Shutting down the central engine in photospheric models of gamma-ray bursts

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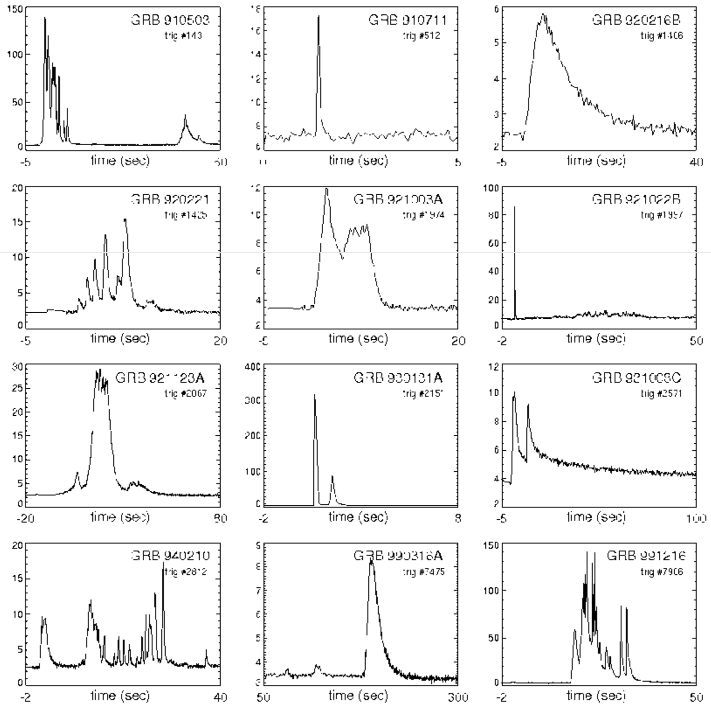
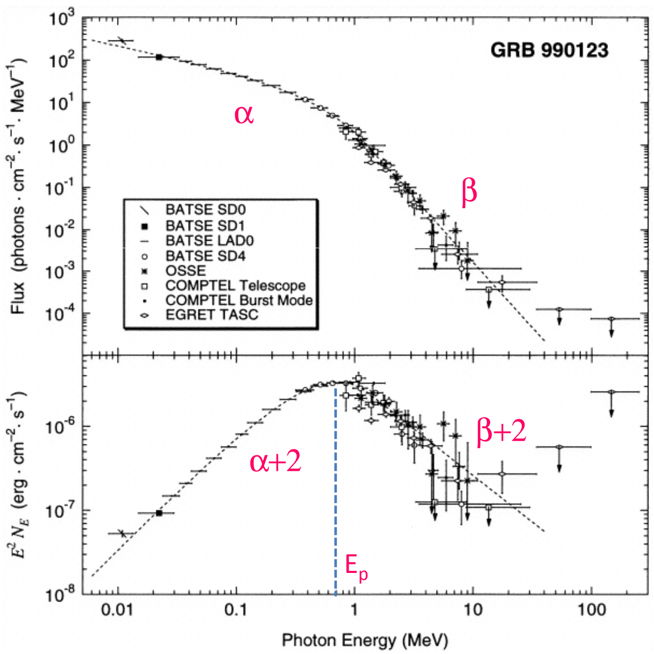
The prompt emission



light curves

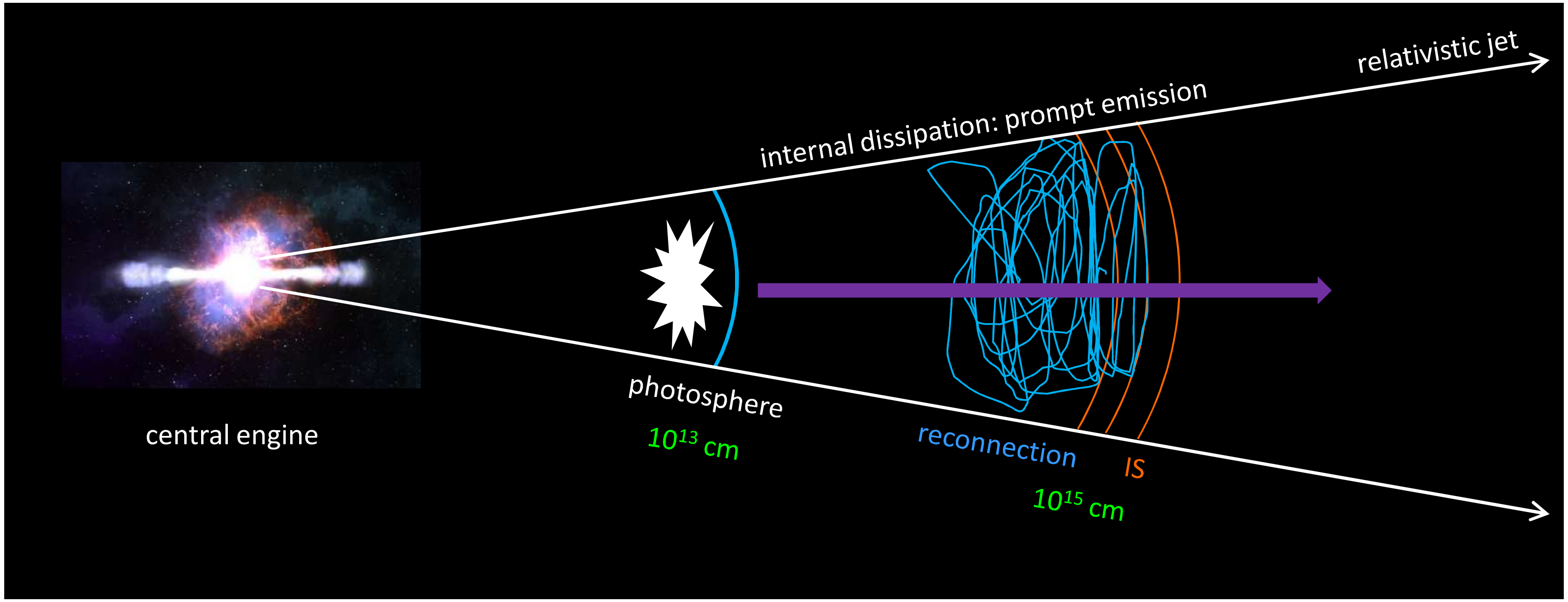
spectra



- duration : 10^{-3} - 10^{3} s
- diversity
- spectrum: broken power-law with $E_p \sim 0.1 - 1$ MeV

The prompt emission results from dissipation in a relativistic jet with $\Gamma > 100$

Three possible sites



Pros and Cons for each site…

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- **internal shocks**

Pros: Many aspects of GRB phenomenology recovered; OK with efficiency issue (Beniamini's talk)

Cons: Spectral shape; synchrotron spectra too broad (talks by van Eerten, Yu, poster by Axelsson)
and too soft $N(E) \propto E^{-3/2}$ in fast cooling regime (improved by IC; Bosnjak & Daigne, 2014)
Shocks suppressed if ejecta is strongly magnetized

- **magnetic reconnection**

Pros: Natural in a magnetized ejecta

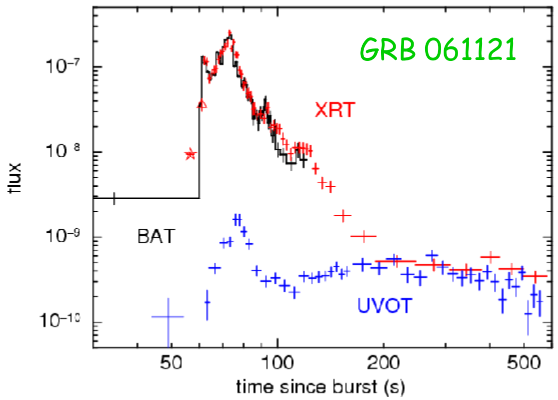
Cons: Phenomenology less explored (but see Beniamini & Granot, 2015 and next talk by O. Bromberg)
Spectral shape (synchrotron + many emitters); continuous acceleration ?

- **dissipative photosphere**

Pros: Better spectra (not synchrotron, flexible)

Cons: Prompt optical emission self-absorbed ?
(Shen & Zhang, 2009)

But what about, e.g. GRB 061121?



Page et al, 2007

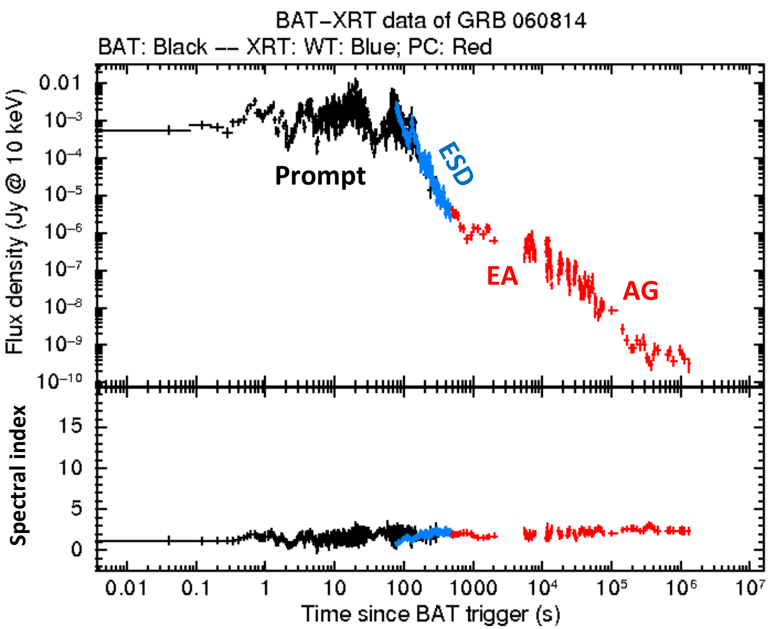
Looking for tests to discriminate among models

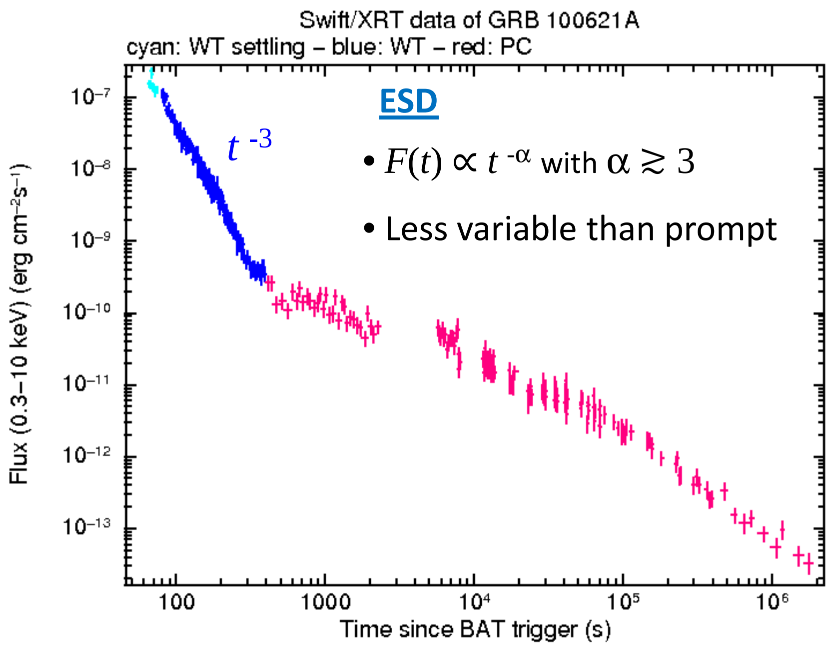
The dissipation radius: $R_{\rm diss}$

- internal shocks: $R_{IS} \approx 2\Gamma^2 c t_{\rm var} \;\rightarrow\; 2\Gamma^2 c t_w \approx 6\,10^{15}\,\Gamma_{2.5}^2 t_w \;\; {\rm cm}$
- reconnection: $\boldsymbol{R_{\rm rec} \lesssim R_{IS}}$ (large range of R possible)
- dissipative photosphere: $R_{photo} \approx \dfrac{\kappa_T\, \dot{E}_K}{4\pi\, c^3 \Gamma^3} f_{\pm} \approx 4\,10^{12} \dfrac{\dot{E}_{53}}{\Gamma_{2.5}^3} f_{\pm} \;\; {\rm cm} \;\; << \;\; R_{IS}$

$\rightarrow$ Observational constraints on $R_{\rm diss}$

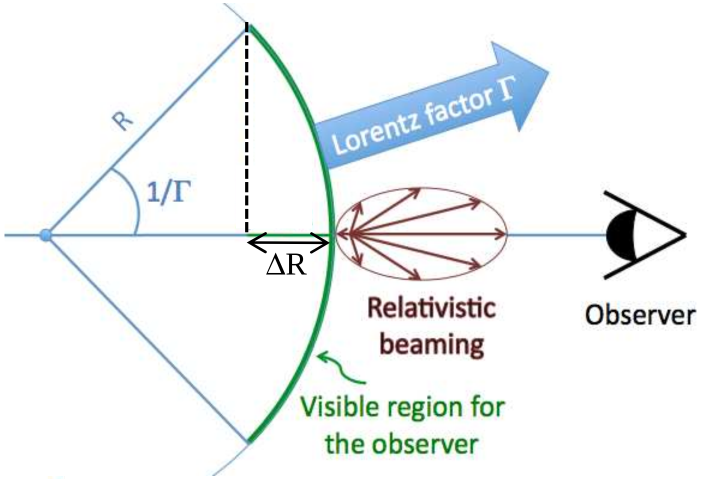
The "**early steep decay**" (ESD)





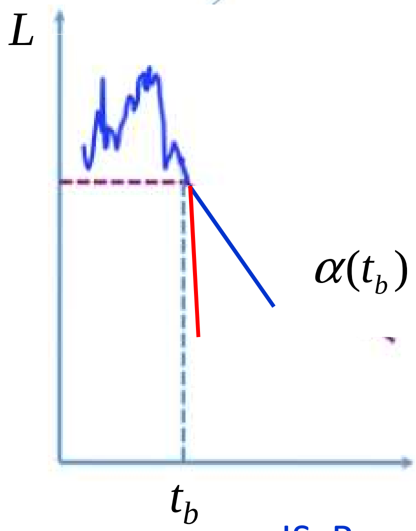
A simple geometrical interpretation for the early steep decay

"high latitude emission" of the last flashing shell (Kumar & Panaitescu, 2000)



$$L(t) \sim \frac{1}{\left(1+\frac{t-t_b}{\Delta t}\right)^3}$$

$$\Delta t = \frac{\Delta R}{c} = \frac{R}{2c\Gamma^2}$$



$$\alpha(t_b) = \left.\frac{d\mathrm{Log}L}{d\mathrm{Log}t}\right|_{t_b} = -3\frac{t_b}{\Delta t}$$

IS, Reconnection (?) : large emission radius → $\Delta t \sim t_b$ → $\alpha \sim -3$

Photospheric models : small emission radius → $\Delta t << t_b$ → much steeper decline

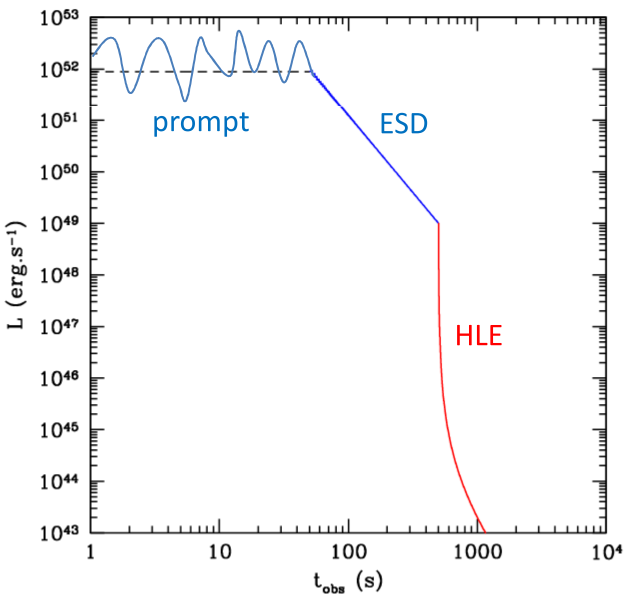
→ **the geometrical interpretation does not work for photospheric models**

→ abandon photospheric models ? **Or…**

The early steep decay: an effective behavior of the central engine ?

Is it possible ? What does it tell us about the source extinction ?

- Observed behavior: $L \propto \left(\frac{t}{t_0}\right)^{-3}$, $E_p \propto L^{\alpha}$ with $\alpha \sim 1/3$
- Define $\varepsilon_{rad} = \left(\frac{L}{\dot{E}}\right)$ radiative efficiency of subphotospheric heating ($\dot{E}$ injected power in jet)
- Compute the evolution of Γ and R_{ph} that reproduce the observed behavior



$$R_{ph} \approx 5\,10^{13}\,\varepsilon_{rad}^{-2/5} L_{52}^{1/10}\ \text{cm}$$

$$\Gamma \approx 65\,\varepsilon_{rad}^{-1/5} L_{52}^{3/10}$$

Reasonable evolution:
as L decreases by a factor 1000
R_{ph} decreases by 2 and Γ by 10

Some questions and one interesting feature

- Questions

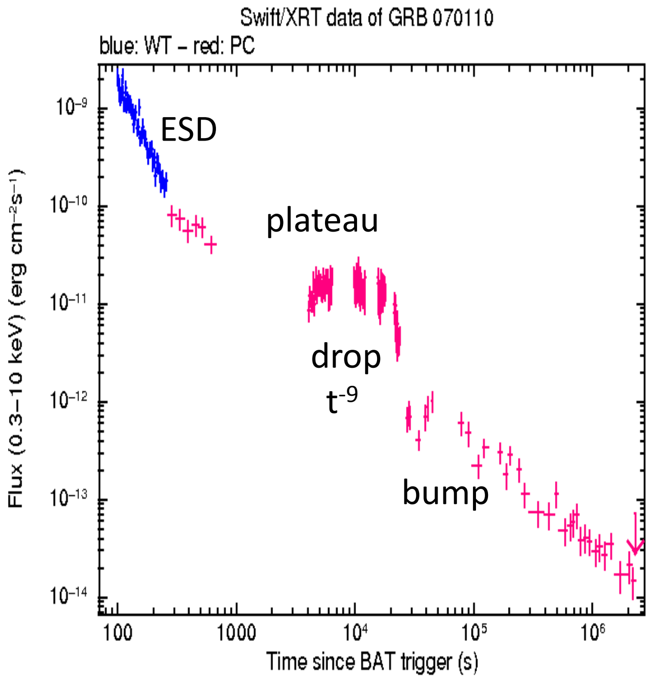
  (i) which sub-photospheric dissipation process ? ($\varepsilon_{rad} \sim 0.1 - 1$)

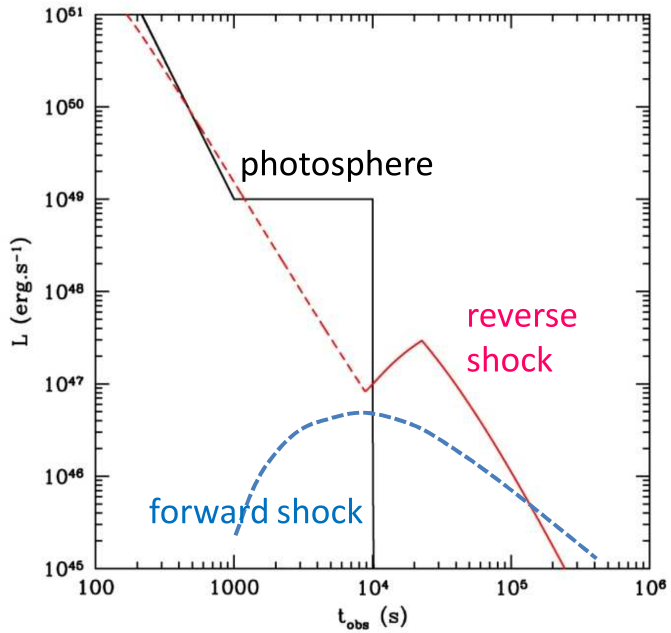
  (should operate over a large range of luminosity)

  (ii) why is the ESD more regular than the prompt phase ?

  (why such a diversity of prompt light curves and a generic behavior for the ESD ?)

- Photospheric models easily produce "Internal Plateaus"





Summary

- in photospheric models the simple geometric interpretation for the ESD does not work

  (if you like the geometric interpretation → (probably) forget about photospheric emission)

- the ESD must correspond to an effective behavior of the central engine

  possible → provides information on how the source shuts down

  but some difficult questions: dissipation process, variability

- search for tests of models is important and can provide guidelines to build new scenarios