The standard model of GRBs in the SWIFT era

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(Mangano et al, 2006)
Present GRB model elaborated from the results of BATSE, BeppoSAX, INTEGRAL and HETE 2

**BATSE: 1991 - 1999**

2704 BATSE Gamma-Ray Bursts

hint for a cosmological distance scale

**Beppo-SAX: 1997 - 2002**

the afterglow era!

**HETE 2: 2000 - 2006 ?**

the GRB/SN connection

• first afterglow of a SHB

• XRFs
The “standard” model: fireball + IS/ES

(1) acceleration of the flow (fireball phase)
(2) coasting phase $\Gamma > 100$
(3) transparency radius thermal precursor ?
(4) internal shocks gamma-ray emission
(5) reverse shock optical flash ?
(6) surface of discontinuity
(7) forward shock afterglow
(8) break in the light curve: $1/\Gamma >$
Every new instrument contributes to make the model more complete and accurate ... but also challenges it!

More sensitive than Beppo/HETE
Early follow-up in X and V
many new redshifts

(Daigne’s talk)

GRB 050904 at $z = 6.29$!
With SWIFT a window opens on the early afterglow evolution

- a complex phase where internal, reverse and forward shocks can be together present

Surprises in X-rays!

- evidence for late energy injection/
- late activity of the central source?

(O’Brien et al, 2006)
Early X-ray afterglow hump

with $v_m < v_c < v_X$ standard theory predicts: $F_X \propto E_f^ {1.1} \times \varepsilon_e^{1.4} \times t^{-1.3}$

If between $10^3$ and $10^4$ s: $F_X \propto t^0$, then

$E_f \propto t^{1.2}$ or $\varepsilon_e \propto t^{0.9}$

i.e. $E_f \times 15$ (!) or $\varepsilon_e \times 6$

during the interval (one decade in time)

Late energy injection means a lot of energy …
An efficiency crisis for internal shocks?

apparent efficiency: \[ f = \frac{E_\gamma}{E_\gamma + E_{fs}} \]

\(E_{fs}\) at late times from burst « calorimetry»
(radio observations in the Sedov phase)

but if \(E_{fs} = k \times E_{fs}^0\)
true IS efficiency:
\[ f_0 = \frac{E_\gamma}{E_\gamma + E_{fs}^0} = \frac{k f}{(k - 1) f + 1} \]

with \(f = 0.1\) and \(k = 10\), \(f_0 = 0.53\)!

efficiency of internal shocks:
\[ \kappa: \text{contrast of Lorentz factor distribution} \]
\[ f_{IS} = f_{\text{diss}}(\kappa) \times \epsilon_e \]

One cannot so easily believe both in IS and in late energy injection...

(but see Dyks’ talk)
A comment on X-ray flares as late internal shocks

- rise and decay too steep for a forward shock origin
  \[ t_d \propto t^{-\alpha} \quad \text{with } \alpha < 3 \text{ for forward shock} \]

- but flare duration long for standard internal shocks
  \[ \Delta t/t \sim 1 \]

\( (\text{Burrows et al; Falcone et al, 2005}) \)

smoother variations of \( \Gamma \) at late times with a longer time scale?
Is there something wrong about internal shocks or afterglow physics?
A critical look at IS:

**PRO**
- can reproduce short time scale variability of GRB profiles
  (if the source produces an outflow with a highly variable $\Gamma$)

\(\Gamma/100\) vs. \(t\) (s) and \(C_{2+3}\) vs. \(t_\text{a} \) (s)

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(Daigne & Mochkovitch, 1998)
- low efficiency \( f_{IS} < 10\% \)
  already a problem even without energy injection
  \( E_{fs} \) underestimated by afterglow modelling? (Fan & Piran, 2006; Dyks)
  release of magnetic energy during IS? (Fan, Wei & Zhang, 2004)
- requires an ultra relativistic outflow \((\Gamma \geq 100)\) not so easy to produce
  alternative model: electromagnetic outflow (Lyutikov & Blandford, 2003)
- radiation mechanism?
  in fast cooling synchrotron predicts a photon low energy index: \( \alpha = -\frac{3}{2} \)
  \(-\frac{3}{2} \quad -\frac{2}{3} \)
  (Preece et al, 2000)
A critical look at afterglow physics:

**PRO**

- a relatively simple physics: relativistic extension of the Sedov problem (Blandford & McKee, 1976; Sari et al, 1998)
- provides good fits of multi-\(\lambda\) data

(Panaitescu & Kumar, 2001)
Are the fits so convincing?

1. They mostly indicate a uniform CSM while a wind \( n \propto r^{-2} \) should a priori be expected ... (GRB 030329)

2. Post-shock electron distribution \( N(\gamma_e) \propto \gamma_e^{-p} \) with \( p < 2 \)?

3. Problems at early times: chromatic breaks

(Panaitescu, 2006)
Solutions?

1. a uniform medium in a massive star environment?

Normally $R_s \sim$ a few pc while $R_s \sim 0.1$ pc would be necessary but not easy to obtain (Eldridge et al, 2006; van Marle et al, 2006)

2,3. variable microphysics parameters: $E_{e,B}(\Gamma, n)$?

- not unrealistic
- obviously adds a lot of flexibility (very early afterglow – wind/uniform medium)
- but poorly constrained (may appear ad hoc if not supported by physical arguments)
The early X-ray afterglow: a reverse shock contribution?

Normally, reverse shock contribution:

\[ F(t) \propto t^{-2} \]

- is short lived
- is supposed to show up in V

so how is it possible to get this?

1. RS can be long-lived if there is a low \( \Gamma \) tail in the relativistic ejecta
2. it can contribute in X-rays if only a small fraction \( \zeta \sim 10^{-2} \) of the electrons are shock accelerated

\[ E_{\text{syn}} \propto \zeta^{-2} \] from less than 1 ev to \( \sim 1 \) keV

\[ t_{\text{syn}} \propto \zeta \] from slow to fast cooling

since \( \Gamma_e \propto \zeta^{-1} \)
One illustrative example

1. extended RS contribution if $\Gamma$ a few during late stages of source activity

9. if $\zeta = 10^{-2}$ a noticeable fraction of this dissipated power comes out in X-rays

may look nice, but raises many questions …
If the reverse shock makes the EXA where is the forward shock contribution?

FS (initially) inefficient in transferring dissipated energy to electrons? $\varepsilon_{e}^{fs} \ll 1$

Then, two possibilities:

1. FS eventually dominates at late times: $\varepsilon_{e}^{fs}$
   
   OK with late afterglow modelling but what happens when FS takes over? bump, change of slope?

4. RS always dominates!?
   
   build a fully consistent multi-$\lambda$ picture (X, Visible, Radio)

WORK IN PROGRESS …
Conclusions

The window opened by SWIFT on the early afterglow challenges GRB models:

**Internal shocks:**
- X-ray hump from late energy injection  
  IS efficiency
- X-ray flares as late IS  change in the dynamics of relativistic ejection at the source

**Afterglow:**
- chromatic breaks during during the first hours

**New ingredients required?**
- evolving microphysical parameters?
- viewing angle effects on a structured jet?  
  (Eichler & Granot, 2005)
- contribution from the reverse shock?

**as always:** more data needed, multi-λ and well sampled during early afterglow phase!