Signatures of particle acceleration on GRB afterglow light curves

Petropoulou Maria[1]

in collaboration with A. Mastichiadis[1] and T. Piran[2]

1: National and Kapodistrian University of Athens

2: Hebrew University of Jerusalem

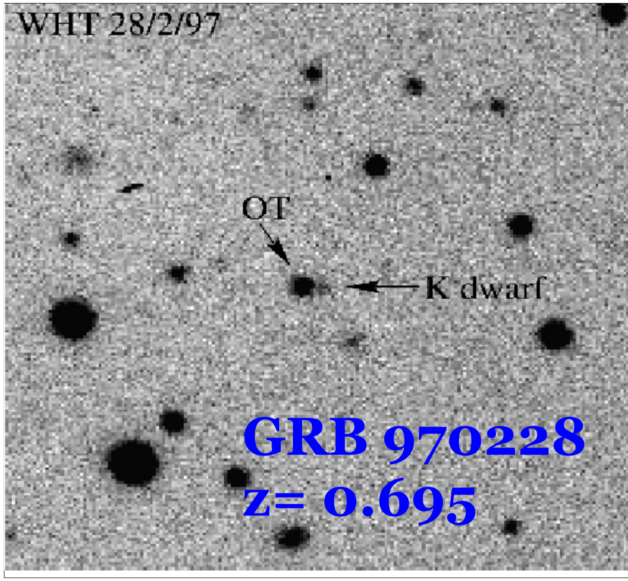
Ioannina, 5 - 8 September 2011

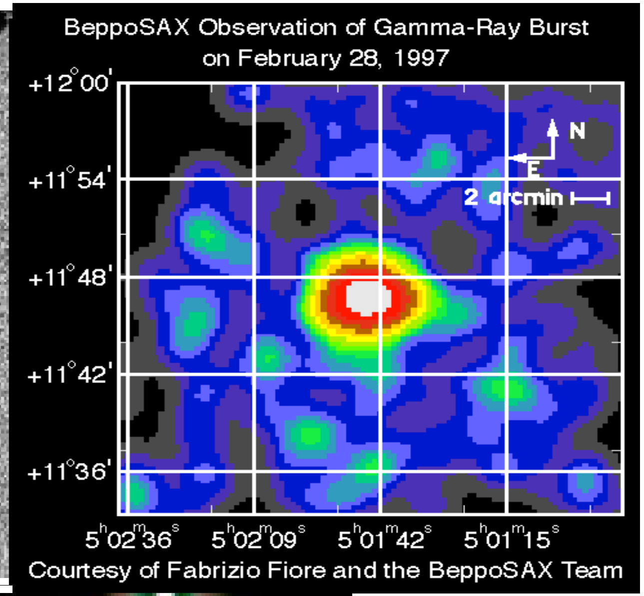
European Union
European Social Fund
OPERATIONAL PROGRAMME
EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION, LIFELONG LEARNING AND RELIGIOUS AFFAIRS
MANAGING AUTHORITY
Co- financed by Greece and the European Union
NSRF 2007-2013
programme for development
EUROPEAN SOCIAL FUND

Outline of the talk

- What is a GRB afterglow ? – some related observations
- "Standard model" for GRB afterglows.
- Maximum electron energy (γ_{max}) and its effects on afterglow lightcurves.
- Two cases are being examined:
    - γ_{max} is a free parameter
    - γ_{max} is determined by continuous acceleration and energy losses of relavistic electrons

GRB afterglows



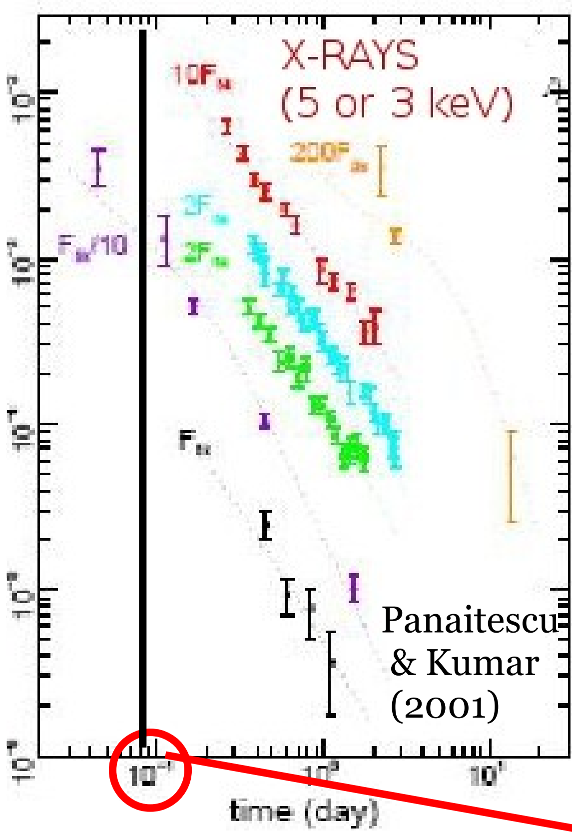


Q: What is GRB afterglow?

A: Long lasting, broad band emission detected after the end of the "prompt" emission.

Light curves of GRB afterglows- observations

Pre -*Swift* era (<2004)

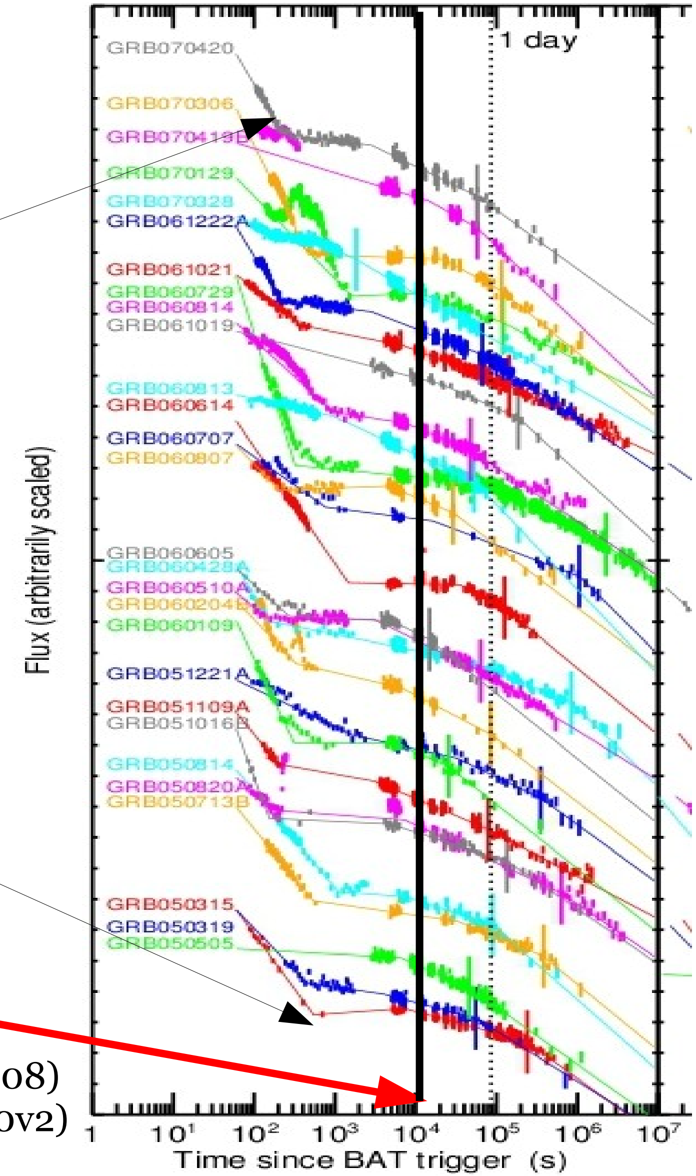


~ 9000s

observations well-interpreted within the "standard model" for GRBs.

Early-time flux measurements are available with XRT and are not easily explained within the "standard model".

Post- *Swift* era (>2004)



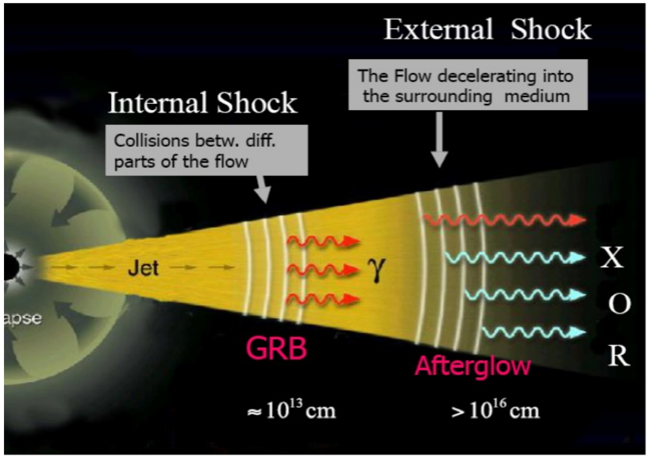
Racusin et al. (2008)
(arXiv: 0812.4780v2)

"Standard model" of GRB afterglows

Paczynski & Rhoads (1993); Meszaros & Rees (1997) ; Piran (1999)

- Relativistic analogue of a supernova remnant evolution

Relativistic Blast Wave (RBW) propagates into the circumburst medium
(ISM or stellar wind-type medium)



- Physical Processes related to the RBW

• Interaction with the circumburst medium ⟶ hydrodynamic evolution

• Non-thermal radiation from high energy particles

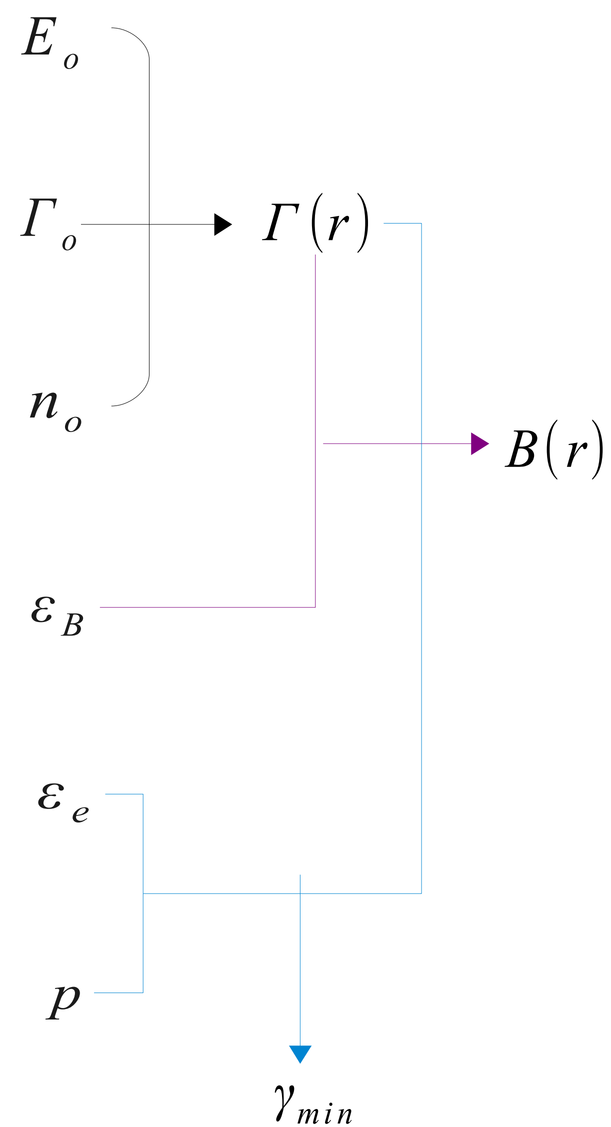
i) Magnetic fields (generation & amplification) $U_B = \varepsilon_B U$

ii) Particle acceleration $U_e = \varepsilon_e U$

Incorporate all the details of the physical mechanisms

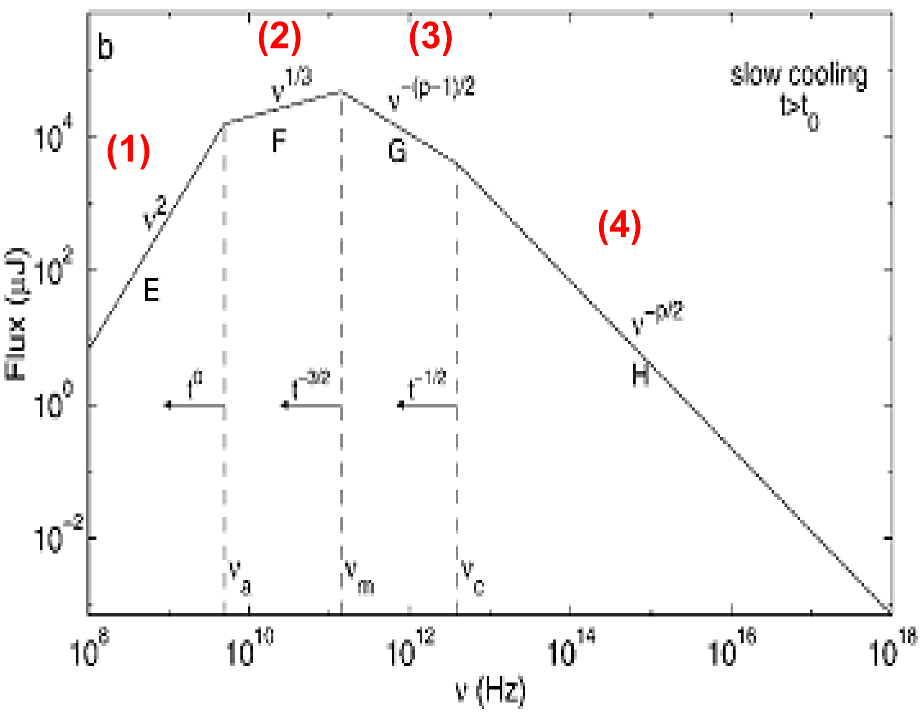
Parameters of the “standard model”

- Initial energy of the RBW
- Initial Lorentz factor of RBW
- Number density of the external medium
- Fraction of energy that goes into the B-field
- Fraction of energy that goes into relativistic e⁻
- Slope of the accelerated e⁻ distribution



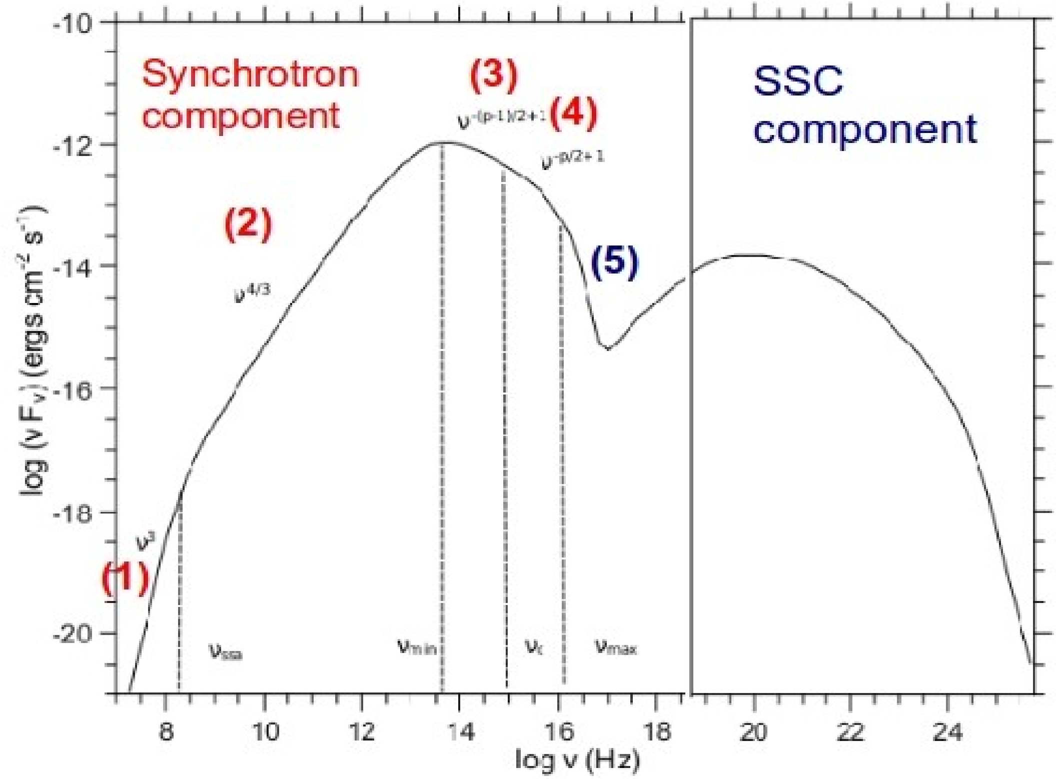
$+\ \gamma_{max}$

Effects of γ_{max} on spectra - (1)



Schematic synchrotron MW spectrum with

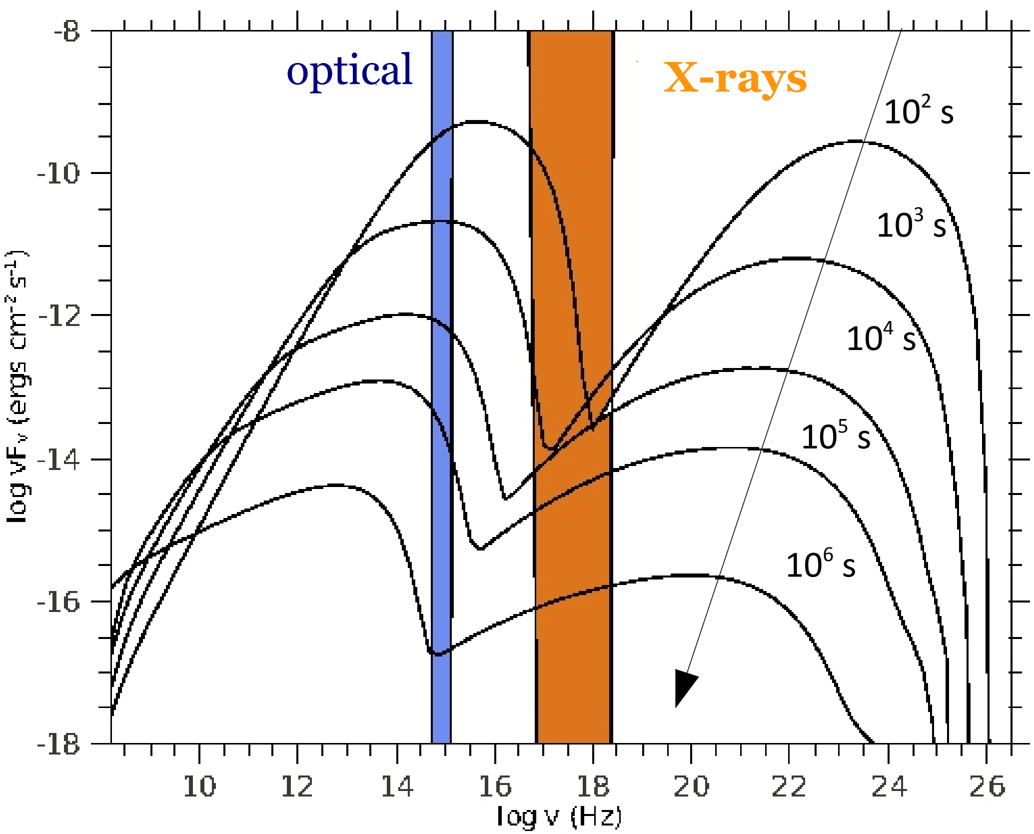
$\gamma_{max} >> \gamma_{min}$ (Sari et al. 1998)



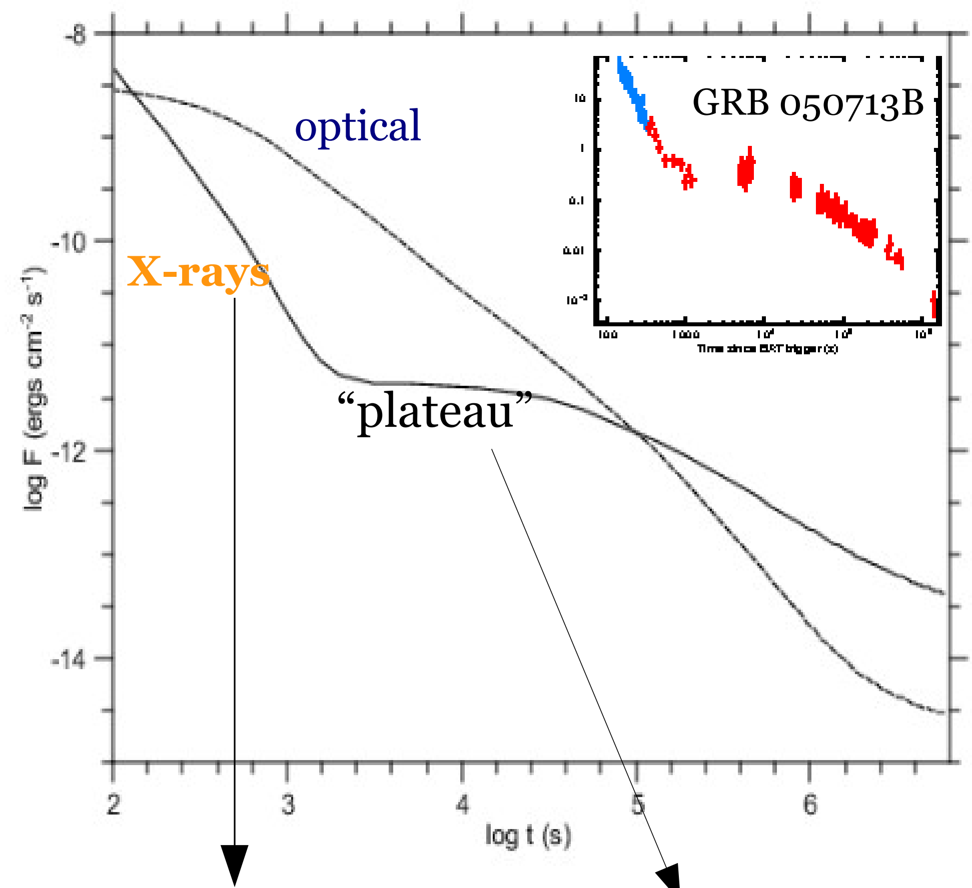
Schematic synchrotron and SSC MW spectrum with $\frac{\gamma_{max}}{\gamma_{min,0}} \approx 2.2$

(Petropoulou, Mastichiadis & Piran 2011)

Effects of γ_{max} on spectra - (2)



Spectra become softer and fainter with time

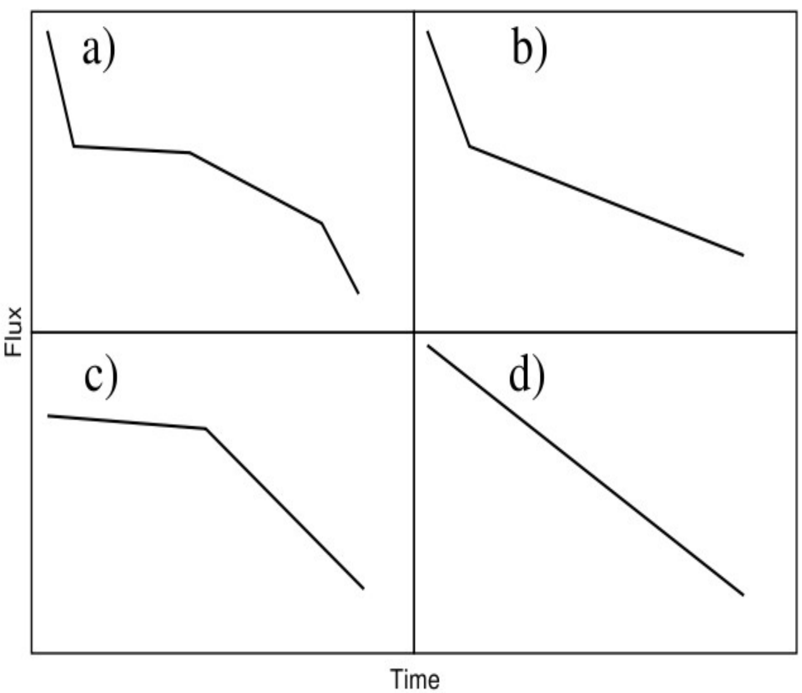


Steep early-time decay because of the dominant synchrotron exponential cutoff in the X-rays

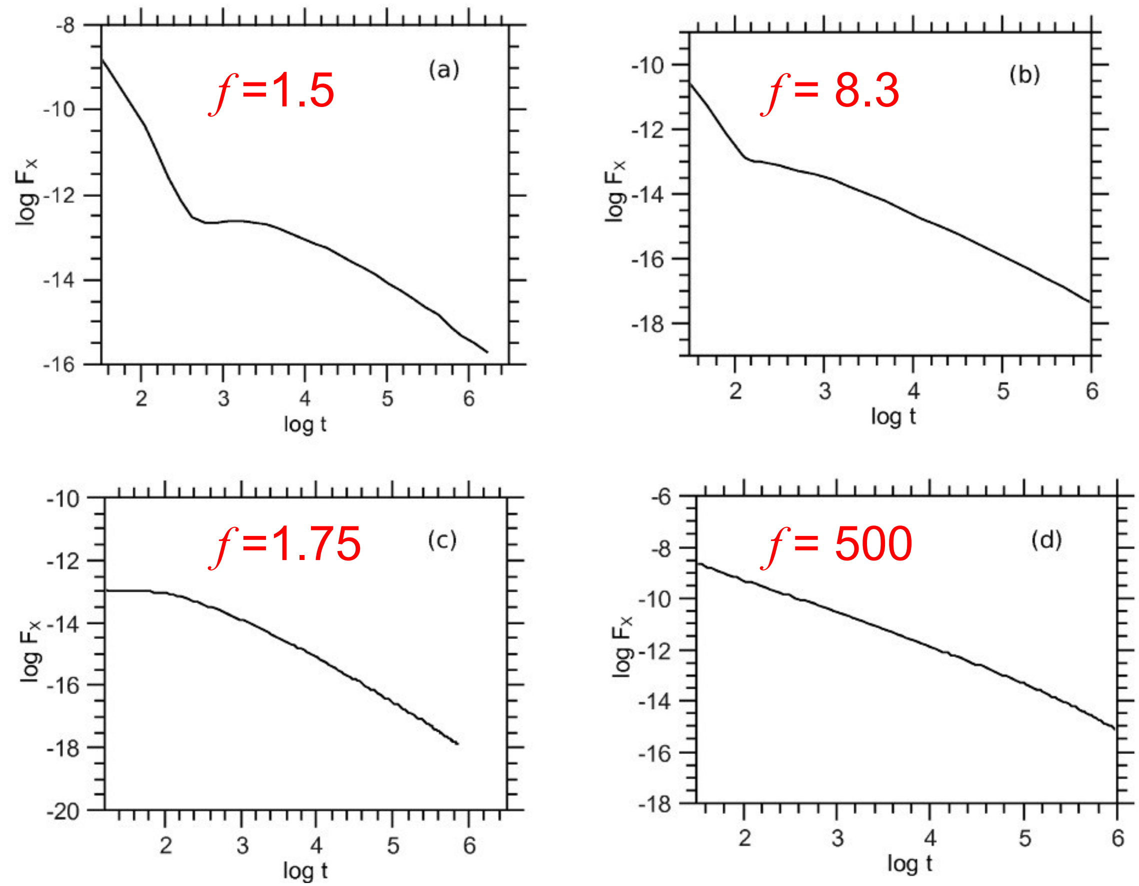
Flattening of the LC because of the emerging flat SSC spectrum

X-ray light curve morphologies

The ratio $f = \frac{\gamma_{max}}{\gamma_{min,0}}$ emerges as a critical parameter for the LC morphology



Evans et al. (2009)



Petropoulou, Mastichiadis & Piran (2011)

Second part

Work in progress . . .

Self-consistent calculation of γ_{max}

γ_{max} is the result of balancing the energy gain due to acceleration with the energy loss due to radiation.

We adopt a general description for the timescales:

Acceleration due to stochastic particle-wave interactions

$$t_{acc} \propto \gamma^{2-q} B(r)^{-s}$$

=

Losses due to synchrotron radiation

$$t_{loss} \propto \gamma^{-1} B(r)^{-2}$$

e.g. Kirk et al. (1994);
Stawarz & Petrosian (2008)

$$\gamma_{max} \propto B(r)^{(s-2)/(3-q)}$$

Towards an one-zone model for GRB afterglows

Our aim is...

... the self-consistent calculation of the electron distribution function *n* and synchrotron spectra by ...

... solving an equation of the form:

$$\frac{\partial n}{\partial t}+\frac{n}{t_{esc}}=\frac{\partial}{\partial \gamma}\left\{\left(b_s(\gamma,t)-\frac{\gamma}{t_{acc}(\gamma,t)}\right)n+D(\gamma,t)\frac{\partial n}{\partial \gamma}\right\}+Q_{inj}(\gamma,t)$$

Escape timescale

$$t_{esc}\propto t_{acc}$$

synchrotron loss term

$$b_s(\gamma,t)\propto\gamma^2 B(t)^2$$

acceleration timescale

$$t_{acc}\propto\gamma^{2-q}B(t)^{-s}$$

diffusion coefficient

$$D(\gamma,t)=\frac{\gamma^2}{t_{acc}(\gamma,t)}$$

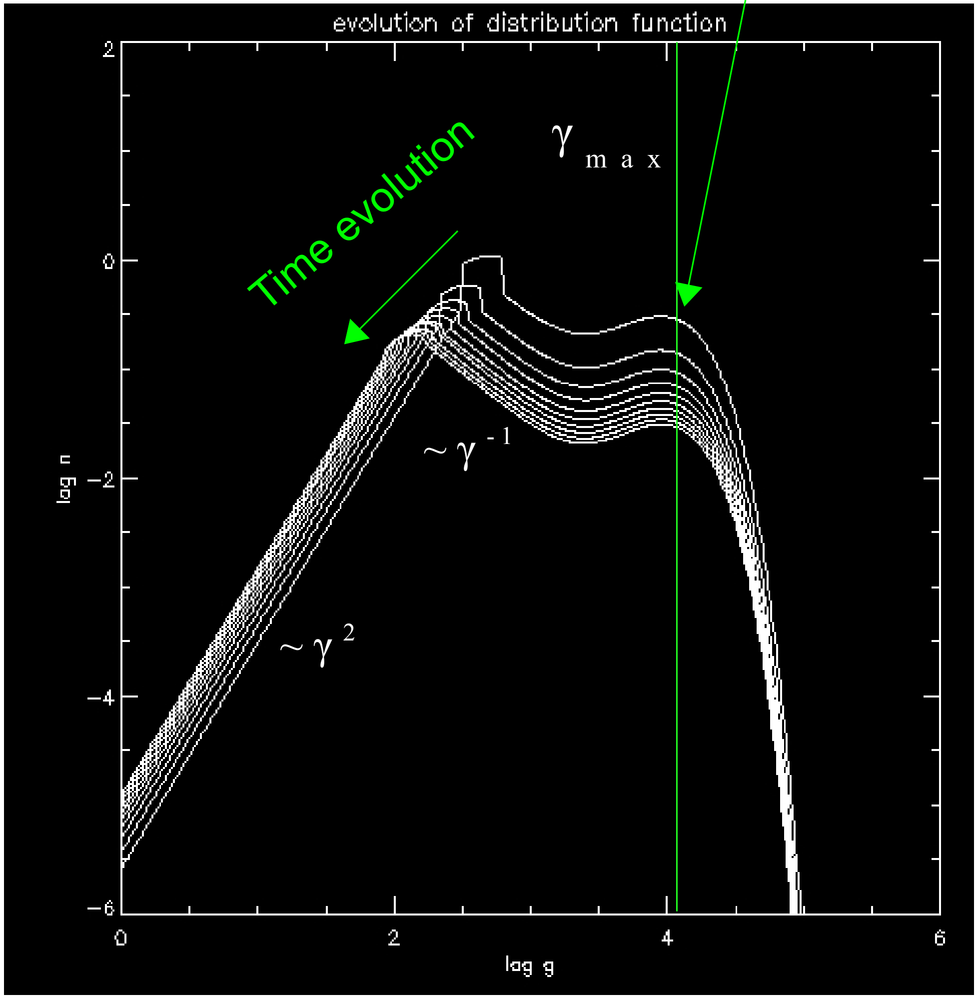
Mono-energetic injection

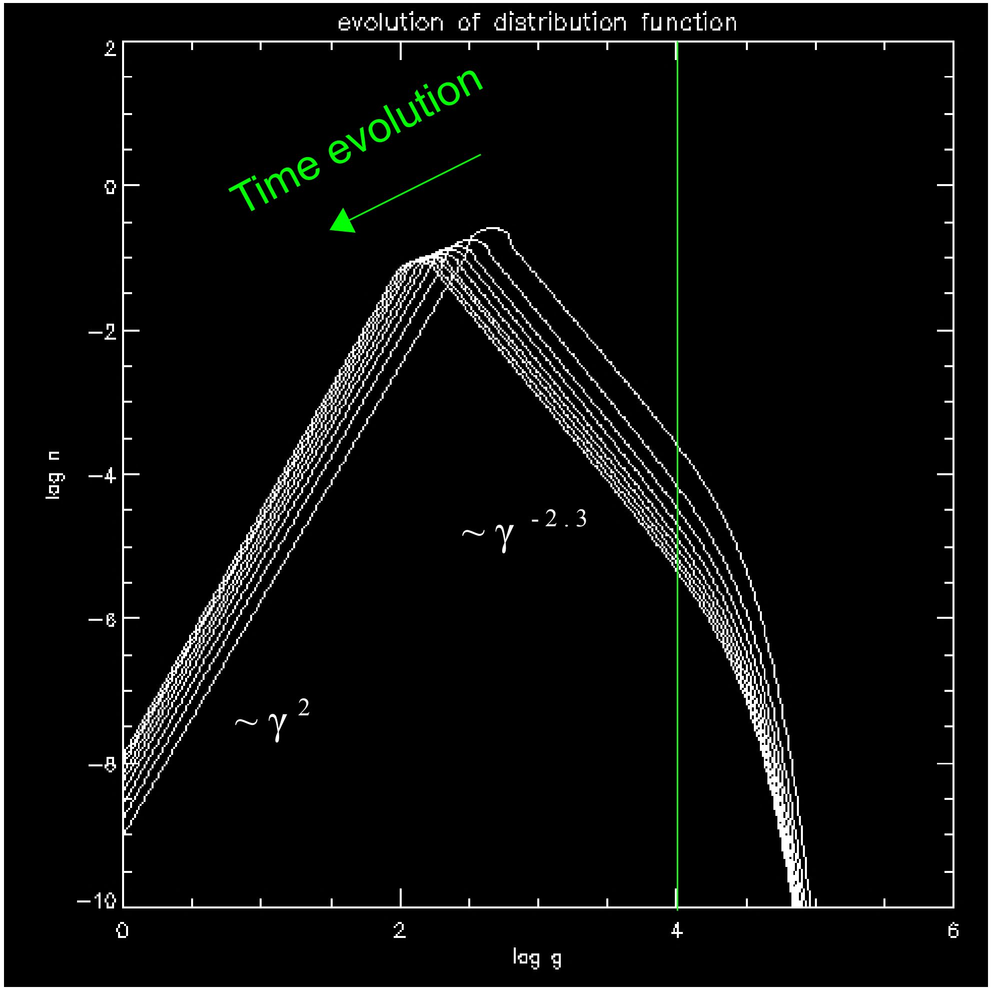
First results - Acceleration vs Escape

Constant maximum energy

$\varepsilon = \frac{t_{acc}}{t_{esc}} = 0.1$ **Pile-up** near the maximum energy because of **fast acceleration**

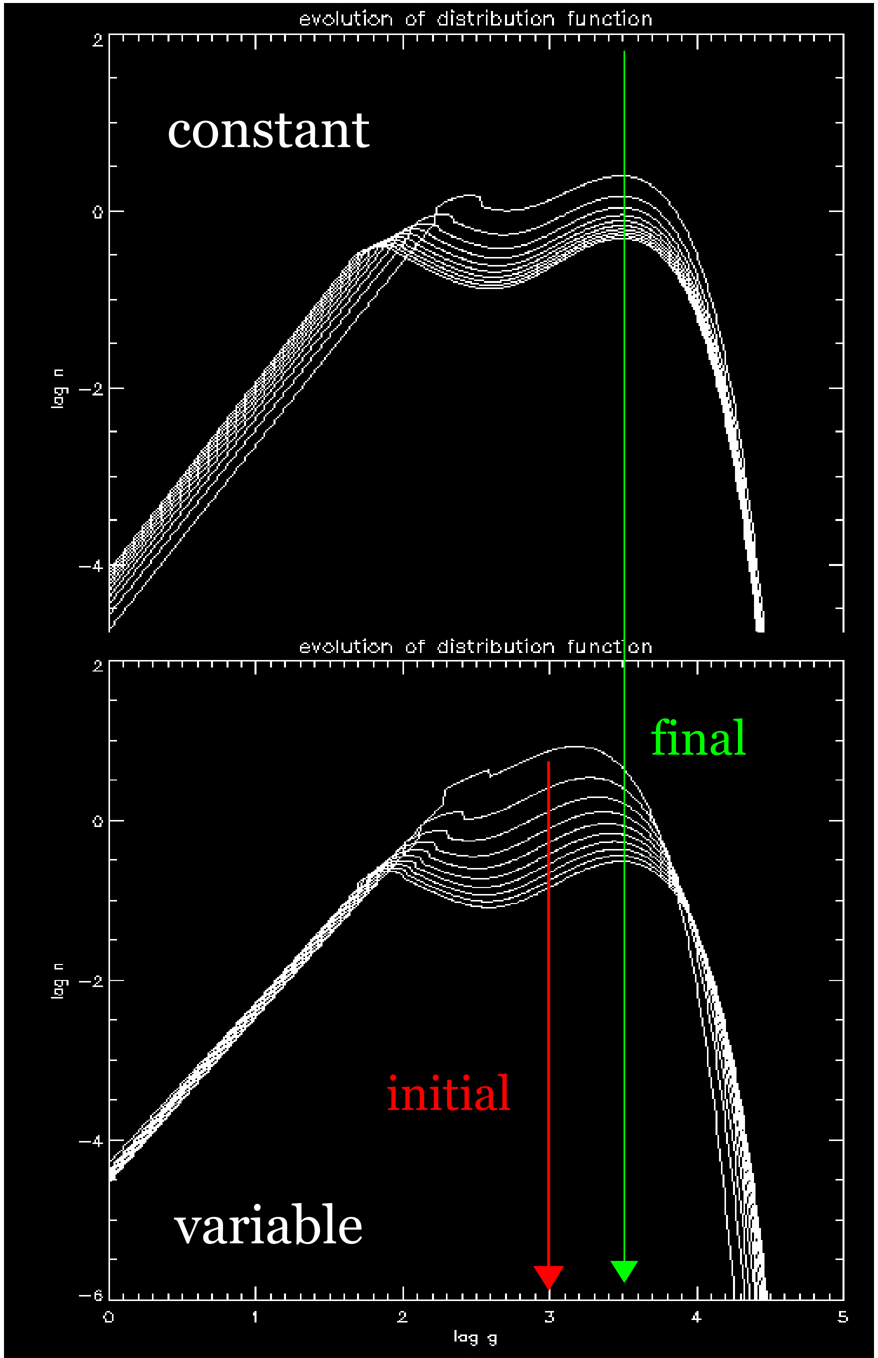
$\varepsilon = \frac{t_{acc}}{t_{esc}} = 3.0$ **No pile-up** effect because of **fast escape**





$q = 2; s = 2$

First results - Constant vs Variable γ_{max}



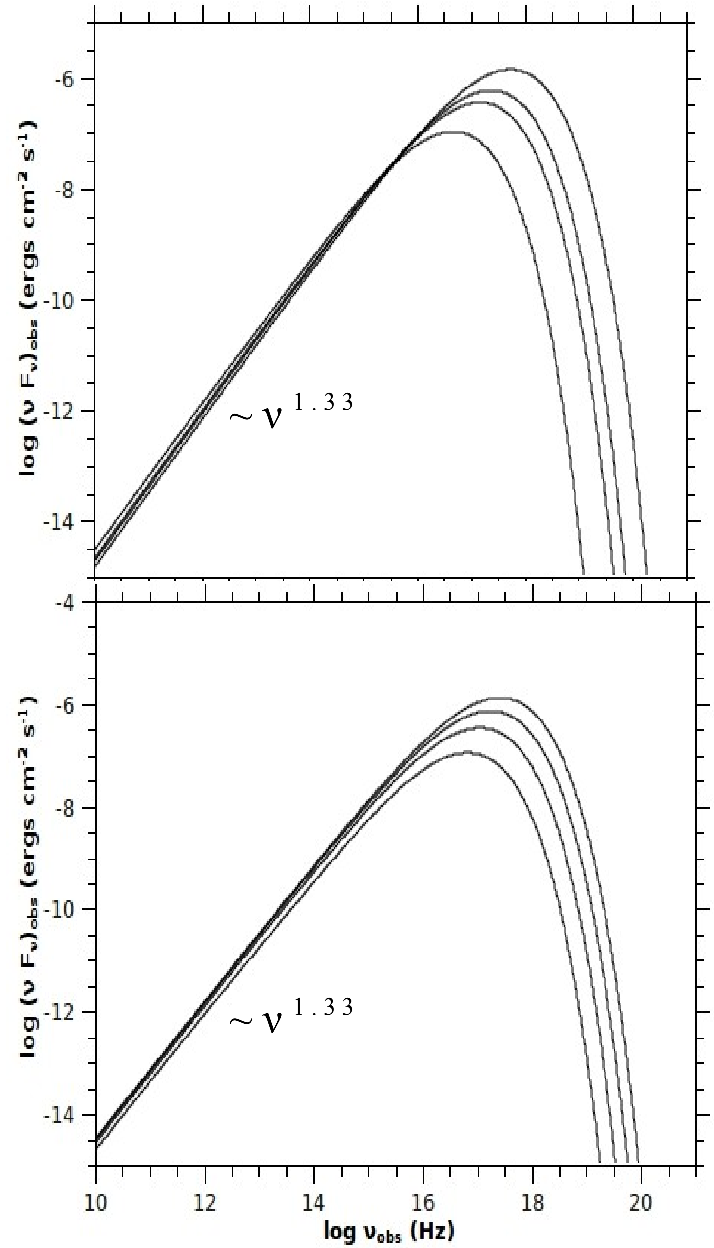
$$\varepsilon = \frac{t_{acc}}{t_{esc}} = 0.1$$

$$q=2\,; s=2$$

$$q=2\,; s=3/2$$

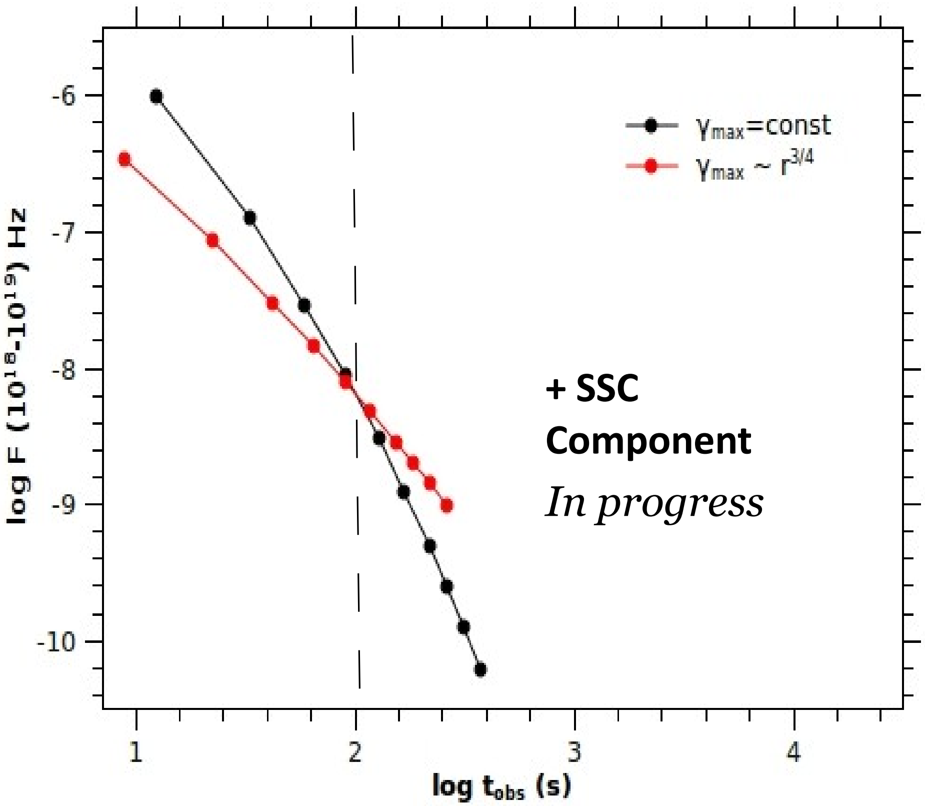
$$\gamma_{max} \propto r^{3/4}$$

Synchrotron spectra



First results – Light curves

Comparison of *early-time light curves* for the two previous cases:



$\gamma_{max} = const$ black

$\gamma_{max} \propto r^{3/4}$ red

Summary

- The “standard model” still explains many features of MW and LC observations.

- New features like early-time steep decay or/and flattening of the X-ray flux can be explained using variations/extensions of the “standard model”.

- Small values of the ratio $f = \frac{\gamma_{max}}{\gamma_{min,0}}$ lead to observed X-ray LC morphologies.

- Maximum electron energy can be self-consistently calculated at each time rather than being a free parameter.

- First results of an “one-zone” model again show the same early-time behavior.


Thank you
And questions …