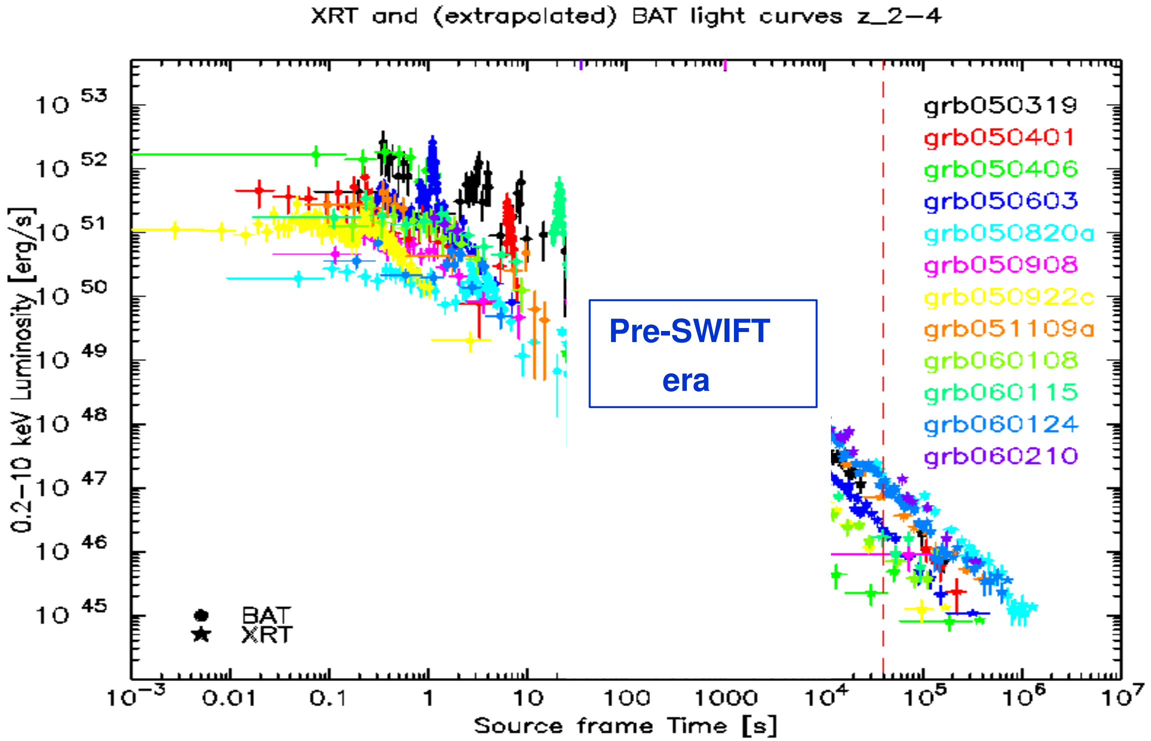
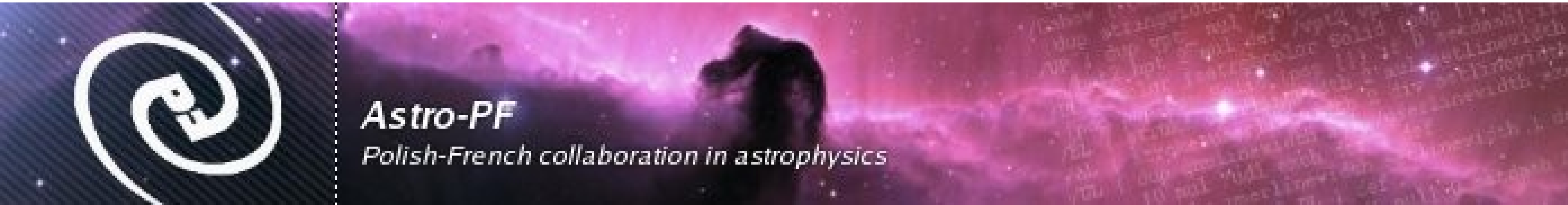
The standard model of GRBs in the SWIFT era



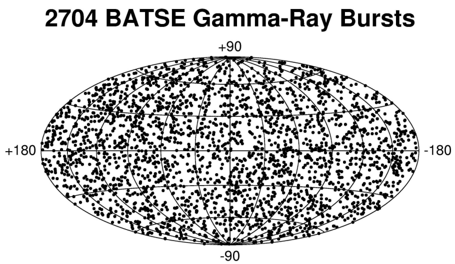
(Mangano et al, 2006)

Robert Mochkovitch (IAP-Paris)



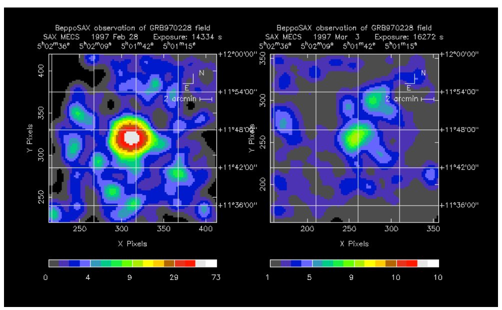
Present GRB model elaborated from the results of BATSE, BeppoSAX, INTEGRAL and HETE 2

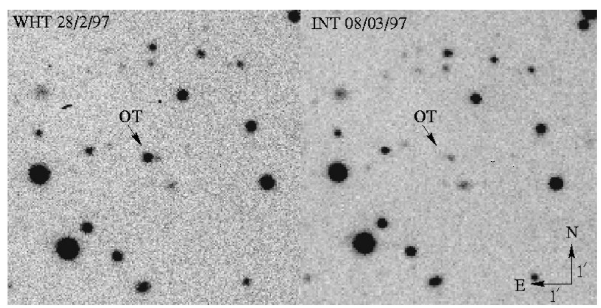
BATSE: 1991 - 1999



hint for a cosmological distance scale

Beppo-SAX: 1997 - 2002



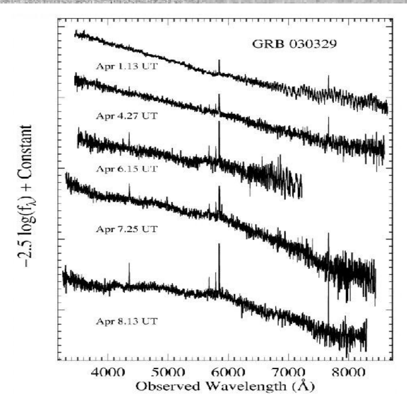


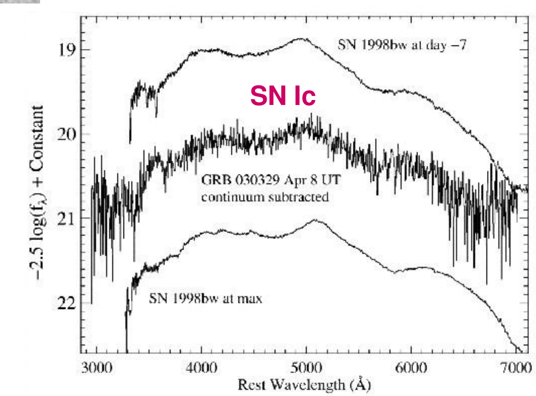
the afterglow era !

HETE 2: 2000 - 2006 ?

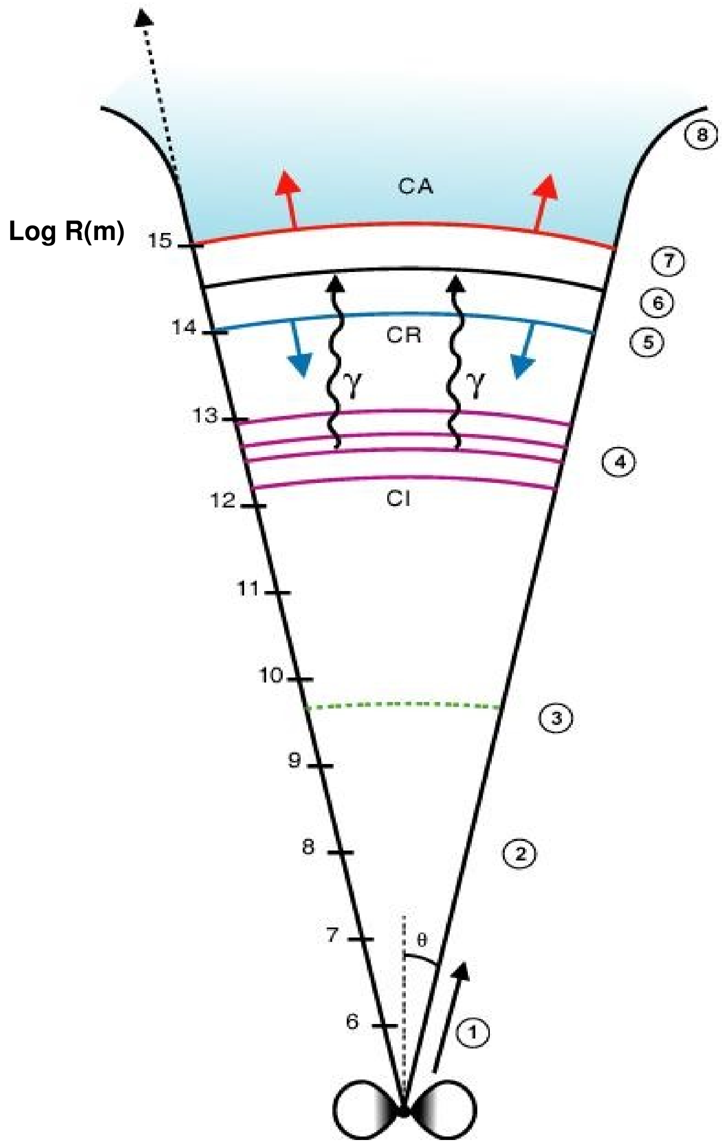
the GRB/SN connection

- 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

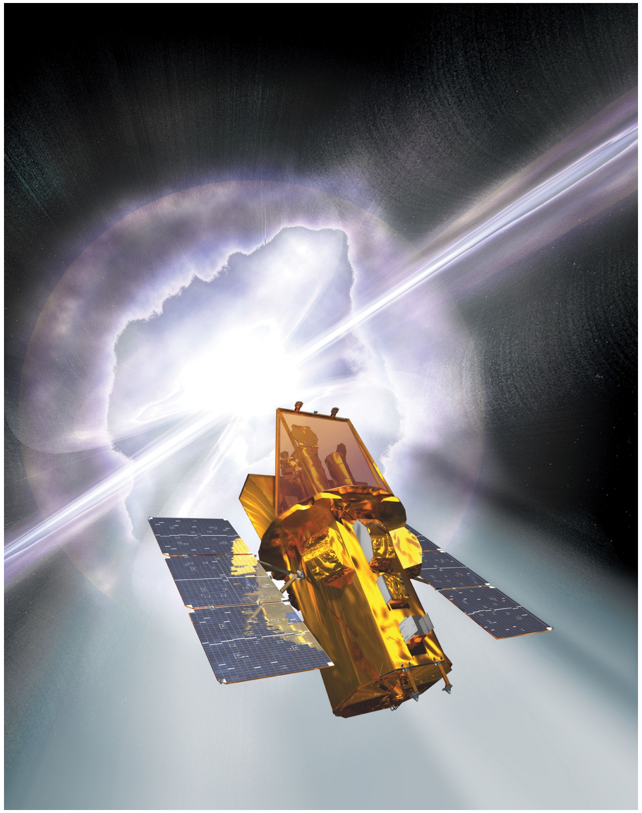
(5) reverse shock optical flash ?

(6) surface of discontinuity

(7) forward shock afterglow

(8) break in the light curve : $1/\Gamma >$

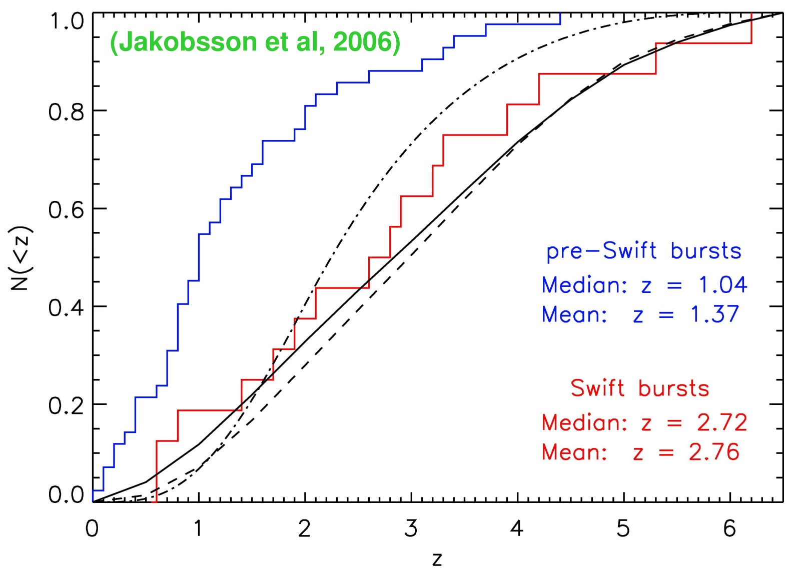
Every new instrument contributes to make the model more complete and accurate … but also challenges it !



More sensitive than Beppo/HETE

Early follow-up in X and V

many new redshifts



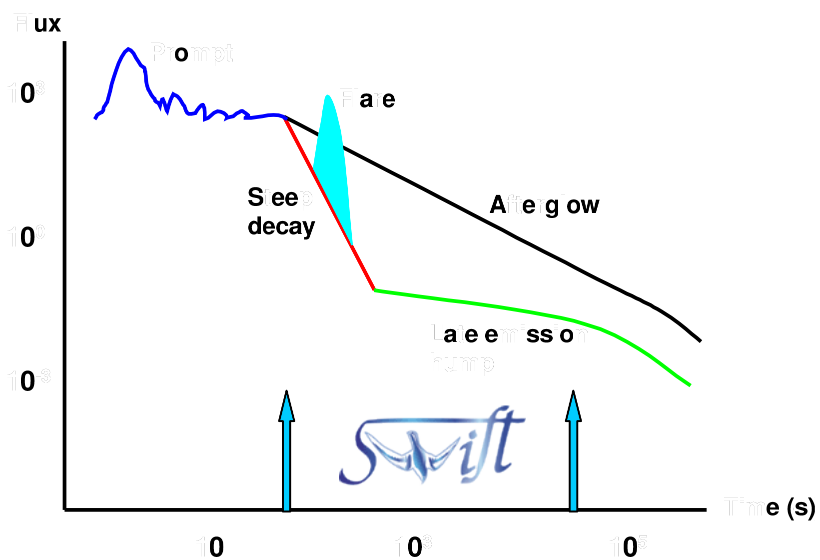
(Daigne's talk)

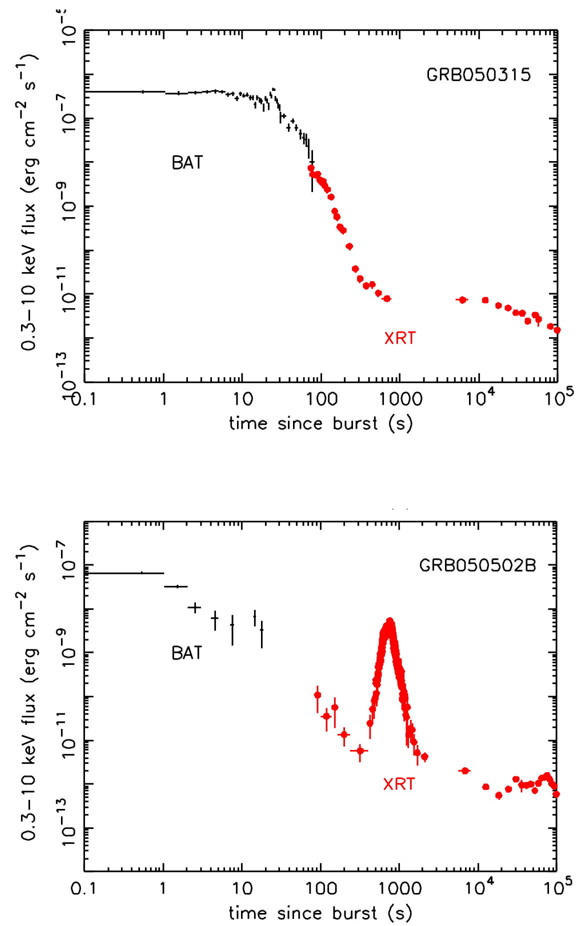
GRB 050904 at z = 6.29 !

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)

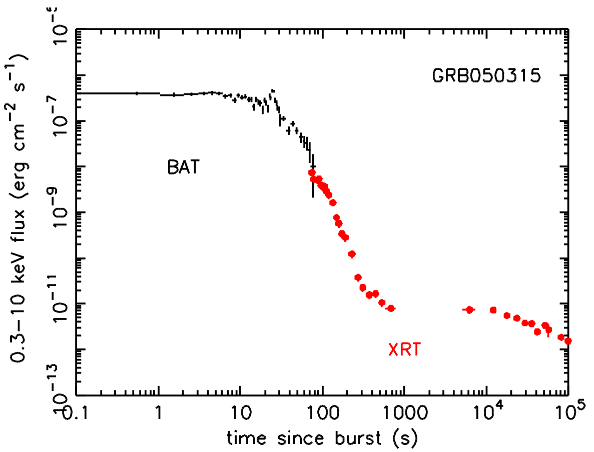
Early X-ray afterglow hump

with $\nu_m < \nu_c < \nu_X$ standard theory predicts : $F_X \propto E_{fs}^{1.1} \times \varepsilon_e^{1.4} \times t^{-1.3}$

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

$E_{fs} \propto t^{1.2}$ or $\varepsilon_e \propto t^{0.9}$

i.e. E_{fs} $\times 15$ (!) or ε_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: $f = \dfrac{E_\gamma}{E_\gamma + E_{fs}}$

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:

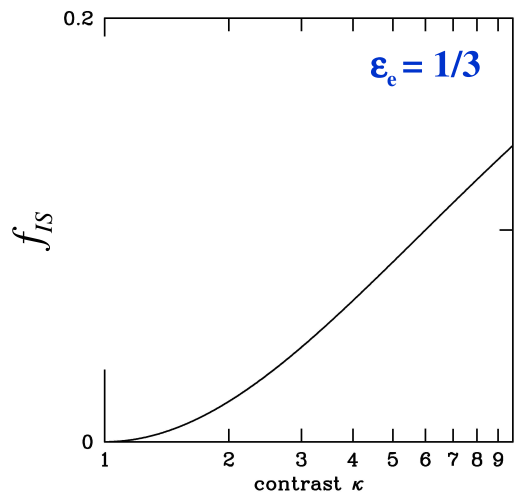
$$f_0 = \frac{E_\gamma}{E_\gamma + E_{fs}^0} = \frac{kf}{(k-1)f+1}$$

with $f = 0.1$ and $k = 10$, $f_0 = 0.53$!

efficiency of internal shocks:

κ: contrast of Lorentz factor distribution

$$f_{IS} = f_{diss}(\kappa) \times \varepsilon_e$$



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

(but see Dyks'talk)

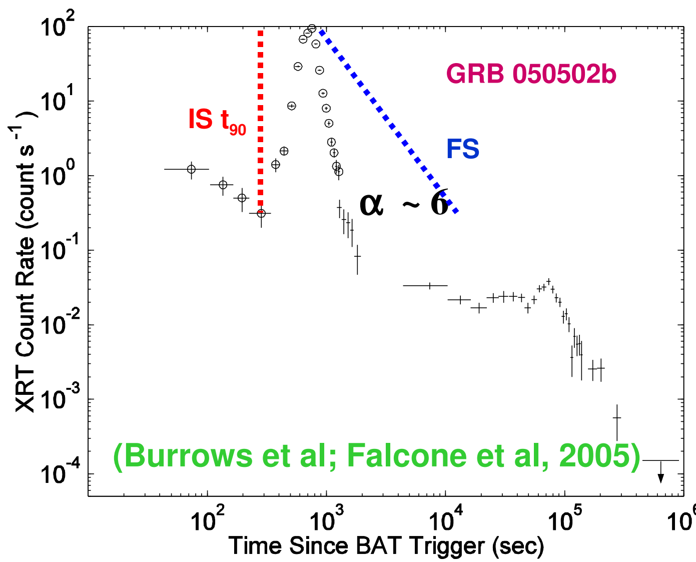
A comment on X-ray flares as late internal shocks

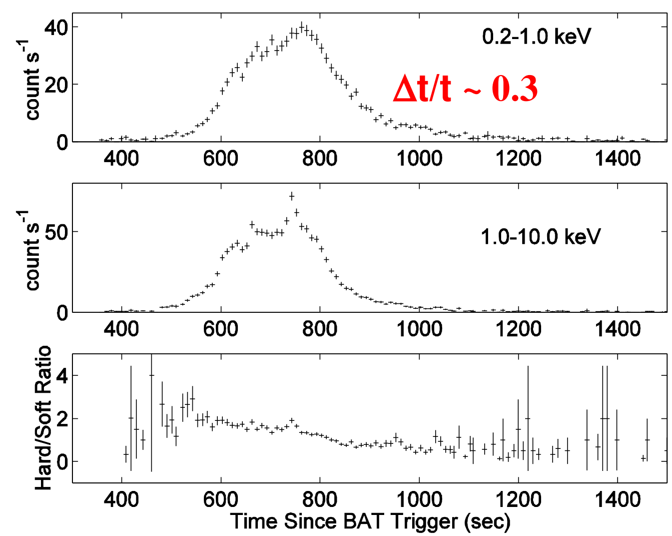
- rise and decay too steep for a forward shock origin

$t_d \propto t^{-\alpha}$ with $\alpha < 3$ for forward shock

- but flare duration long for standard internal shocks

$\Delta t/t \quad 1$





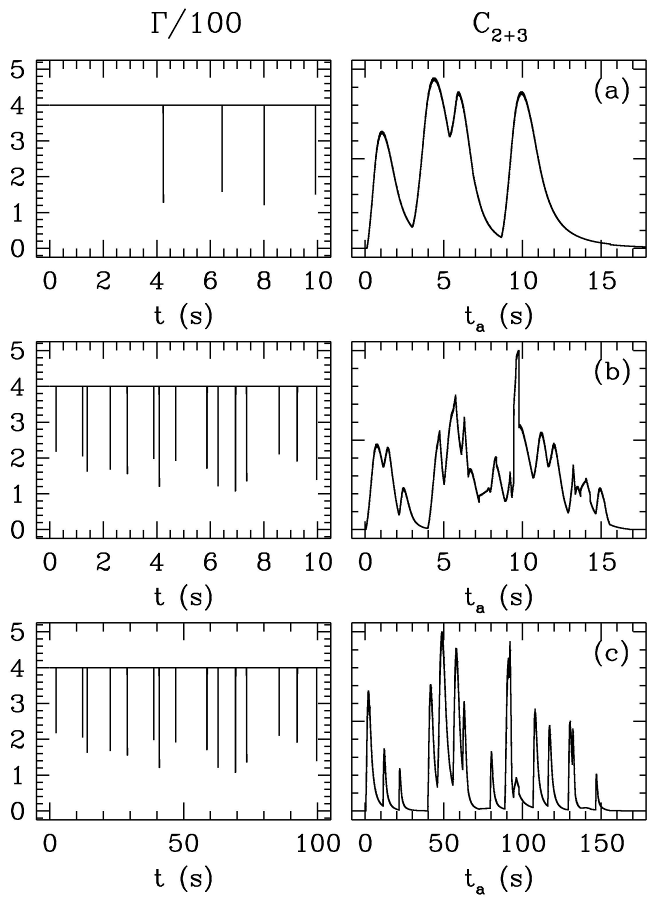
smoother variations of Γ at late times with a longer time scale ?

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 Γ)



(Daigne & Mochkovitch, 1998)

CON

- 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

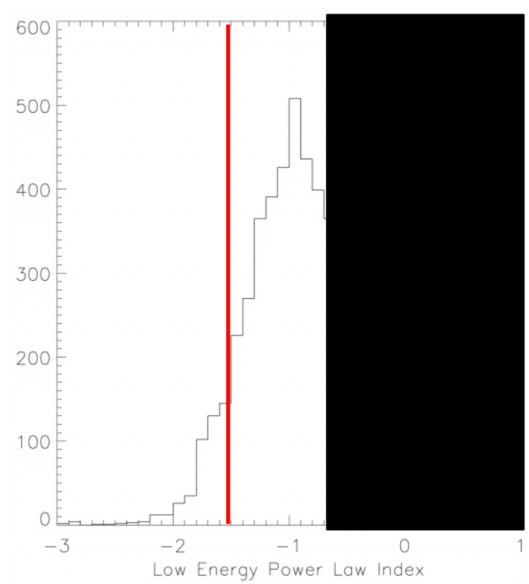
  alternative model: electromagnetic outflow (Lyutikov & Blandford, 2003)

- radiation mechanism ?

  in fast cooling synchrotron predicts a photon low energy index : α = -3/2

  (Ghisellini et al, 2000)

$-3/2$ $-2/3$

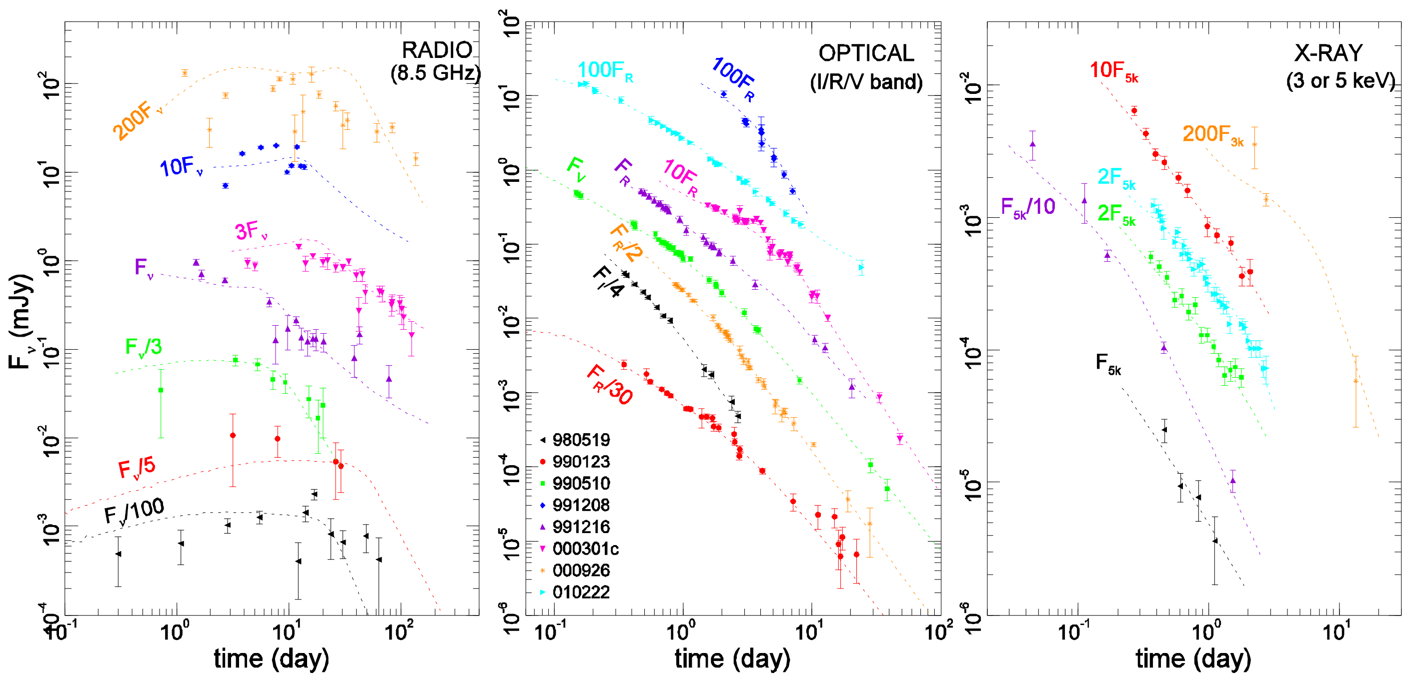


(Preece et al, 2000)

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-λ data

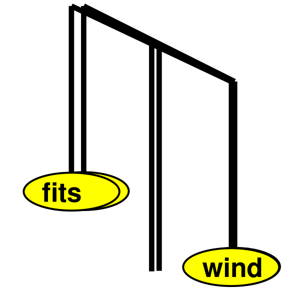


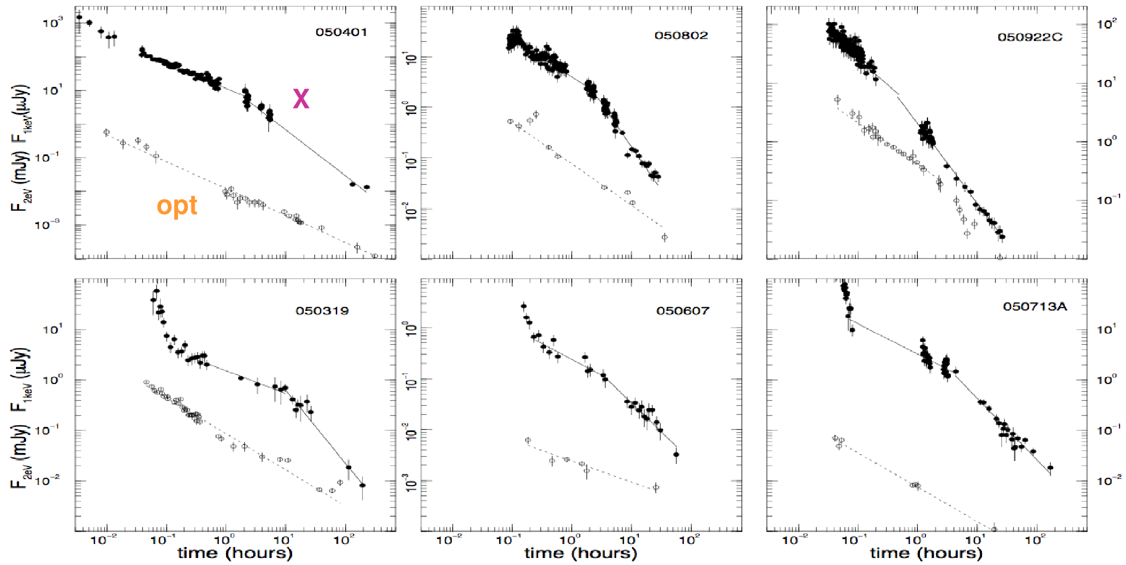
(Panaitescu & Kumar, 2001)

CON

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

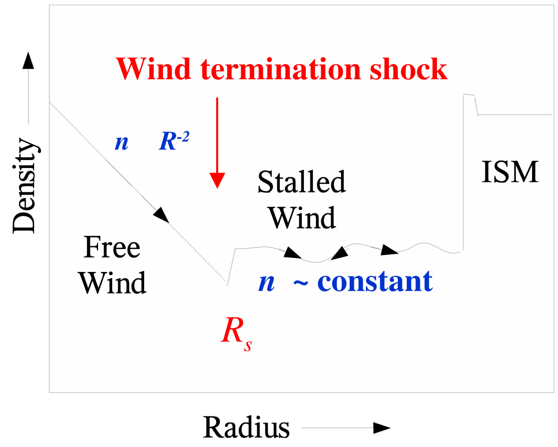




(Panaitescu, 2006)

Solutions ?

1. a uniform medium in a massive star environment ?



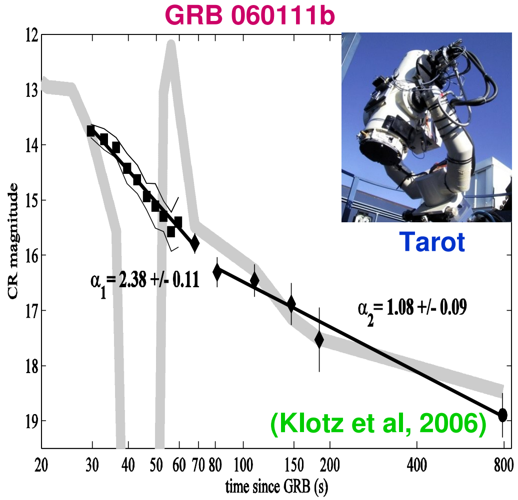
Normally R_s ~ a few pc while $R_s \sim 0.1$ pc would be necessary but not easy to obtain (Eldridge et al, 2006; van Marle et al, 2006)

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

- 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)

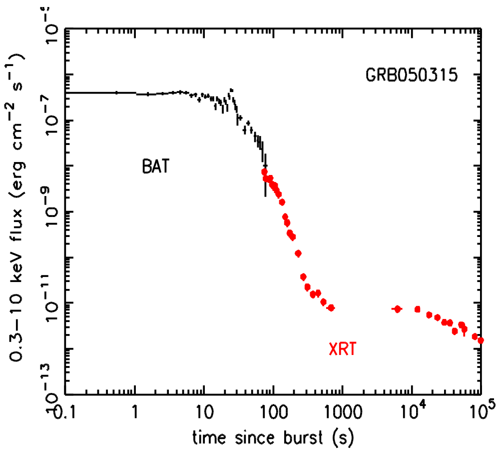
The early X-ray afterglow: a reverse shock contribution ?

Normally, reverse shock contribution :



- is short lived $F(t) \propto t^{-2}$
- 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 Γ 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

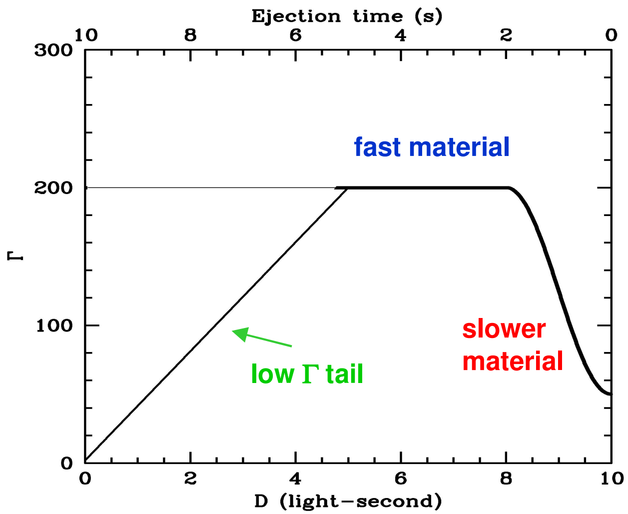
$E_{syn} \propto \zeta^{-2}$ from less than 1 ev to ~ 1 keV

$t_{syn} \propto \zeta$ from slow to fast cooling

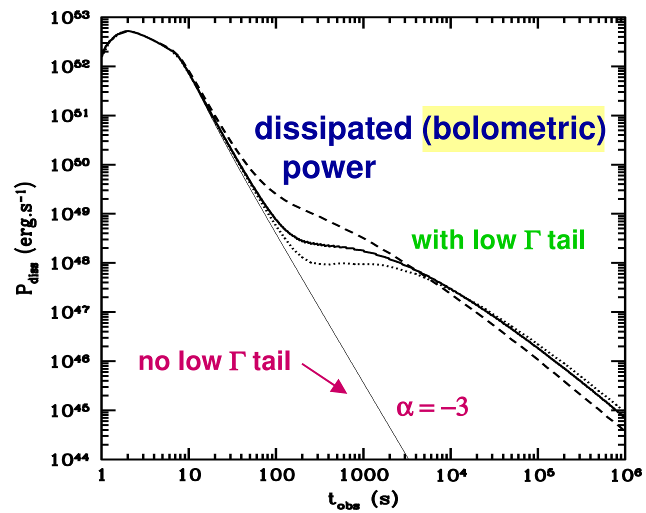
since $\Gamma_e \propto \zeta^{-1}$

One illustrative exemple

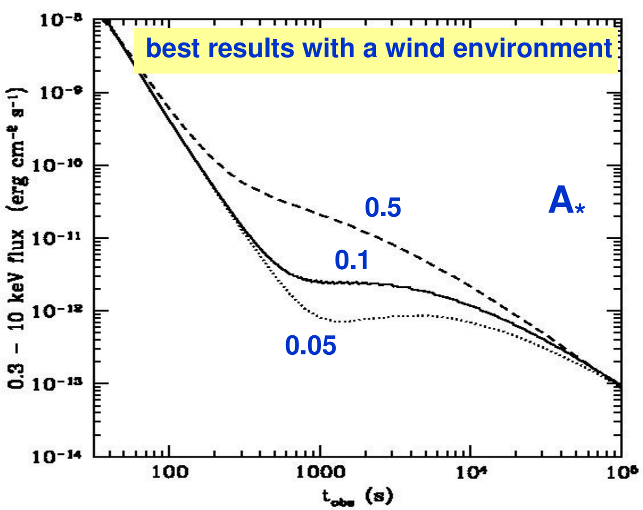
1. extended RS contribution if Γ a few during late stages of source activity



leads to



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 : $\varepsilon_e^{fs} \nearrow$

   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-λ 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 !