The canonical GRB scenario

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(some) Key Features of the Model

- No need for beaming to reduce energy budget ($10^{55}$ ergs allowed).
- Prompt emission made of two different components: the Proper GRB (P-GRB) and the extended afterglow peak.
- (Quasi)-Thermal spectrum in the fireshell co-moving frame for the prompt emission.
- Short and Long GRBs differ only by their different fireshell baryon loading and surrounding medium.
- Need to distinguish “genuine” short and “disguised” short GRBs.
The Dyadosphere

\[ \mu = \frac{M}{M_\odot} \quad \zeta = \frac{Q}{M} \]

\[ r_+ \simeq 1.47 \times 10^5 \mu \left(1 + \sqrt{1 - \zeta^2}\right) \text{ cm} \]

\[ r_{ds} \simeq 1.12 \times 10^8 \sqrt{\mu \zeta} \text{ cm} \]

The Dyadotorus

The optically thick *fireshell*: The PEMB Pulse

\[ E_{e^+}^{\text{tot}} = 1.44 \times 10^{49} \text{ erg} \]

![Graph showing the Lorentz \( \gamma \) factor as a function of the fireshell radius. The graph includes several curves for different magnetic field strengths, denoted as \( B = 10^{-2}, B = 10^{-3}, \ldots, B = 10^{-8} \).]
The optically thick *fireshell*: The PEMB Pulse

\[ E_{\text{e}^+}^{\text{tot}} = 1.22 \times 10^{55} \text{ erg} \]
Fireshell pair number density: the role of the rate equation

$E_{\text{e}^+}^{\text{tot}} = 1.44 \times 10^{49} \text{ erg}$

[Graph showing the dependence of fireshell co-moving pair number density on radius]
Fireshell pair number density: the role of the rate equation

\[ E_{e^+}^{\text{tot}} = 1.22 \times 10^{55} \text{ erg} \]

![Graph showing fireshell pair number density vs. fireshell radius]
Fireshell Temperature

$E_{e^+}^{\text{tot}} = 1.44 \times 10^{49} \text{ erg}$

Doppler blue-shifted toward the observer

In the co-moving frame

Fireshell radius (cm)

Fireshell temperature (keV)
Fireshell Temperature

$E_{e^+}^{\text{tot}} = 1.22 \times 10^{55}$ erg

Doppler blue-shifted toward the observer

In the co-moving frame

Fireshell temperature (keV)

$B = 10^{-2}$
$B = 10^{-3}$
$B = 10^{-4}$
$B = 10^{-5}$
$B = 10^{-6}$
$B = 10^{-7}$
$B = 10^{-8}$

Fireshell radius (cm)
**Fireshell transparency:**

the P-GRB emission and the optically thin *fireshell*

- All photons produced by the electron-positron pair recombination are emitted in a short but strong energy flash: *the P-GRB*

- Out of the PEMB pulse it remains only an optically thin *fireshell* of baryonic matter accelerated at ultra-relativistic velocities: the ABM Pulse, which gives origin to **the extended afterglow**.

- The ratio between the fraction of PEMB Pulse internal energy converted into ABM Pulse kinetic energy and that emitted in the P-GRB depends on the $B$ parameter.

\[
B \equiv \frac{N_B m_p c^2}{E_{dy}} \equiv \frac{M_B c^2}{E_{dy}}
\]

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\[
\frac{2B}{1} \equiv \frac{N_B m_p c^2}{E_{\text{dy}a}} \equiv \frac{M_B c^2}{E_{\text{dy}a}}
\]
“Canonical GRB” Bolometric luminosity

Two different phases:

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- **P-GRB**: emitted at the PEMB pulse transparency point.
- (still work in progress)

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**P-GRB:** emitted at the PEMB pulse transparency point. (still work in progress)

**Extended Afterglow:** due to the interaction between ABM pulse and ISM. Includes E-APE

\[
\frac{dE_{\gamma}}{dt_a d\Omega} = \int_{EQTS} \left( \frac{t_a^d}{4\pi} \right) \Delta \varepsilon \ v \ \cos \vartheta \ \Lambda^{-4} \ \frac{dt}{dt_a^d} \ d\Sigma
\]

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

"Canonical GRB" Bolometric luminosity

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t_a^d = (1 + z) \left( t - \frac{\int_0^t v(t') dt' + r_{ds}}{c} \cos \vartheta + \frac{r_{ds}}{c} \right)
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Fireshell transparency: P-GRB vs. Extended Afterglow
The observed spectrum (e.g. for GRB 031203): a double convolution of thermal spectra

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**Observed spectrum:**
Convolution of instantaneous spectra over the observation time, i.e. convolution of convolutions of thermal spectra.

**Instantaneous spectrum:**
Convolution of thermal spectra over the EQTS.

The observed spectrum of GRB 031203

Prompt emission spectrum as a convolution of quasi thermal spectra

\[ I_\nu = \frac{2\nu^3}{c^2} \left( \frac{\nu}{k_B T} \right)^\alpha \frac{1}{\exp\left( \frac{\nu}{k_B T} \right) - 1} \]

\[ E_{\text{dy}} = 1.0 \times 10^{54} \text{ erg} \]
\[ B = 2.5 \times 10^{-3} \]
\[ n_{\text{ism}} \sim 6.06 \#/\text{cm}^3 \]

GRB 080319B
\[ \alpha = -1.8 \]
GRB 050315: BAT + XRT Light curve

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Extended Afterglow

P-GRB (not shown)

GRB 050315: BAT + XRT Light curve

Theoretical fit in 15-350 keV band
Theoretical fit in 0.2-10 keV band
XRT observation in 0.2-10 keV band

“Prompt Emission”
(extended afterglow peak)
GRB 050315: BAT Light curve (15-350 keV)

Theoretical fit in 15-350 keV band
BAT observation in 15-350 keV band

$E_{\text{dy}a} = 1.46 \times 10^{53} \text{ erg}$
$B = 4.55 \times 10^{-3}$
$E_{P-GRB} = 1.35\% \ E_{\text{dy}a}$
$n_{cbm} \sim 1.0 \#/\text{cm}^3$
"Canonical GRB"

$B \rightarrow 0$
"Canonical GRB"

$B \rightarrow 0$

![Graph showing the relationship between Radius (cm) and Lorentz factor. The graph also shows the observed flux (erg/cm² s) versus detector arrival time (s).](image-url)
“Canonical GRB”

$B \rightarrow 0$

"Genuine short" GRBs

Detector arrival time (s)

Observed flux (erg/cm$^2$/s)

Radius (cm)

Lorentz $\gamma$ factor

P-GRB
“Canonical GRB”  

$B \rightarrow 10^{-2}$
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$B \rightarrow 10^{-2}$
"Canonical GRB"

\[ B \rightarrow 10^{-2} \]
"Canonical GRB"

$B \rightarrow 10^{-2}$

"Long" GRBs

\[
<n_{ism}> = 1 \text{ cm}^{-3}
\]
A new class of GRBs

- GRB 060614 (Gehrels et al., 2006; Mangano et al., 2007):
  - A short pulse ~ 4 s + long-lasting multipeaked structure.
  - “Hybrid” properties between short and long bursts.
    ⇒ Hard to classify in terms of short/long categories.

- BATSE + HETE-II + Swift catalogue (Norris & Bonnell, 2006):
  - “Occasional softer, extended emission lasting tens of seconds after the initial spikelike emission”.
  - Softer extended emission “relatively strong, with peak intensities only 2-10 lower than the spike emission”.
  - “The strength of the extended emission converts an otherwise short burst ... making it appear to be a long burst”.

⇒ The current nomenclature for the two classes (short – hard / long – soft) is at best misleading.
GRB 970228
prompt emission
(BeppoSAX)

GRB 970228
prompt emission
(BeppoSAX)

$E_{dya} = 1.4 \times 10^{54}$ erg
$B = 5.0 \times 10^{-3}$
$E_{P-GRB} = 1.1\% \ E_{dya}$
$n_{ism} \sim 10^{-3} \ #/cm^3$

GRB 970228 detected in the halo of its host galaxy.

$E_{dya} = 1.4 \times 10^{54} \text{ erg}$
$B = 5.0 \times 10^{-3}$
$E_{P-GRB} = 1.1\% \ E_{dya}$
$n_{ism} \sim 10^{-3} \text{ #/cm}^3$
The role of the low ISM density

The role of the low ISM density

Deflates” ext. afterglow peak luminosity with respect to the P-GRB (increasing its duration, since total energy is fixed by $B$)

"Disguised" short GRBs

“Canonical GRB”

$B \rightarrow 10^{-2}$

"Long" GRBs

Detector arrival time (s)

Radius (cm)

Lorentz $\gamma$ factor

Observed flux (erg/cm$^2$/s)

$n_{ism} = 1$ cm$^{-3}$
"Canonical GRB" 

$B \rightarrow 10^{-2}$

"Long" GRBs and/or "Disguised short" GRBs
GRB060614

\[ E_{dya} = 2.9 \times 10^{51} \text{ erg} \]

\[ B = 2.8 \times 10^{-3} \]

\[ E_{P-GRB} = 3.9\% \, E_{dya} \]

\[ n_{ism} \sim 10^{-3} \, \#/\text{cm}^3 \]


See L. Caito’s talk on Thursday.
$E_{\text{dy}a} = 5.0 \times 10^{51}$ erg

$B = 2.0 \times 10^{-4}$

$E_{P-GRB} = 20\% \ E_{\text{dy}a}$

$n_{\text{ism}} \sim 10^{-3}$ #/cm$^3$
GRB050509b

$E_{dy} = 5.5 \times 10^{48}$ erg

$B = 6.0 \times 10^{-4}$

$E_{P-GRB} = 28\% \ E_{dy}$

$n_{ism} \sim 10^{-3} \#/cm^3$

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• The Amati relation is fulfilled only by the so-called “long” GRBs, i.e. the canonical GRBs in which the P-GRB is negligible and the “prompt emission” is dominated by the extended afterglow. Instead, it is not fulfilled by the “short” GRBs, i.e. the canonical GRBs in which the “prompt emission” is dominated by the P-GRB.
Implications for the Amati relation

• The usually called “prompt emission” actually mixes together both the P-GRB and the peak of the extended afterglow. Being different physical phenomena, they must be analyzed separately.

• The Amati relation is fulfilled only by the so-called “long” GRBs, i.e. the canonical GRBs in which the P-GRB is negligible and the “prompt emission” is dominated by the extended afterglow. Instead, it is not fulfilled by the “short” GRBs, i.e. the canonical GRBs in which the “prompt emission” is dominated by the P-GRB.

• In “disguised” short GRBs, therefore, the Amati relation must be fulfilled only by the prolonged soft tail (which is the extended afterglow peak) alone, but not by the initial spikelike emission (which is the P-GRB). This is a key point for the identification of this novel GRB class.

GRB071227

See L. Caito’s talk on Thursday

See L. Cai
to’s talk on Thursday.

De Barros, Amati, Bernardini, Bianco, Cai
The “canonical GRB” scenario
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$B \leq 10^{-5}$

The total time-integrated P-GRB luminosity is larger than the extended afterglow one.

“Genuine” short GRBs:
The P-GRB is the leading contribution to the emission and the extended afterglow is negligible. Do not follow the “Amati” relation.

The “canonical GRB” scenario

For $B \leq 10^{-5}$, the total time-integrated P-GRB luminosity is larger than the extended afterglow one.

For $10^{-4} \leq B \leq 10^{-2}$, the total time-integrated P-GRB luminosity is smaller than the extended afterglow one.

"Genuine" short GRBs: the P-GRB is the leading contribution to the emission and the extended afterglow is negligible. Do not follow the “Amati” relation.

The "canonical GRB" scenario

$B \leq 10^{-5}$

The total time-integrated P-GRB luminosity is larger than the extended afterglow one.

"Genuine" short GRBs:
The P-GRB is the leading contribution to the emission and the extended afterglow is negligible. Do not follow the "Amati" relation.

$10^{-4} \leq B \leq 10^{-2}$

The total time-integrated P-GRB luminosity is smaller than the extended afterglow one.

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

Normal ("long") GRBs:
(e.g. GRB 991216, GRB 050315, etc.). Do follow the "Amati" relation.

The “canonical GRB” scenario

$B \leq 10^{-5}$
The total time-integrated P-GRB luminosity is larger than the extended afterglow one.

"Genuine" short GRBs:
the P-GRB is the leading contribution to the emission and the extended afterglow is negligible.
Do not follow the “Amati” relation.

"Disguised" short GRBs:
the P-GRB appears to be the leading contribution to the prompt emission because the extended afterglow is deflated by the small ISM density (e.g. GRB 970228, GRB 060614, etc.).
Only the prolonged soft tail alone follows the “Amati” relation.

$10^{-4} \leq B \leq 10^{-2}$
The total time-integrated P-GRB luminosity is smaller than the extended afterglow one.

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

Normal ("long") GRBs:
(e.g. GRB 991216, GRB 050315, etc.).
Do follow the “Amati” relation.

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