The Early Afterglow as a Diagnostic Tool of GRBs’ outflow

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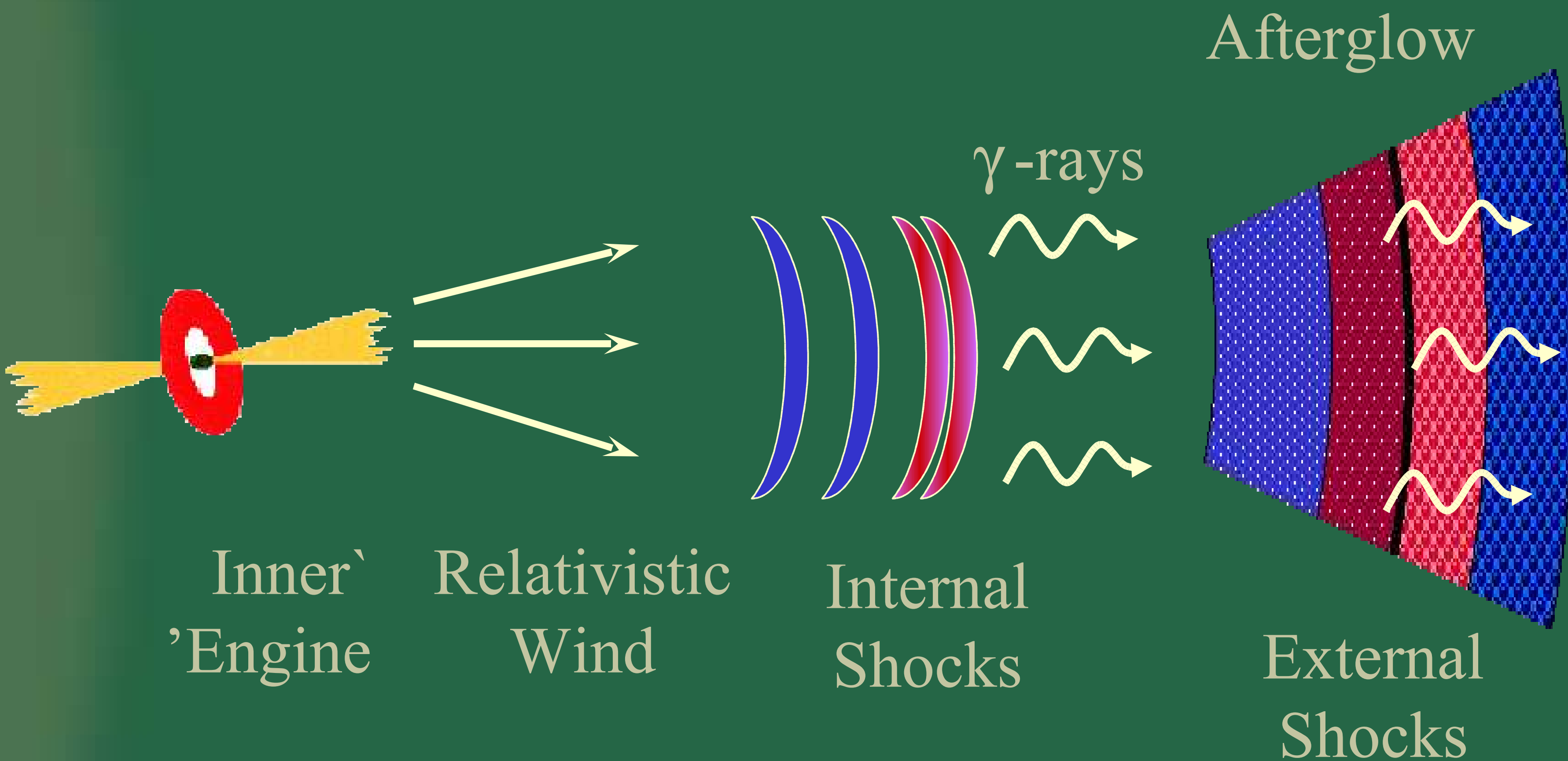
URJA, Banff, 14 July, 2005

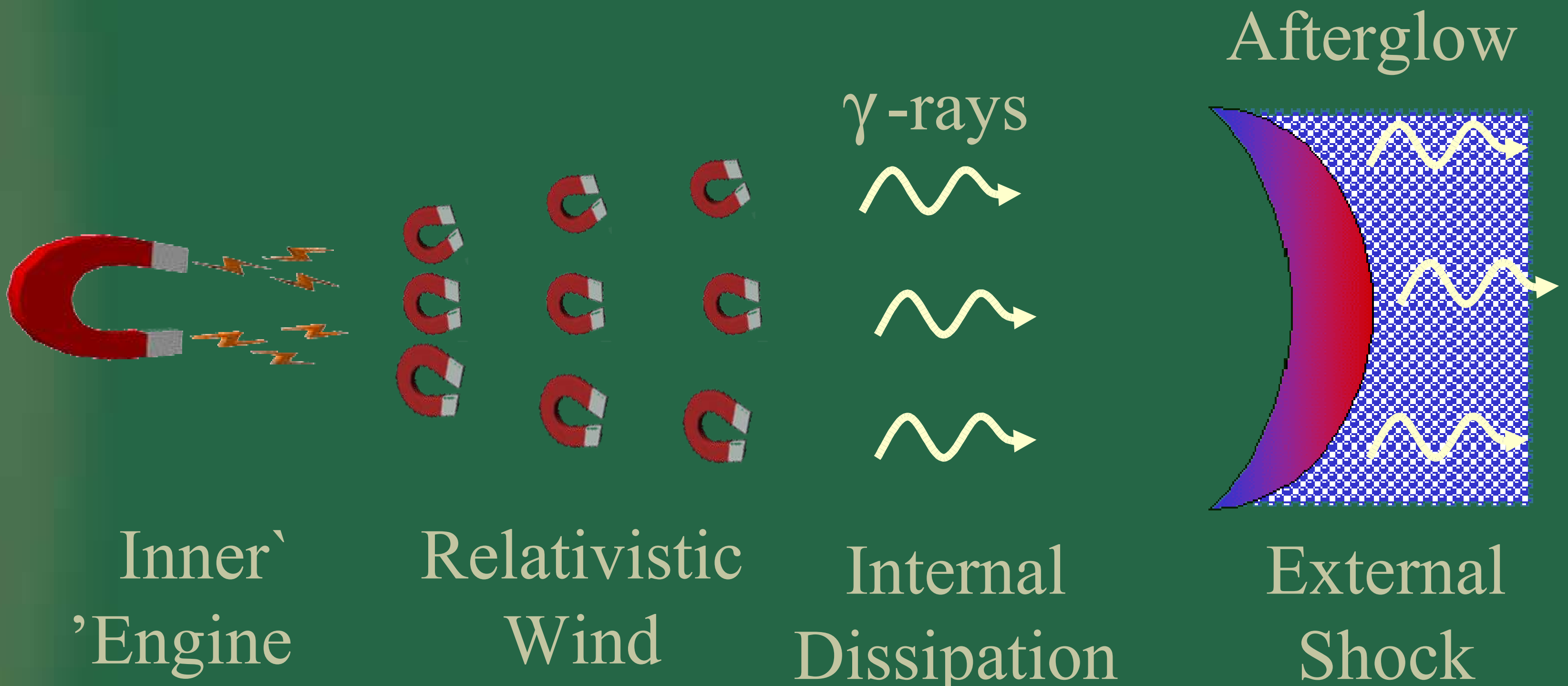
The Internal-External Fireball Model



Baryonic wind

_ _.… ;Goodman 86'; Paczynski 86'; Shemi & Piran 90'; Rees & Meszaros 92,94'; Sari & Piran 96

The Internal-External Fireball Model



Poynting Flux

Thompson 94, Usov 94, Katz 97, Meszaros & Rees 97; Lyutikov & Blandford 02,04; Lyutikov 04

The early afterglow

Observationally

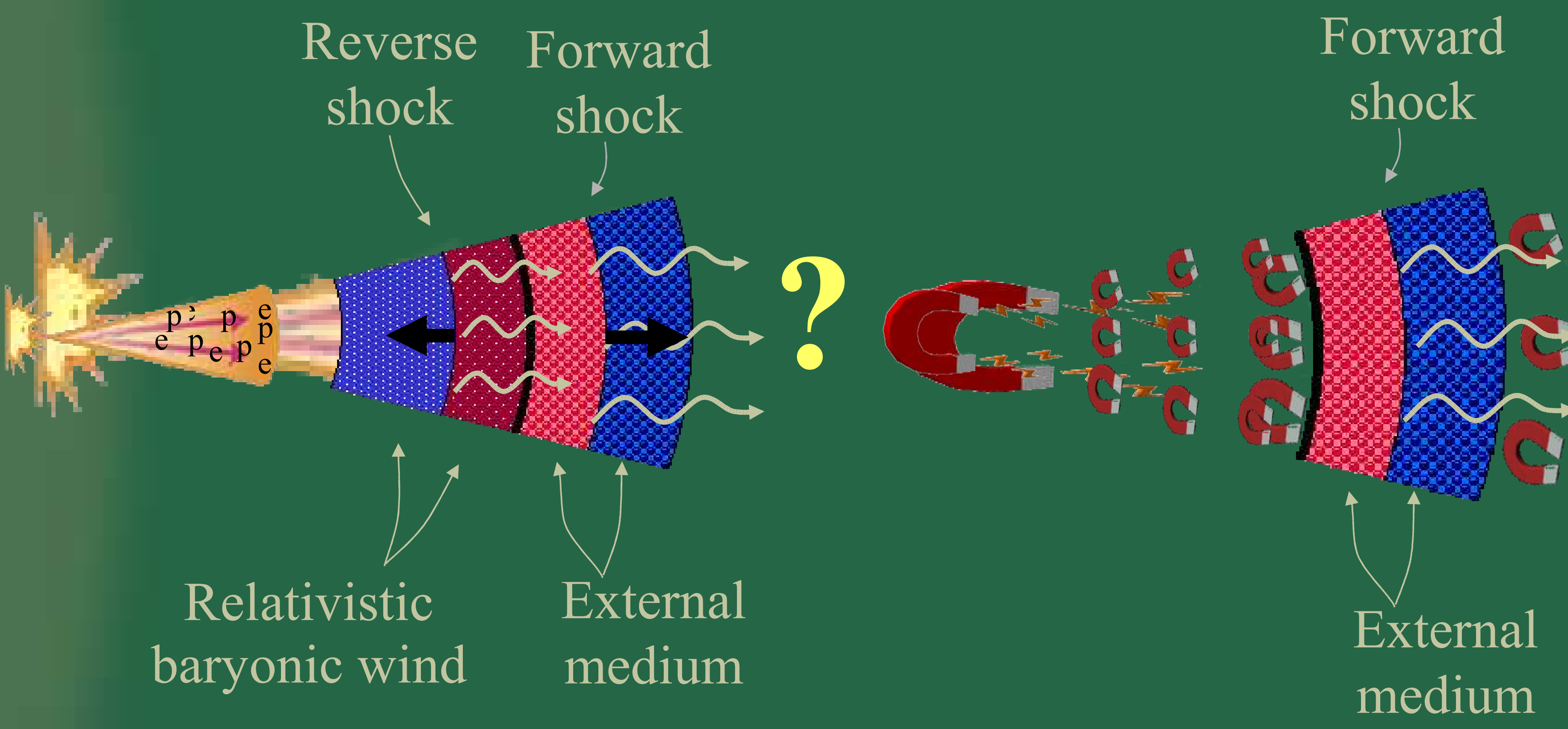
- Optical and x-rays: seconds – minutes
- Radio: hours – a day

Theoretically

A signature of the interaction between the .relativistic wind and the circumburst medium

Why is ?this phase important

?Baryonic flow or Poynting flux •



Theprompt emission should carry asignature of the content as well. However itschaotic nature prevented the identification. so far

- ?Baryonic flow or Poynting flux
- Reveals the structure and the properties (e.g. initial Lorentz factor) of the outflow
- Distinguish between different models of the circumburst medium (interstellar medium or a wind of a (massive star

Outline

A baryonic ejecta interacting with an ISM

Sari & Piran 1999; M´esz´aros & Rees 1997,1999; Kulkarni et al. 1999; Kobayashi 2000; Sari & M´esz´aros 2000; Kobayashi & Sari 2000; Wang et al. 2000; Fan et al. 2002; Soderberg & Ramirez-Ruiz 2003; Kumar & Panaitescu 2003; Zhang, Kobayashi & M´esz´aros 2003; Zhang & Kobayashi 2004; Panaitescu & Kumar 2004; Beloborodov 2004

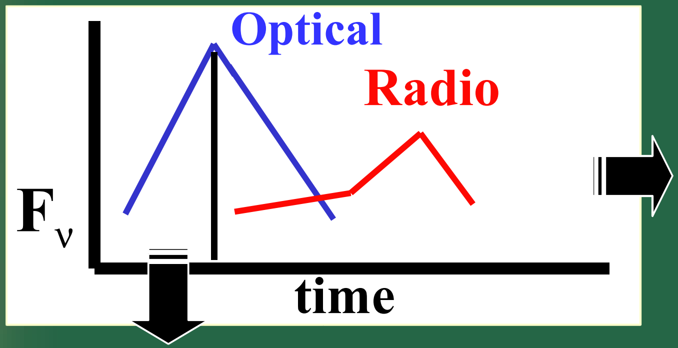
Nakar & Piran, 2004, MNRAS, 353, 647

Nakar & Piran, 2005, ApJL, 619, 147

Outline

A baryonic ejecta interacting with an ISM

- Introduction



A signature of a Reverse Shock Emission

A diagnostic of the initial properties of the ejecta

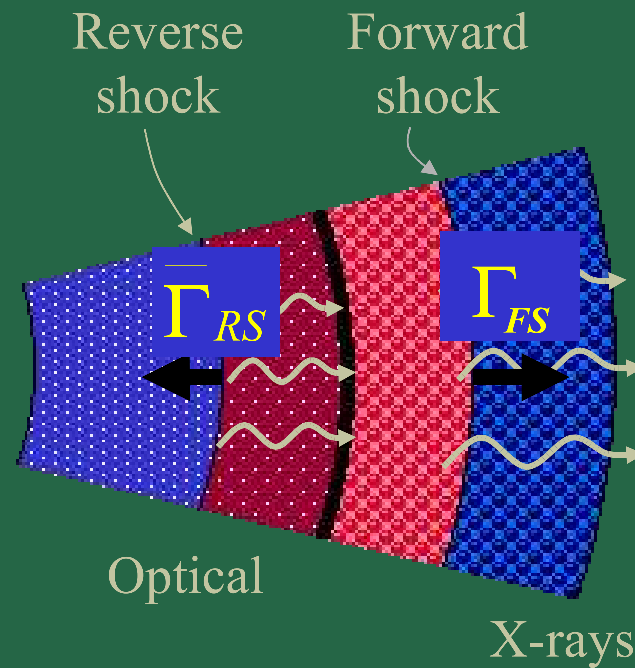
- Internal shocks signature

- Observations

:The synchrotron frequency

$\nu_m \propto \gamma_e^2 B$

$\gamma_e \propto \Gamma_{sh}-1$

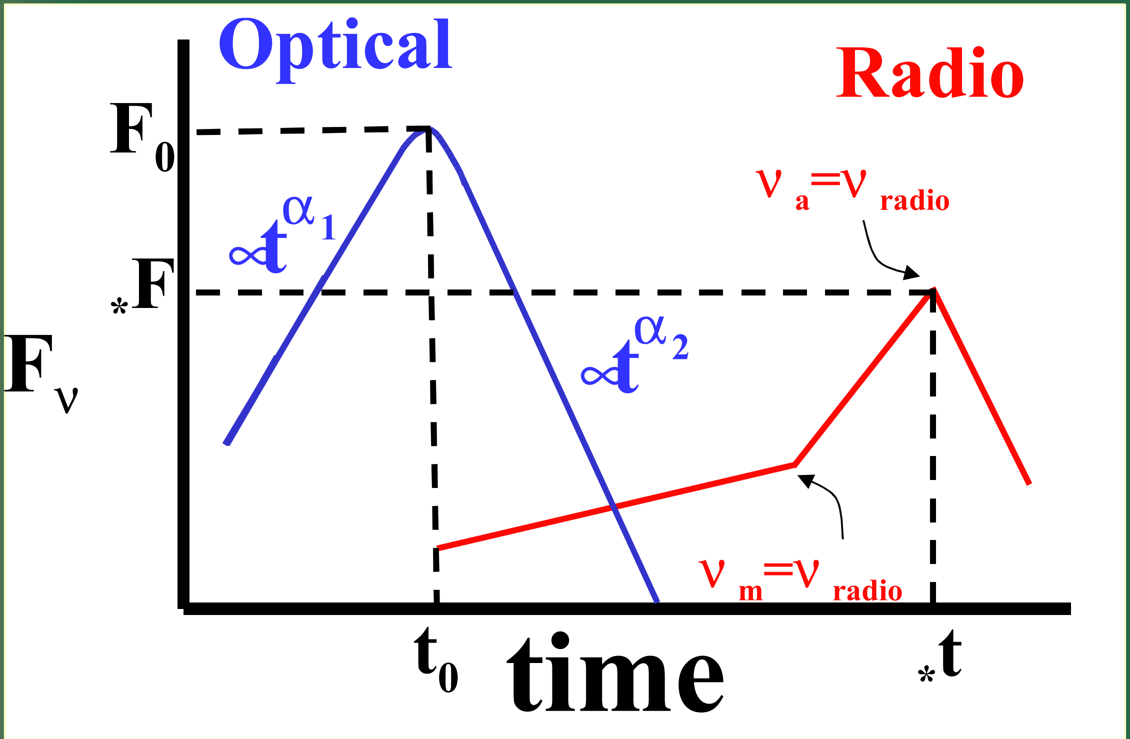


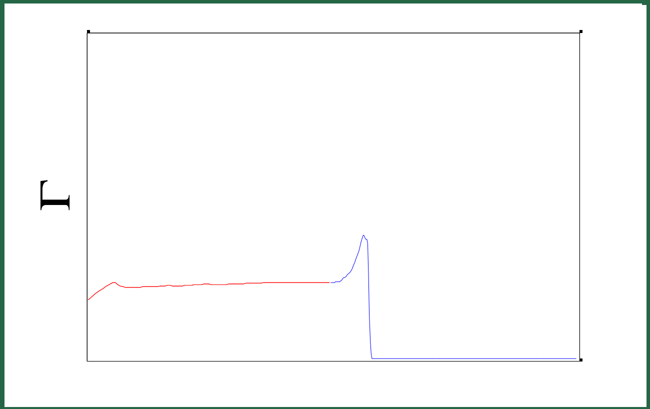
Γ_{RS} -Ultra relativistic ~ 100

$\bar{\Gamma}_{RS}$ Mildly relativistic ~ 1.5 -

The brightness of the optical flash depends

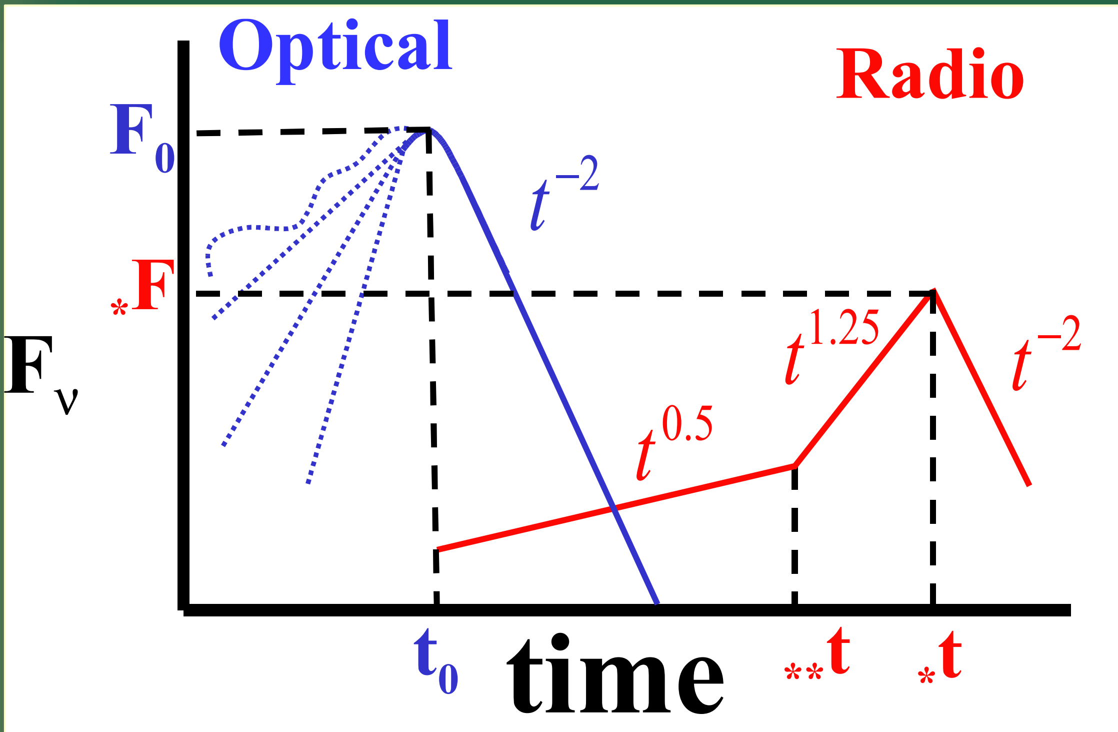
$\bar{\Gamma}_{RS} = \bar{\Gamma}_{RS})E, n, \Delta, \Gamma_0($ **strongly on**





The light curve of the reverse shock alone
((without the contribution of the forward shock

$t > t_0$



$$\nu_a(t_0) \approx \nu_{radio} \frac{t_*}{t_0}$$

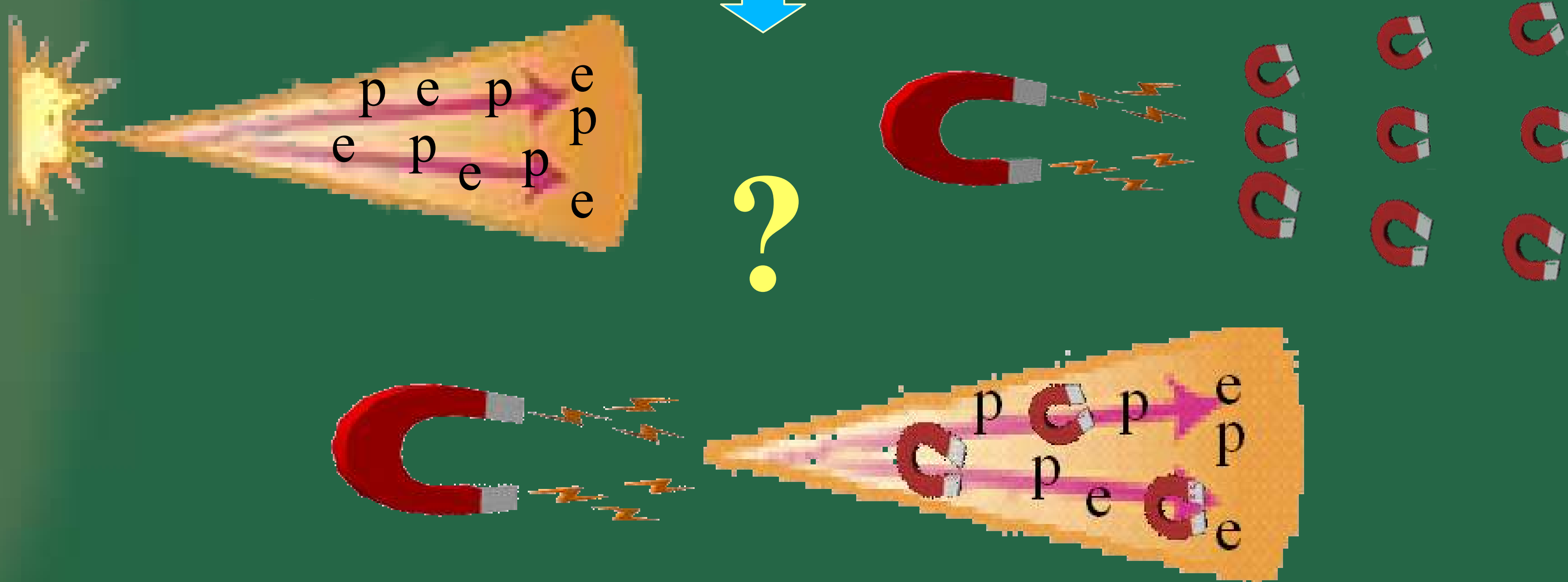
$$\nu_m(t_0) \approx \nu_{radio} \left(\frac{t_{**}}{t_0}\right)^{1.5}$$

The optical and the radio light curves at $t>t_0$ are insensitive to the initial conditions [[Kobayashi & Sari 00

$$\frac{F_*}{F_0}\left(\frac{t_*}{t_0}\right)^{1.3+\frac{p-1}{2}} \approx \left(\frac{\nu_{optical}}{\nu_{radio}}\right)^{\frac{p-1}{2}} = 800 - 4000$$

Early afterglows that pass all these tests

.A Reverse Shock in an ISM



?How bright is the optical flash

$$F_{0,opt} \approx 0.2\ \mathrm{mJy}\ \ R)_{mag} = 18(E_{52}^{1.3} n^{1/2} \left(\frac{t_0}{100\,s}\right)^{-1} \frac{\Gamma_{RS}-1}{0.25} D_{L,28}^{-2}$$

E – isotropic equivalent energy (10^{51}-10^{54}(erg

(n – External density (0.01-10 cm^{-3}

t_0(– Time of the peak (10-500 sec

(Γ_{RS}-1) – 0.05-5

D_L- Luminosity distance

Assuming 10% of the internal energy is in the electrons

and 1% is in the magnetic field and $\nu_a, \nu_m < \nu_{opt} < \nu_c$

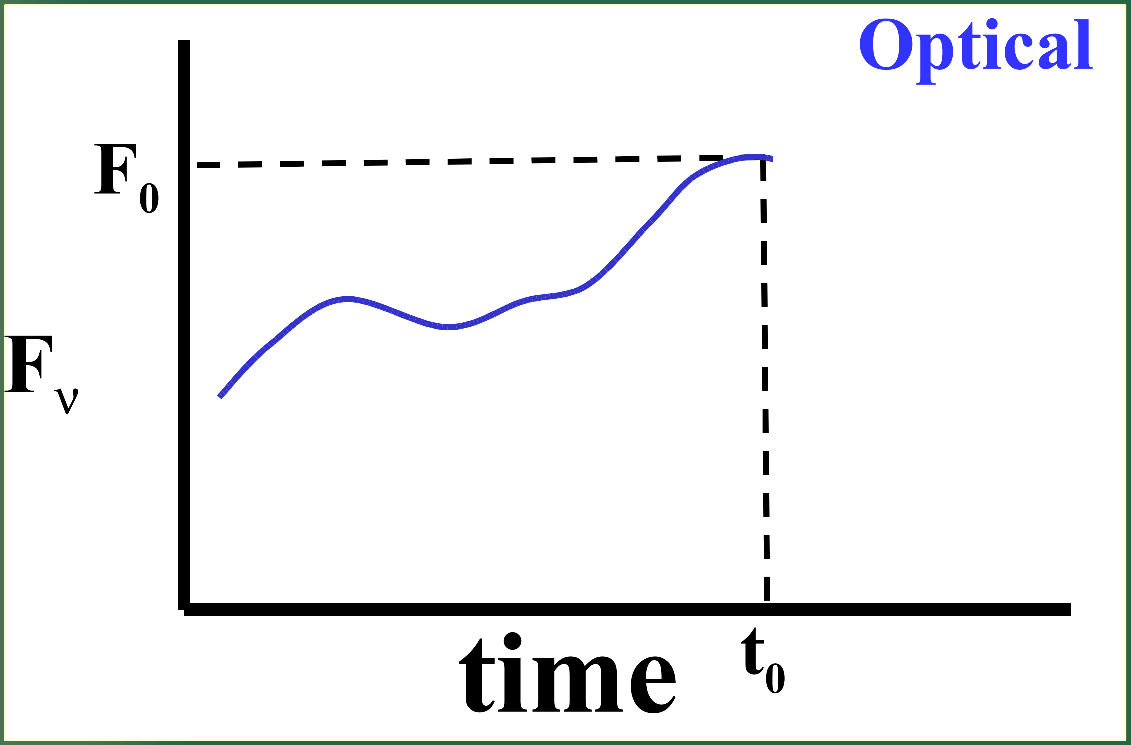
?When is the peak of the optical flash

$$\frac{t_0}{T} \approx 1 + \frac{0.2}{\Gamma_{RS} - 1}$$

T – the duration of the prompt γ -ray burst

- Relativistic reverse shock – no delay
- Newtonian reverse shock – delay of the order of the burst duration

if the burst is short the shell might spread significantly* between the internal and the reverse shocks $t_0 \gg T$



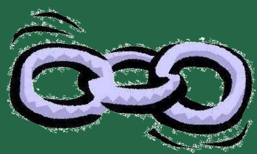
$t < t_0$

An irregular hydrodynamic profile

- **Contains information of the exact profile**
- **A signature of the internal shocks**

Internal shocks + reverse shocks (temporal features)

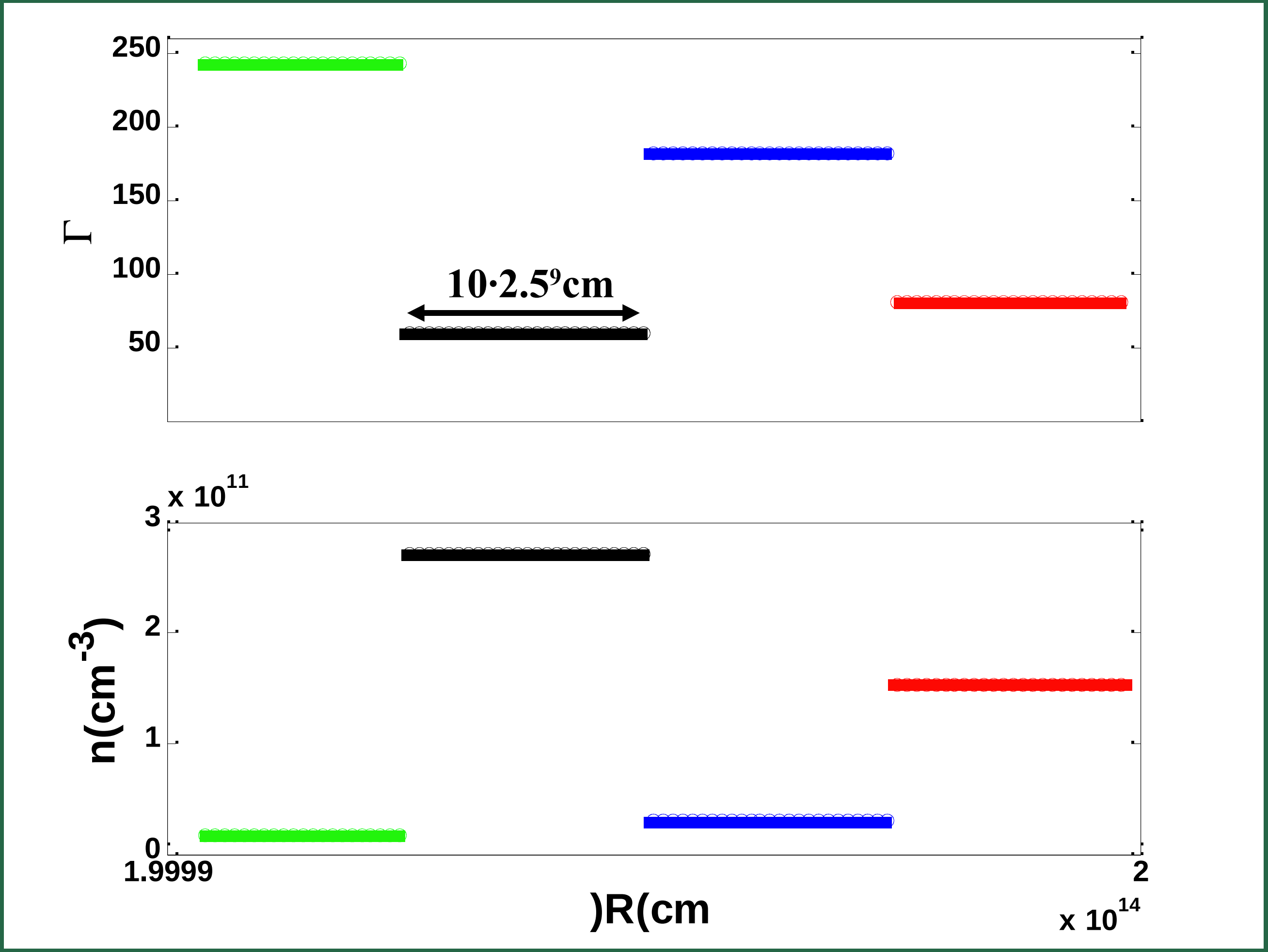
The light curve of internal shocks



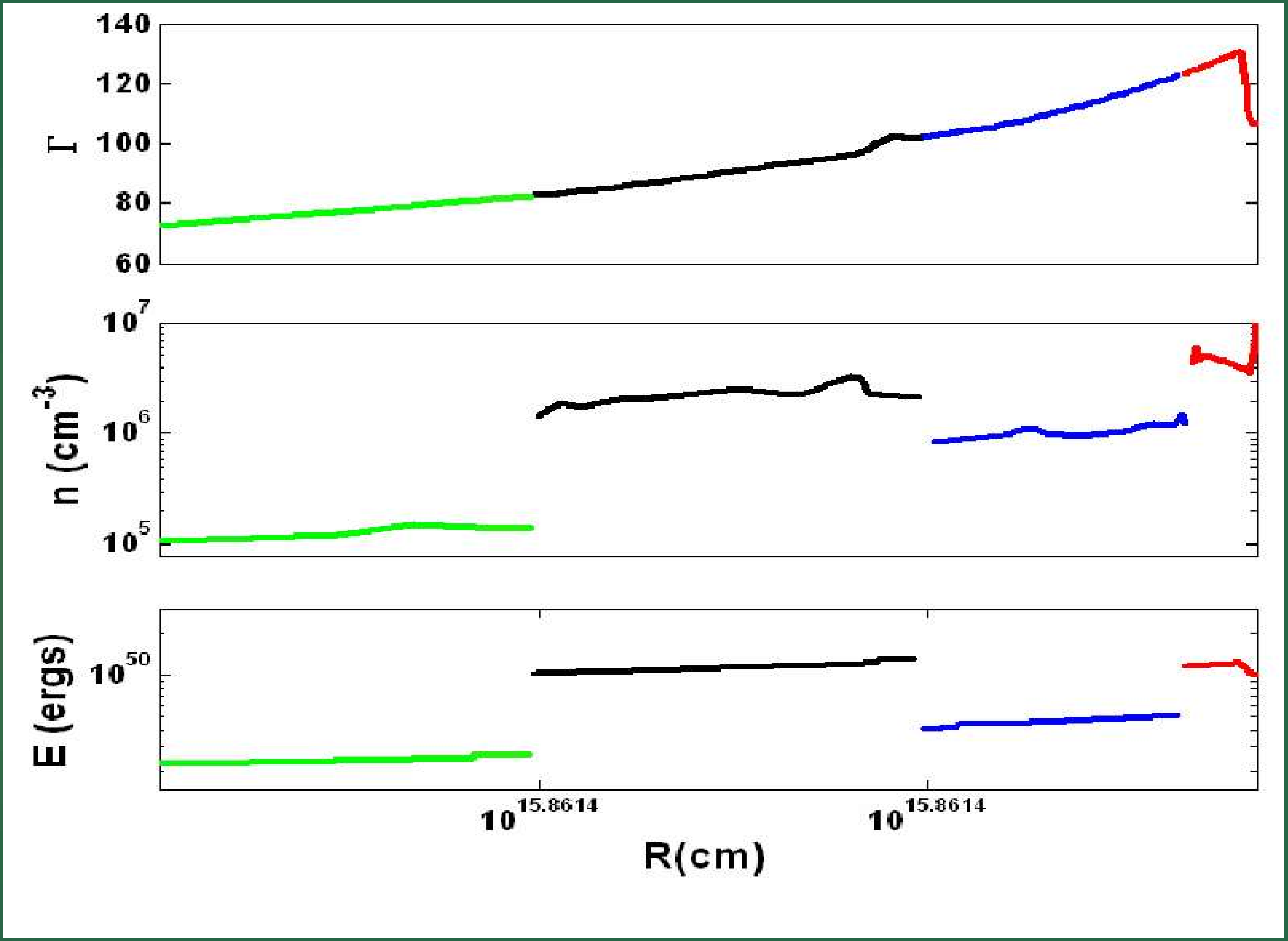
(Optical light curve ($t<t_0$) of reverse shock

Hydrodynamic shocks homogenize Γ and *p* but they do not homogenize *n*

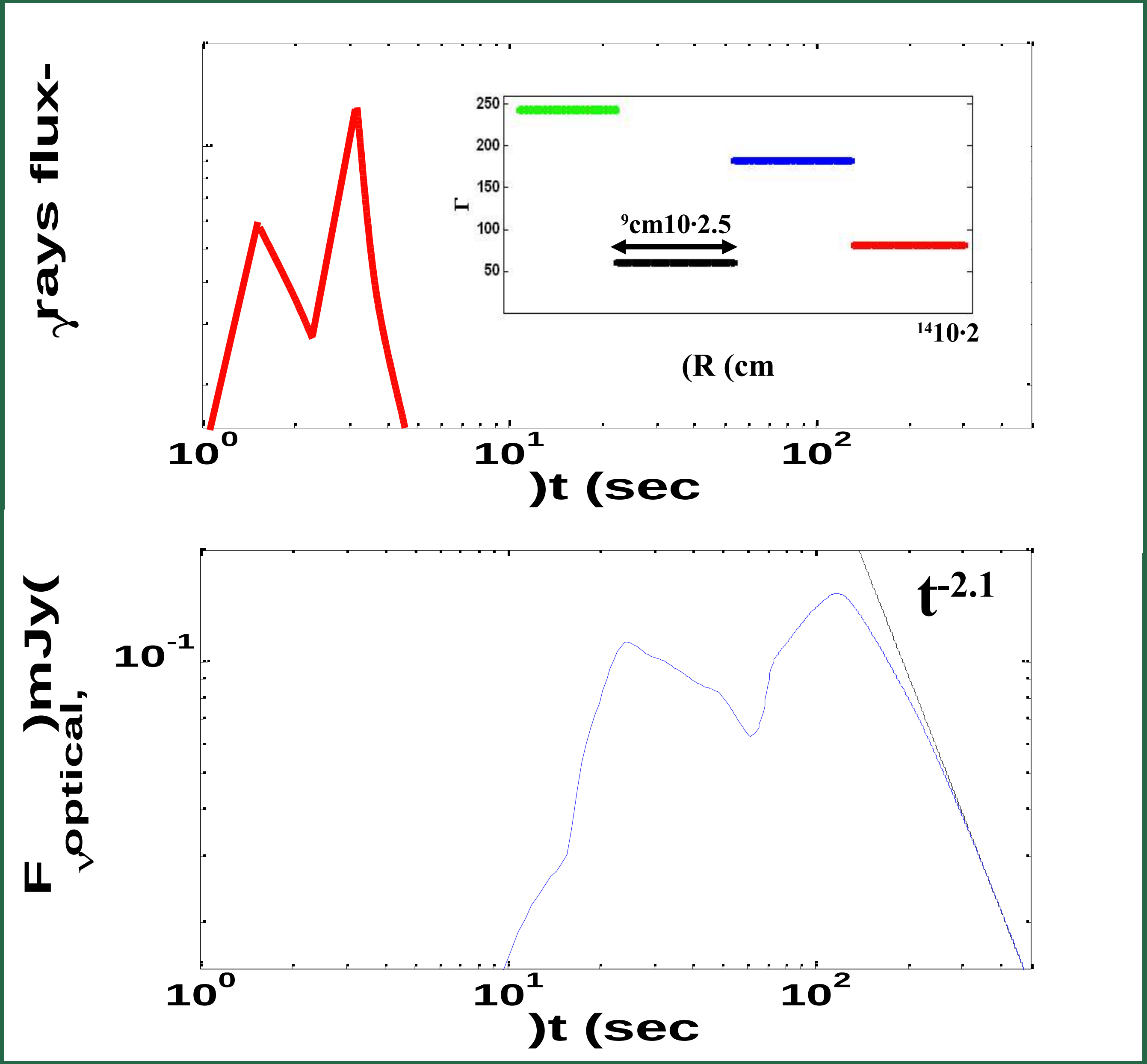
An example



The 1D relativistic hydrodynamic code was given to us generously by **Shiho Kobayashi & Re'em Sari**



Lorentz factor, density and energy profiles at the beginning of the reverse shock



γ rays flux-
250
200
150
100
50
Γ
9cm10·2.5
1410·2
(R (cm
10⁰
10¹
10²
)t (sec
F ν optical,)mJy(
10⁻¹
t-2.1
10⁰
10¹
10²
)t (sec

If the prompt γ-ray emission results from internal :shocks than

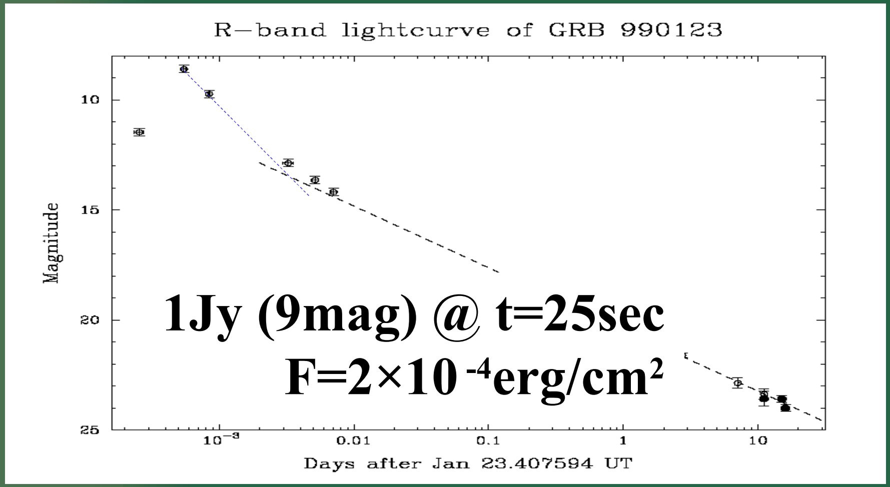
The prompt optical light curve should be a smoothed version of the γ-rays light curve ((maybe, but not necessarily, delayed

Other mechanism that can produce prompt optical emission

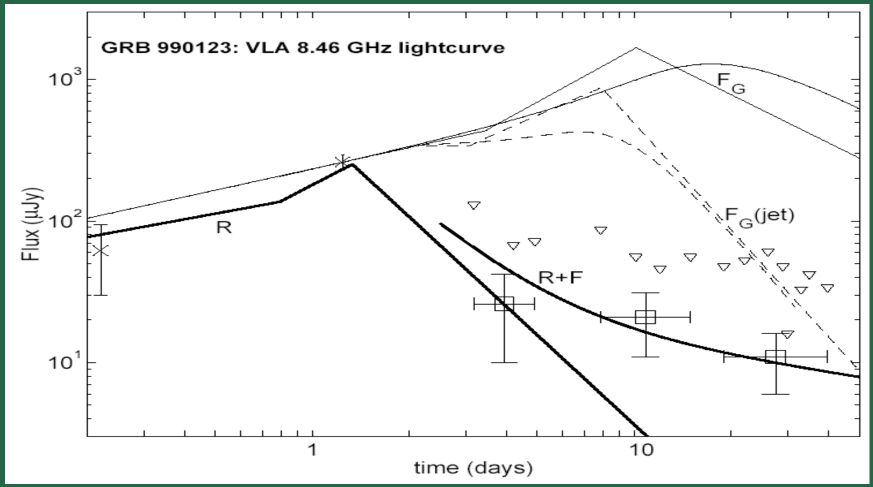
- The same mechanism that produces the γ -rays (Meszaros & Rees 97; Vestrand et al. 05) –Expected to peak, but not necessarily decay with the γ-rays emission (e.g. if $\nu_{opt}<\nu_{c}<\nu_{\gamma}$)
- Pairs enriched forward shock (by interaction of the γ-rays with the circumburst medium; Thompson & Madau 00, (Meszaros et al. 2001, Beloborodov 2002
- The forward shock

None of these is expected to produce an optical decay of t^{-2} !!! or a radio flare

Observations



Optical Flash((Akerlof et al. 99



Radio flare((Kulkarni et al. 99

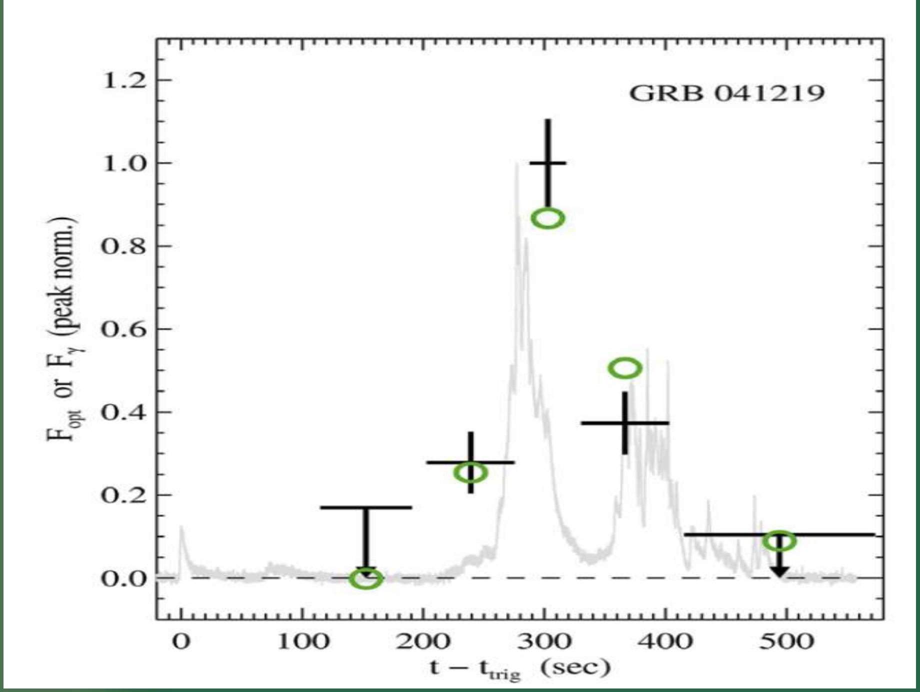
GRB 990123

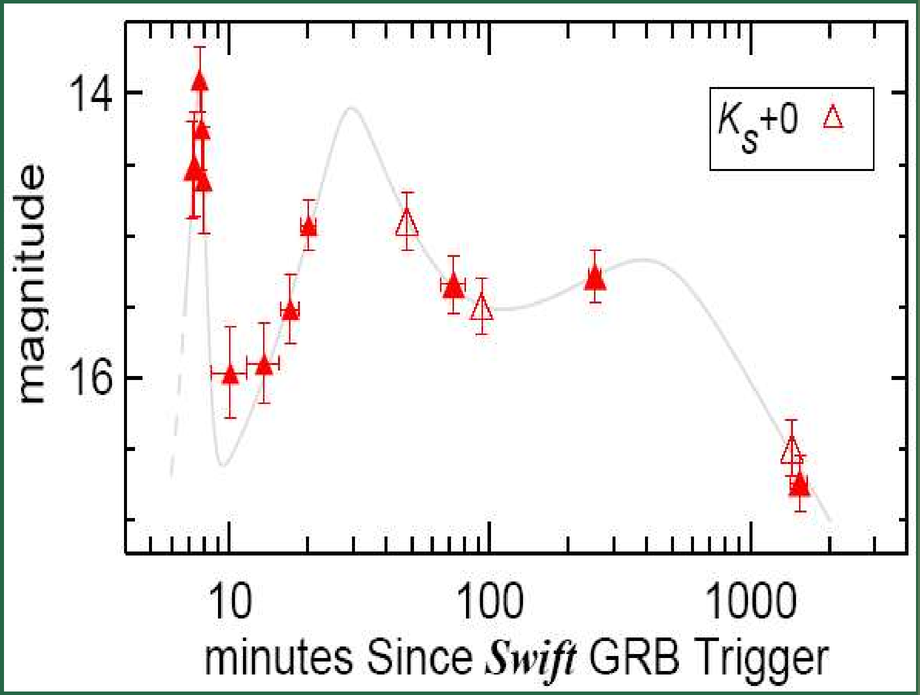
Reverse shock optical flash (decay as t^{-2}) + Radio Flare

(Sari & Piran `99)

$$\frac{F_*}{F_0}\left(\frac{t_*}{t_0}\right)^{1.3+\frac{p-1}{2}} \approx \left(\frac{\nu_{optical}}{\nu_{radio}}\right)^{\frac{p-1}{2}} = 1300 \quad (\text{expected} \quad 800-4000)$$

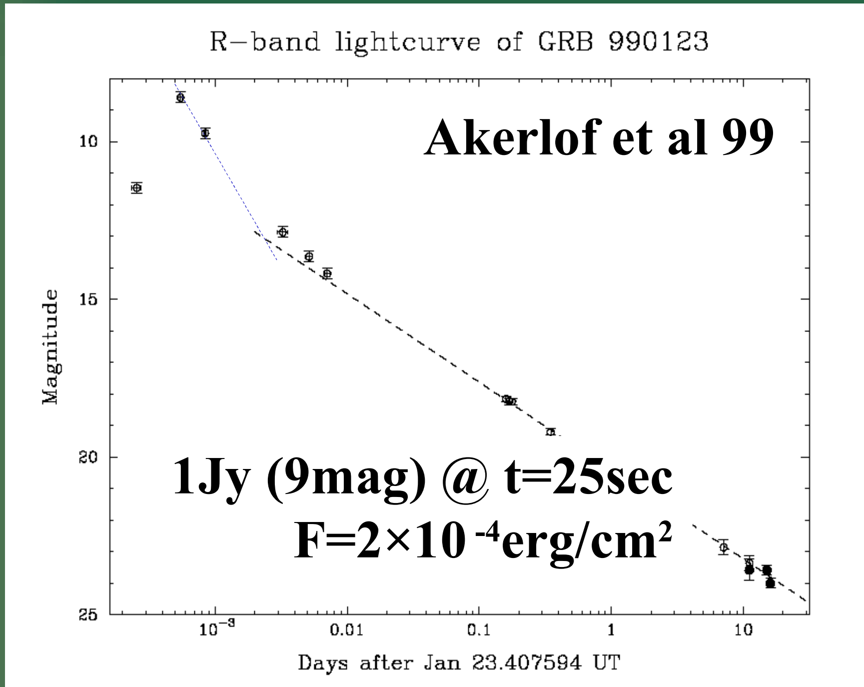
GRB 041219

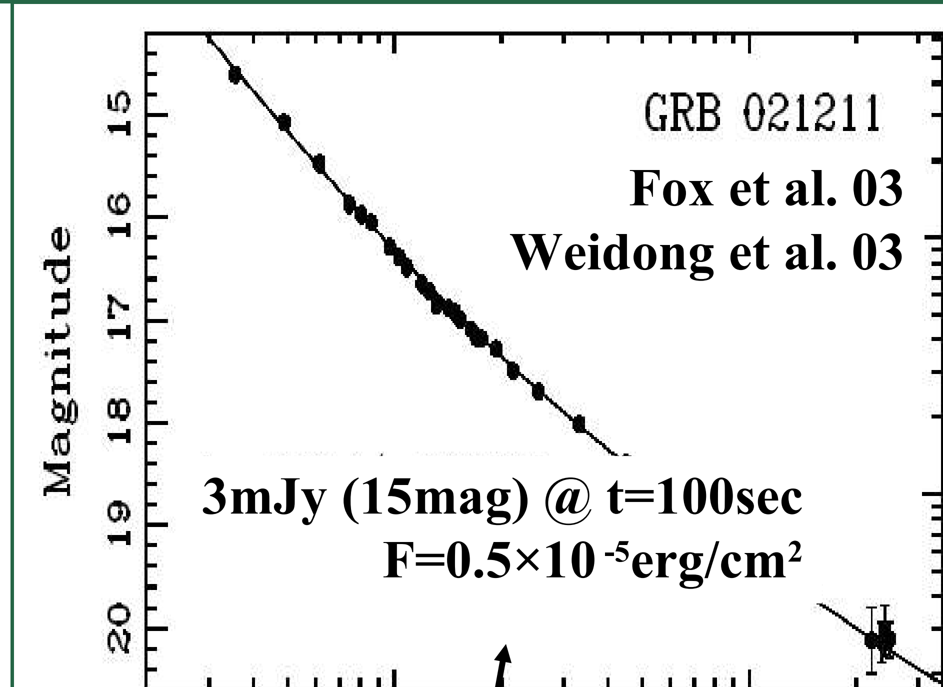


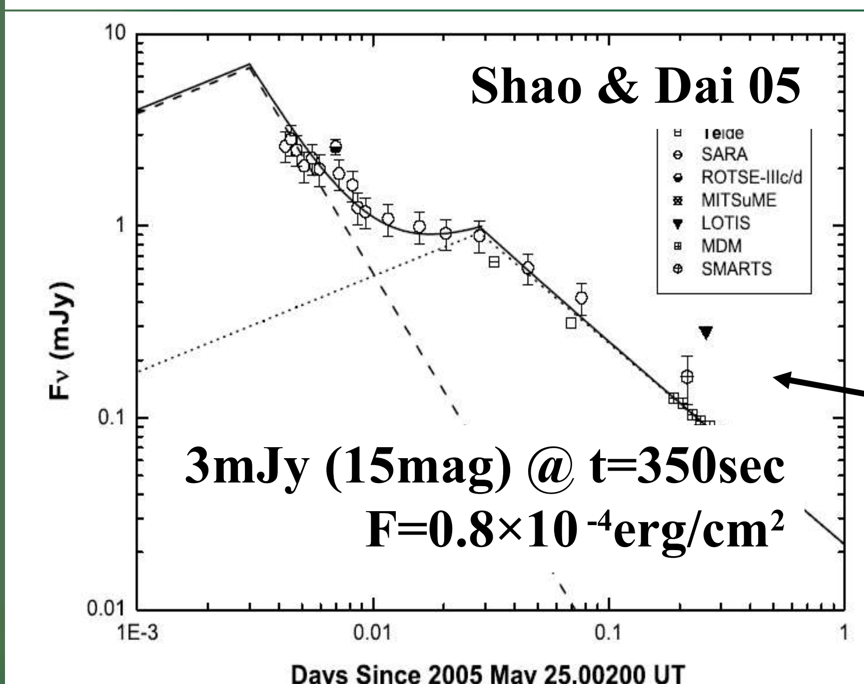


Vestrand et al. 2005

Blake et al. 2005







No radio detection

No early radio observation

Early optical emission ($\propto t^{-2}$) :+ radio flare

- 1 bursts

Early optical emission ($\propto t^{-2}$) -:no radio detection

- 2 bursts

Early radio flare -:no early optical observations

- 2 bursts

Early optical emission that do not decay as t^{-2}

- 4 bursts

Tight upper limits (R>17mag) on any early (t<100sec) :optical emission

- 6 bursts (all are faint; fluence $\leq 10^{-6}$ erg/cm^2)

Why in some cases there is no bright ?early optical emission

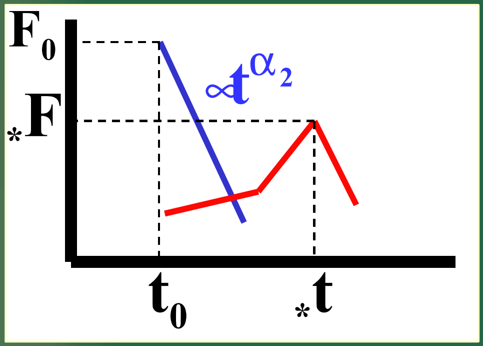
- Highly magnetized jet
- Newtonian reverse shock
- Very dense external density as expected for a wind of a (massive star ($\nu_c << \nu_{opt}$
- Cooling of the reverse shock by IC of the prompt γ-ray GeV-TeV flash Beloborodov 2005))

Why in some cases the bright early optical ?emission do not decay as t^{-2}

- Not a reverse shock (e.g. internal shocks or forward (shock
- (Energy injection (refreshed shocks

Conclusions

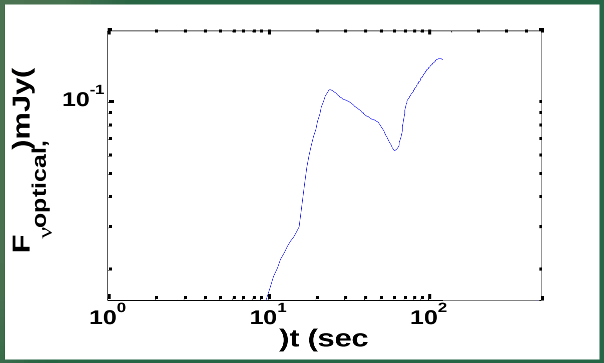
Optical flash decay + radio flare



A distinctive Reverse Shock signature

- Baryonic flow
- ISM like external density

The rising phase of the Optical flash



Reveal the ejecta initial properties

- Internal shocks signature

Current observations at are not conclusive

of the bursts show some 1/3~
signature of reverse shock

of the bursts do not show any 1/3~
bright prompt optical emission (in all
these cases the γ-ray emission is faint
(as well

!Thank you