The GRB classification within the fireshell model: short, long and fake short GRBs

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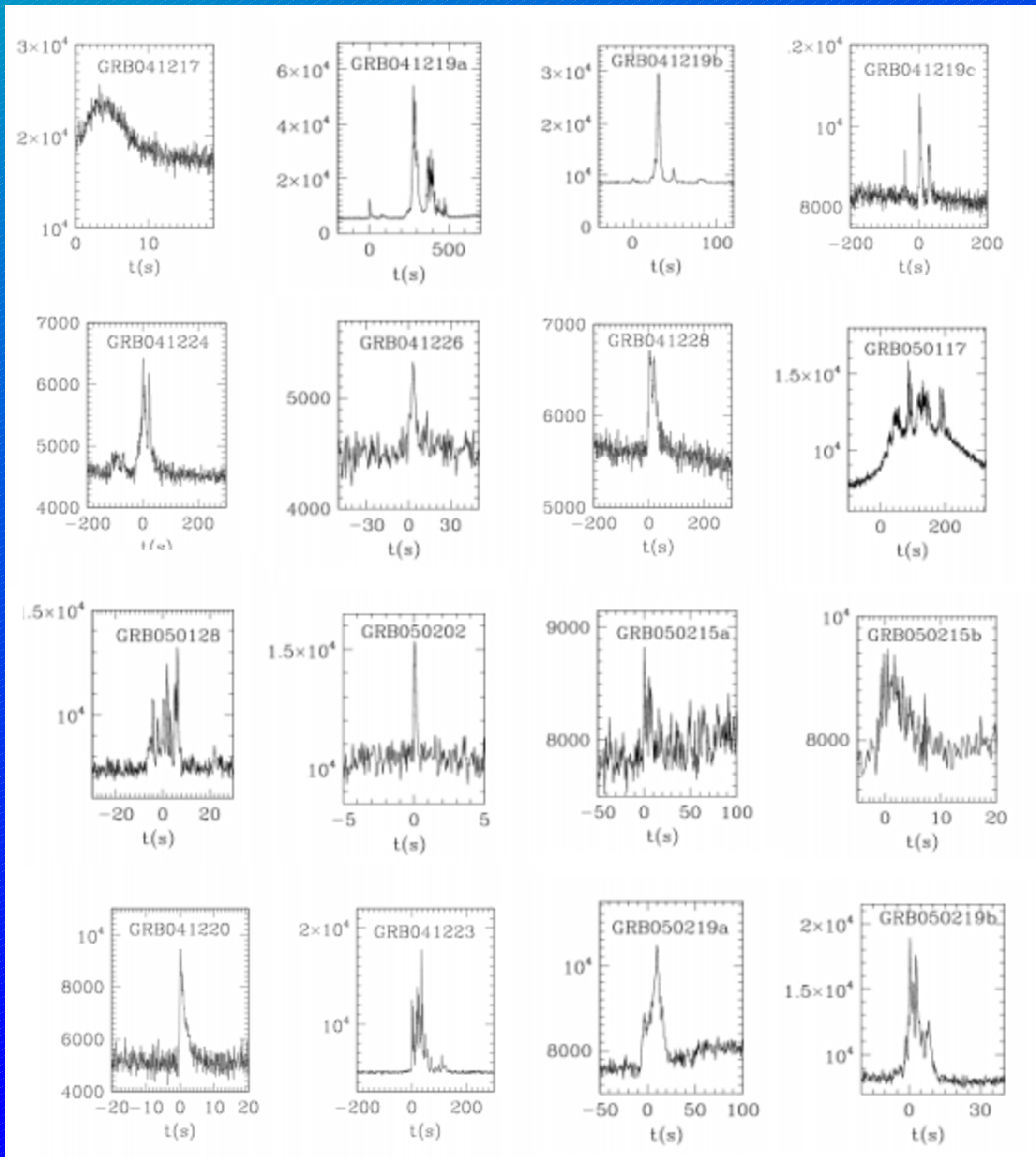
Pescara, Italy.

The Prompt Emission

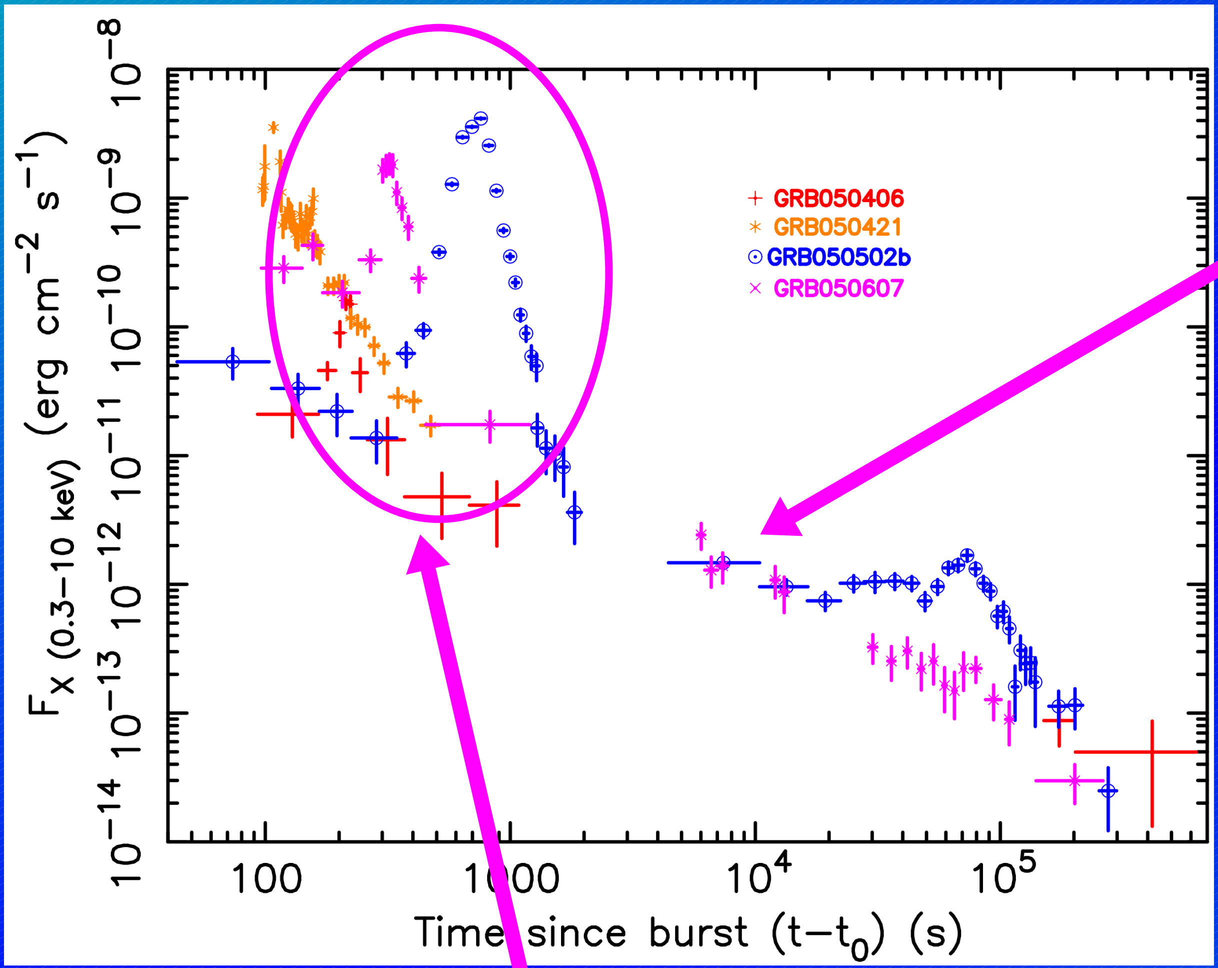


Great variety of temporal profiles

- ✓ FRED structure
- ✓ Hard-to-soft evolution
- ✓ Spectral lag

Norris et al., 1996, ApJ, 459, 393.
Piran, 2004, Phys. Rep., 76, 1143.

The Afterglow



Canonical Afterglow:

$F \propto t^{-a}$

- ✓ Early rapid decay ($3 < a < 5$)
- ✓ Shallow intermediate decay ($0.5 < a < 1$)
- ✓ Steeper decay ($1 < a < 1.5$)

Flares:

flux changing significantly on timescales $\delta t_a \ll T_a$

Nousek et al., 2006, ApJ, 642, 389.
Chincarini et al., 2005, astro-ph/0506453.
Burrows et al., 2005, Science, 309, 1833.

The optically thin fireshell phase

- ✓ All the $e^{\pm}$ annihilate and a flash of photons is emitted: the **P-GRB**
- ✓ The accelerated baryons continue their expansion and, interacting with the CBM via inelastic collisions, produce a prolonged emission: the **AFTERGLOW**.

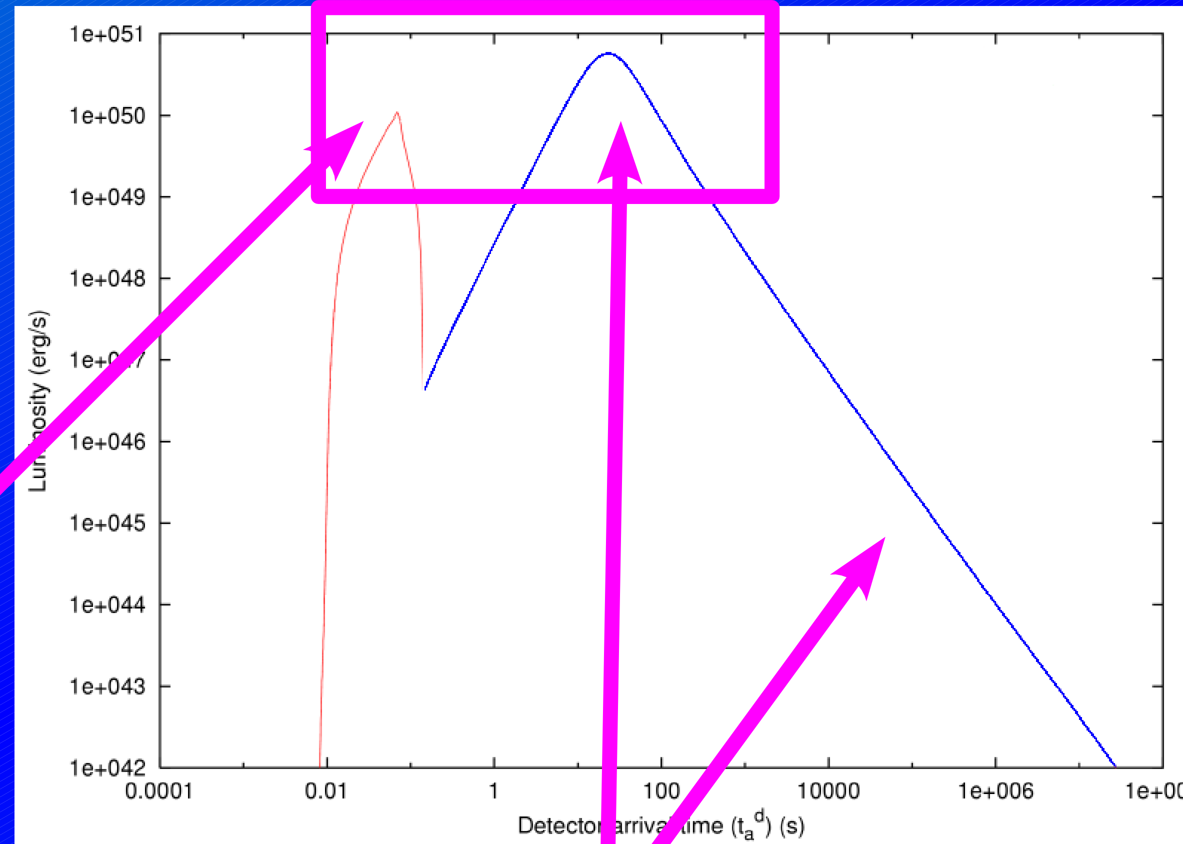
➡ **"Canonical" GRB** : P-GRB + Afterglow

Ruffini et al. 2001, ApJ, 555, L113 & 2003, AIP, 668, 16 & 2006, ApJ, 645, L109.

"Canonical GRB" Bolometric luminosity

"<u>IBS Paradigm</u>"
(2001):

P-GRB: emitted at the fireshell transparency point



+

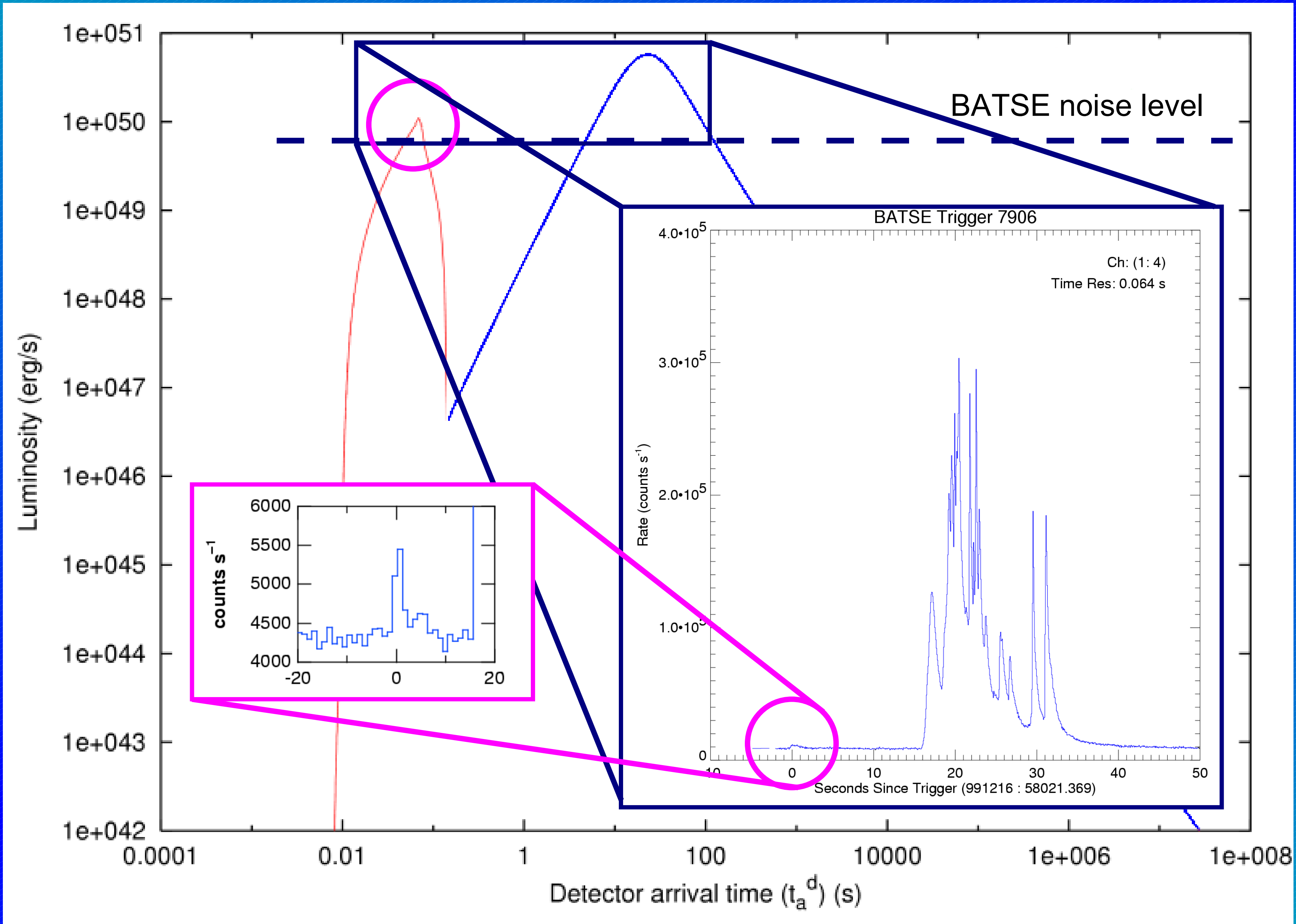
Afterglow: due to the interaction between the optically thin fireshell and CBM:

$$\frac{dE_\gamma}{dt_a^d d\Omega} = \int_{EQTS\left(\hat{t}_a^d\right)} \frac{\Delta\varepsilon}{4\pi} \, v \, \cos\vartheta \, \Lambda^{-4} \frac{dt}{dt_a^d} d\Sigma$$

$$t_a^d = (1+z)\left(t - \frac{\int_0^t v\left(t'\right) dt' + r_{ds}}{c} \cos\vartheta + \frac{r_{ds}}{c}\right)$$

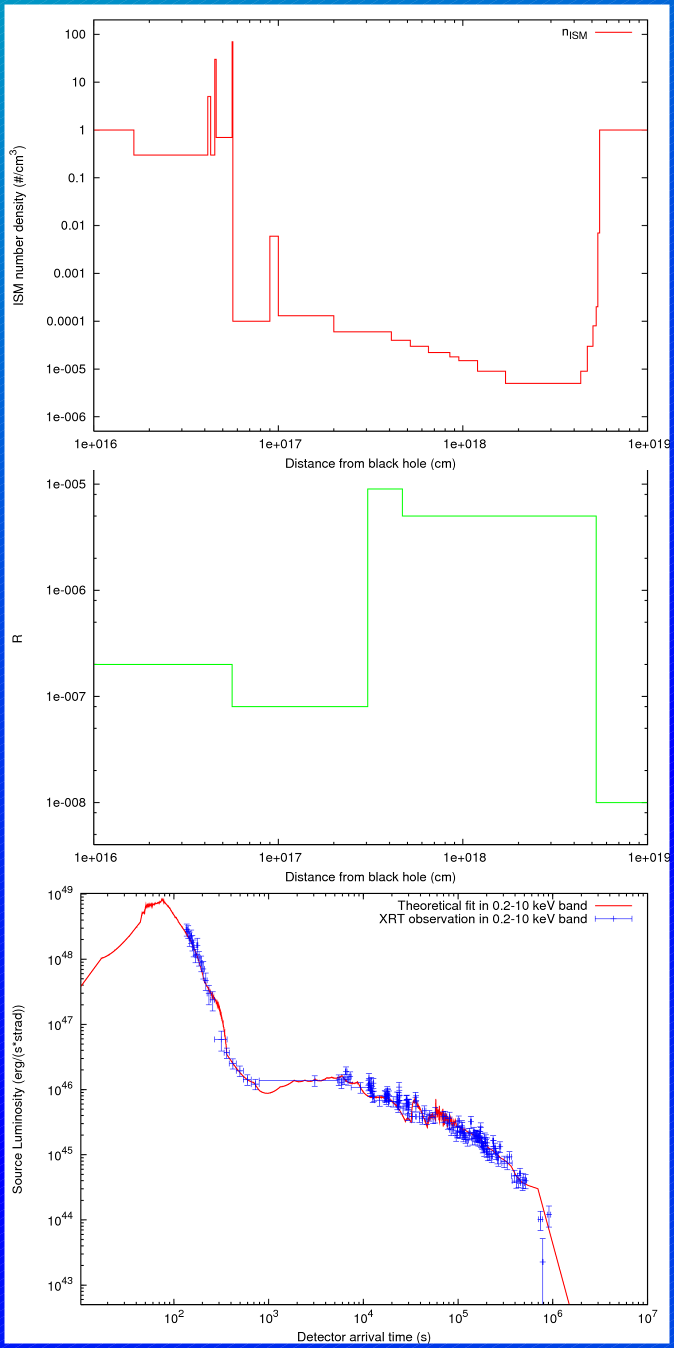
Ruffini et al. 2001, ApJ, 555, L113 & <u>2003, AIP, 668, 16</u> & <u>2006, ApJ, 645, L109.</u>

GRB991216



Ruffini et al., 2001, ApJ, 555, L113; 2002, ApJ, 581, L19; 2003, "Cosmology and Gravitation", AIP, 668.

The afterglow lc



- ✔ Don't need to invoke different physical processes
- ✔ Interaction with inhomogeneous CBM, modeled in spherical shells (radial approximation $n_{cbm}=n_{cbm}(r)$)
- ✔ Main difference: Gamma factor
- ✔ Temporal variability <-- variability in the CBM parameters

Ruffini et al., 2001, ApJ, 555, L107.
Bianco & Ruffini, 2005, ApJ, 620, L23.
Ruffini et al., 2003, "Cosmology and Gravitation", AIP, 668.

GRB spectrum

$$N(\nu) = N_0 \begin{cases} (h\nu)^{\alpha} e^{-\frac{h\nu}{E_0} t}, & h\nu < H \\ ((\alpha-\beta)E_0)^{(\alpha-\beta)} (h\nu)^{\beta} e^{(\beta-\alpha)}, & h\nu > H\,. \end{cases}$$

Observed non-thermal Band spectrum

Energy density released in the int. with CBM

$$\Delta\epsilon = \frac{\Delta E_{\rm int}}{V \Delta t} = \frac{4\pi r^2}{V} \mathcal{R} \sigma T^4$$

$$\mathcal{R} = \frac{A_{eff}}{A_{tot}}$$

Surface filling factor

$$\frac{dE^{[\nu_1,\nu_2]}}{dt_a^d d\Omega} = \int_{EQTS} \frac{\Delta\varepsilon}{4\pi} v \cos\vartheta \, \Lambda^{-4} \frac{dt}{dt_a^a} W(\nu_1,\nu_2,T_{arr}) \, d\Sigma$$

"Effective weight": $W(\nu_1,\nu_2,T_{arr}) = \frac{1}{a T_{arr}^4} \int_{\nu_1}^{\nu_2} \rho(T_{arr},\nu)\, d\left(\frac{h\nu}{c}\right)^3$

Plankian distribution at T_{arr}: $\rho(T_{arr},\nu) = \frac{2}{h^3} \frac{h\nu}{e^{h\nu/(kT_{arr})} - 1}$

Ruffini et al., 2004, Int. J. Mod. Phys. D, 13, 843.
Ruffini et al., 2005, Int. J. Mod. Phys. D 14, 97.

GRB050315

- ✓ $z = 1.949$
- ✓ Good example of "canonical afterglow"

$E^{tot}_{e\pm} = 1.46 \times 10^{53}$ erg, $B = 4.55 \times 10^{-3}$

--> $N_{e\pm} = 7.9 \times 10^{57}$, $T = 2.0$ MeV, $\gamma = 218$

Prompt Emission:

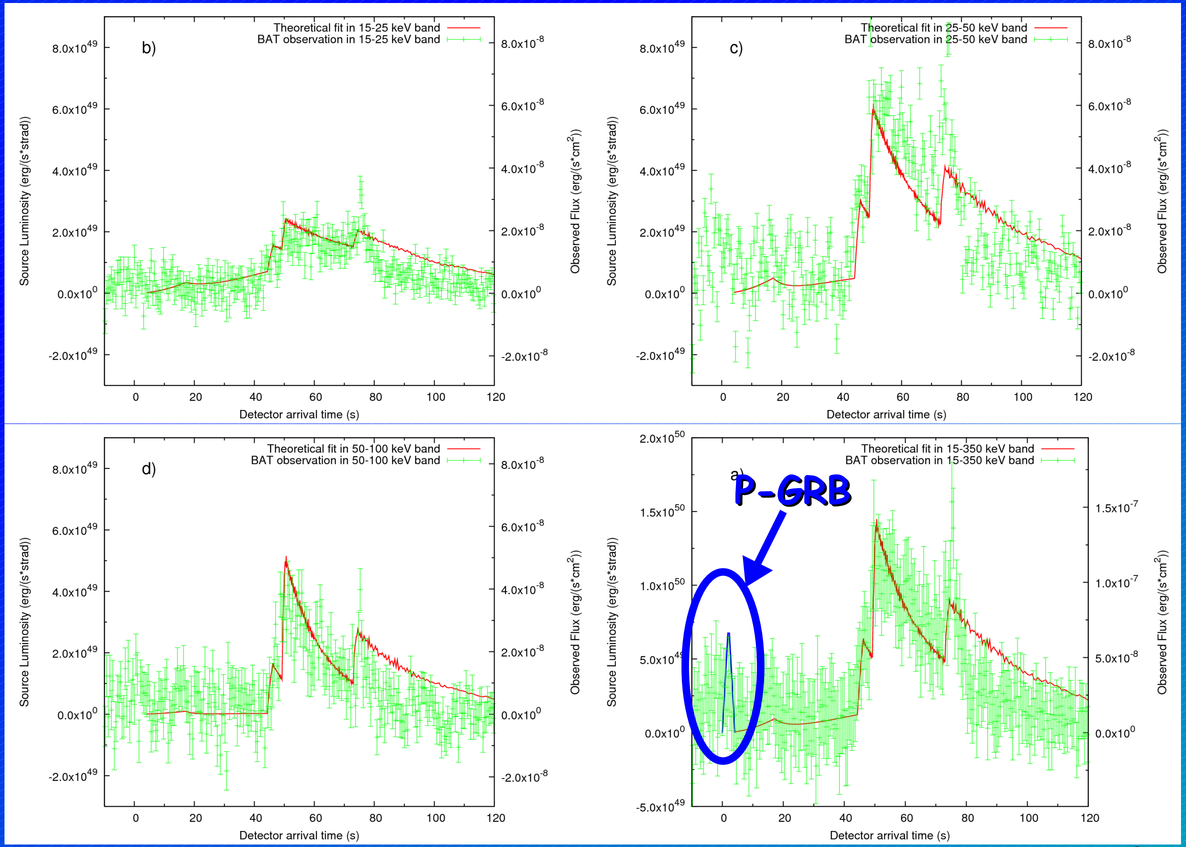
$\langle n_{cbm} \rangle = 0.81\ \#/cm^3$

$\langle \mathcal{R} \rangle = 1.4 \times 10^{-7}$

$\delta n/n \sim 10\ \#/cm^3$

$\Delta \sim 10^{14}$ cm

$E_{P\text{-}GRB} = 1.98 \times 10^{51}$ erg



Kelson & Berger, 2005, GCN3101.

Ruffini et al., 2006, ApJ, 645, L109.

Vaughan et al., 2006, ApJ, 638, 920.

GRB050315

Afterglow:

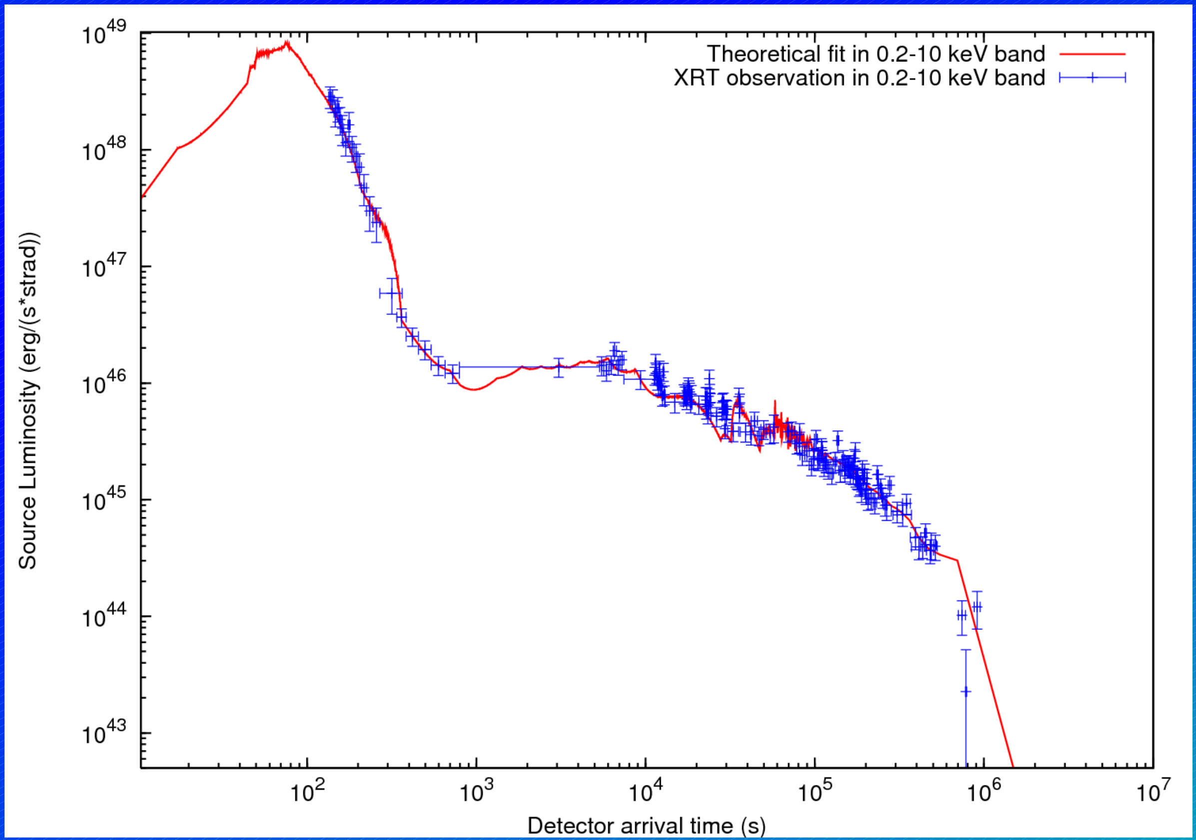
$\langle n_{cbm} \rangle = 4.8 \times 10^{-4}$ #/cm^3

$\langle \mathcal{R} \rangle = 7.0 \times 10^{-6}$

$E^{tot}_{e\pm} = 1.46 \times 10^{53}$ erg, $B = 4.55 \times 10^{-3}$

--> $N_{e\pm} = 7.9 \times 10^{57}$, $T = 2.0$ MeV, $\gamma = 218$

The "canonical behavior" naturally arises from the fluctuations of the CBM parameters



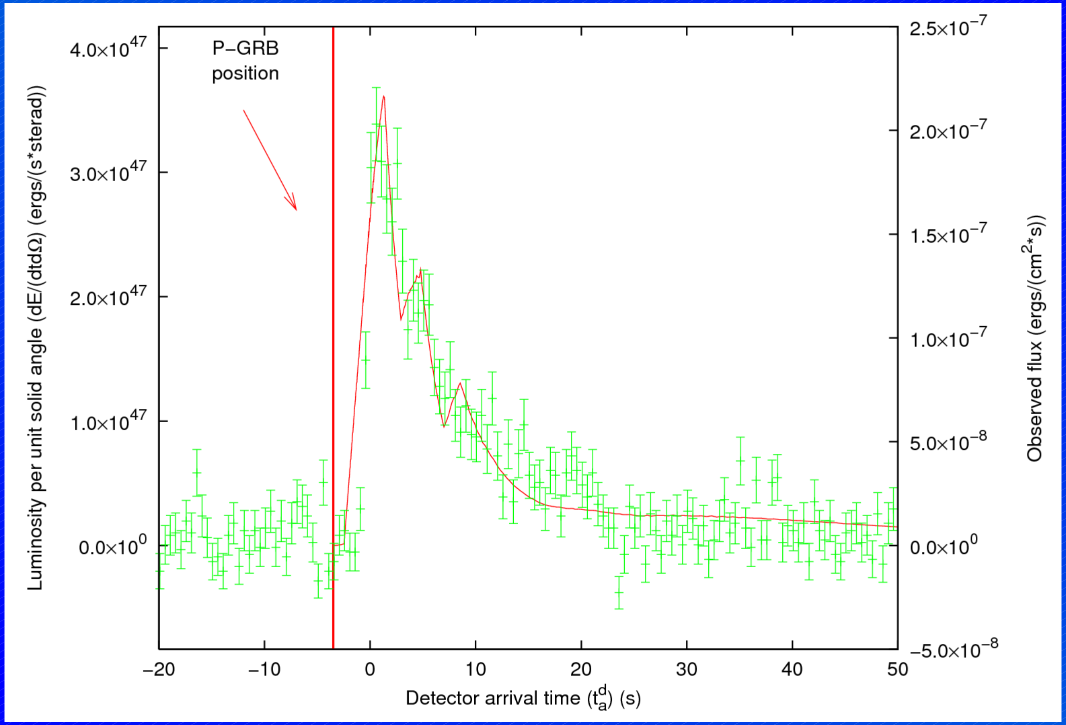
Ruffini et al., 2006, ApJ, 645, L109.

Vaughan et al., 2006, ApJ, 638, 920.

GRB031203

$E^{tot}_{e\pm} = 1.8 \times 10^{50}$ erg, $B = 7.4 \times 10^{-3}$
--> $N_{e\pm} = 3.0 \times 10^{55}$, $T = 1.5$ MeV, $\gamma = 133$
$\langle n_{cbm} \rangle = 0.16$ #/cm^3, $\langle \mathcal{R} \rangle = 1.0 \times 10^{-8}$

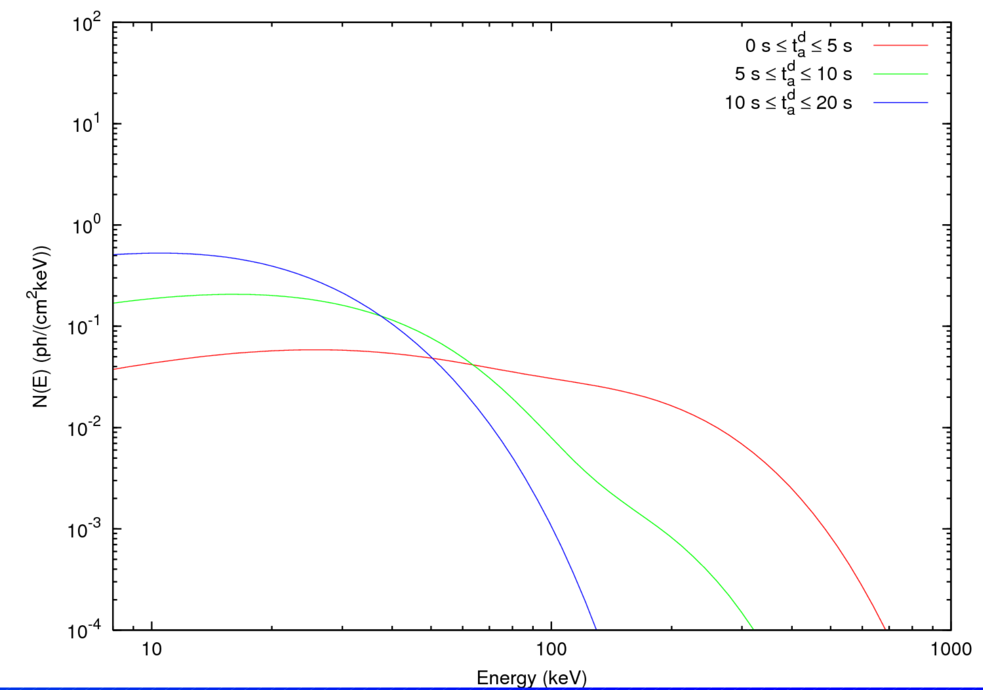
- ✓ $z = 0.106$
- ✓ "unusual" burst



Its gamma-ray luminosity is interpreted within our model in a natural way

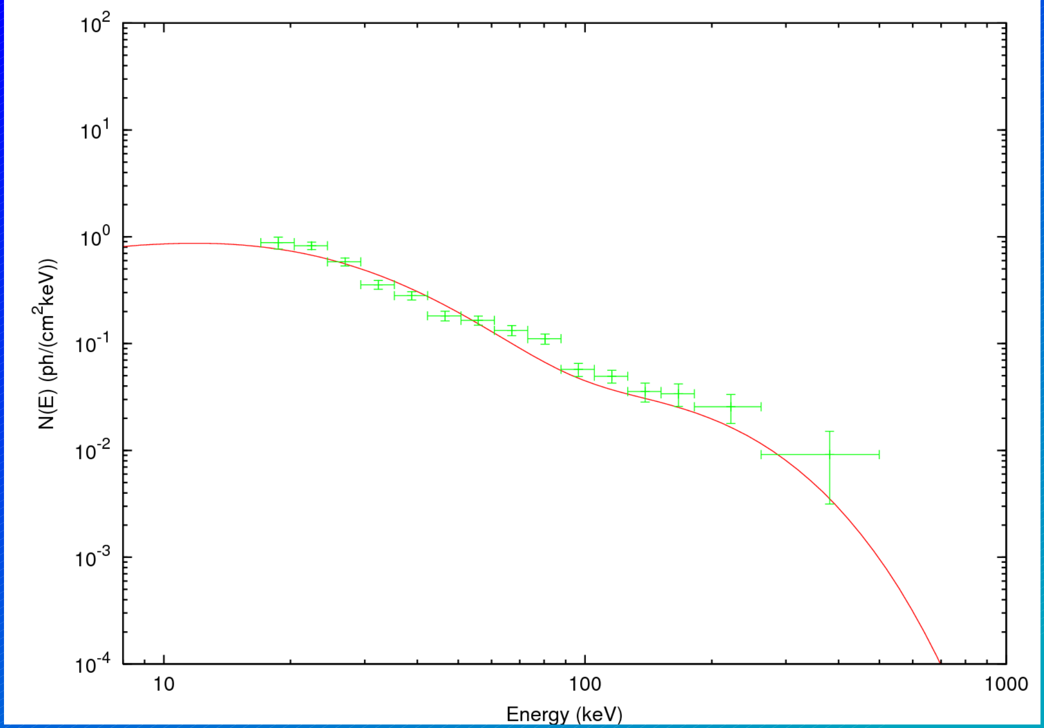
Bernardini et al., 2005, ApJ, 634, L29.
Sazonov et al., 2004, Nature, 430, 646.
Watson et al., 2004, ApJ, 605, L101.

The time-integrated spectrum



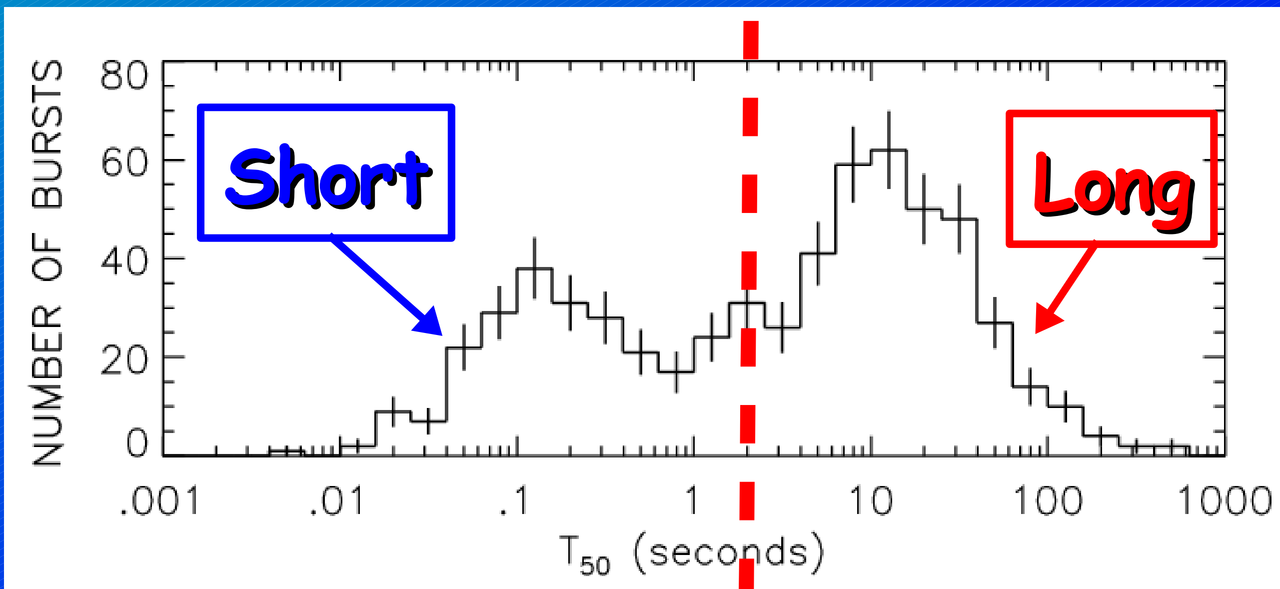
Double intergration over EQTS and observation time

The power-law behavior of the GRB observed spectra can be obtained starting from thermal spectra



Bernardini et al., 2005, ApJ, 634, L29.

Short vs Long GRBs

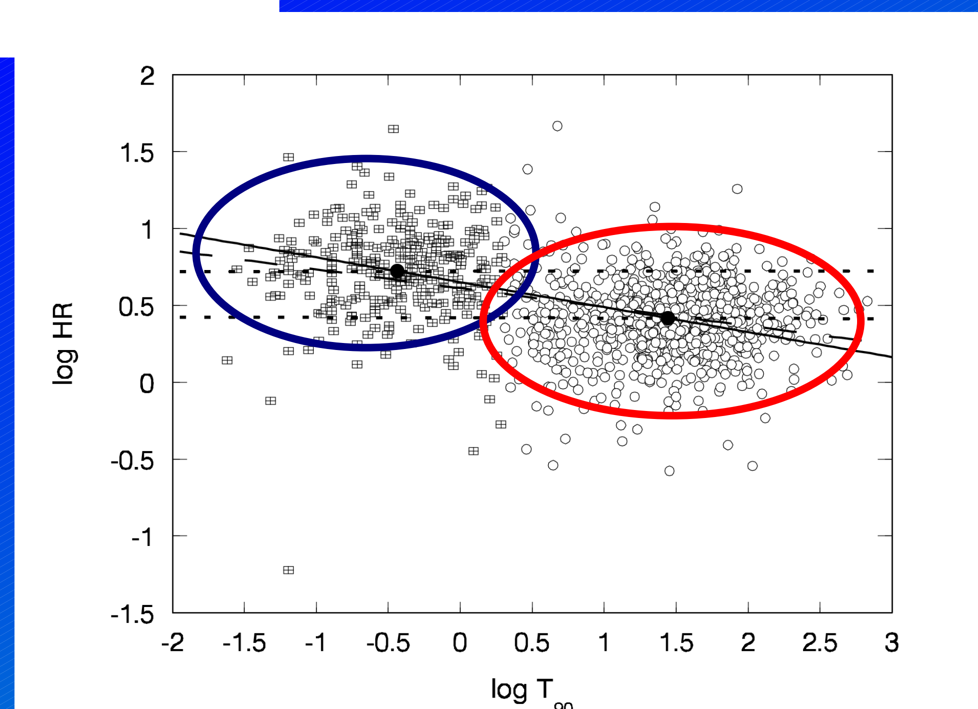


Long GRBs :

$T_{90} > 2$ s

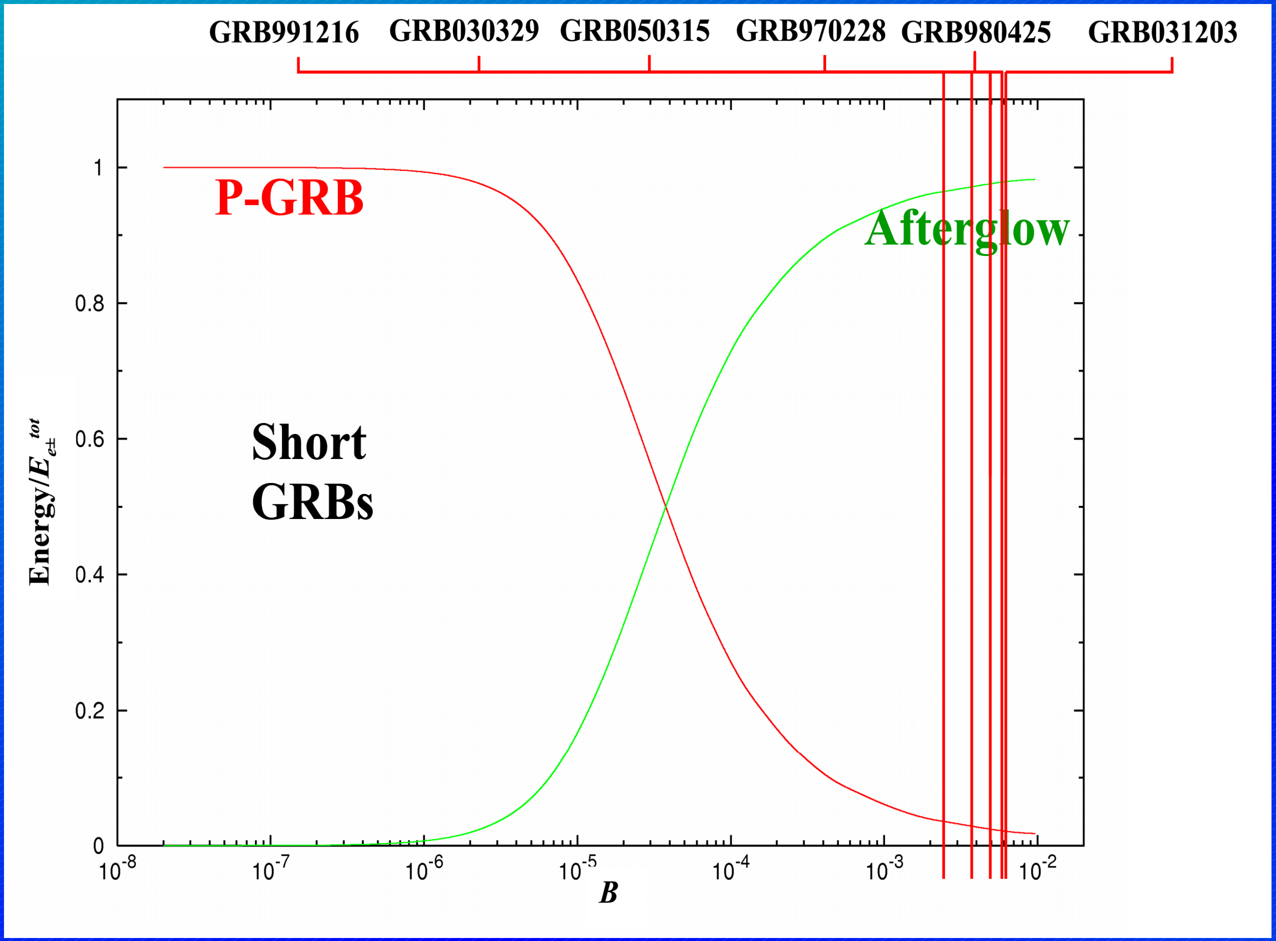
Short (hard) GRBs :

$T_{90} < 2$ s



Kouveliotou et al., 1996, AIP Conf. Proc., 384, 42.
Paciesas et al., 1999, ApJS, 122, 465.
Donaghy et al., 2006, astro-ph/0605570.

P-GRB vs Afterglow



- ✓ B -> 10^{-2} : the P-GRB total energy decreases and it is negligible w.r. to the afterglow one.
- ✓ B -> 0 : the afterglow total energy decreases and it is negligible w.r. to the P-GRB one.

"Genuine" Short GRBs

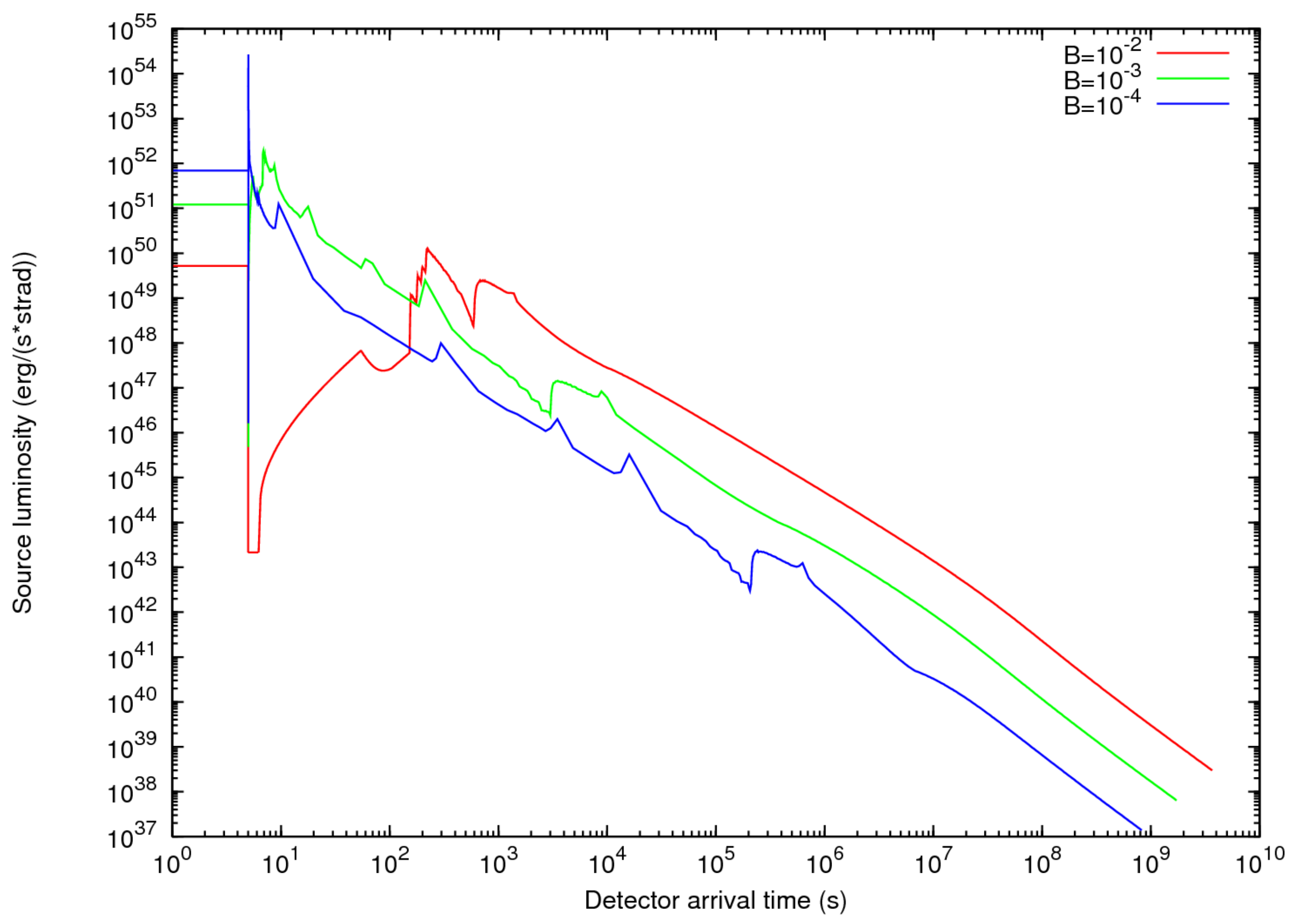
"Genuine" Short GRBs are Canonical GRBs with B<10^{-5}

... see De Barros' talk

Ruffini et al. 2001, ApJ, 555, L113.

Effects on the light curves

$E^{tot}_{e\pm} = 4.8 \times 10^{53}$ erg, <n> = 1.0 #/cm^3



- ✓ $B = 10^{-2}$: the P-GRB is often under the instrumental threshold
- ✓ $B = 10^{-4}$: the prompt emission is dominated by the P-GRB

Simulations by L. Caito

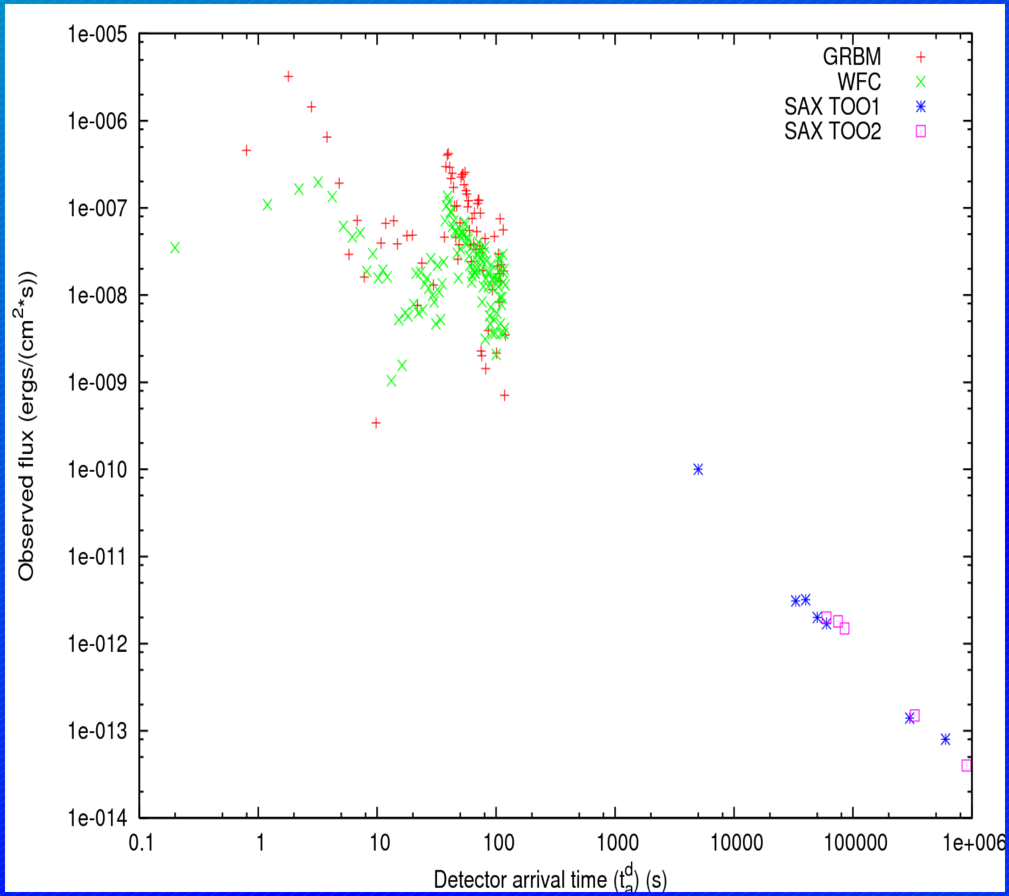
A new family of sources

- ✓ Norris & Bonnell (2006): “occasional softer, extended emission lasting tens of seconds after the initial spikelike emission comprising an otherwise short burst”
- ✓ GRB060614: “hybrid” properties between short and long bursts (... see Caito's talk)
- ✓ Short GRBs' Afterglow Revolution

“the current nomenclature for the two classes (...) is at best misleading”

Norris & Bonnell, 2006, ApJ, 643, 266.
Gerhels et al., 2006, Nature, 444, 1044.
Gehrels et al., 2005, Nature, 437, 851.

GRB970228



- ✓ A "normal" long GRB, with a duration ~ 80 s
- ✓ Long GRBs "Afterglow revolution"
- ✓ z = 0.695
- ✓ Prompt emission <- strong pulse during ~ 5 s + three additional pulses of decreasing intensity
- ✓ Localized on the outskirt of a faint galaxy

Frontera et al. 1998, ApJ, 493, L67.
Costa et al. 1997, Nature, 387, 783.
Bloom, Djorgovski & Kulkarni, 2001, ApJ, 554, 678.
Van Paradijs et al., 1997, Nature, 386, 686.

GRB970228

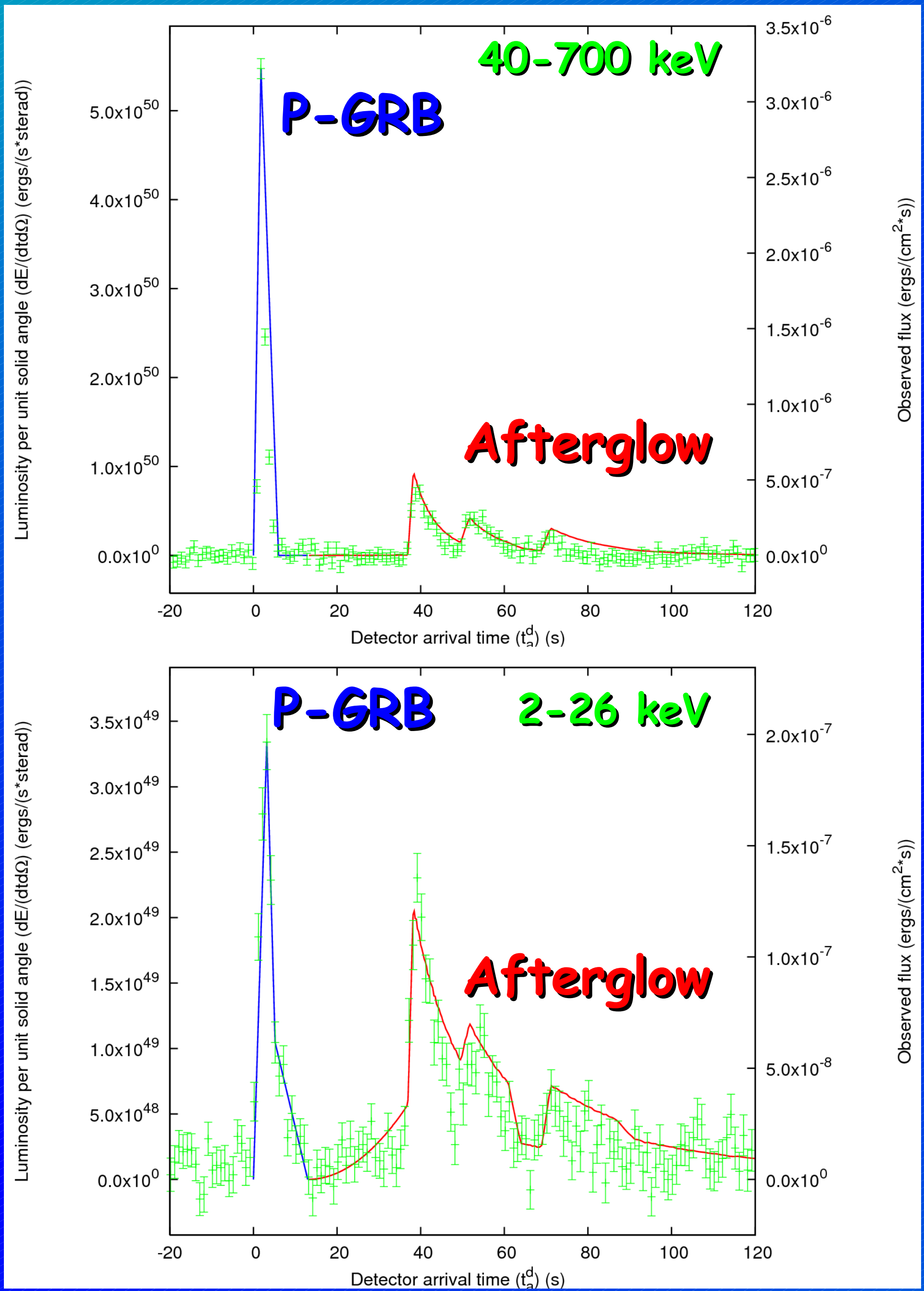
What can we learn from observations?

- ✓ The spectral behavior of the last three pulses differs from that of the first one
- ✓ The last three GRB pulses and the X-ray afterglow have a similar spectrum

"**the emission mechanism producing the X-ray afterglow might be already taking place after the first pulse**" (Frontera et al.)

Frontera et al. 1998, ApJ, 493, L67.

GRB970228 prompt emission



$E^{tot}_{e\pm} = 1.4 \times 10^{54}$ erg, $B = 5.0 \times 10^{-3}$

--> $N_{e\pm} = 1.6 \times 10^{59}$, $T = 1.7$ MeV, $\gamma_0 = 199$

$\langle n_{cbm} \rangle = 9.5 \times 10^{-4}$ #/cm^3,

$\langle \mathcal{R} \rangle = 1.5 \times 10^{-7}$

$E^{theo}_{P\text{-}GRB} = 1.1\%\ E^{tot}_{e\pm} = 1.54 \times 10^{52}$ erg

vs

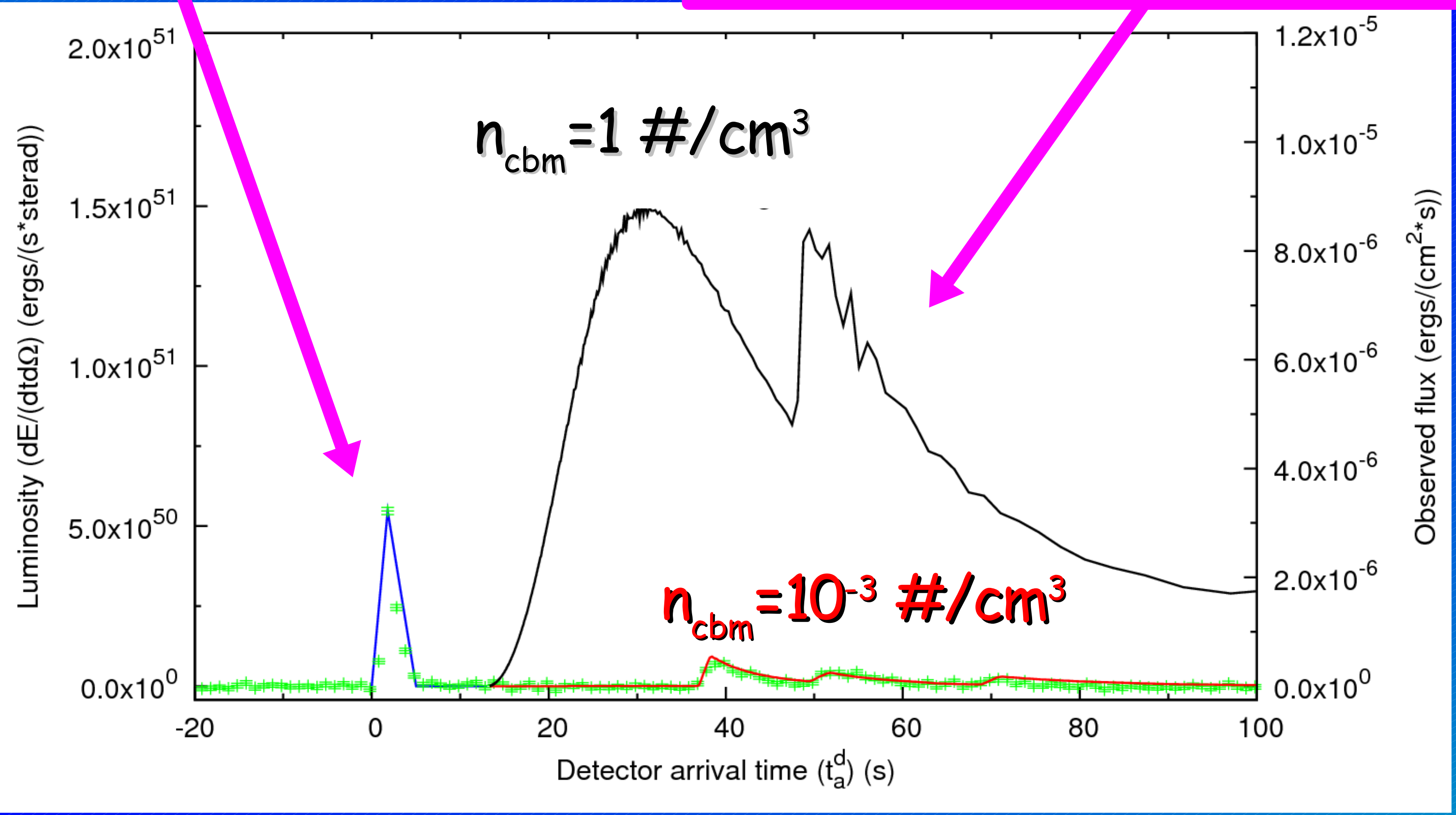
$E^{obs}_{P\text{-}GRB} = 1.5 \times 10^{52}$ erg

Bernardini et al. 2007, A&A, 474, L13.
Frontera et al. 1998, ApJ, 493, L67.

The role of the CBM density

P-GRB: unchanged!!

Afterglow peak emission: duration & flux modified



$E^{tot}_{e\pm} = 1.4 \times 10^{54}$ erg, $B = 5.0 \times 10^{-3}$

Bernardini et al. 2007, A&A, 474, L13.

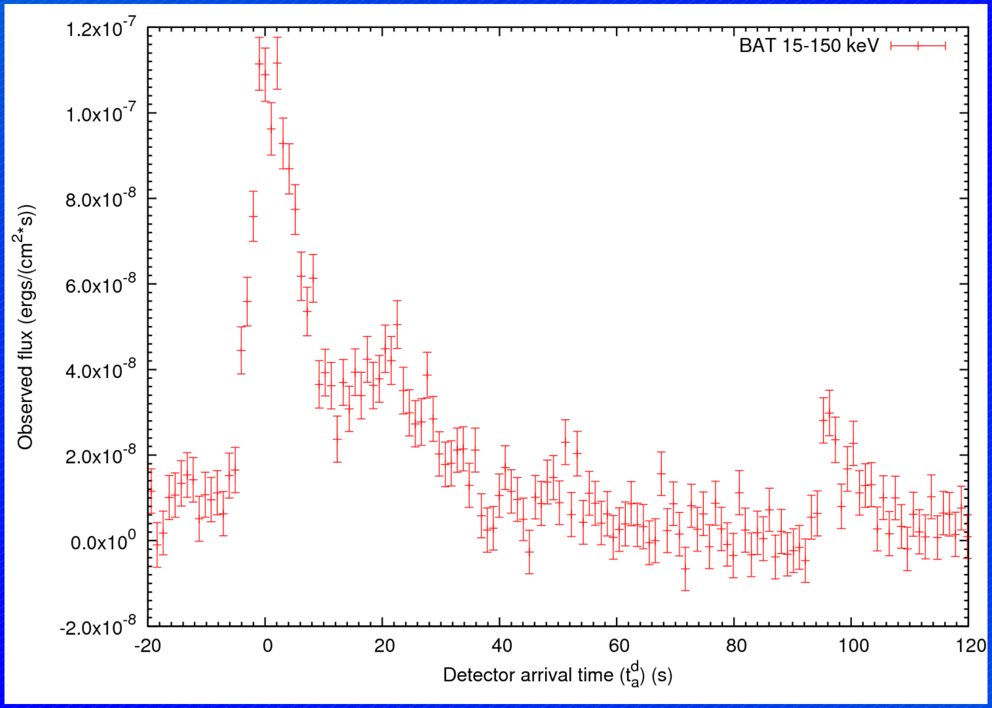
Prototype for the new class

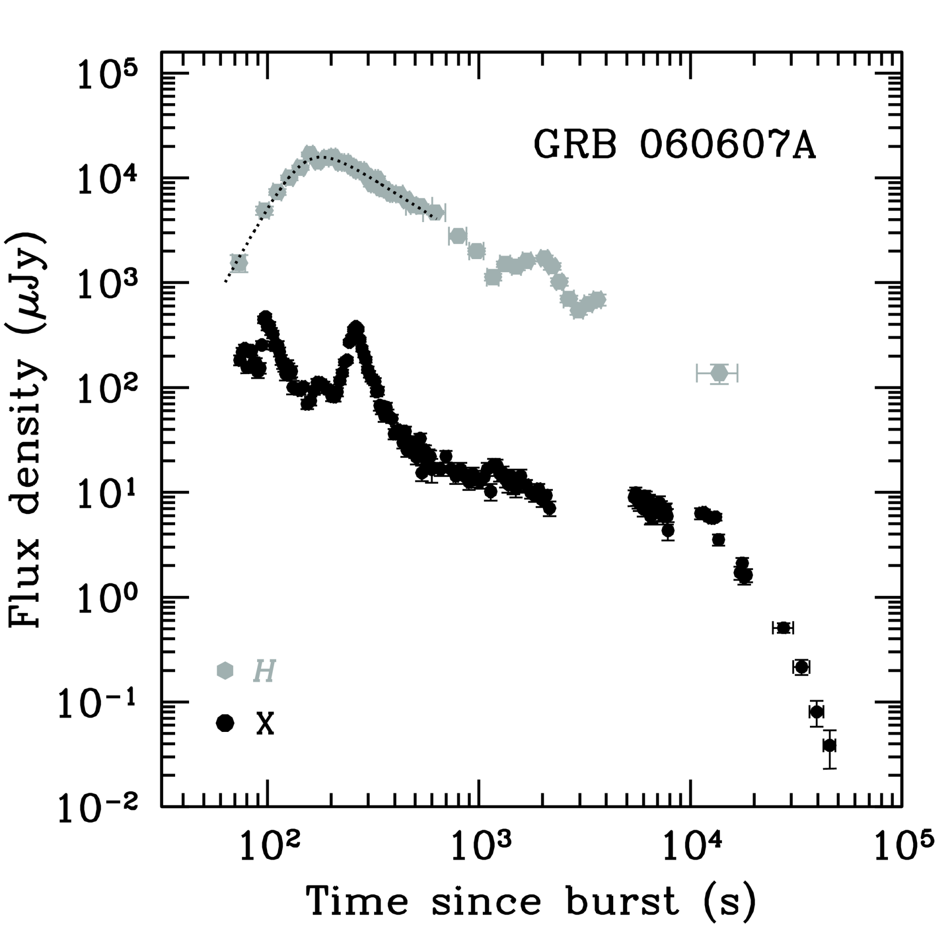
- Same morphology and spectral properties:
  - initial spikelike emission (= P-GRB) <-- physics of P-GRB
  - soft extended emission (= "deflated" afterglow) <-- physics of the fireshell
- $\langle z \rangle \sim 0.4$ <-- deflated afterglow hard to detect
- Most of GRBs observed in galaxy outskirts or in galaxy clusters --> low CBM density + binary nature of the progenitors

Bernardini et al. 2007, A&A, 474, L13.

GRB060607A

- ✔ BAT lc: initial spikelike emission ~ 15 s
- ✔ XRT lc: canonical behavior + flaring activity
- ✔ Peak of the IR emission observed by REMIR
- ✔ z = 3.082





Molinari et al. 2007, A&A, 469, L13.
Covino et al., arXiv:0710.0727.

GRB060607A as a "fake short" GRB

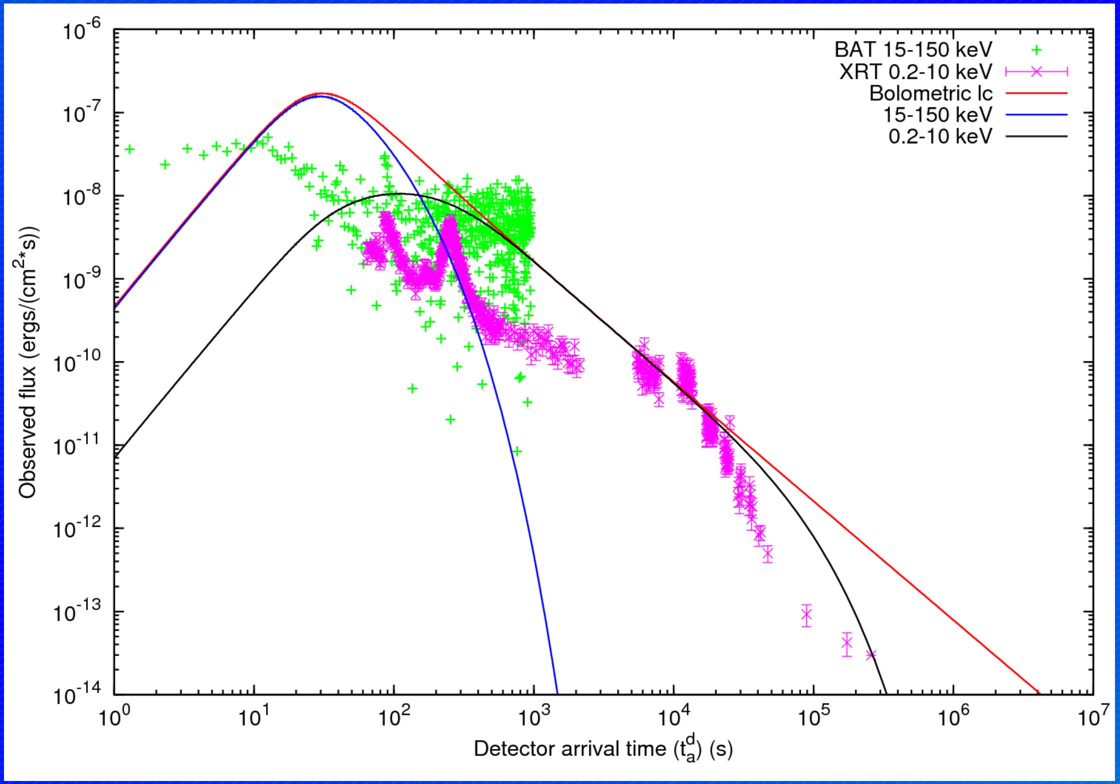
$E^{tot}_{e\pm} = 4.1 \times 10^{53}$ erg OK

$B = 3.0 \times 10^{-4}$ small

$E_{P\text{-}GRB} = 4.0 \times 10^{52}$ erg OK

$n_{CBM} = 4.0 \times 10^{-9}$ #/cm^3 ??!!

$\mathscr{R} = 1.0 \times 10^{-9}$ OK



GRB060607A cannot be interpreted as a fake short GRB with realistic values of the parameters!!!!!!

…… as a typical long GRB ……

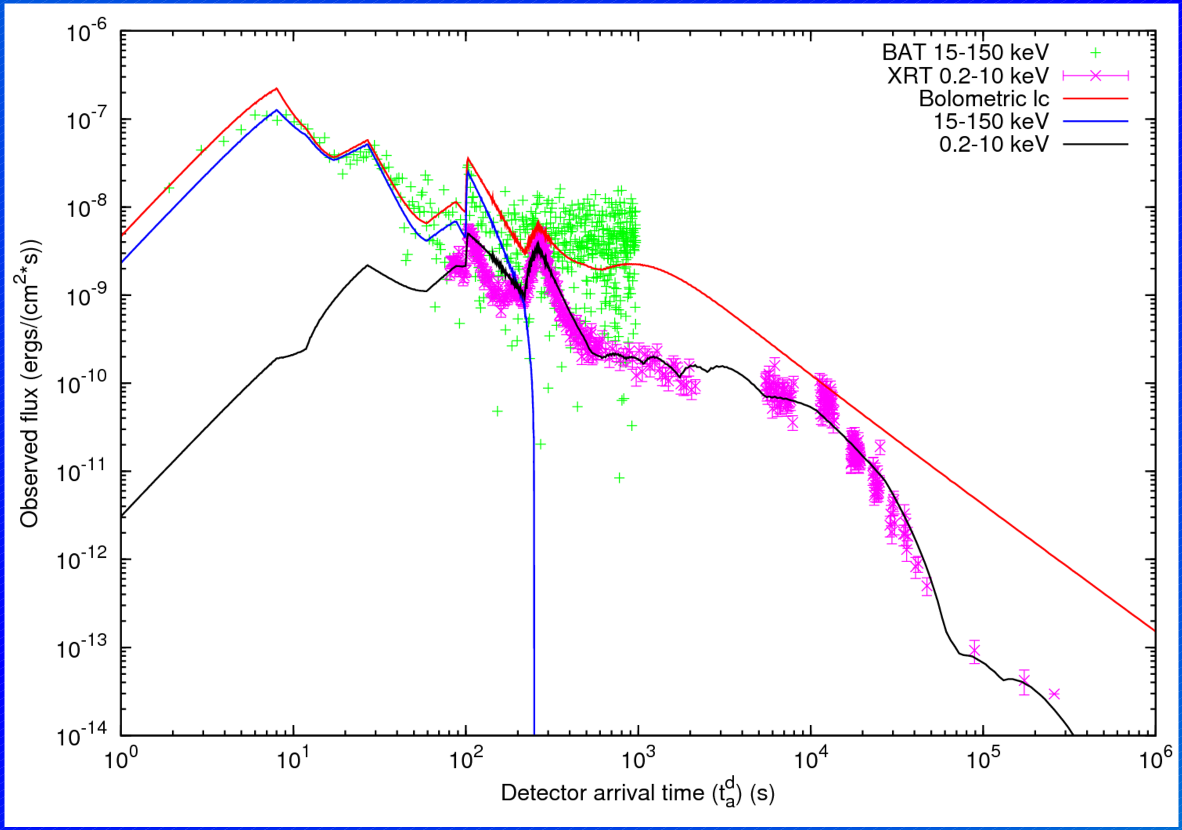
$E^{tot}_{e\pm}$ = 2.5 x 10^{53} erg

B = 3.0 x 10^{-3}

--> $N_{e\pm}$ = 2.6 x 10^{58},

T = 1.7 MeV

γ_0 = 330

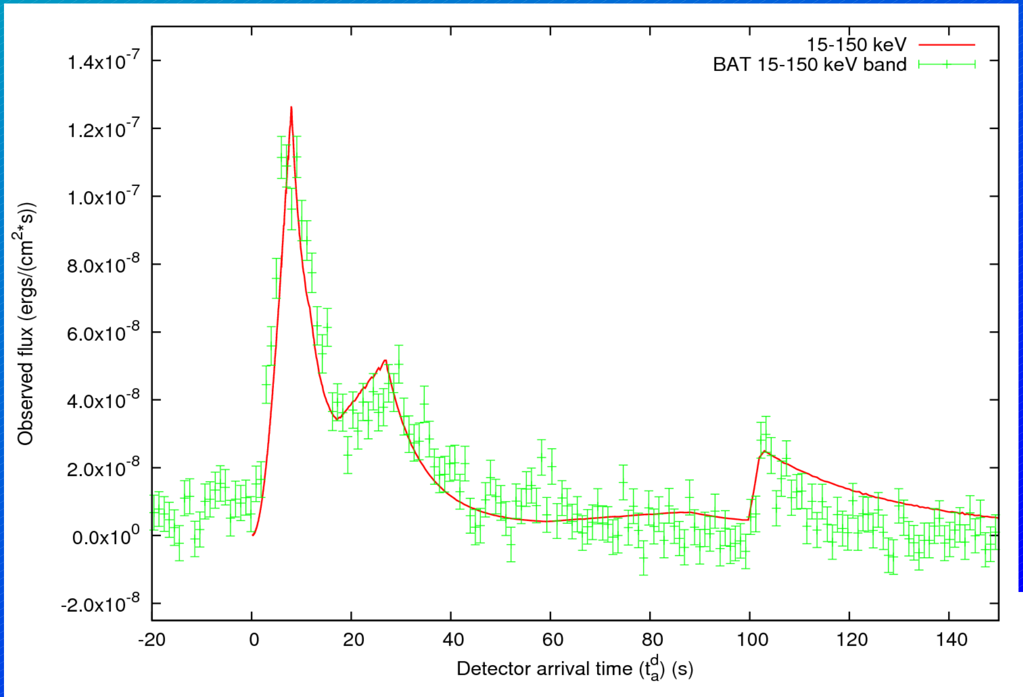


- ✓ LCs well reproduced
- ✓ $E_{P\text{-}GRB}$=1.9% $E^{tot}_{e\pm}$ = 4.7 x 10^{51} erg --> under threshold

Molinari et al. 2007, A&A, 469, L13.

Covino et al., arXiv:0710.0727.

Details on the LCs

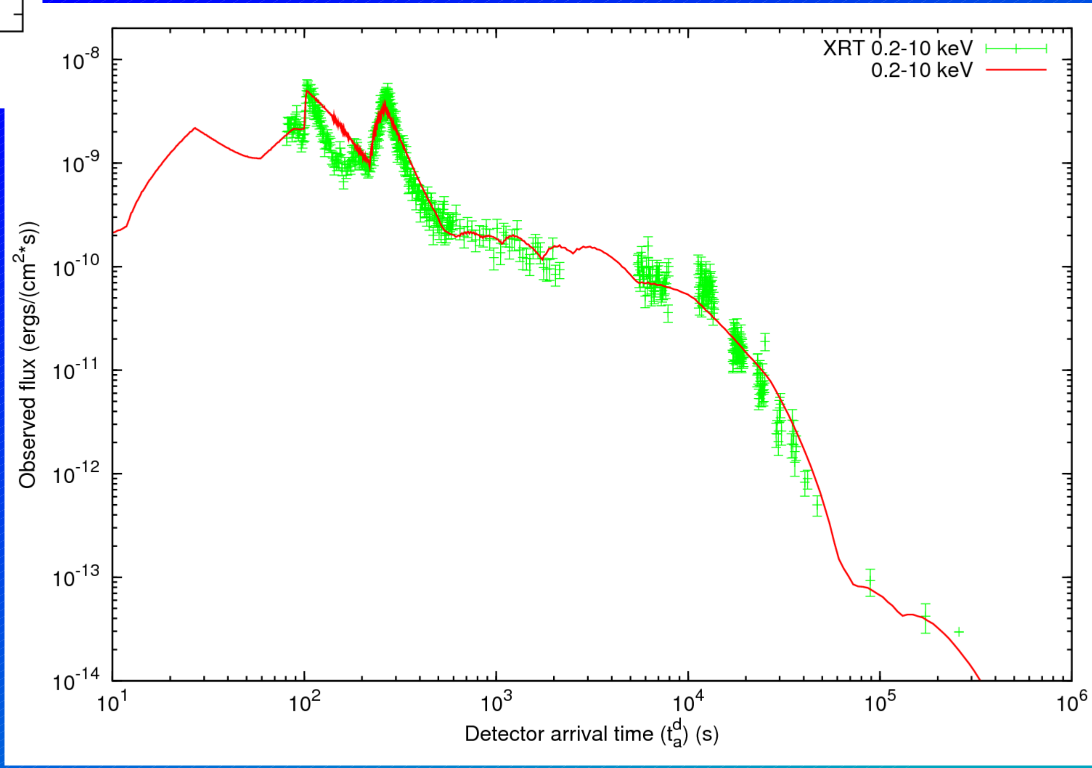


Prompt emission:

$\langle n_{CBM} \rangle = 0.1 \#/cm^3$

X-Ray Afterglow:

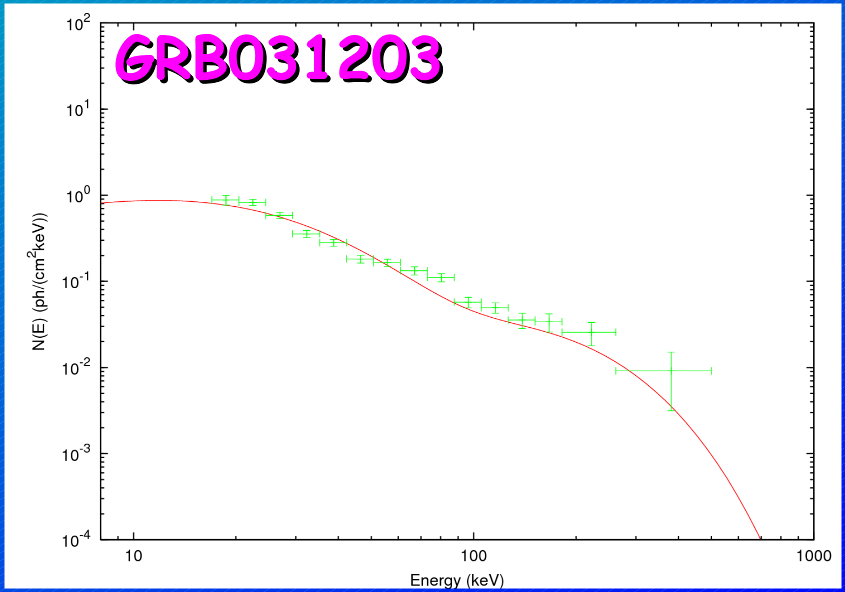
... see Dainotti's talk



Molinari et al. 2007, A&A, 469, L13.

Guidorzi, Vergani private communication.

The time-integrated spectrum



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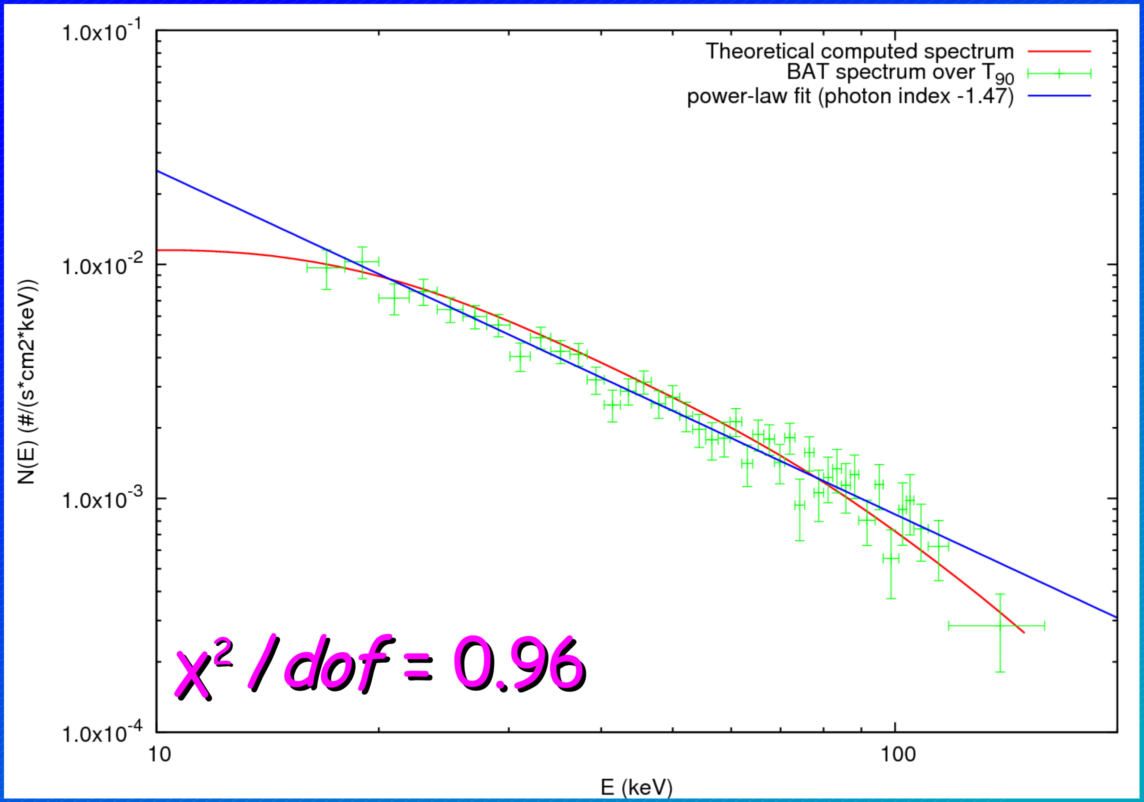

Bernardini et al., 2005, ApJ, 634, L29.

The "Canonical GRB" scenario

$B < 10^{-5}$
The total P-GRB energy is *larger* than the afterglow one.

→

"Genuine" short GRBs:
the P-GRB is the *leading* contribution and the afterglow is negligible

$10^{-4} < B < 10^{-2}$
The total P-GRB energy is *smaller* than the afterglow one.

→

$n_{cbm} \sim 10^{-3}$ #/cm^3
(compatible with a galactic halo environment)

→

"Fake" short GRBs:
the P-GRB *appears to be* the leading contribution since the afterglow is deflated by low CBM density
(GRB 970228, GRB 060614).

→

$n_{cbm} \sim 1$ #/cm^3

→

Normal ("long") GRBs:
(GRB 991216, GRB 050315..)

Bernardini et al., 2007, A&A, 474, L13.
Bianco et al., 2007, AIP Conf. Proc., 966, 12.

Conclusions

- ✓ "Canonical GRB" scenario:

  "Genuine" S-GRBs <-- $B < 10^{-5}$

  "Fake" S-GRBs <-- $B > 10^{-5}$, $\langle n_{cbm} \rangle \sim 10^{-3}$ #/cm^3

  "Normal" L-GRBs <-- $B > 10^{-5}$, $\langle n_{cbm} \rangle \sim 1$ #/cm^3

- ✓ GRB lc and spectra successfully reproduced (see also De Barros, Caito & Dainotti talks)
- ✓ Role of the CBM density <-- possibly binary system in galactic halo