Gamma-Ray Bursts:
Open Questions and Looking Forward

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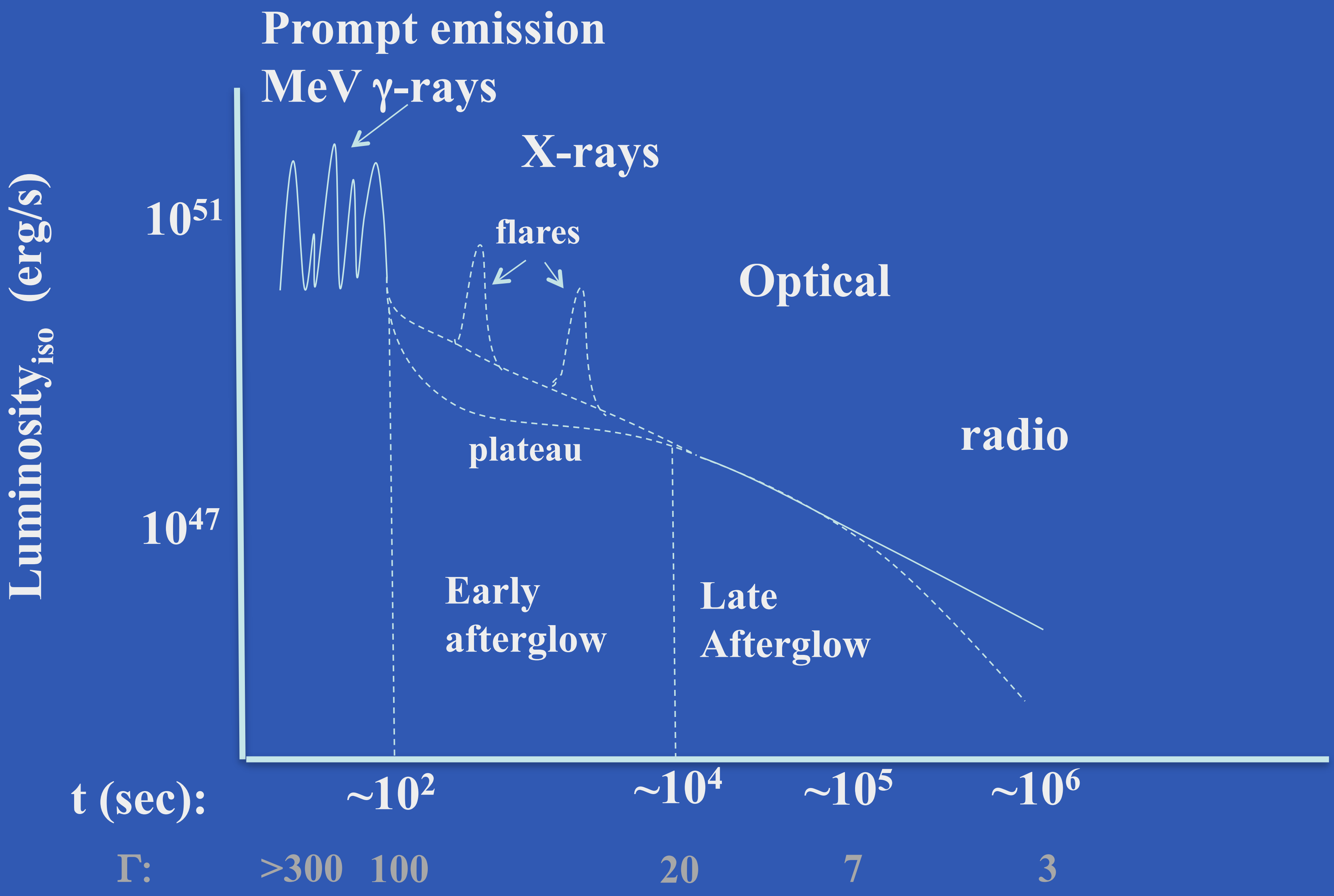
Outline

- What do we really know about GRB physics (a very short substitution to a comprehensive discussion of what we do not know)

- Several major open questions that may be addressed by Fermi observations:
  - Short GRB progenitor (GRB classification)
  - The content of the relativistic outflow
  - The outflow angular structure (GeV orphan afterglows)
  - The prompt emission radiation mechanism
  - GRB microphysics

A *long* GRB light curve



Prompt emission
MeV γ-rays

X-rays

flares

Optical

radio

plateau

Early
afterglow

Late
Afterglow

Luminosity$_{iso}$ (erg/s)

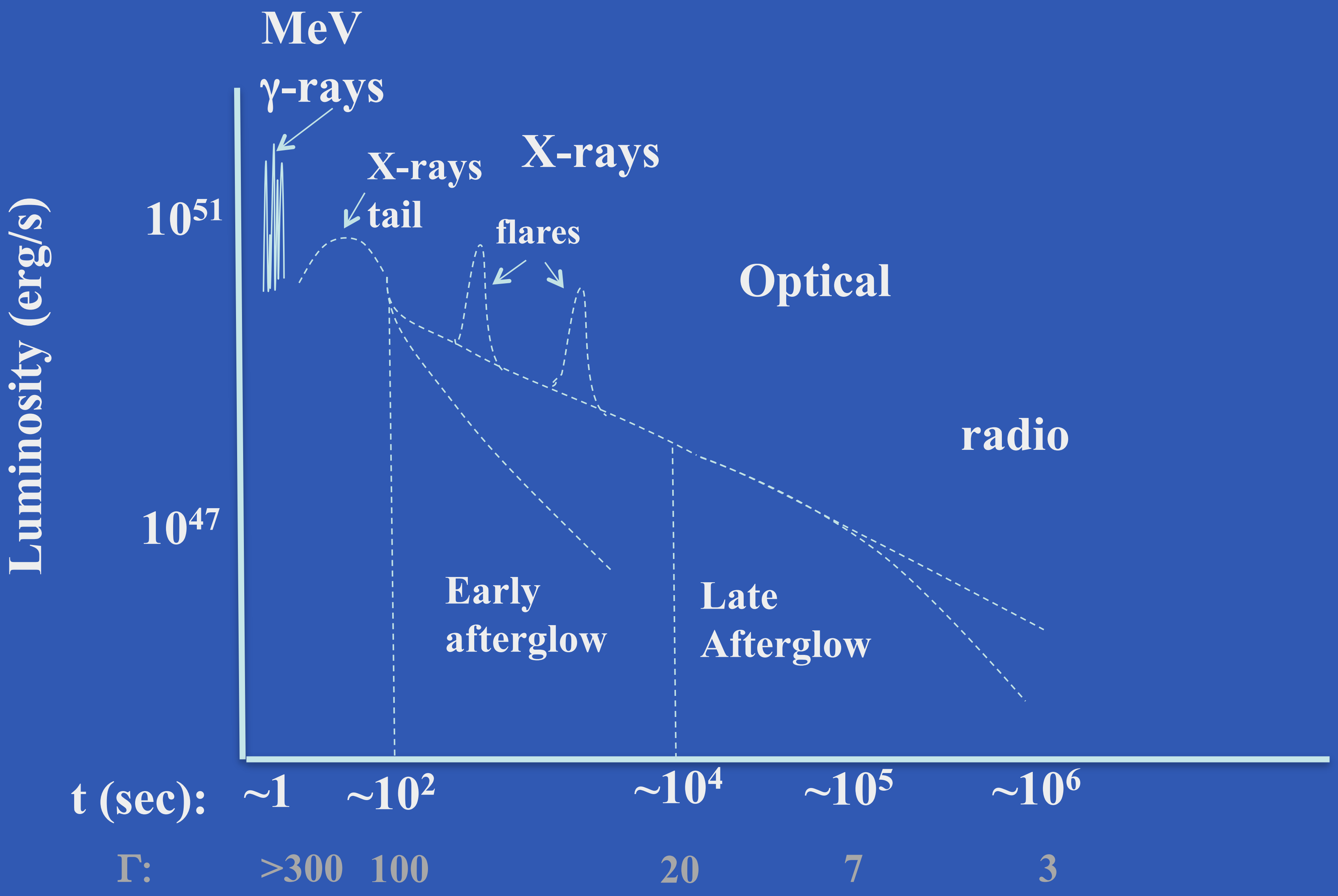
10^{51}

10^{47}

t (sec): $\sim10^2$ $\sim10^4$ $\sim10^5$ $\sim10^6$

Γ: >300 100 20 7 3

A *short* GRB light curve



What do we know with high confidence about the physics of GRBs

Progenitors

Long GRBs:

- The progenitor system includes a very massive star

Associated SN; Host galaxy type; Location within the hosts

- At least some progenitors produce Ib/c SN (or SN like emission) within about ±1 day of the GRB

SN association (mostly based on GRB 030329)

Short GRBs:

- Different progenitor than long GRBs

Host galaxy type ;No Associated SN;

- Do not necessarily include massive stars

Occur in galaxies with very low star formation rate

Central engine and outflow properties

- Compact ($<10^7$ cm) central engine that converts gravitational energy to relativistic outflow
Time and energy scales

- Relativistic - Lorentz factor >~30 in all GRBs.
In some $\Gamma > 1000$.
γγ opacity and radio afterglow size measurements

- Collimated -At least some GRBs are narrowly beamed
Many independent strong, yet not conclusive, evidence: $E_{iso} > 10^{54}$ *erg, jet breaks, radio calorimetry*

- Carry energy of 10^{50}-10^{53} erg (based on collimation estimates and *radio calorimetry*)

Prompt emission

- Dissipation of the outflow energy to the non-thermal prompt emission at distances $10^{12} – 10^{17}$ cm

$\gamma\gamma$ and Thomson opacity (lower limit)

Interaction with the circumburst medium (upper limit)

Afterglow

- The late afterglow is generated by interaction with the circumburst medium, most likely by external shocks

The decelerated expansion of the afterglow image of GRB 030329.

Afterglow modeling

Some open questions

And potential Fermi contribution

What is (are) the progenitor(s) of short GRBs

Main suspects: NS-NS or BH-NS mergers

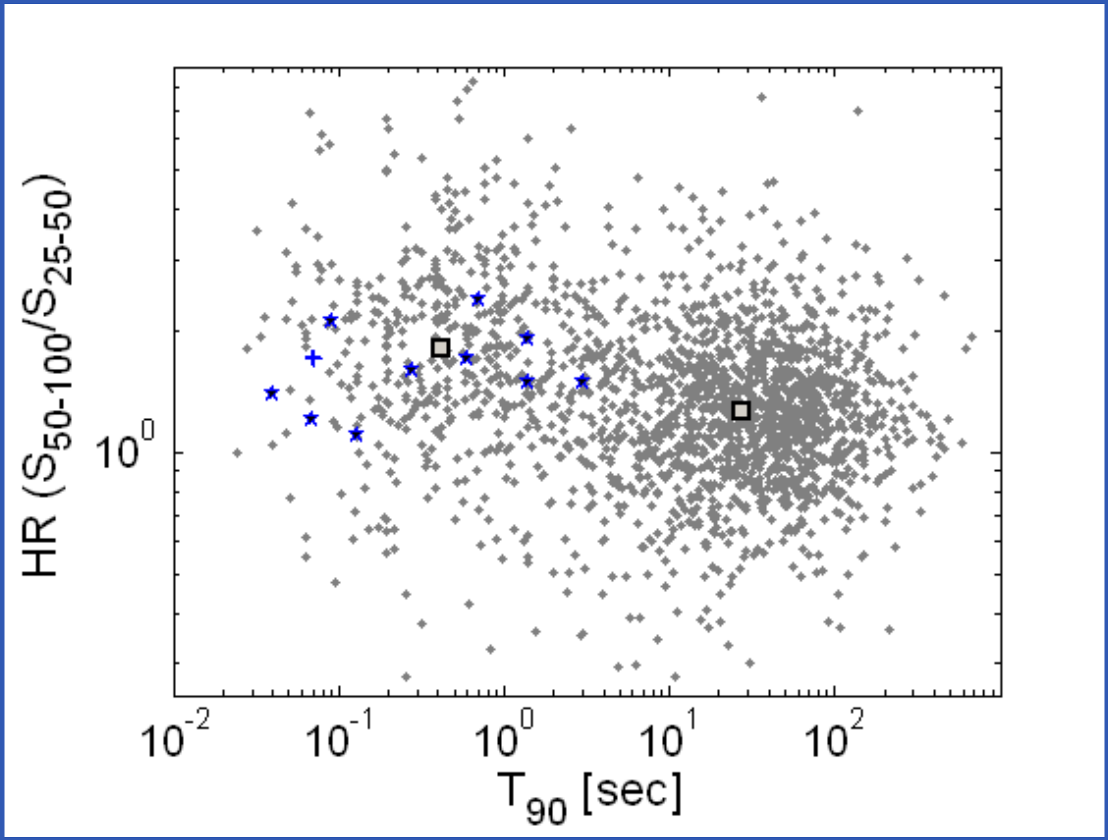
Why:
Can potentially produce most of the main observations such as energy and most time scales, rates, host galaxy types etc.

Why not:
Difficult to produce the X-ray tail

How to constrain:
Controlled large sample of bursts with redshift, host type and location within the host.

But first we need to know how to classify bursts

We do not know how to classify a burst based on its γ-ray emission alone



The new window opened by Fermi may help solve this problem

What component in the outflow is energetically dominant (baryons, leptons, magnetic field etc.)?

In a baryonic outflow which is accelerated by radiation pressure (fireball):

$$\Gamma_{\max} \cong 1000 \left(\frac{L}{10^{51}\, erg/s} \right)^{1/4} \left(\frac{R_0}{10^{6}\, cm} \right)^{-1/4}$$

$$\frac{E_{th}}{E_{baryons}} \cong \left(\frac{\Gamma}{\Gamma_{\max}} \right)^{8/3}$$

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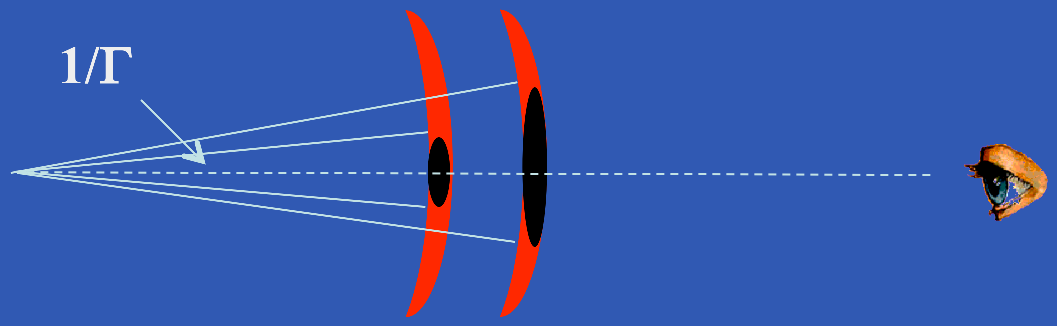
Fermi observations of GeV photons put a lower limit on Γ. Future observation may even measure Γ.

GBM observations can put a stringent limit on any thermal component in the spectrum.

Current Fermi observation already push this limit
Future observations may rule it out (or prove it correct)

What is the structure of the outflow?

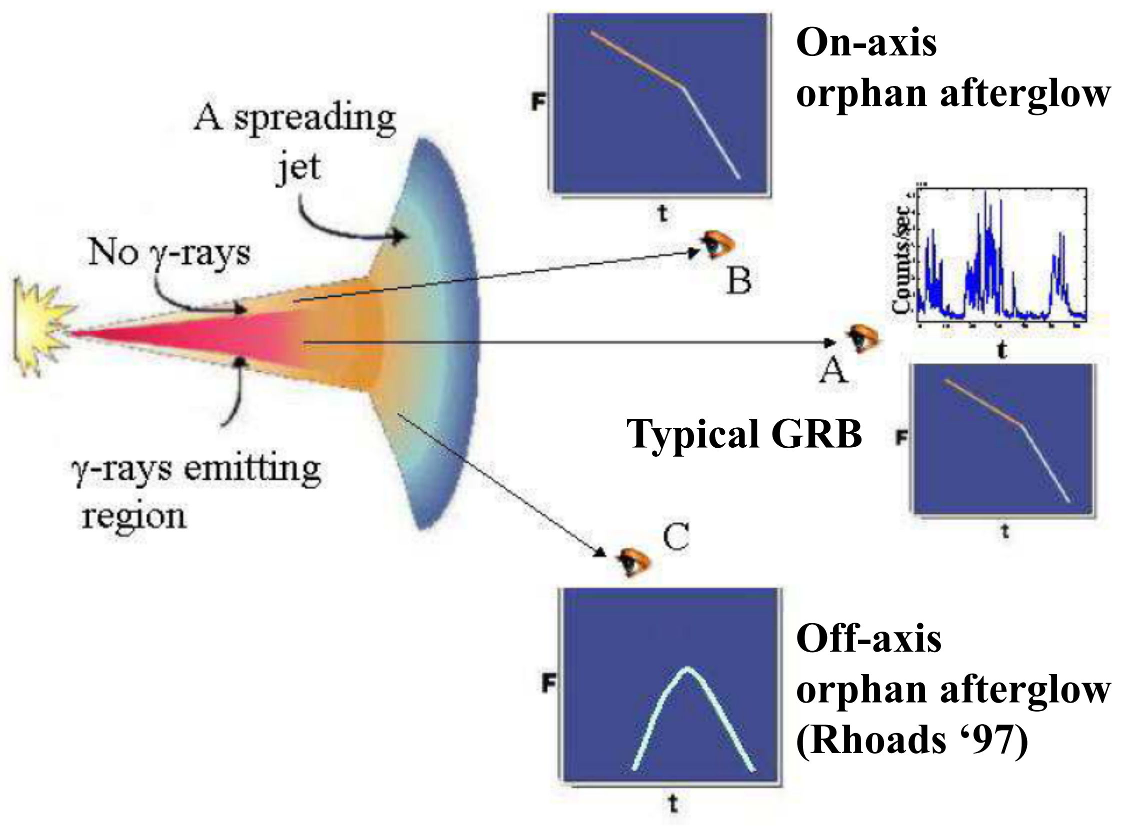
What is the opening angle? Is the outflow patchy? Are there areas within the relativistic outflow that do not emit MeV photons?



During the prompt emission we observe only a tiny patch with an angular size <1/300 rad.

The observed area increases during the afterglow, when the outflow decelerates.

GeV orphan afterglows
(or MeV dark prompt emission)



Advantage (over optical): Large Field of view; Very low contamination

Disadvantage: Small number of photons

How can we significantly increase the sensitivity?

Initiate a joint LAT – XRT search:
Low significance LAT events (say at a rate of 10 false alarms every year) trigger on time scale of a day an XRT search.

The risk is high, but so is the gain!

The prompt emission

Theory should explain:

- Rapid variability
- High (but not too high) efficiency
- multi GeV photons
- Similarity of long and short GRBs
- Spectral evolution
- spectrum:
  - Non-thermal, well fitted by a broken power-law
  - Typical peak at $E_p \sim 0.1$-1 MeV
  - In some cases low energy slope harder than $F_\nu \propto \nu^{1/3}$
  - In some cases show more than one component

There is no accepted model that can explain it all !

What is the prompt emission radiation process?

Even the emission mechanism is unknown.
Fermi detailed spectrum may reveal it

Synchrotron:
The main candidate due to the broken power-law spectrum.

But:

- Cannot produce spectrum harder than $F_\nu \propto \nu^{1/3}$ (a.k.a synchrotron line of death; Preece 98).
- E_p is expected to vary significantly between bursts and probably also within a single burst.
- Maximal photon energy $\sim 50\left(\Gamma/1000\right)\mathrm{GeV}$ (Lyutikov 09)

What is the prompt emission radiation process?

Synchrotron self-Compton:
Ruled out as a general radiation process by the upper limits on optical and GeV emission (Piran et al 08)

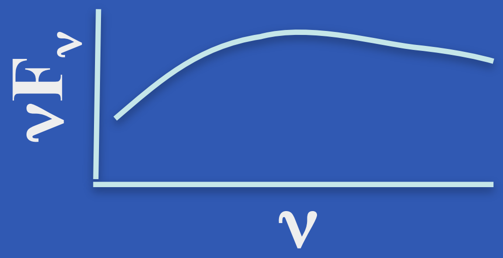
External inverse Compton

- Required highly fine tuning in order to have ~50% efficiency
- What is the external photon source?

What is the prompt emission radiation process?

Comptonized thermal component:
An attractive possibility. Can explain hard low-energy spectrum

We typically observe



We almost never observe

- Comptonization take place just below the photosphere by at most mildly relativistic electrons that carries at least comparable amount of energy to the radiation but has higher temperature .
- Cannot explain additional spectral components

GRB microphysics

What are the microphysical processes that take place during the prompt and afterglow phase:

- How particles are accelerated?
- How strong magnetic fields are generated?
- What is the structure of relativistic unmagnetized collisionless shocks (afterglow)?
- If the outflow is magnetized then how unmagnetized collisionless shocks or relativistic magnetic reconnection works (Prompt emission)?

Fermi may put better constraints of the electron distribution and magnetic field in the emitting regions

Summary

Almost all the detailed processes that takes place during the different phases of GRBs are still unknown

The new window opened by Fermi can potentially help to understand (among other things) the:

- origin of short GRBs
- content of the outflow
- prompt emission radiation process
- GRBs microphysics
- The angular structure of the outflow

I hope that the LAT team will be able to initiate a joint search with Swift for low significance LAT triggers