

HIGH ENERGETIC GRBs AND THEIR SPECTRAL PROPERTIES WITHIN THE FIRESHELL MODEL

Barbara Patricelli,

M. G. Bernardini, C. L. Bianco, L. Caito, G. de Barros, L. Izzo,
R. Ruffini and G. Vereshchagin

ICRA-International Center for Relativistic Astrophysics
and
Physics Department, University of Rome “La Sapienza”

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GRB luminosity and the spectrum within the Fireshell Model

GRB luminosity

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

$$\Delta\epsilon = \frac{\Delta E^{int}}{V}, \quad \Lambda = \{\gamma (1 - v \cos \theta / c)\}^{-1}$$

$$W(\nu_1, \nu_2, T_{arr}) = \frac{\int_{\epsilon_1}^{\epsilon_2} \left(\frac{dN_\gamma}{dV d\epsilon} \right) \epsilon d\epsilon}{\int \left(\frac{dN_\gamma}{dV d\epsilon} \right) \epsilon d\epsilon}$$

$$T_{arr} = \frac{\Lambda^{-1} T}{(1+z)}$$

Ruffini et al. 2004; see also Bernardini's talk

The spectral energy distribution

Assumption: the radiation emitted has a **thermal spectrum** in the comoving frame of the fireshell ...

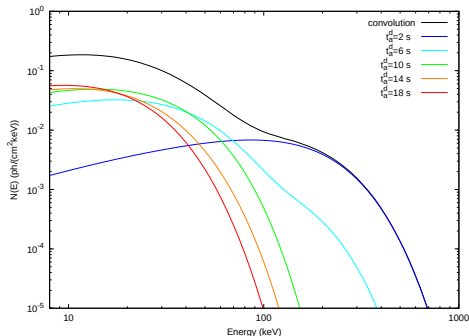
$$\frac{dN_\gamma}{dV d\epsilon} = \left(\frac{8\pi}{h^3 c^3} \right) \frac{\epsilon^2}{\exp(\frac{\epsilon}{k_B T}) - 1}$$

$$\Rightarrow W(\nu_1, \nu_2, T_{arr}) = \frac{\int_{\epsilon_1}^{\epsilon_2} \left(\frac{dN_\gamma}{dV d\epsilon} \right) \epsilon d\epsilon}{a T^4}$$

where $T = \left(\frac{\Delta E_{int}}{4\pi r^2 \Delta\tau \sigma \mathcal{R}} \right)^{1/4}$, with $\Delta\tau$ the time interval in which the energy ΔE_{int} is developed and $\mathcal{R} = \frac{A_{eff}}{A_{vis}}$ (Ruffini et al. 2004)

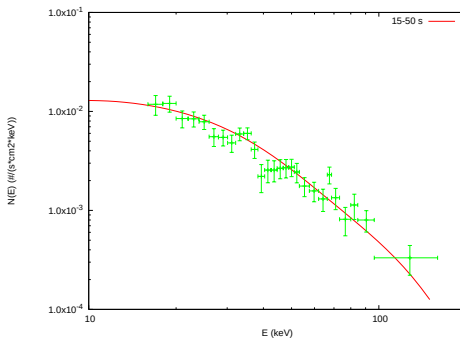
The spectral energy distribution

...but the final spectrum is **non-thermal**, being the convolution of thermal spectra over the EQTS and the observational time

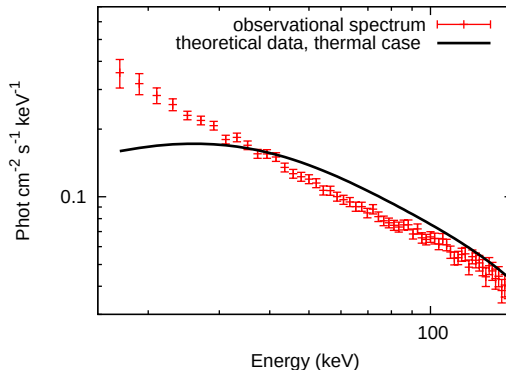


Bianco & Ruffini 2005, Bernardini et al. 2005

With the assumption of thermal spectrum it has been possible to interpret successfully the observational properties of several low energetic GRBs ($E_{iso} \lesssim 10^{53}$ ergs) such as, for example, GRB 060607A (Bernardini et al. 2009; see also Bernardini's talk)



... nevertheless, there are very energetic GRBs ($E_{iso} \gtrsim 10^{54}$ ergs) for which it does not allow to correctly reproduce the observational data, see for example GRB 080319B:



We want to generalize the comoving
spectral energy distribution of the photons
to study high energetic GRBs

The “modified” thermal spectrum

We propose a phenomenologically **“modified” thermal spectrum** (Patricelli et al. 2010):

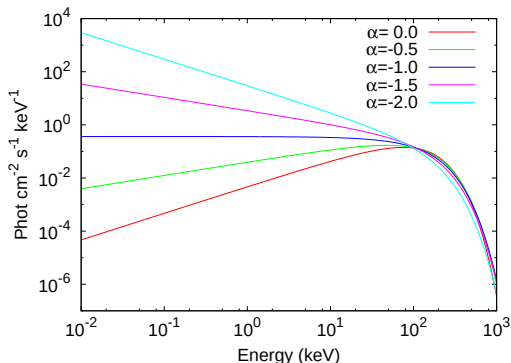
$$\frac{dN_\gamma}{dV d\epsilon} = \left(\frac{8\pi}{h^3 c^3} \right) \left(\frac{\epsilon}{k_B T} \right)^\alpha \frac{\epsilon^2}{\exp\left(\frac{\epsilon}{k_B T}\right) - 1}$$

$$\Rightarrow W(\nu_1, \nu_2, T_{arr}) = \frac{\int_{y_1}^{y_2} \frac{y^{\alpha+3}}{\exp(y)-1} dy}{\Gamma(4+\alpha) Li_{4+\alpha}(1)}$$

where $y = \frac{\epsilon}{k_B T}$, $\Gamma(z) = \int_0^\infty t^{z-1} e^{-t} dt$ and $Li_n(z) = \sum_{k=1}^\infty \frac{z^k}{k^n}$

Instantaneous spectra

Example: numerically simulated instantaneous spectra obtained by assuming $E_{e\pm}^{tot} = 10^{54}$ ergs, $B = 2.5 \cdot 10^{-3}$ and $n_{cbm} = 1$ part/cm³



Application of the modified thermal spectrum:

the cases of

GRB 080319B, $E_{iso} = 1.32 \times 10^{54}$ ergs (Golenetskii et al. 2008)

and **GRB 050904**, $E_{iso} = 1.04 \times 10^{54}$ ergs (Sugita et al. 2007)

GRB 080319B

BAT spectrum integrated over the time interval $3s \leq t_a^d \leq 28s$

Parameters

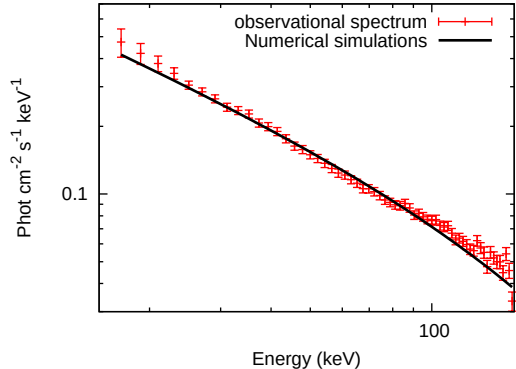
$$E_{e^\pm}^{tot} = 1.0 \cdot 10^{54} \text{ ergs}$$

$$B = 2.5 \cdot 10^{-3}$$

$$\mathcal{R} = 3.5 \cdot 10^{-10}$$

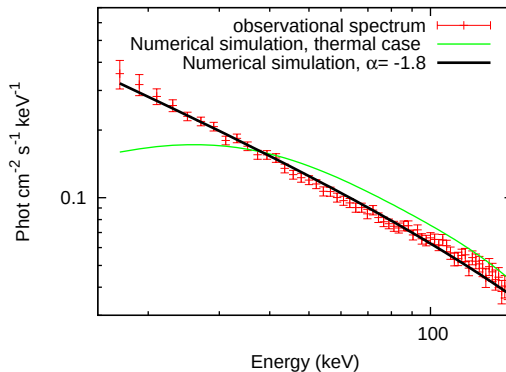
$$\alpha = -1.8$$

$$\langle n_{cbm} \rangle \sim 6 \text{ part cm}^{-3}$$



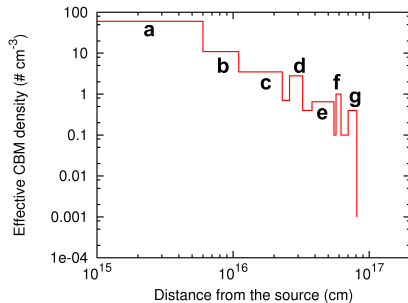
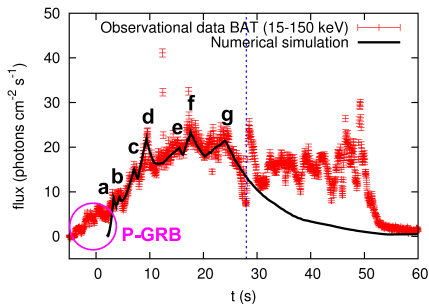
GRB 080319B

BAT spectrum integrated over the time interval $3s \leq t_a^d \leq 13s$



GRB 080319B

Phase I BAT Light Curve



GRB 050904

BAT spectrum integrated over T_{90}

Parameters

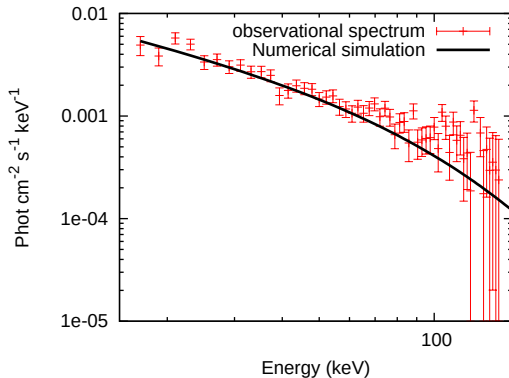
$$E_{e\pm}^{tot} = 1.0 \cdot 10^{54} \text{ ergs}$$

$$B = 2.5 \cdot 10^{-3}$$

$$\mathcal{R} = 2 \cdot 10^{-11}$$

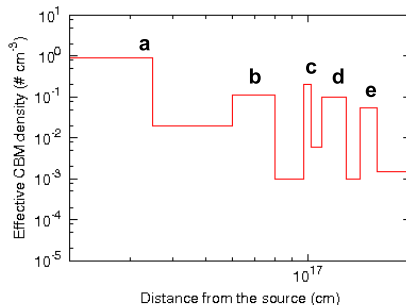
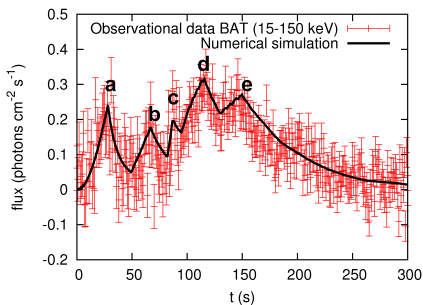
$$\alpha = -1.8$$

$$\langle n_{cbm} \rangle \sim 10^{-1} \text{ \# cm}^{-3}$$



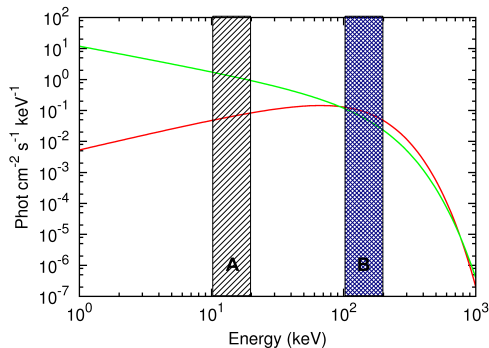
GRB 050904

BAT Light Curve



Why for higher energetic bursts ($E_{iso} \gtrsim 10^{54}$ ergs) we need
to introduce a modified thermal spectrum, while for
lower energetic bursts ($E_{iso} \lesssim 10^{53}$ ergs) the observational data
can be reproduced by assuming a pure thermal spectrum?

Let's consider GRB spectra observed by two instruments covering a different energy range...



Example:

- Instrument **A**:
10 - 20 keV
- Instrument **B**:
10² - 2 × 10² keV

GRB whose spectra have been analysed within the fireshell model: **031203** (Bernardini et al. 2005b); **060607A** (Bernardini et al. 2009); **080319B** (Patricelli et al. 2010); **050904** (Patricelli et al. 2010).

GRB	031203	060607A	080319B	050904
z	0.106	3.082	0.937	6.29
E_{iso} (ergs)	10^{50}	1.1×10^{53}	1.34×10^{54}	1.04×10^{54}
E_{peak}^i (keV)	158 ± 51	478^{+314}_{-69}	1261 ± 65	2291^{+1263}_{-634}
E_{peak}^{obs} (keV)	144 ± 46	117^{+77}_{-17}	675 ± 22	314^{+173}_{-89}
Satellite	INTEGRAL	Swift	Swift	Swift
Instrument	IBIS/ISGRI	BAT	BAT	BAT
ΔE (keV)	$17 \div 500$	$15 \div 150$	$15 \div 150$	$15 \div 150$

Conclusions

- We have introduced a phenomenologically modified thermal spectrum: a spectrum characterized by a different low energy slope with respect to the thermal one, given by a free parameter α .
- We have tested this spectrum by comparing the numerical simulations with the observational data of two highly energetic bursts ($E_{iso} \gtrsim 10^{54}$ ergs): GRB 080319B and GRB 050904
- We have shown that the observational properties of these bursts can be correctly reproduced by assuming a modified thermal spectrum with $\alpha = -1.8$
- We have proposed the possible reason why the observational data of lower energetic GRBs can be interpreted by assuming a pure comoving thermal spectrum, while for higher energetic GRBs the modified thermal spectrum is needed.

Future Developments

- Extension of the analysis to a larger sample of GRBs, also with data by different satellites (for example MIRAX)

References |

- [1] Bernardini, M. G., Bianco, C. L., Caito, L., et al., 2009, AIP Conf. Proc., 1111, 383
- [2] Bernardini, M.G., Bianco, C.L., Chardonnet, P., et al. 2005, ApJ, 634, L29
- [3] Bianco, C. L., Ruffini, R. 2005, ApJ, 620, L23
- [4] Golenetskii, S., Aptekar, R., Mazets, E., et al., 2008, GCN Circular 7482
- [5] Patricelli, B., Bernardini, M.G., Bianco, C.L., et al., submitted to A&A
- [6] Ruffini, R., Bianco, C.L., Chardonnet, P., et al. 2004, IJMPD, 13, 843
- [7] Sugita, S., Yamaoka, K., Ohno, M. et al. 2009, PASJ 61, 521