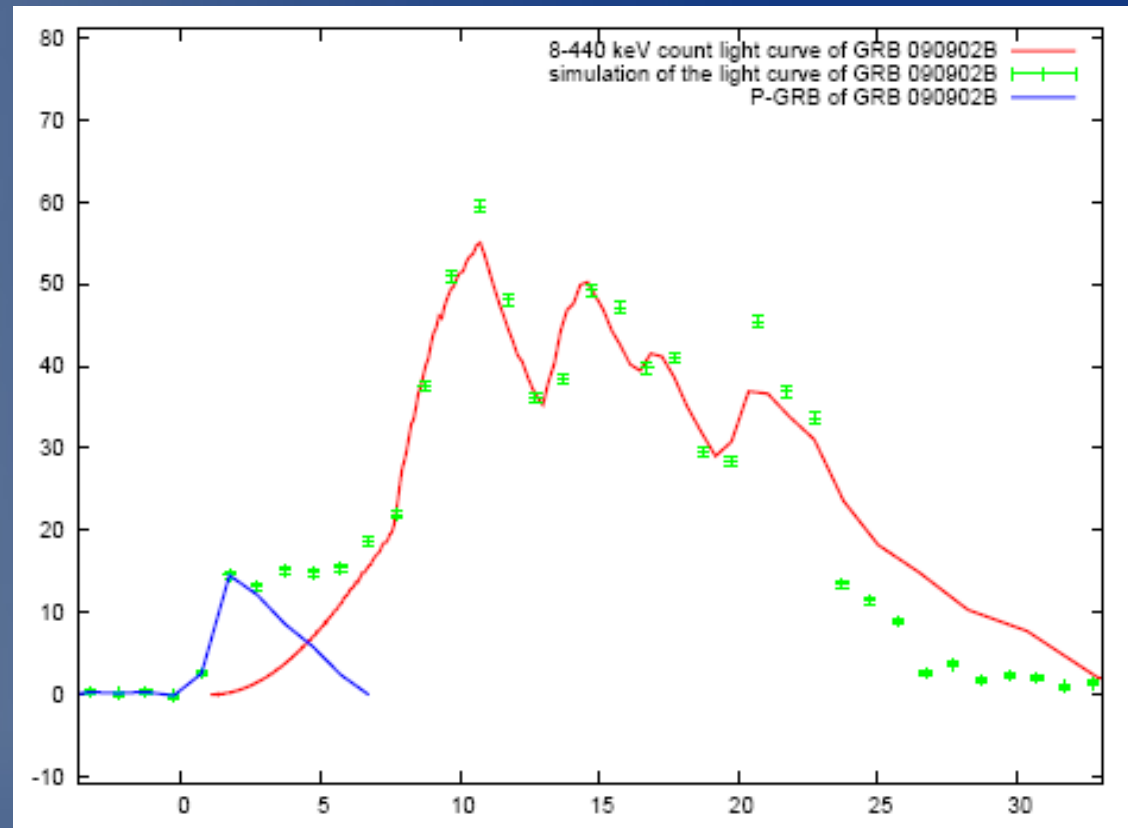
$$E_{\text{PGRB}} = 2.37 \% E_{\text{dya}}$$

Results

$$\text{Bulk Lorentz } \Gamma = 1080$$

$$T_{\text{PGRB}} = 25.3 \text{ keV}$$

$$\alpha = -1.80$$



**Strong influence of the extra component at low energies in the ext afterglow
=> the spectrum is strongly affected ...but not the P-GRB !!!**

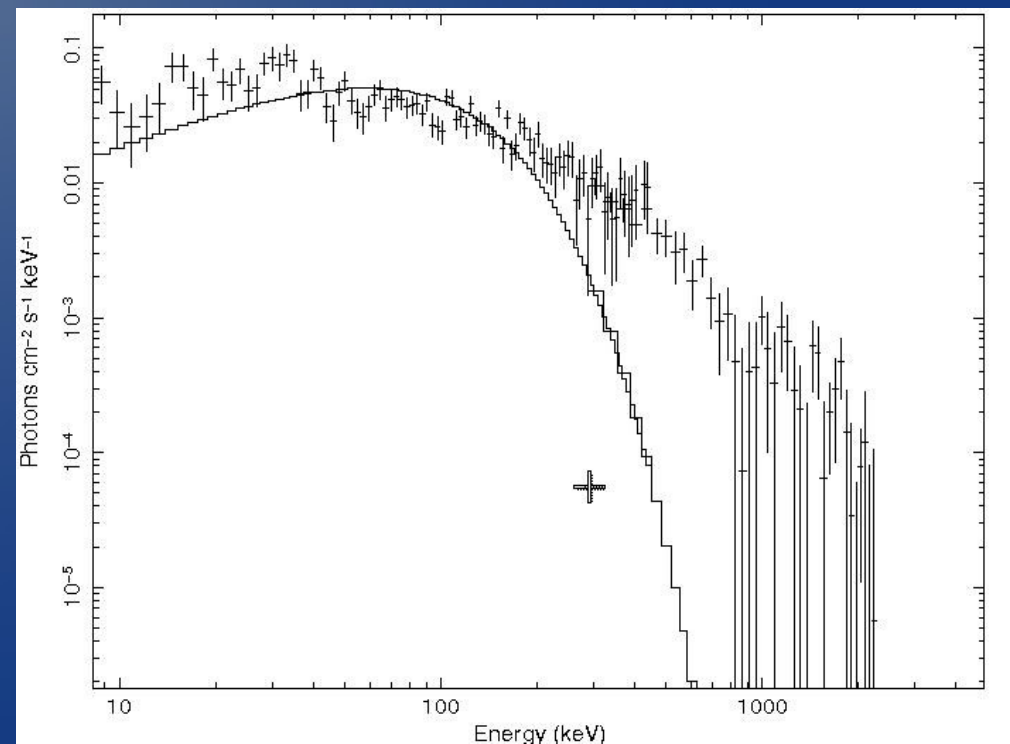
The first structure observed in both GRBs could be associated to the P-GRB emission



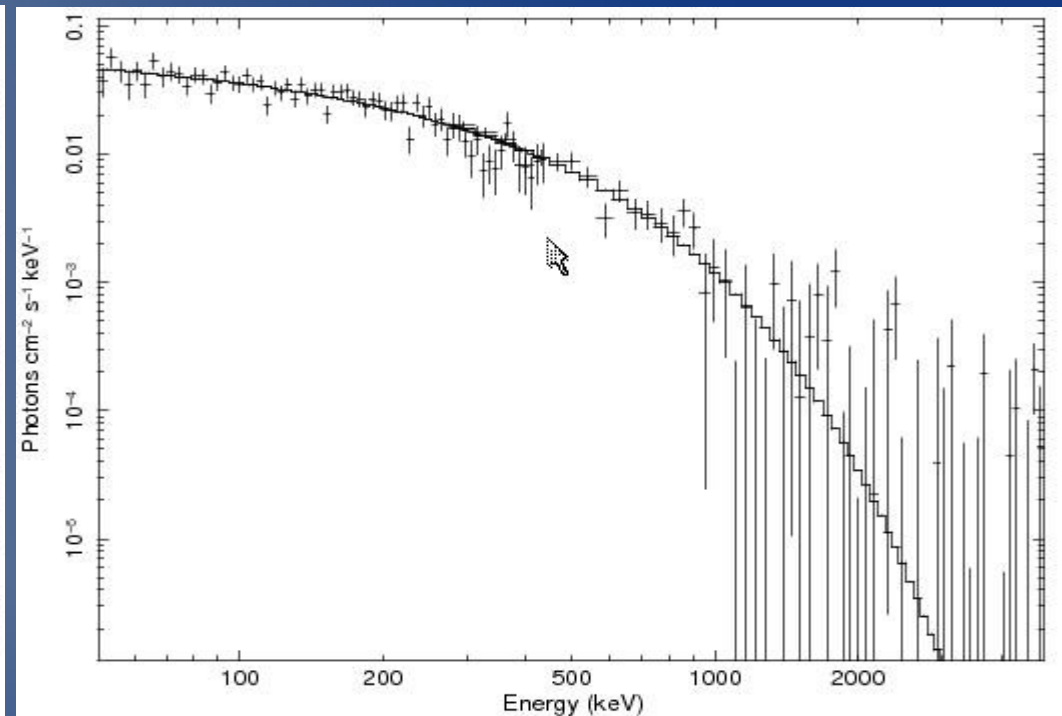
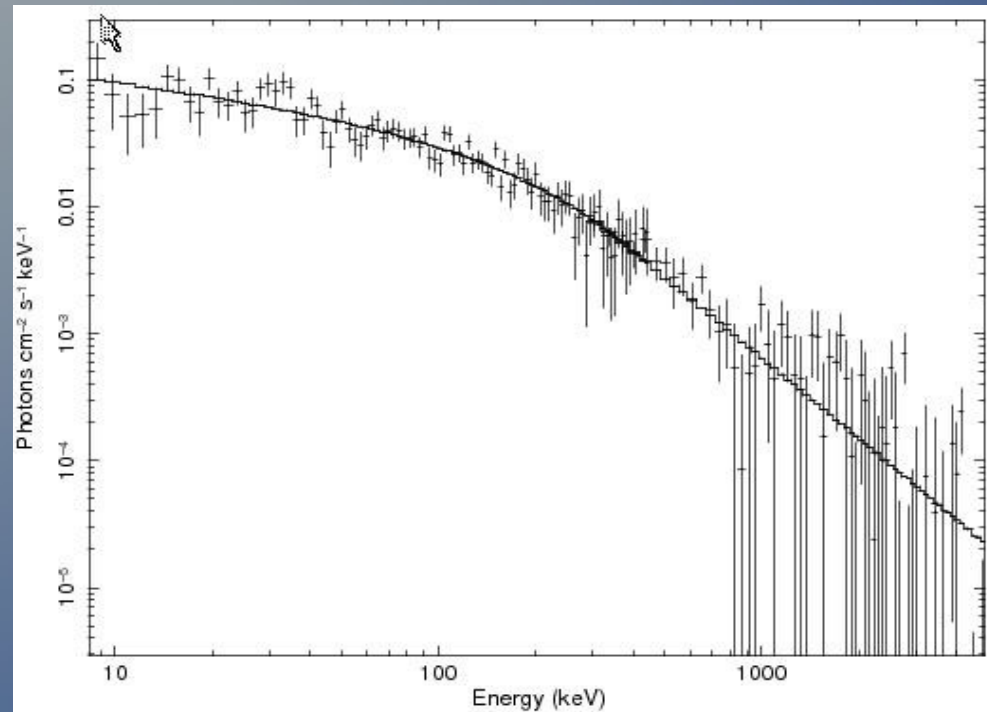
P-GRB spectral analysis

- Band spec model
- Black-body spec model with an extra power-law component
- Modified Black-body spec model, used for the ext afterglow

We expect a classical Black-body spectrum...
... but it is not the case !!!

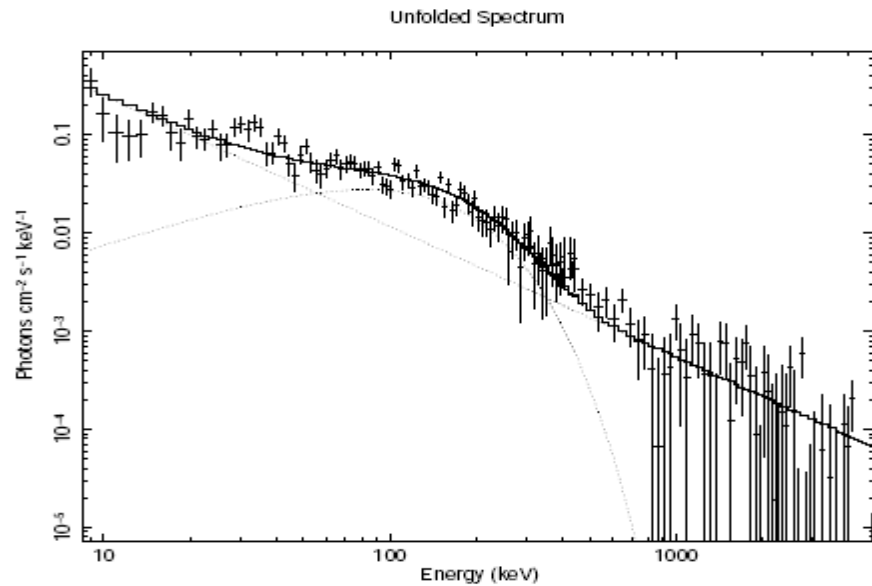


Band function

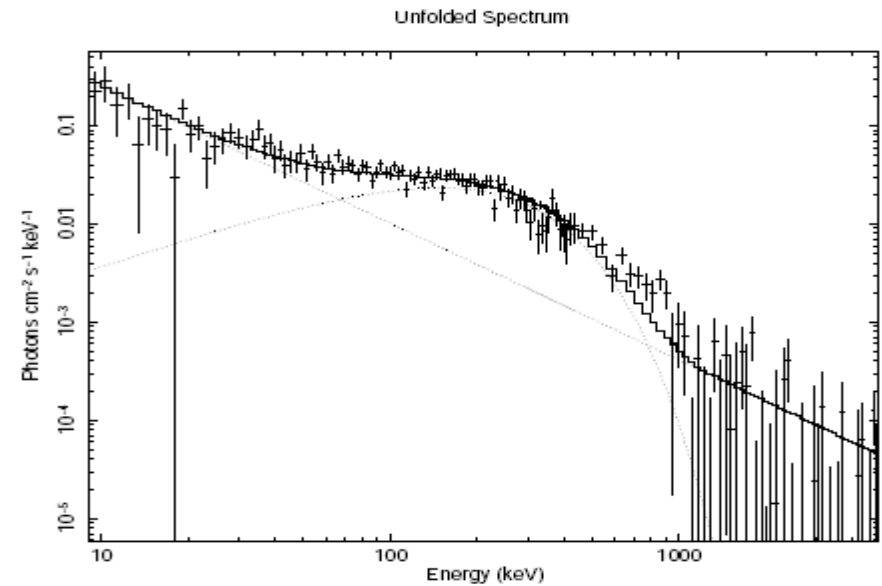


GRB 080916C				
Interval	α	β	E_0 (keV)	$\bar{\chi}^2$
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(4 s, 9 s)	-0.89 ± 0.06	-1.78 ± 0.10	413.9 ± 96.5	1.11
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(0 s, 4 s)	-0.13 ± 0.09	unconstrained	290.9 ± 30.9	1.13
(6 s, 13 s)	-0.37 ± 0.02	-4.76 ± 1.62	622.1 ± 22.7	1.60

BB + extra power-law



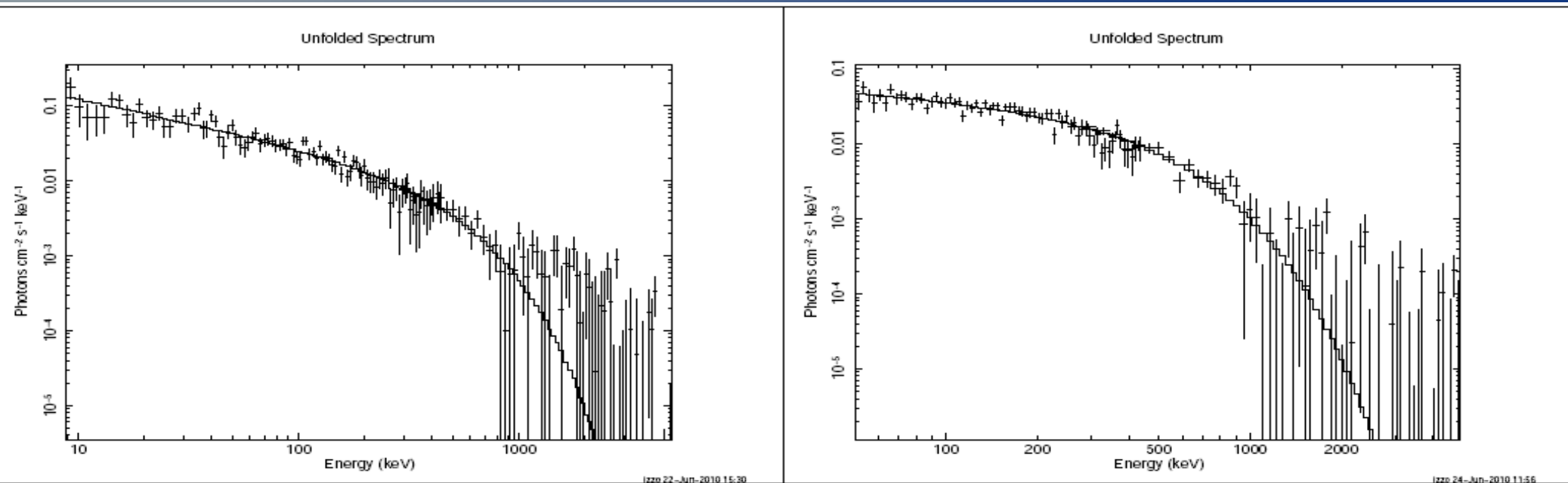
1220 10-Jun-2010 18:57



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GRB 080916C			
Interval	kT(keV)	γ	$\tilde{\chi}^2$
(0 s, 3.956 s)	51.75 ± 2.23	-1.33 ± 0.03	1.43
(4 s, 9.93 s)	54.58 ± 3.62	-1.37 ± 0.02	1.27
GRB 090902B			
(0 s, 3.953 s)	93.19 ± 2.86	-1.39 ± 0.05	1.417
(6 s, 13 s)	176.14 ± 0.31	-1.65 ± 0.02	2.07

BB extended edition



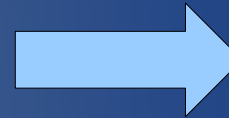
GRB 080916C			
Interval	kT(keV)	α	$\tilde{\chi}^2$
(0 s, 3.956 s)	236.06 ± 24.49	-1.33 ± -1.61	1.13
(4 s, 9.93 s)	762.74 ± 120.65	-2.00 ± 0.03	1.15
GRB 090902B			
(0 s, 3.953 s)	205.96 ± 18.25	-1.23 ± 0.08	1.13
(6 s, 13 s)	449.29 ± 13.55	-1.47 ± 0.02	1.49

Conclusion I

→ H.E. delayed onset determines the P-GRB

→ No simple Black-body emission !!!

→ BB + power-law and modified BB



OK !



→ Thermalization at the transparency must be reviewed

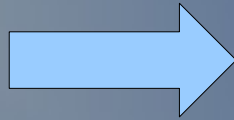
→ Symmetries?

Inhomogeneities?

Scattering process in the interiors?

High Energy emission ... in the Fireshell.

Main
Idea



Pion decay
From *pp* collisions

(Katz ApJ 1994)

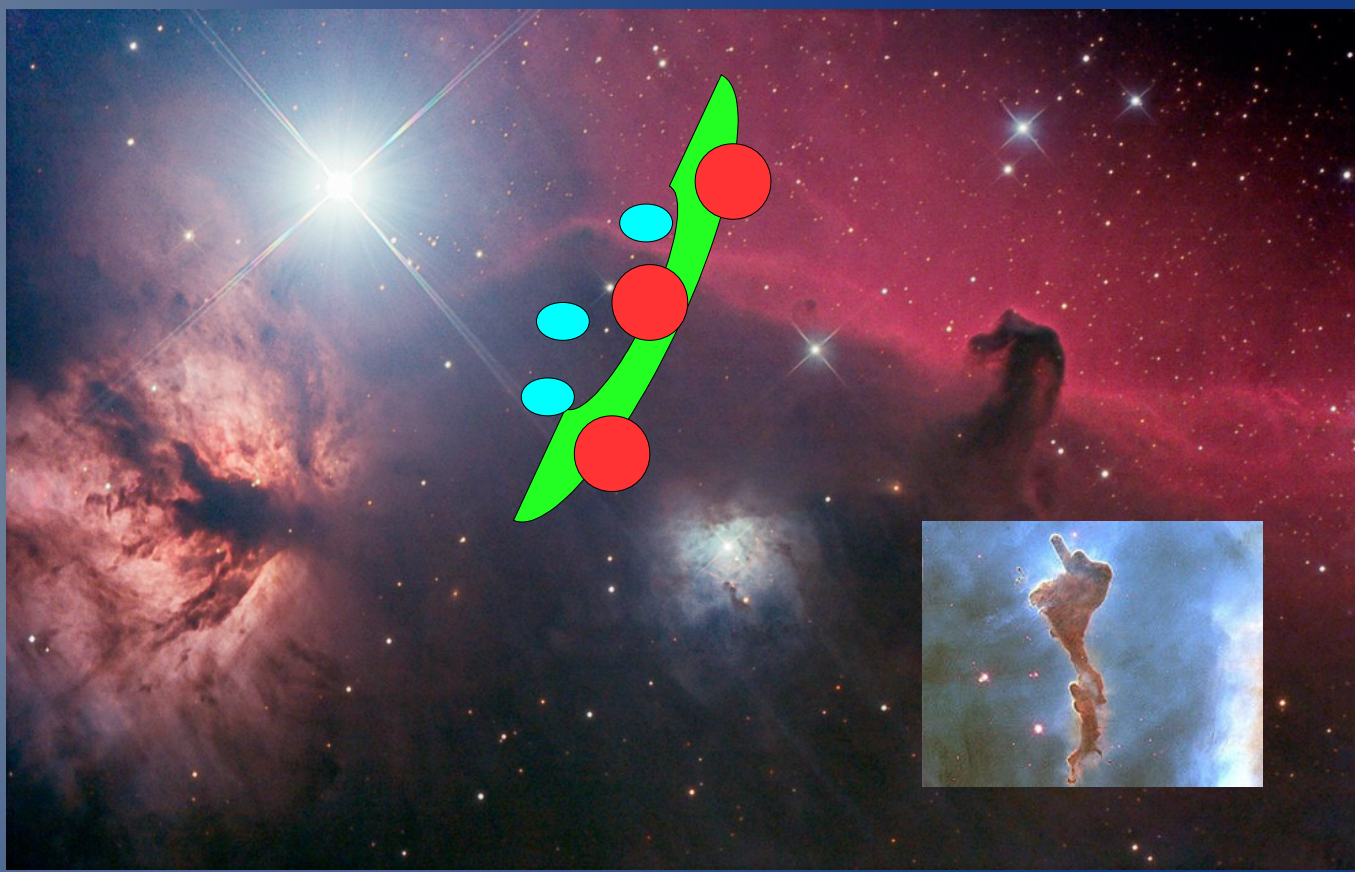
The main mechanism producing very h.e. photons > 100 MeV

Other possible process

- ✓ **Synchrotron**
- ✓ **Inverse Compton**
- ✓ **Self-Synchrotron Compton**

Threshold $\sim 2.2\text{GeV}$

Ultra-rel. protons
interact with nucleons
located in some GMC
near the burst site



Requirements

High density of the GMC ($10^{9-10} \text{ \#/cm}^3$)

Large distance from the GRB

- A GMC could “evaporate” (L_{edd} progenitor)

→ Distance ~ 1 l. y. (10^{17-18} cm)

- $B \sim 10^{-4,-6}$ Gauss ($r_g 10^{14-16}$ cm)

→ Protons should gyrate, emitting sync rad
as ultra-rel. Leptons

Extra component observed in GRB 090902B ???

- Protons cooling time $t = E/P$ too low...

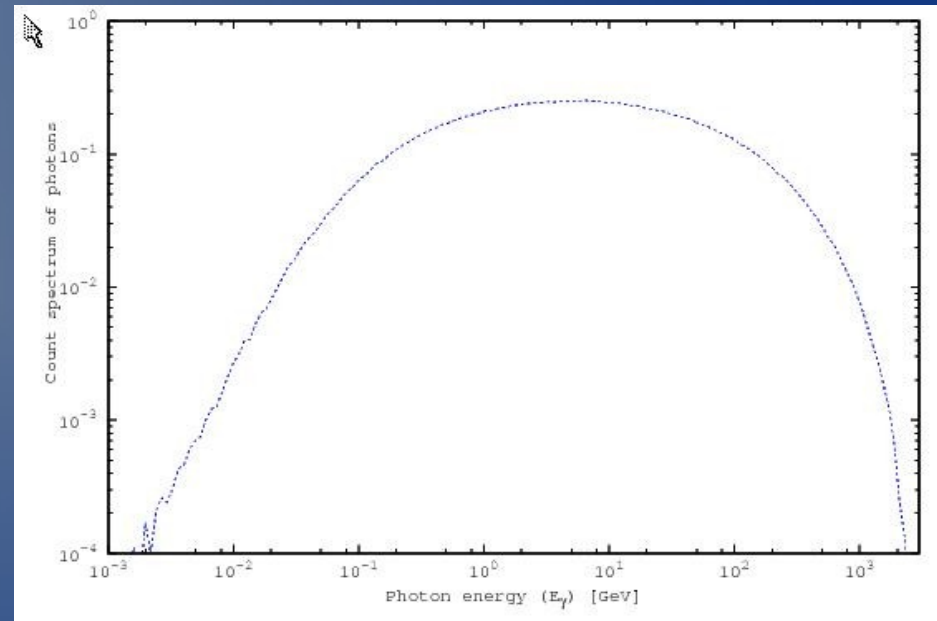
Non-thermal distribution of protons ?

Simulation of pp collisions (SYBILL)

(details in the next talk by Rangel Lemos)

10^6 pp -collisions in the comoving frame – $E_p = 3$ TeV

Spectrum of total photons
produced in all of the
decay channels
(pion and η -meson)



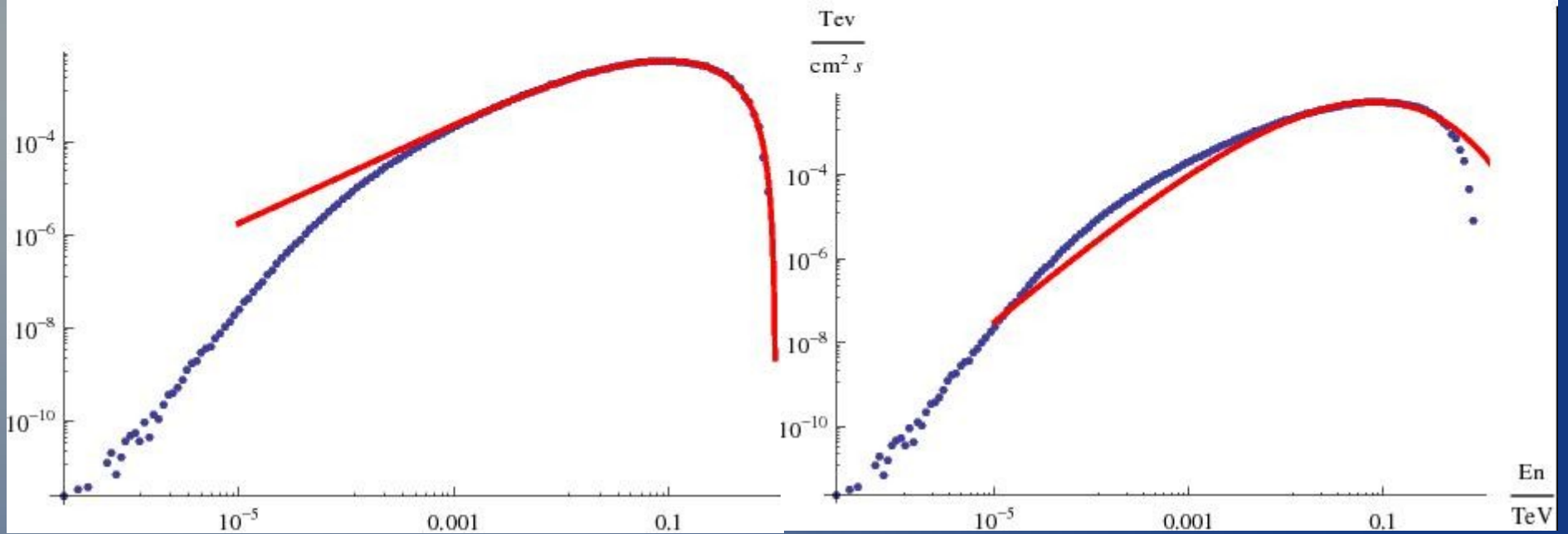
Kelner, Aharonian, Bugayov

$$F_{\gamma}(x, E_p) = B_{\gamma} \frac{\ln(x)}{x} \left(\frac{1 - x^{\beta_{\gamma}}}{1 + k_{\gamma} x^{\beta_{\gamma}} (1 - x^{\beta_{\gamma}})} \right)^4 \left[\frac{1}{\ln(x)} - \frac{4\beta_{\gamma} x^{\beta_{\gamma}}}{1 - x^{\beta_{\gamma}}} - \frac{4k_{\gamma} \beta_{\gamma} x^{\beta_{\gamma}} (1 - 2x^{\beta_{\gamma}})}{1 + k_{\gamma} x^{\beta_{\gamma}} (1 - x^{\beta_{\gamma}})} \right]$$

Hillas

$$F_{\gamma} = K \exp(A x^{\alpha})$$

(less accurate)



Next steps

Obtaining the observed spectrum



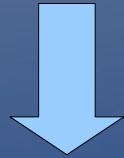
Considering the effects of the EBL on the obs spectrum

Compute the photon spectrum in the case of an energy distribution of protons (non-thermal

Conclusion II

If pp is responsible for the H.E. Emission in GRBs:

- Long cooling time of protons
- Very energetic GRBs (high number of p in the fireshell)
- GMC near (but not too much) the burst site



- Energy distribution of protons
(non-thermal particles?)
- Presence of synchrotron emission

