Gamma-Ray Bursts

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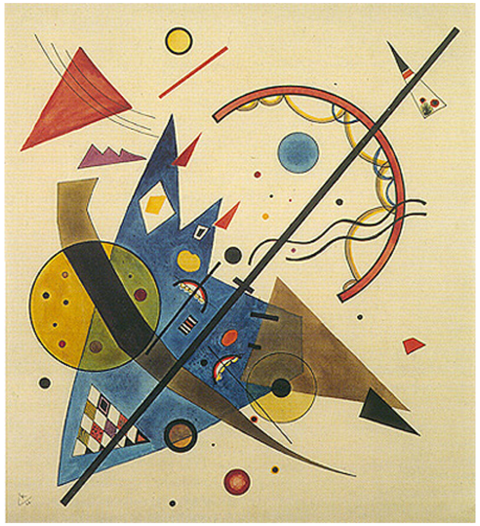


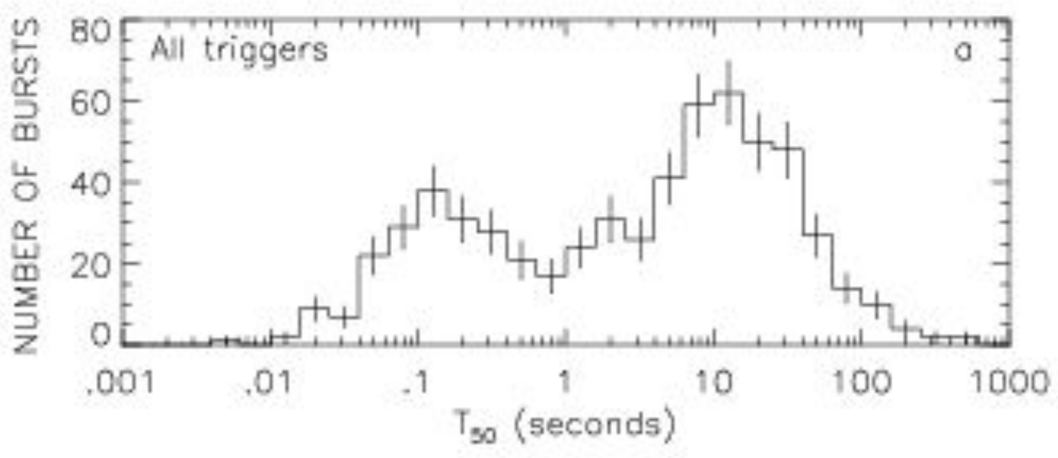
Kandinksy – Curves and sharp angles - 1923

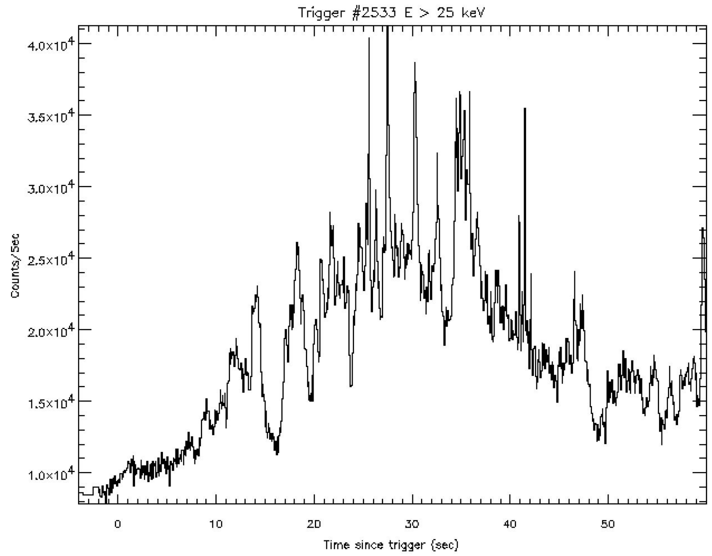
From neutrino to multimessenger astronomy : status and perspectives – Marseille – April 4-6, 2011

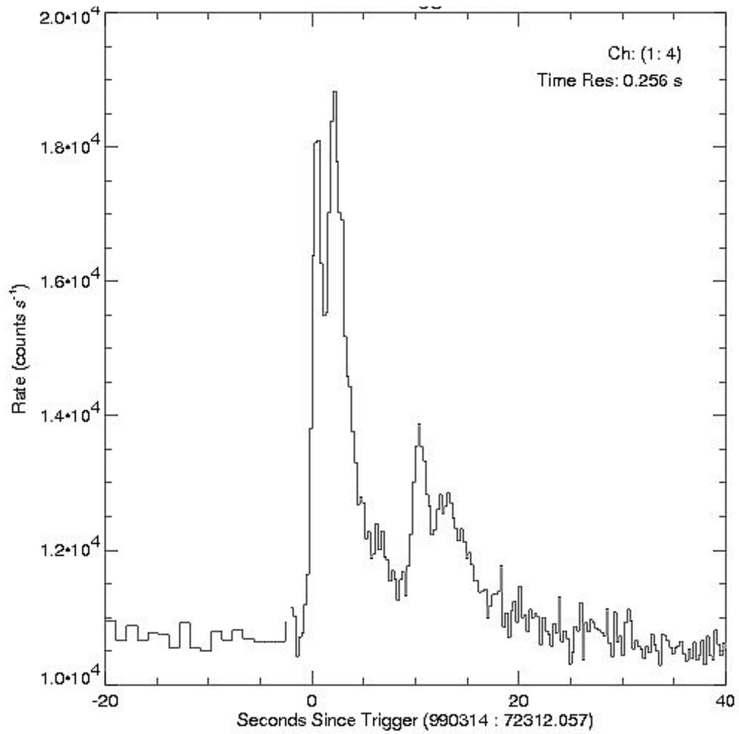
GRB prompt emission

Highly variable lightcurves

Two groups : short vs long





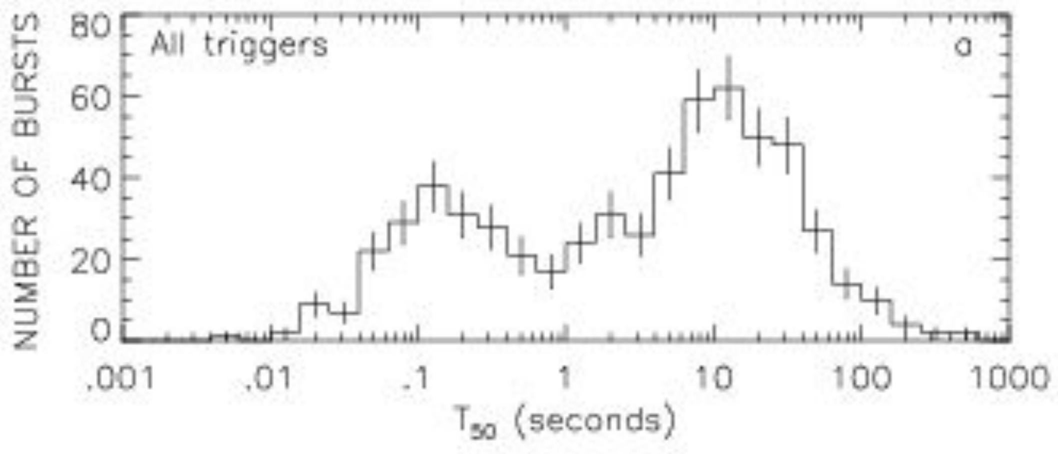


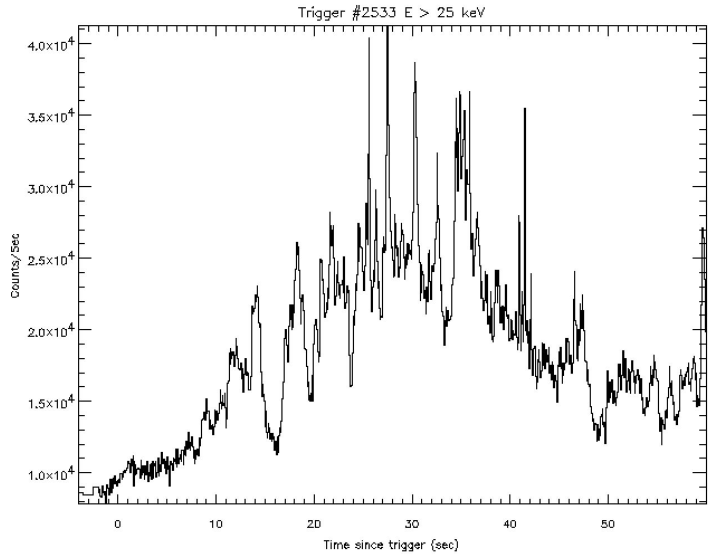
BATSE catalog

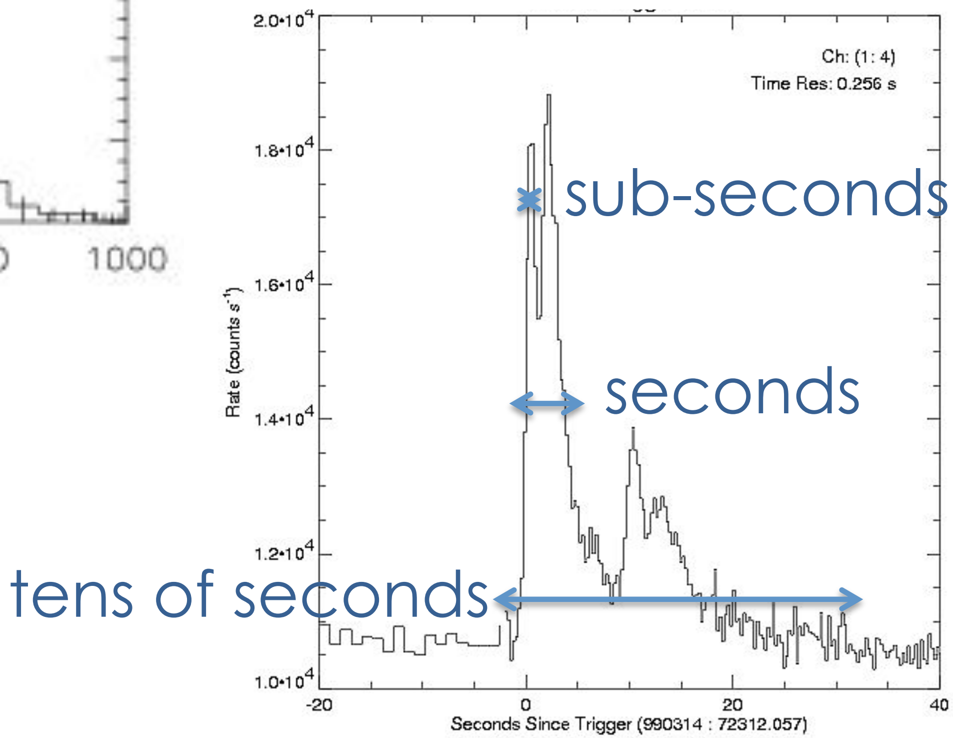
GRB prompt emission

Highly variable lightcurves

Two groups : short vs long



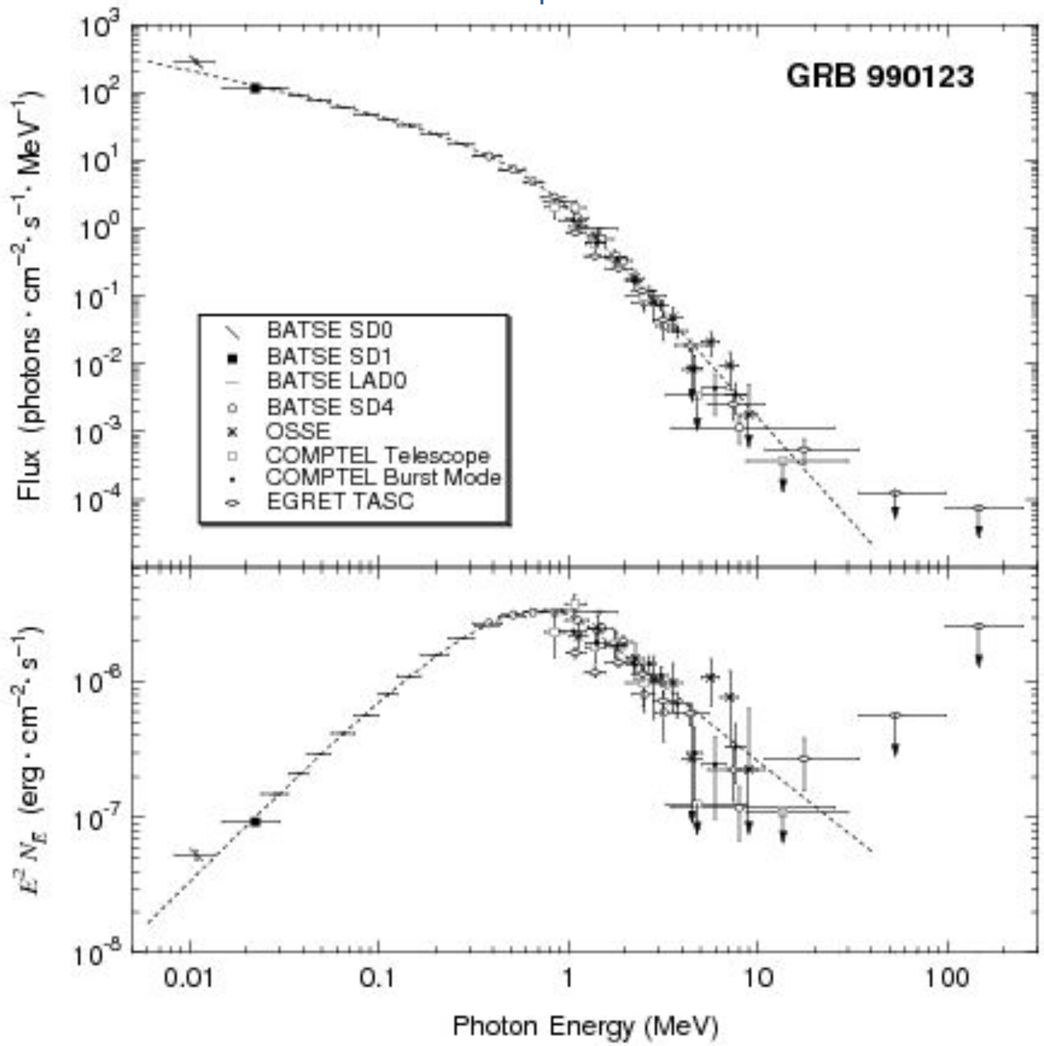




BATSE catalog

GRB prompt emission

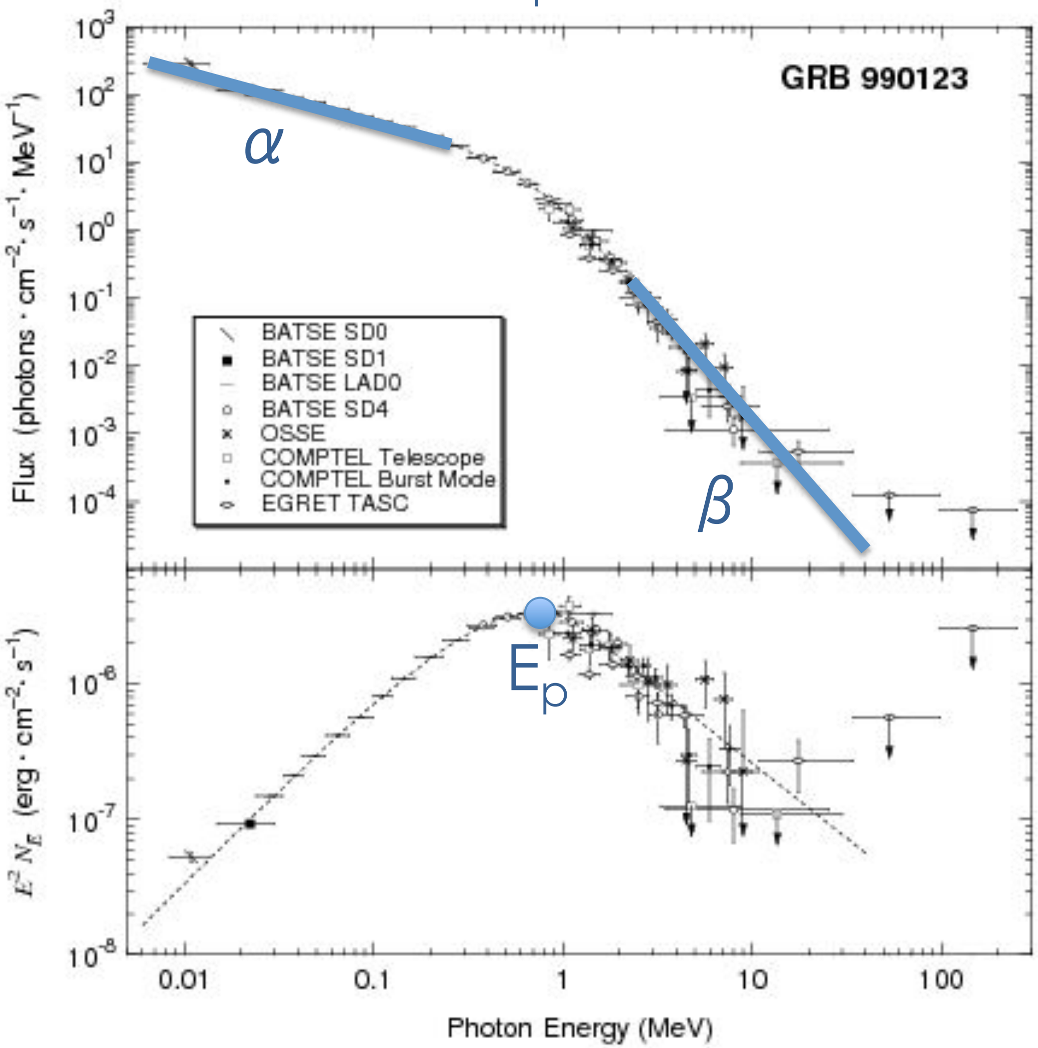
Non-thermal spectrum : E_p ~ keV → MeV



Briggs et al. 1999

GRB prompt emission

Non-thermal spectrum : E_p ~ keV → MeV

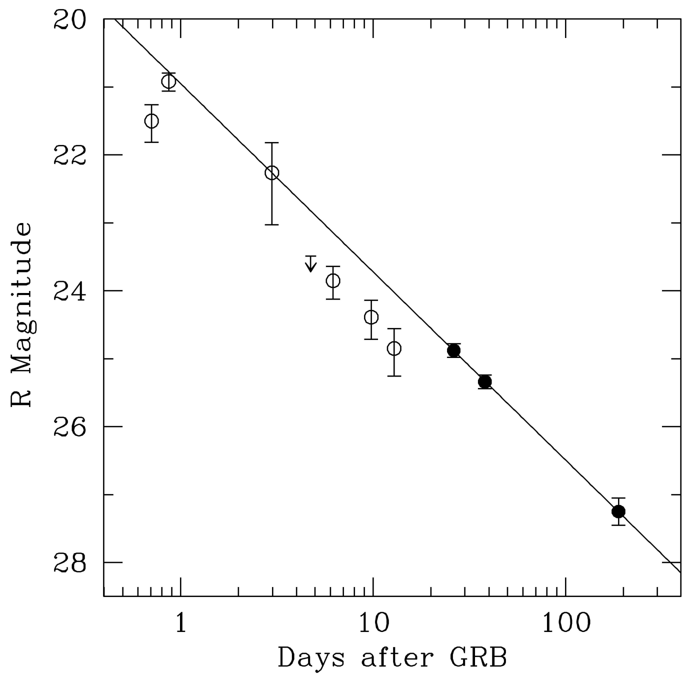


Briggs et al. 1999

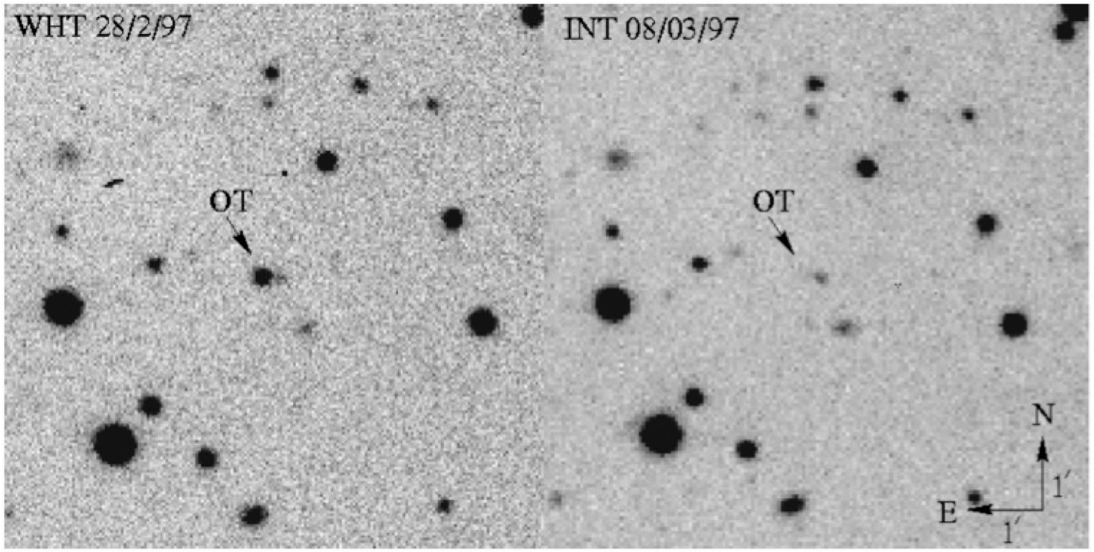
GRB afterglow

X-rays → visible/IR → radio

Rapid decay (power-law)



Fruchter et al. 1999

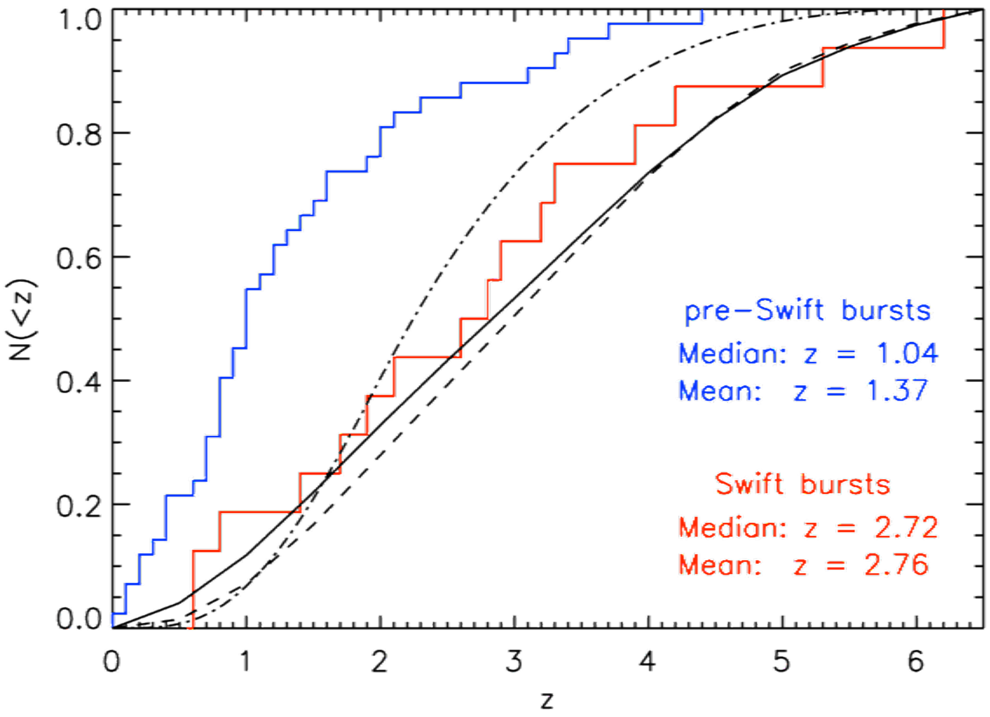


Groot et al. 1997

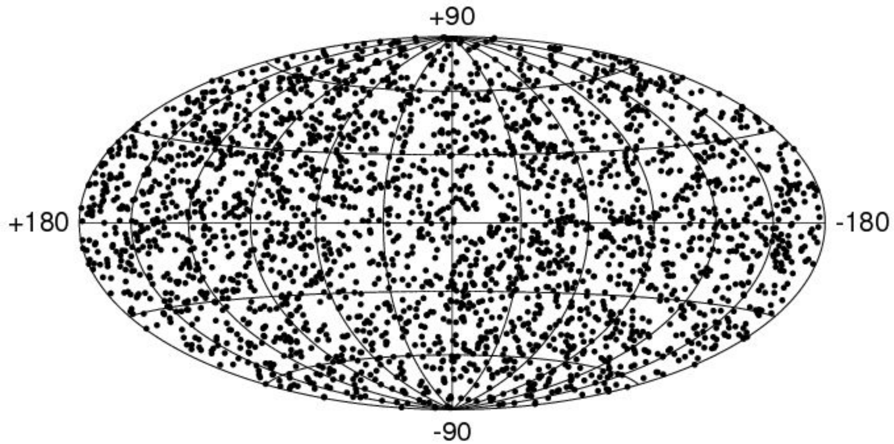
GRB distance

z_{max} = 8.3 ! (GRB 090423)

$E_{\gamma,iso} = 10^{50}$-10^{54} erg

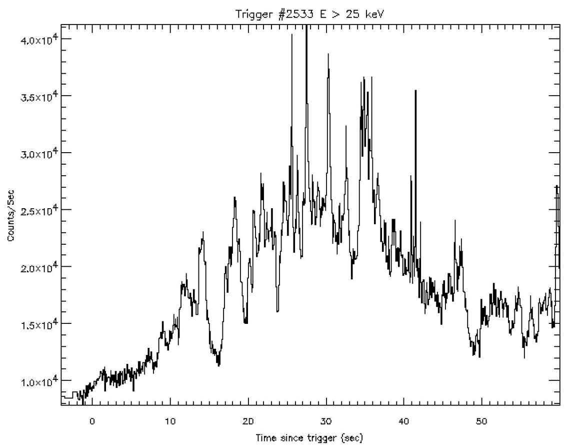


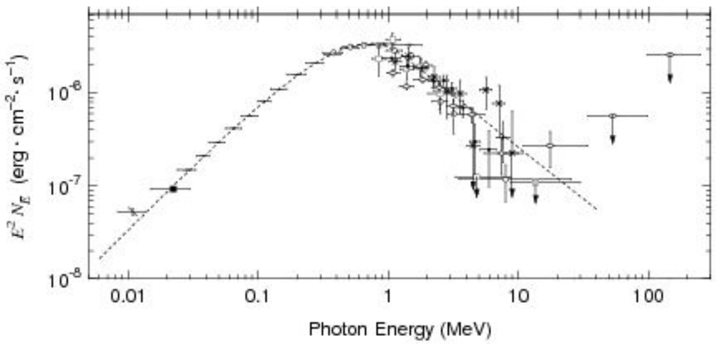
Jakobsson et al. 2006

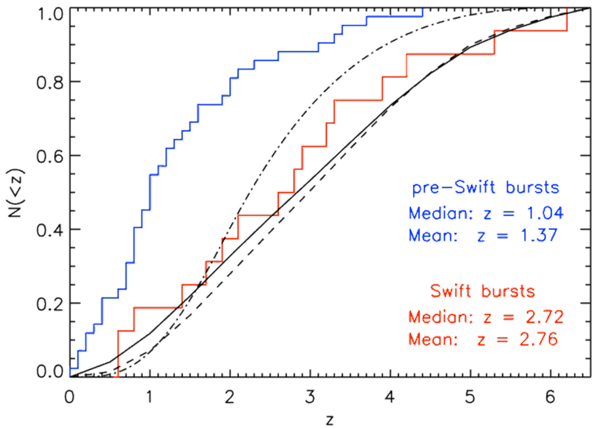


BATSE catalog

Relativistic motion







γ -rays (>MeV)

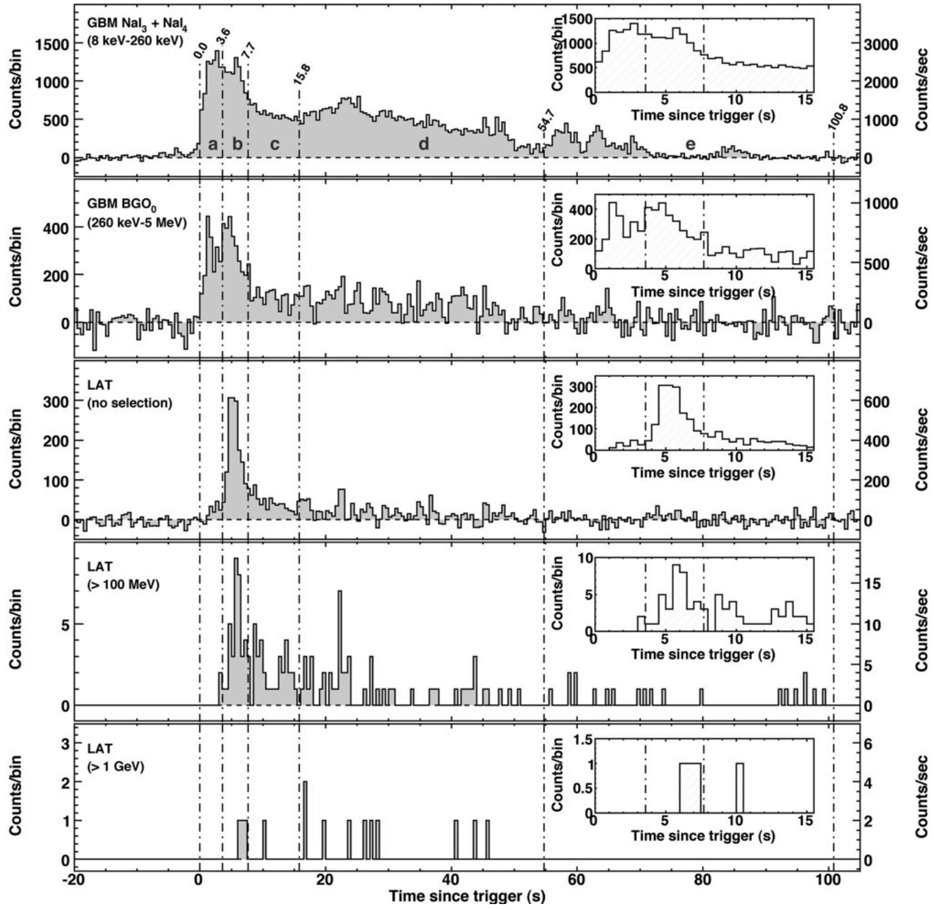
High Variability (<10 ms)

Huge energy release (>10^{51}erg)

γ -rays should not be observed (γ γ annihilation)

Solution : high Lorentz factors (Γ >100)

Fermi-LAT observations

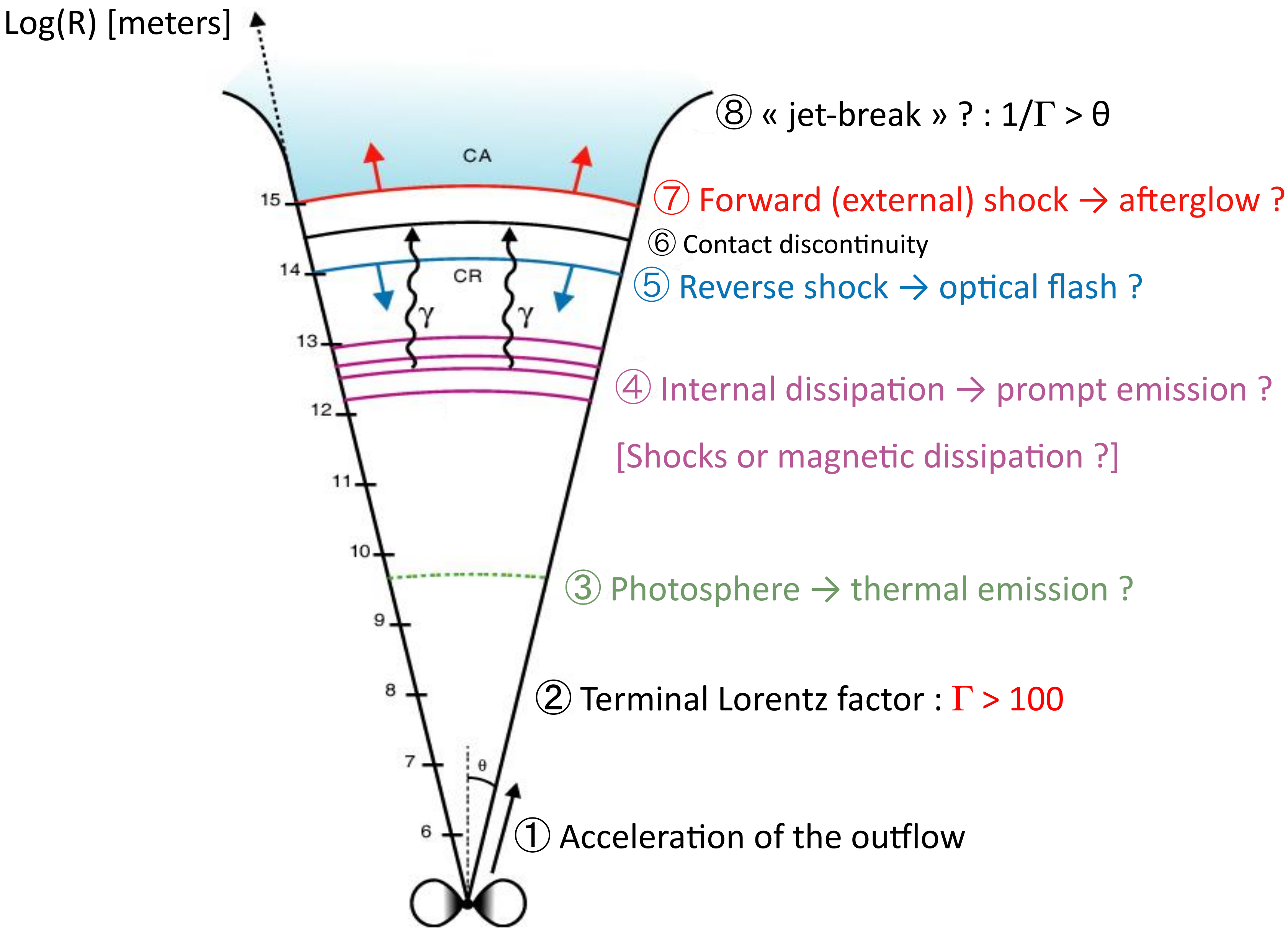


Abdo et al. 2008

GeV photons : Γ~1000 ?

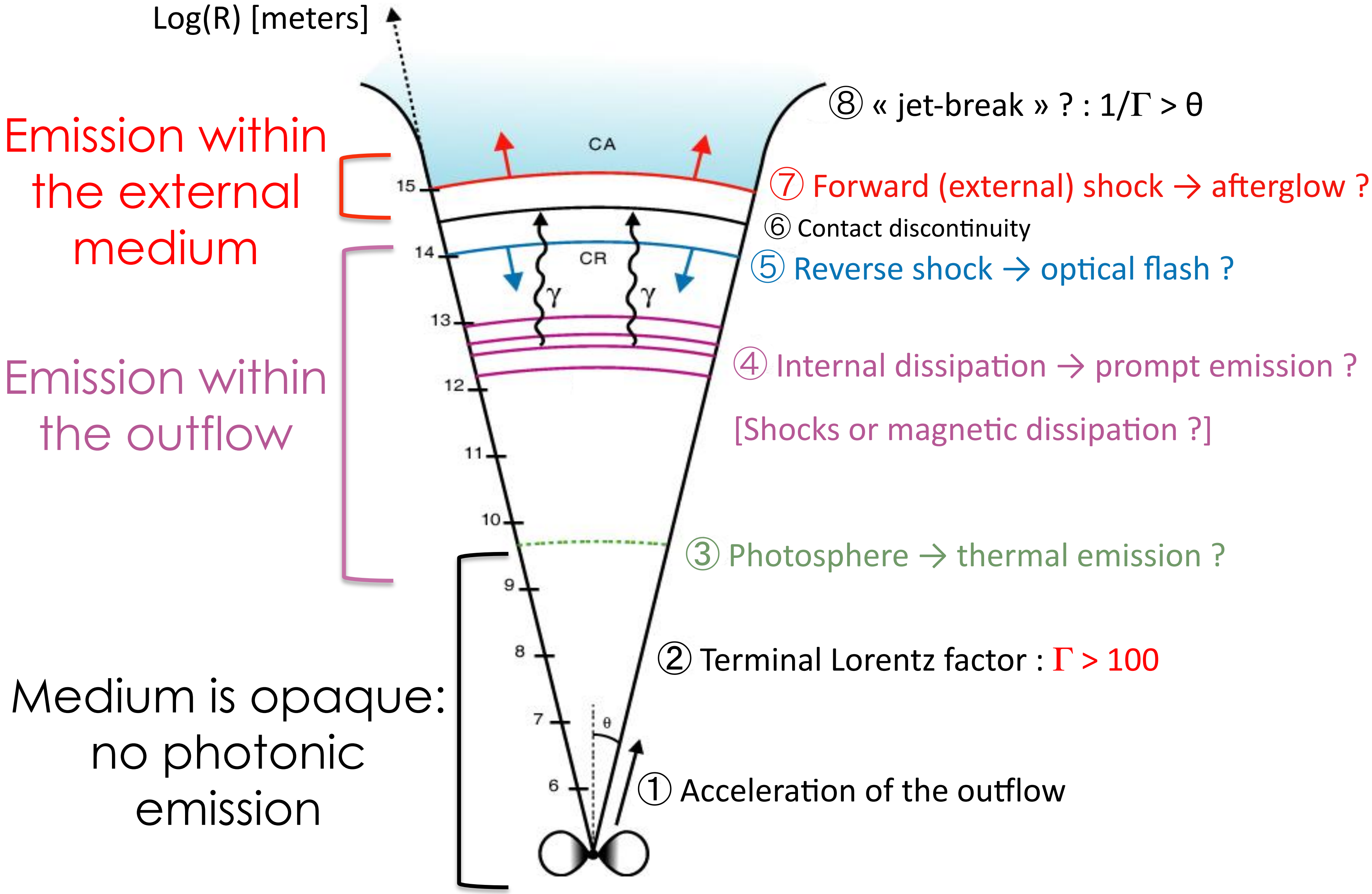
Detailed model : Γ~300 (MeV-GeV emitted at the same place)
(geometry/time evolution) Γ< 300 (GeV emitted at a different place)
(Hascoët, Daigne, Mochkovitch & Vennin to be submitted)

GRB Model



Log(R) [meters]
CA
CR
γ
γ
15
14
13
12
11
10
9
8
7
6
θ
⑧ « jet-break » ? : 1/Γ > θ
⑦ Forward (external) shock → afterglow ?
⑥ Contact discontinuity
⑤ Reverse shock → optical flash ?
④ Internal dissipation → prompt emission ?
[Shocks or magnetic dissipation ?]
③ Photosphere → thermal emission ?
② Terminal Lorentz factor : Γ > 100
① Acceleration of the outflow

GRB Model


Log(R) [meters]
Emission within the external medium
Emission within the outflow
Medium is opaque: no photonic emission
CA
CR
15
14
13
12
11
10
9
8
7
6
θ
γ
γ
⑧ « jet-break » ? : 1/Γ > θ
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High-energy neutrinos ?

- Relativistic jet
- Matter : e^- + p,n
- Electron acceleration to high Lorentz factors

GRBs are excellent cosmic accelerators !

Then :

- Proton acceleration ?
- Interaction with γ-rays : high energy neutrinos

10^{14} eV neutrinos are produced from ~10^{15} eV protons interacting with MeV photons

HE neutrino flux from GRBs

- If GRBs are the source of UHECRs :
the UHECR flux provides a normalization
(see e.g. Waxman & Bahcall)

- Without this assumption, predictions rely on several parameters :
  - efficiency of the prompt GRB phase
  - ratio : energy in protons / energy in electrons
  - GRB rate

  …

These parameters are unknown but partially constrained by observations

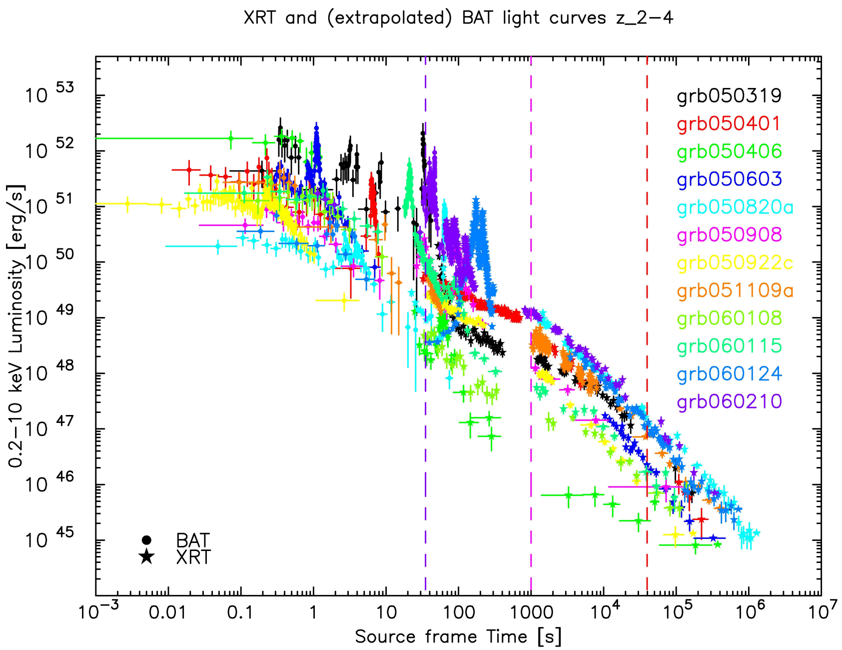
(see e.g. Spada et al. 2001)

Questions

• Does acceleration occur in (mildly-) relativistic shocks ?
(under investigation … ; alternatives ?)

Prompt emission : internal shocks ?

Afterglow : forward shock ?



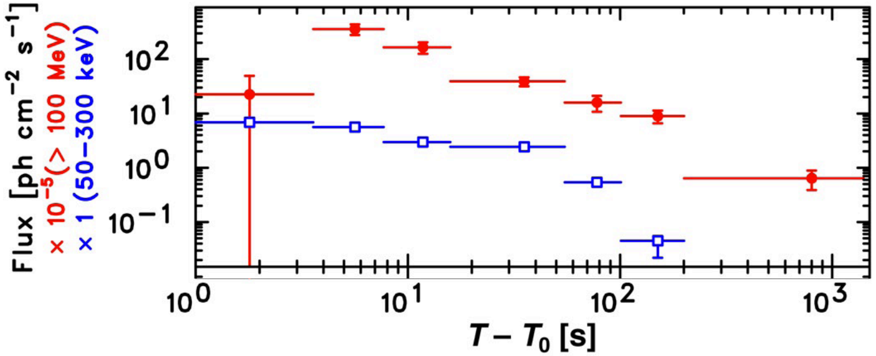
Mangano et al. 2007

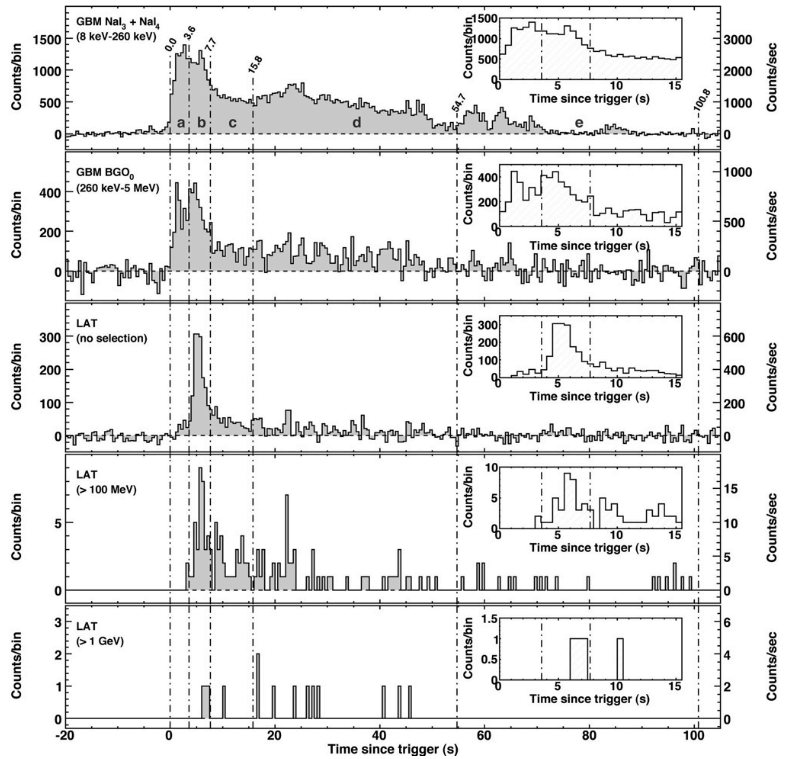
Questions

- What is the maximum energy of accelerated electrons ?
- Where is the best place for acceleration (IS/RS/FS) ?
- Are protons accelerated ?

Fermi-LAT observations

• GeV emission :
prompt + afterglow ?





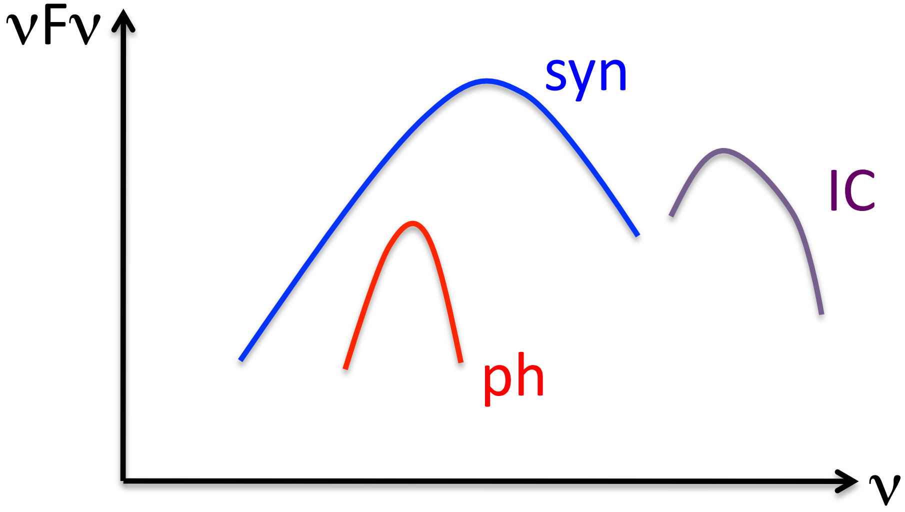
Abdo et al. 2008

•No need for an hadronic component ?

Detailed models based on internal shocks + emission from shock-accelerated electrons can reproduce most features of the Fermi-LAT observations.
(see e.g. Bosnjak et al. 09 ; Zou et al. 09 ; Piran et al. 09 ; Daigne et al. 10 ; …)

Fermi-LAT observations

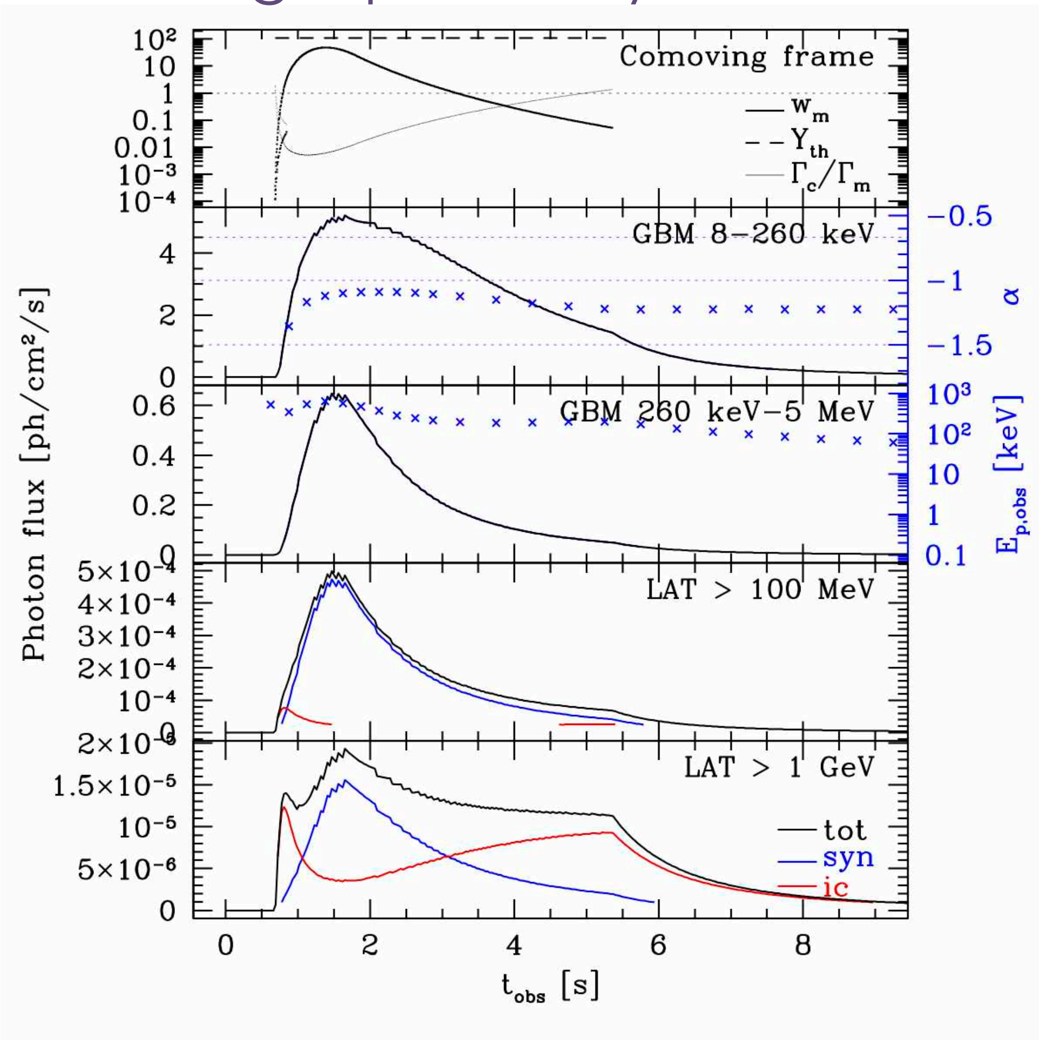
- Emission from shock accelerated e^- in internal shocks

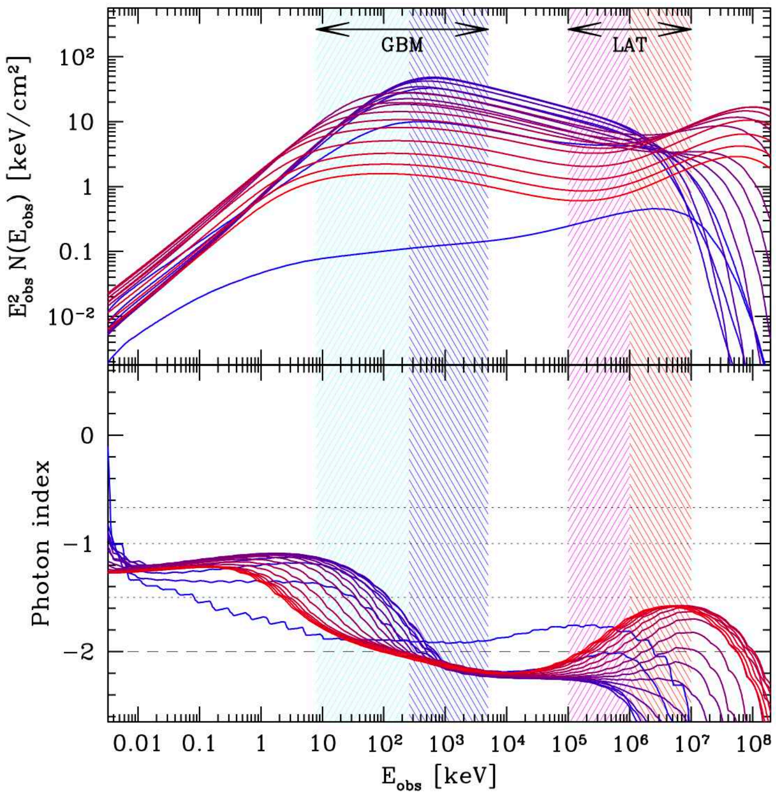


- Weak HE emission : Klein-Nishina regime
(high Lorentz factors for electrons)

Detailed modelling of the prompt GRB emission

- A single pulse : dynamics + detailed radiative code





(Daigne, Bosnjak & Dubus 2010)

Questions

- If protons are accelerated : maximum energy ?
- Are GRBs the source of UHECRs ?

  Hillas criterion : OK

  Detailed acceleration mechanism ?

  Local rate within the GZK volume ?

  Note :

  10^{14} eV neutrinos are produced from 10^{15} eV protons

  GRBs are promising sources of HE neutrinos even if they are not at the origin of UHECRs.

Conclusions

Predicting the GRB HE neutrino flux requires :
-to constrain the non-thermal population of protons in GRBs (internal shocks, reverse shock, forward shock) ;
-to constrain the local GRB rate.

Present status :
-physical conditions in GRB jets are better known (Lorentz factor, radius of emission, ...)
-Fermi-LAT observations : constraints on the non-thermal leptons ? (then : indirect constraints on protons)

Going farther :
-detecting nearby GRBs above 10 GeV ? (possible hadronic signatures)
-understanding GRB progenitors and environment (spectroscopy, GWs, ...)