The origin of GeV emission in Gamma-Ray Bursts

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Common properties of the LAT emission:

✓during the usual prompt emission (=emission seen by the GBM in the keV-MeV range)

✓small delay (few seconds or less) compared to the prompt

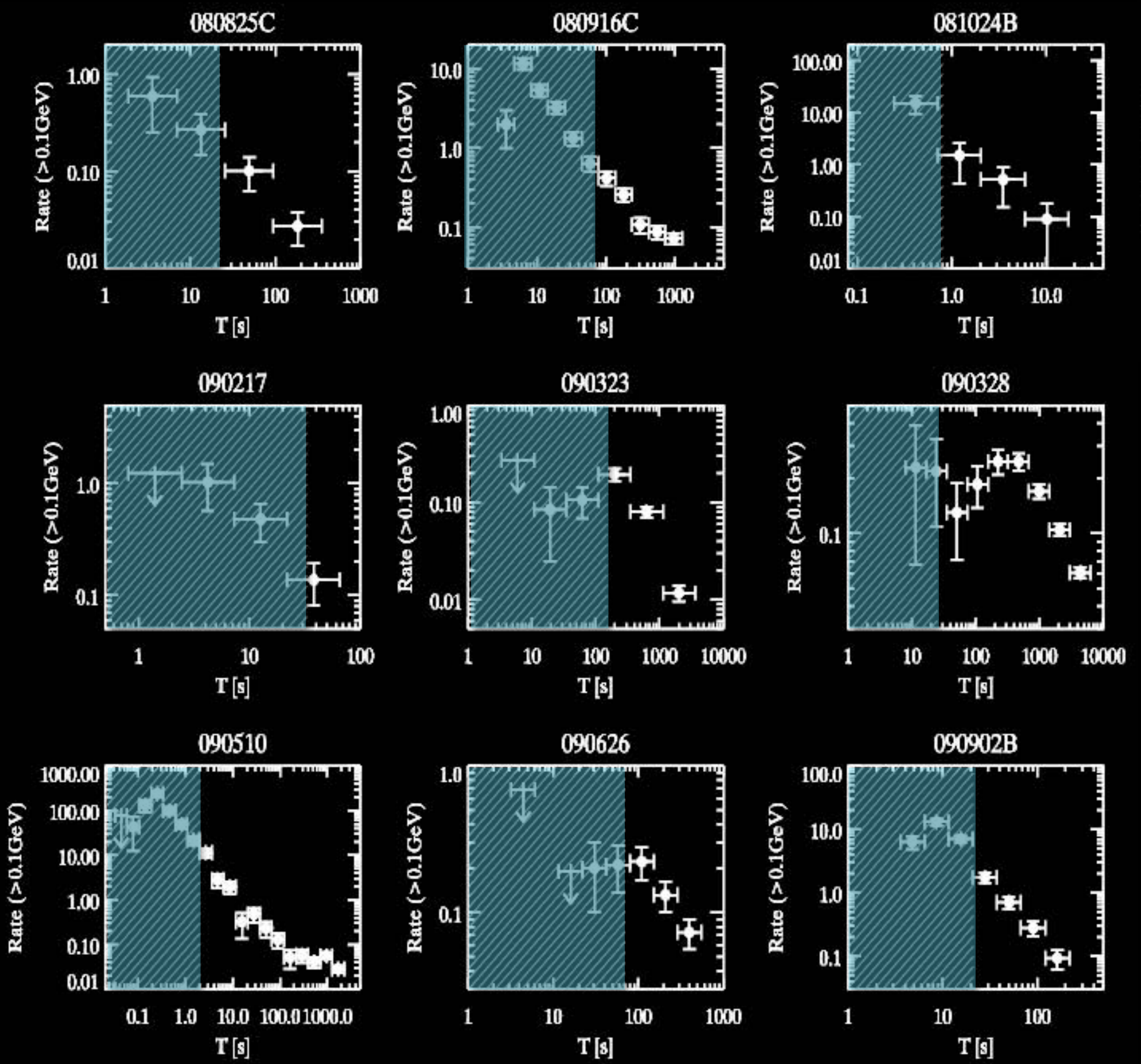
✓long lasting

Origin of the high-energy emission?

Other common features?

Spectral and temporal analysis

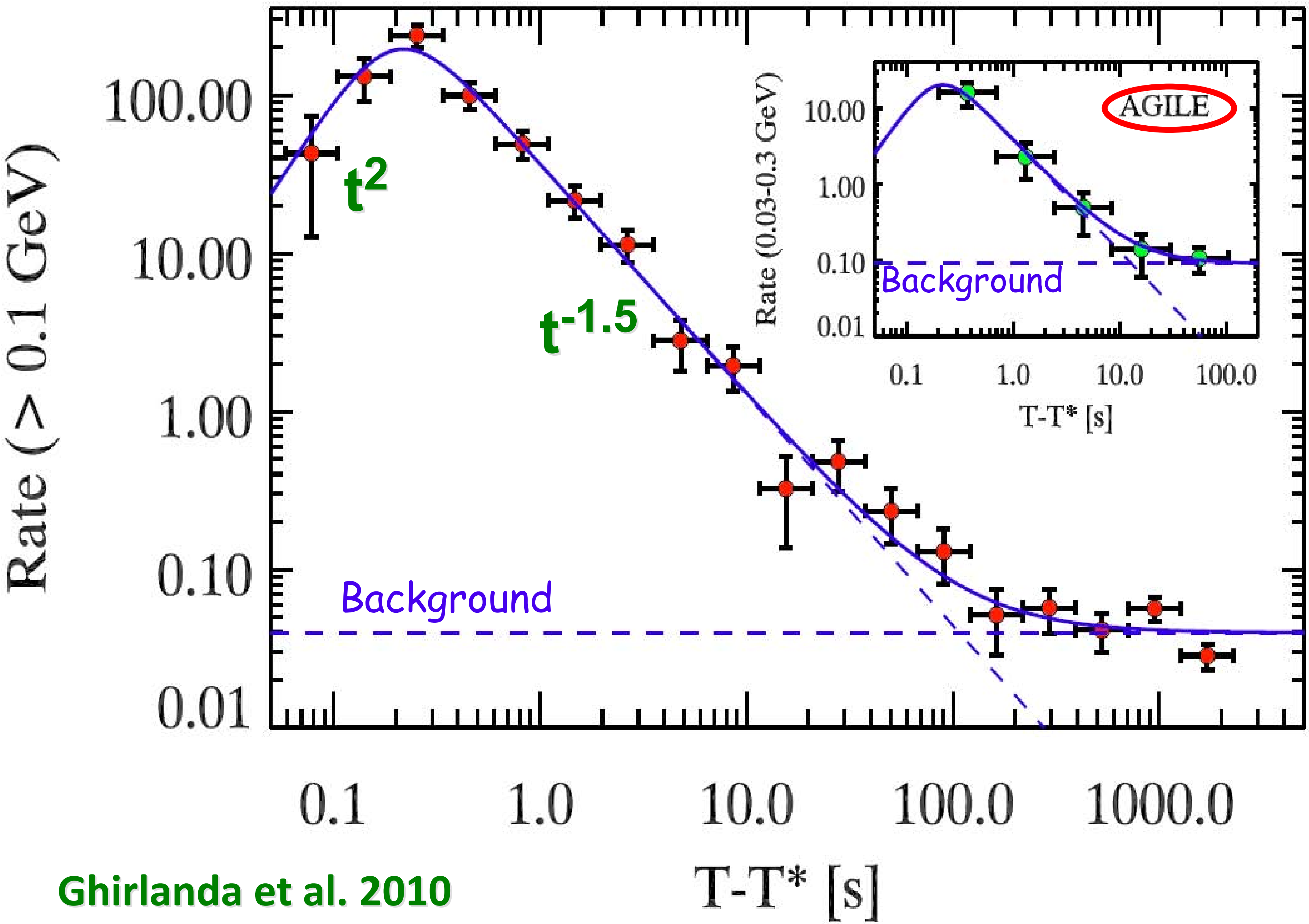
of all bursts with LAT detection
as of Oct. 2009 (11 GRBs – 9 long and 2 short)



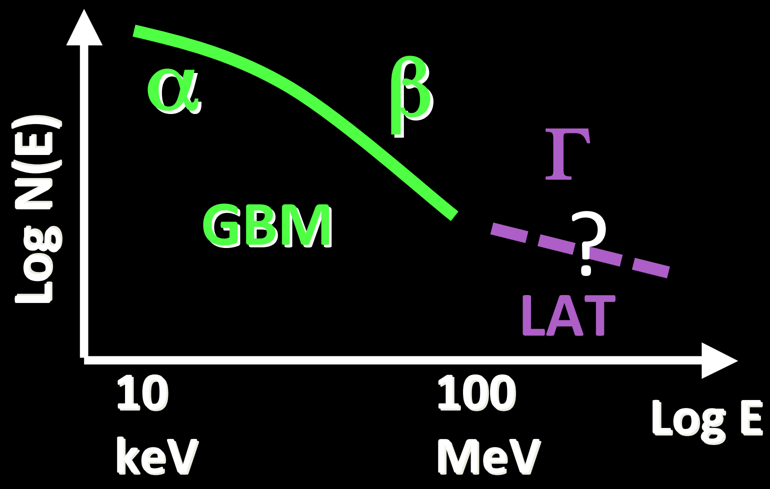
All LAT GRB lightcurves

Ghisellini + 2010

GRB 090510

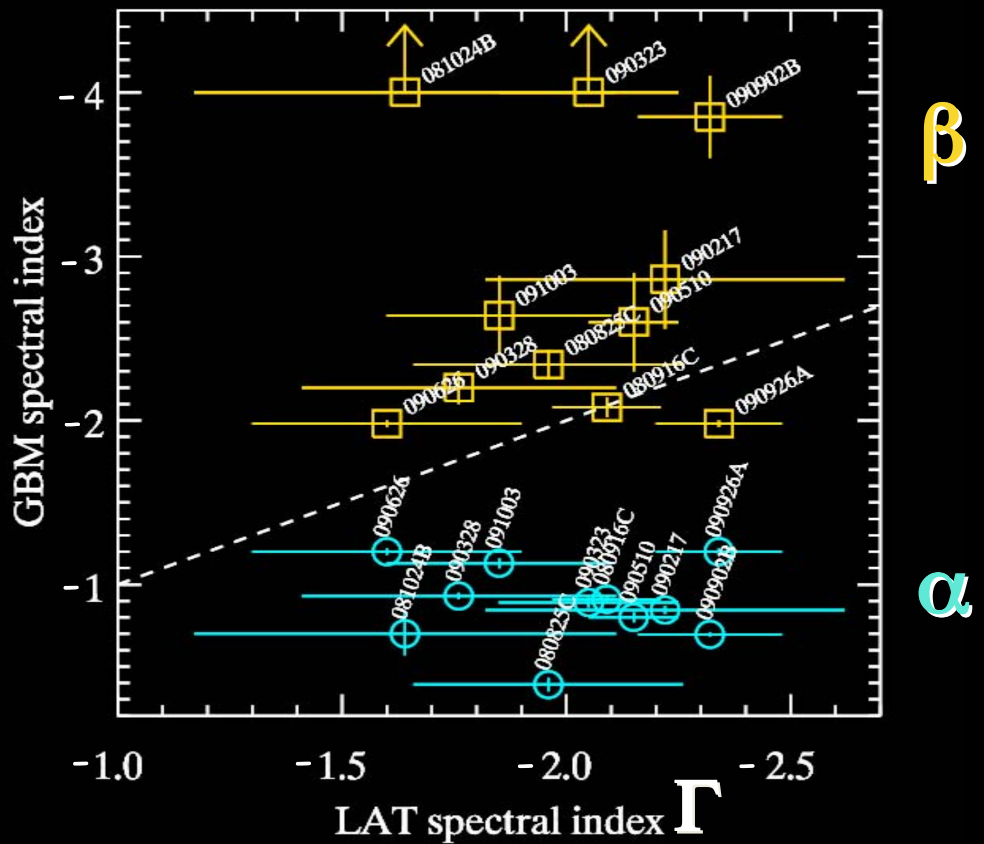


Ghirlanda et al. 2010

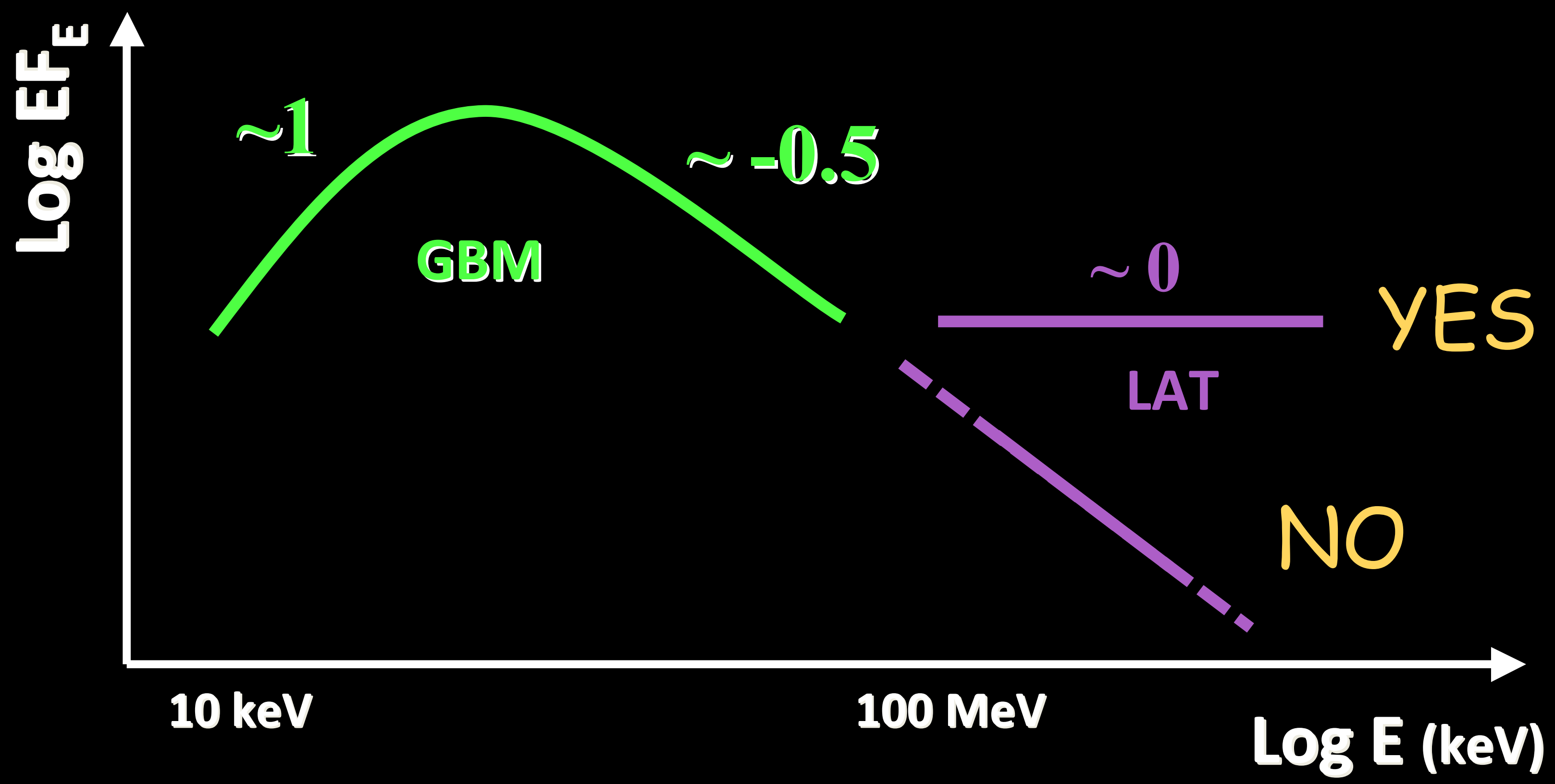


Comparison

α vs Γ and β vs Γ

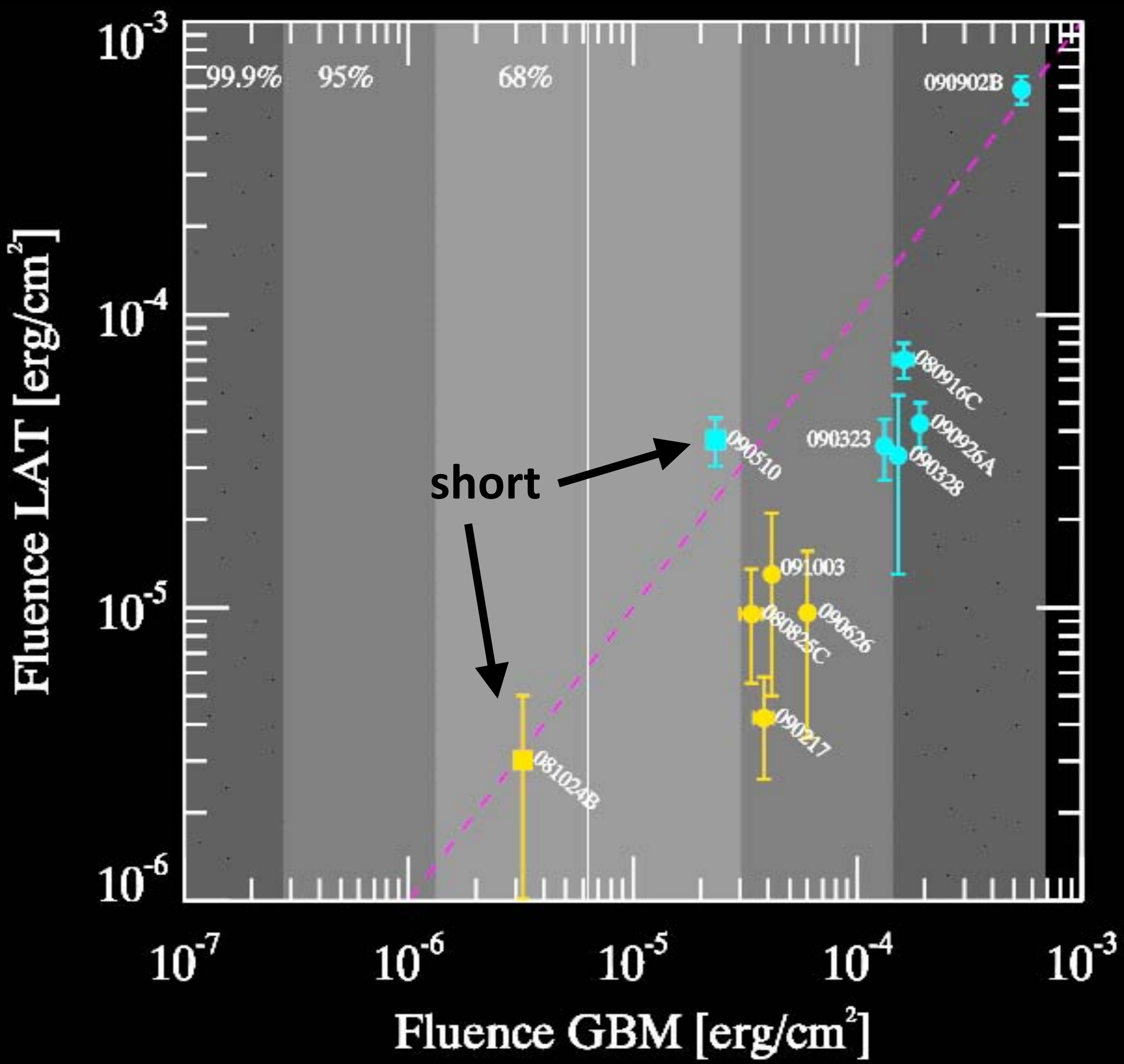


GBM and LAT spectra



Two different components !

GBM vs LAT fluences



Grey regions: GBM fluence distribution of all Fermi bursts

Bursts with redshift

Bursts without redshift

Ghisellini et al. 2010

Spectra

GBM and LAT *inconsistent* → suggest *different component*

Light curves

✓*smooth* ✓*peaked* ✓*similar decay* ✓*long lasting*

⇩

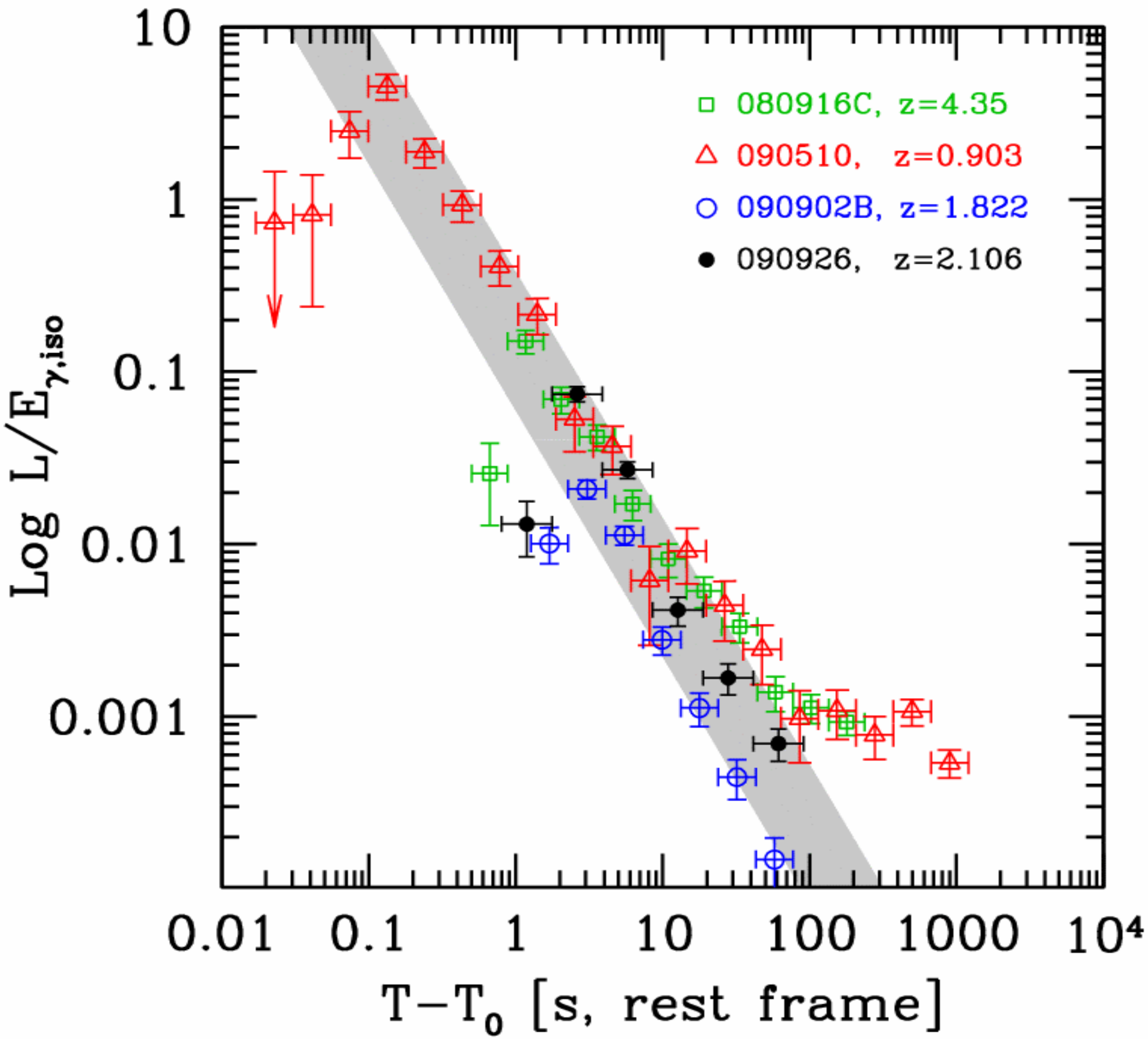
same origin as the X-ray and Optical afterglow:

-- External Shocks --

synchrotron emission from forward shocks

(Kumar & Barniol Duran 2009, 2010; Gao et al. 2009;
Corsi, Guetta & Piro 2010; De Pasquale et al. 2010)

Consistency check 1 - Peak time



4 brightest GRBs (with redshift)

t_{peak} (rest frame) all between 0.15 - 3 sec

Consistency check 1 - Peak time

$$t_{peak}^{rest} \approx 0.3 \left(\frac{E_{k,53}}{\Gamma_3^8 n} \right)^{1/3} seconds$$

E_k = initial kinetik energy of the fireball

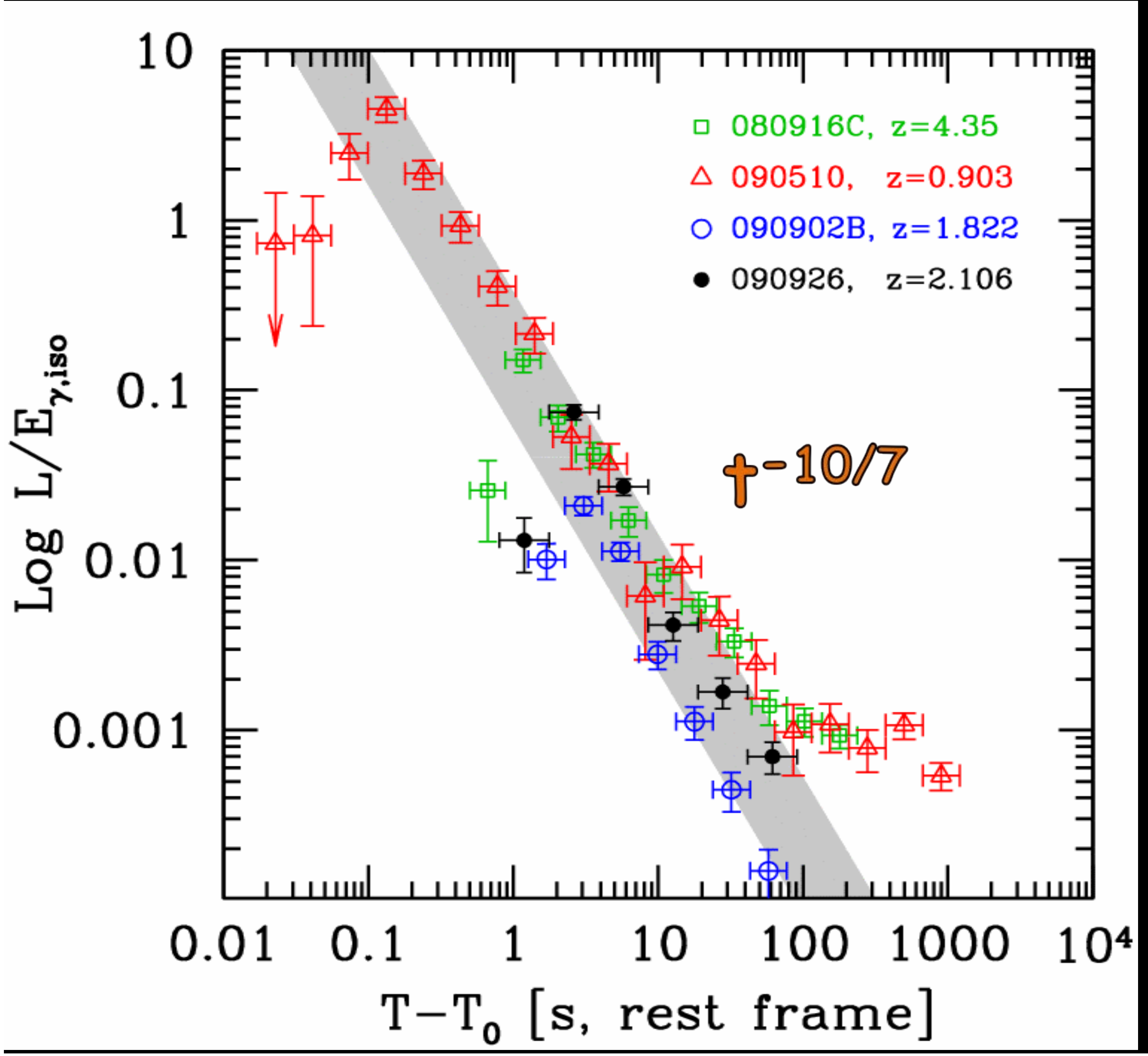
Γ = initial bulk Lorentz factor

n = ISM number density (uniform medium)

Measure of the peak time ⇨ Estimate of Γ

Γ between 600 and 2000 for the 4 brightest bursts

Consistency check 2 - Decay

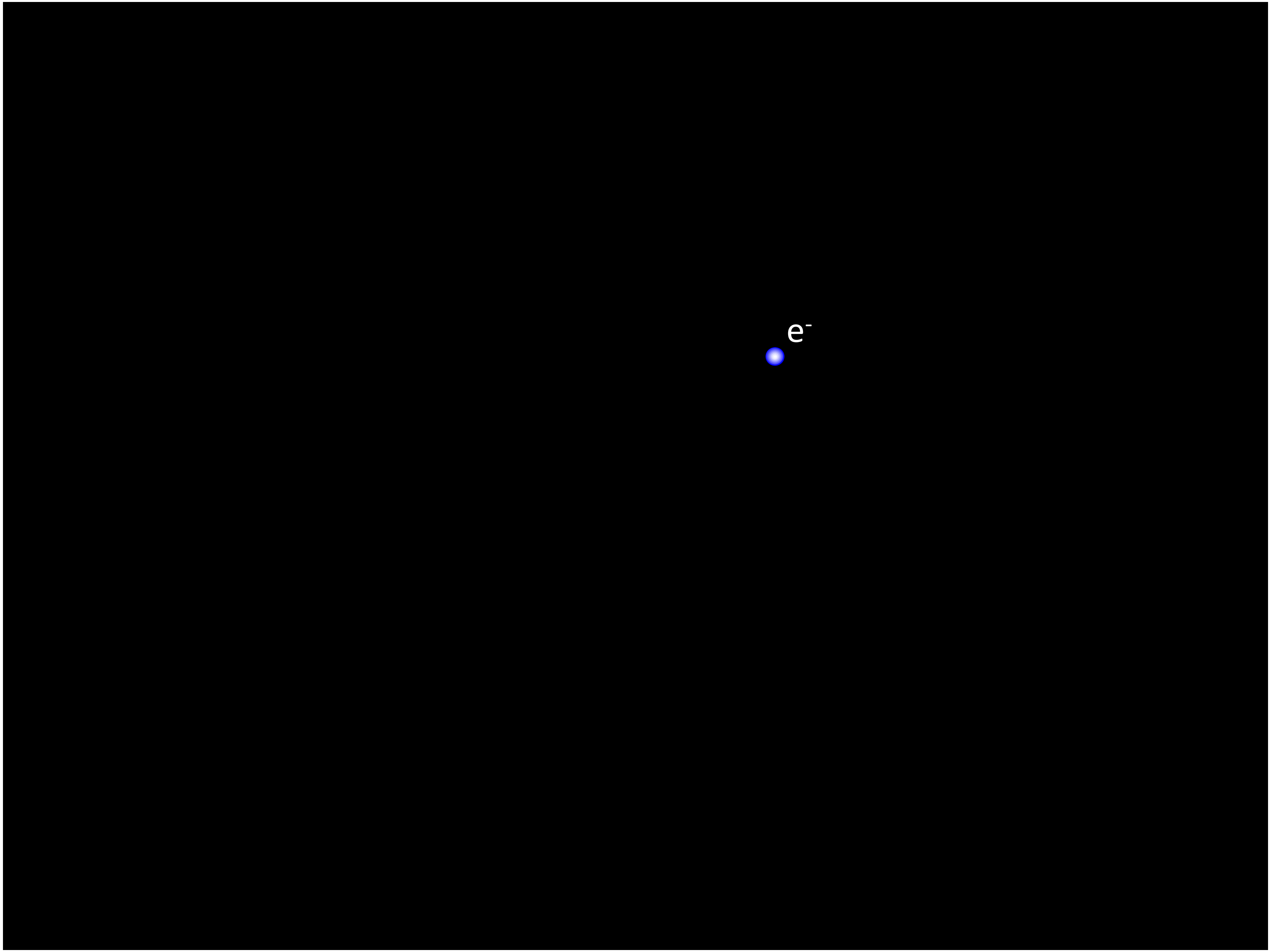


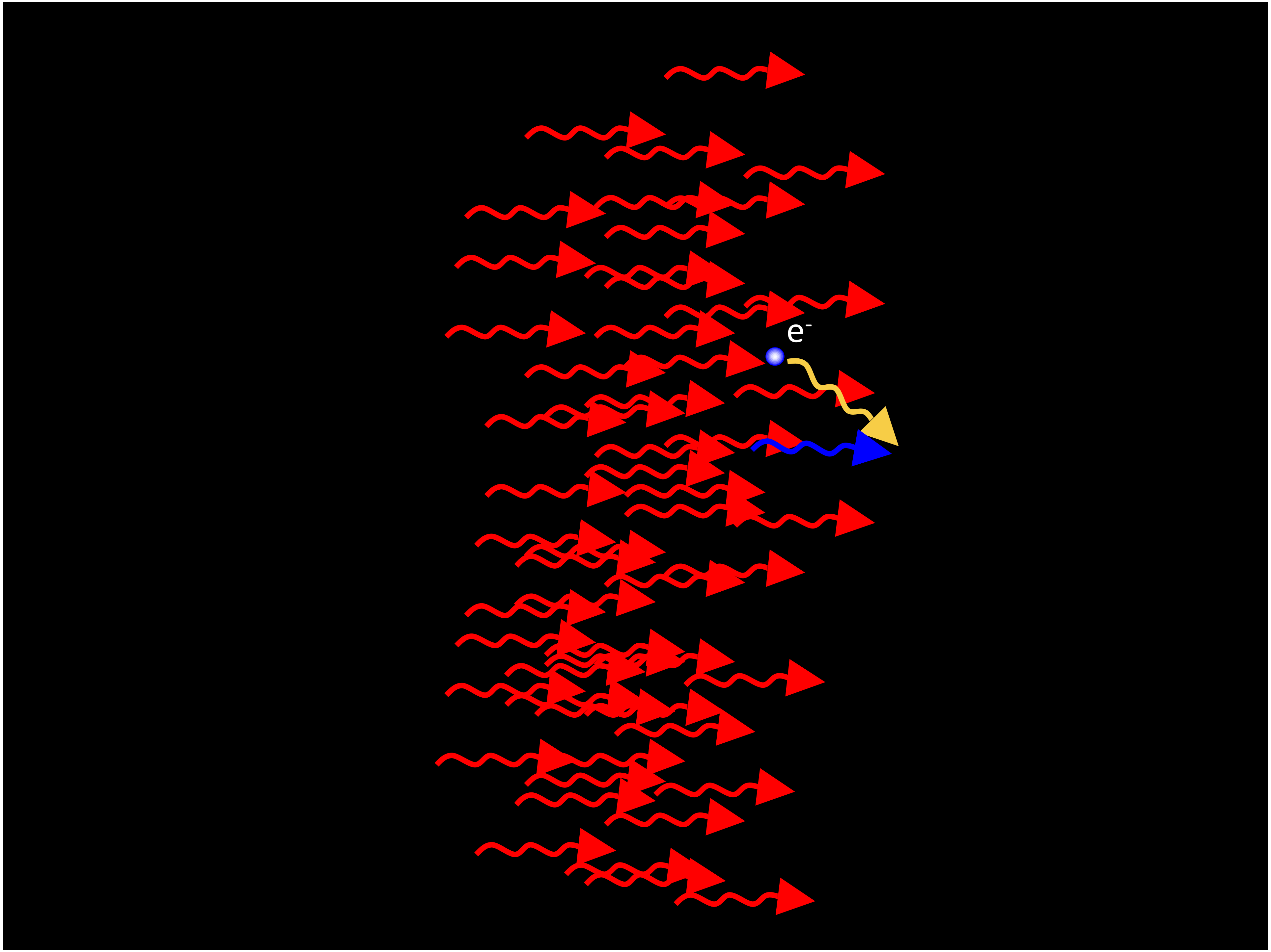
"standard" adiabatic afterglow:

t^{-1}

radiative afterglow:

$t^{-10/7}$


e-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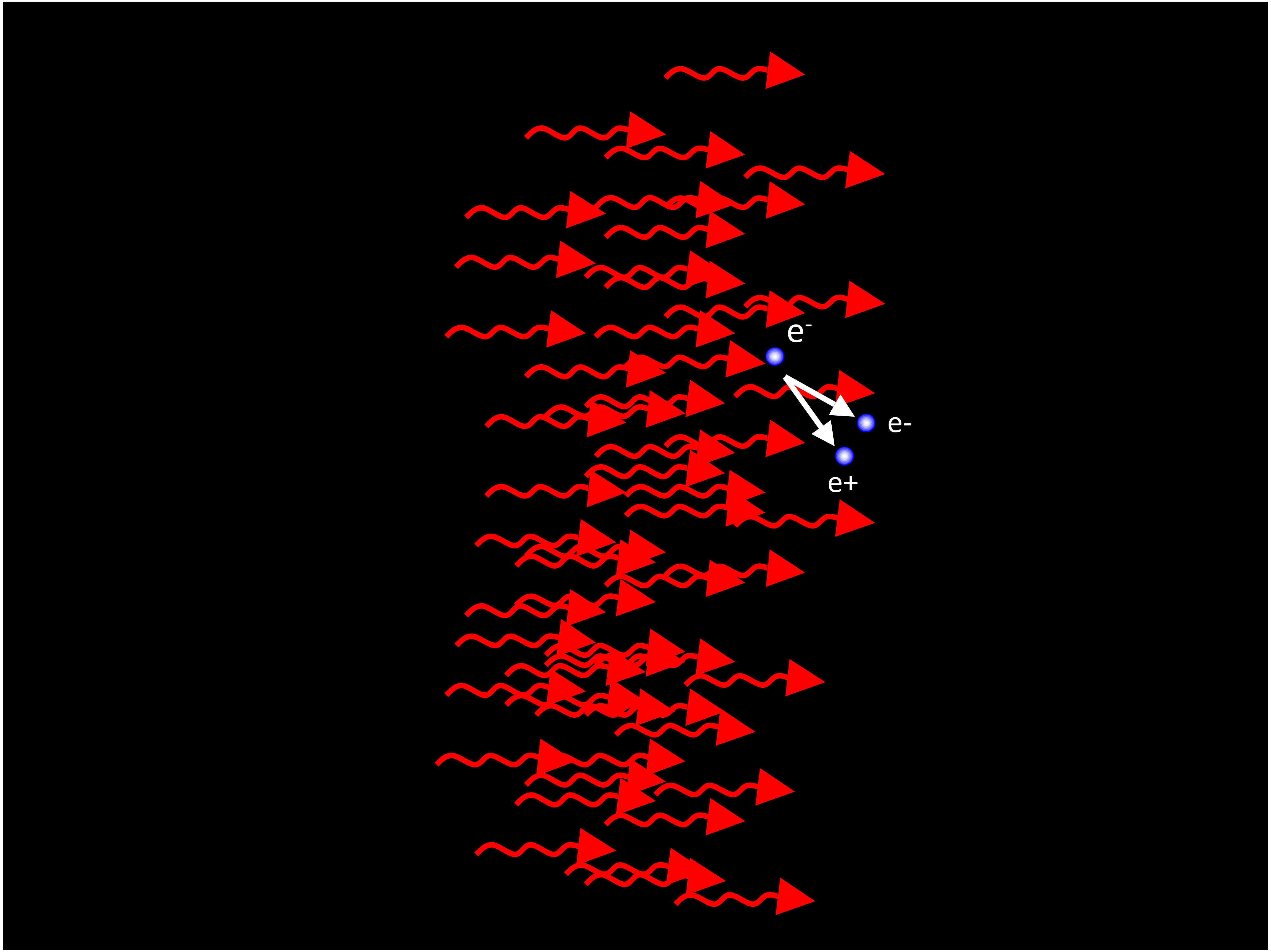
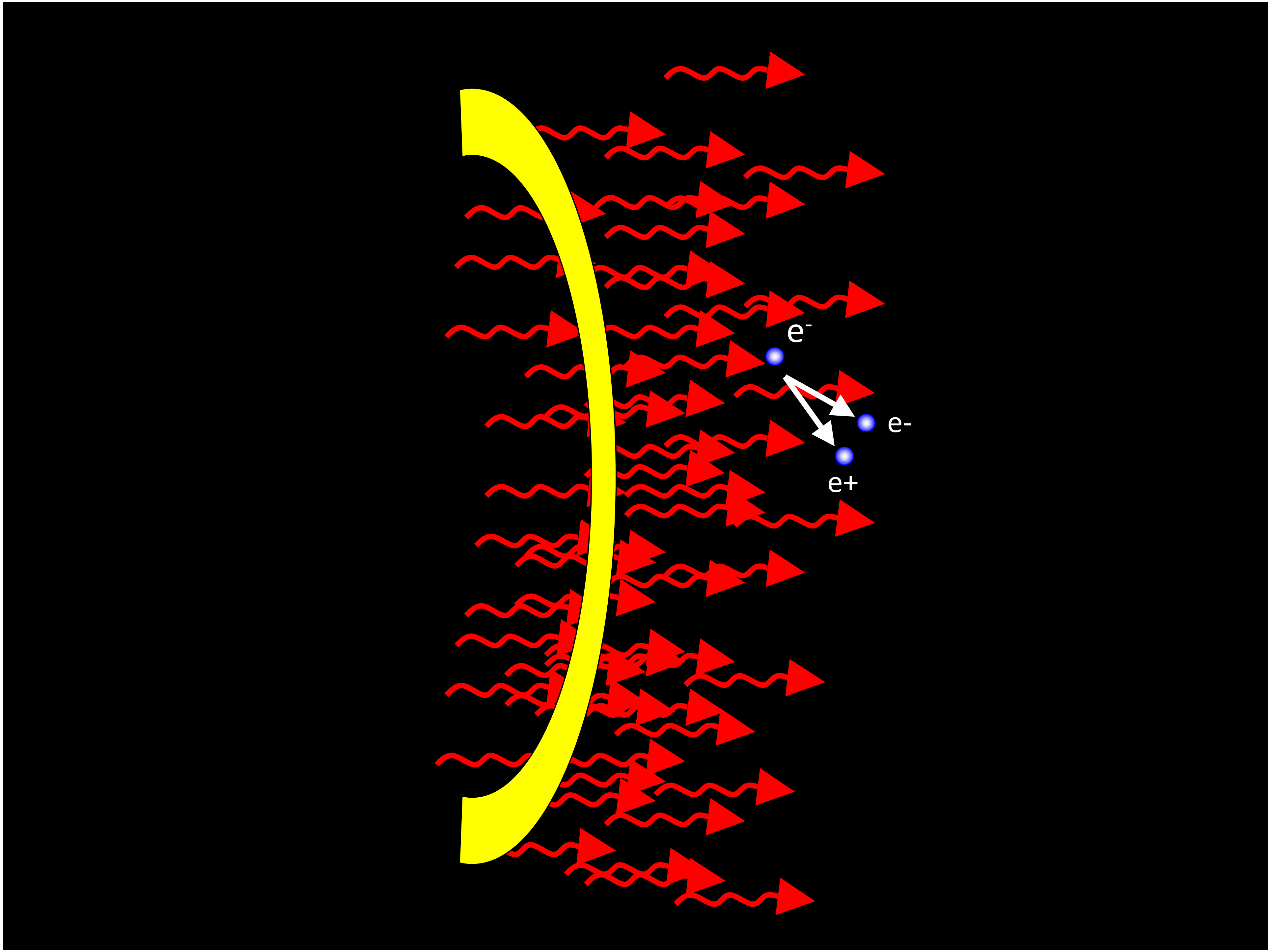
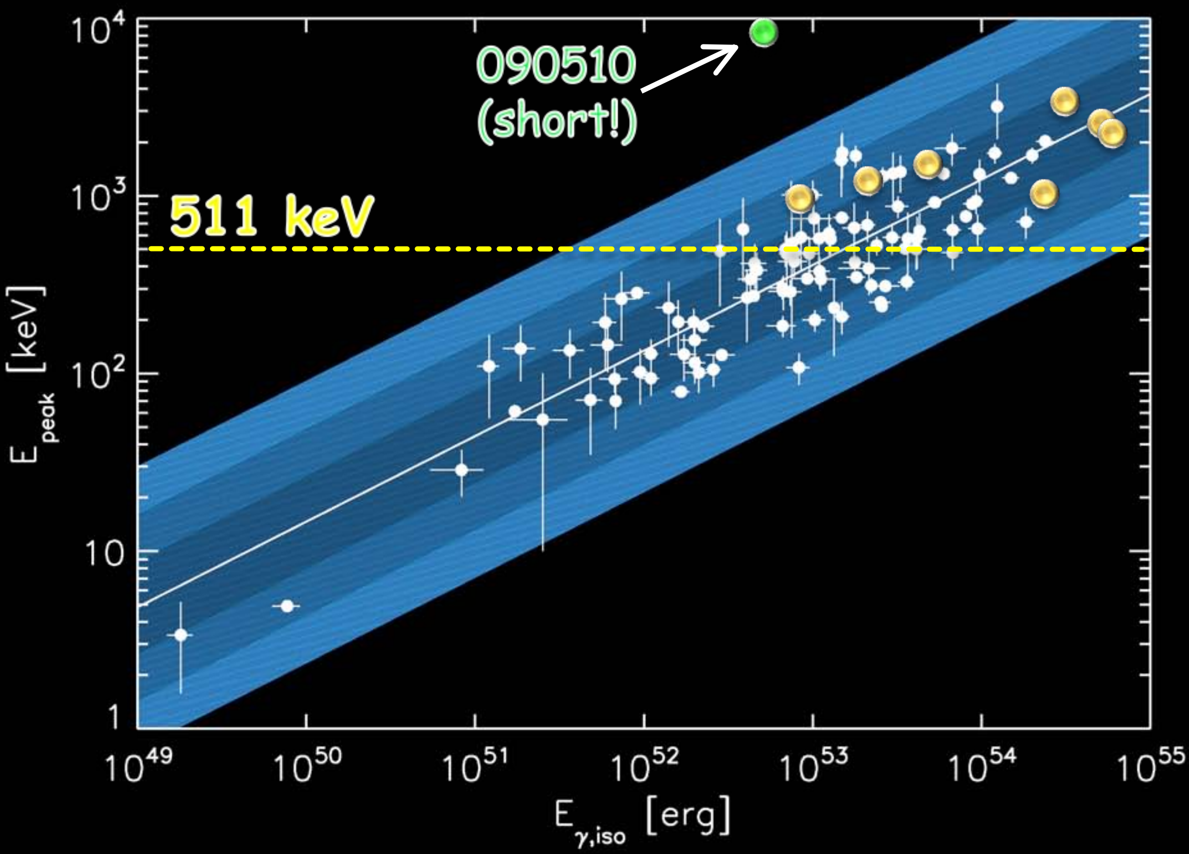

e-
e-
e+


e-
e-
e+

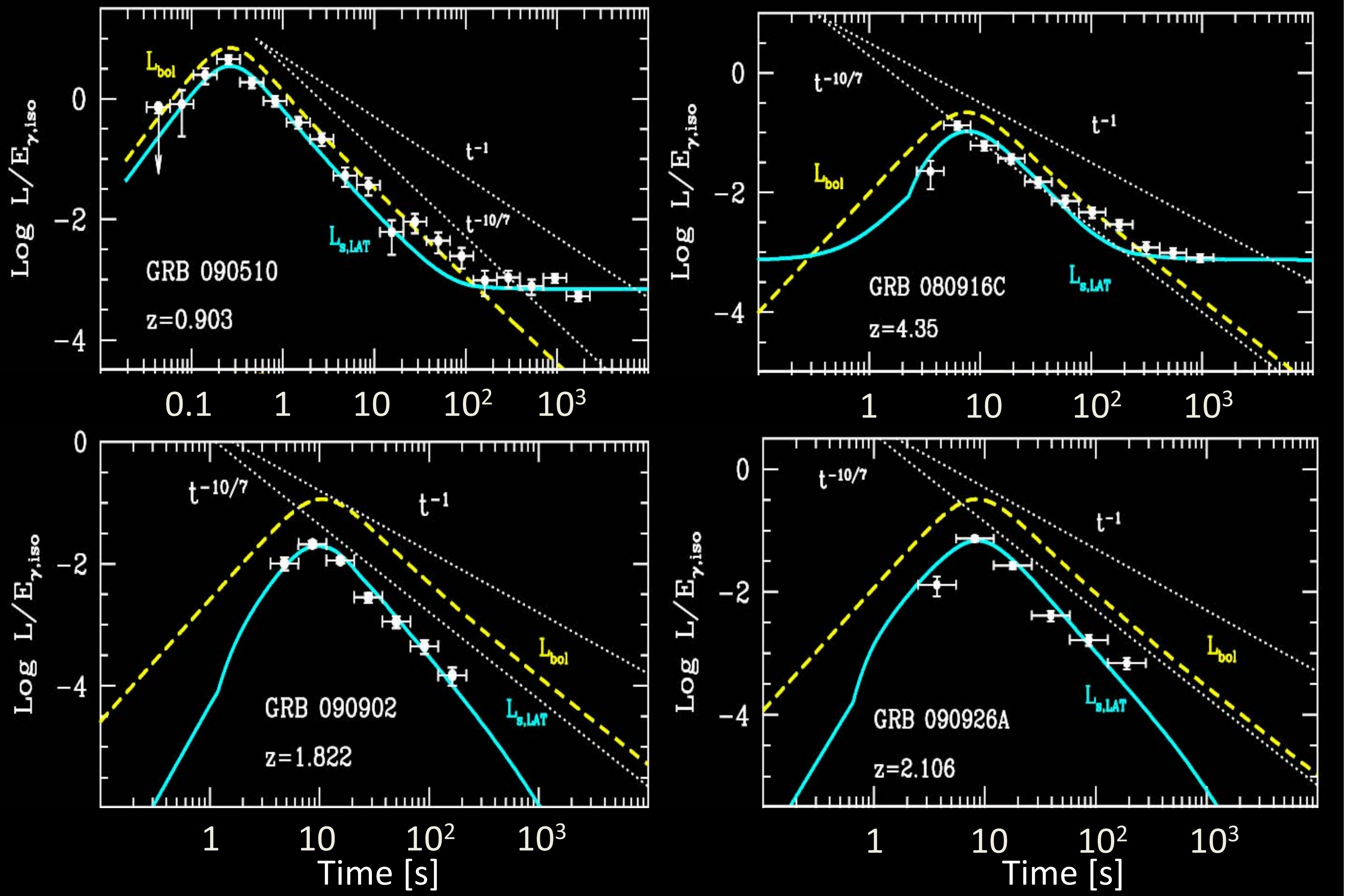
Consistency check 3 - Pair enrichment

If pair enrichment is required
GeV detected GRBs should be the ones with

$$E_{peak} > m_e c^2 > 511 \text{ keV}$$



Radiative + pairs: lightcurve modeling



Conclusions

- When Γ is large → early onset of the afterglow → very bright → Fermi/LAT detection
- E_{aft} increases: it helps to understand E_{prompt}/E_{aft}…but still it does not solve the problem
- Decay suggests radiative afterglows
- GeV preferentially in E_{peak}>511 keV GRBs

[redacted]

Problems

Fast variability of the GeV emission (Abdo+ 2009).
No evidence

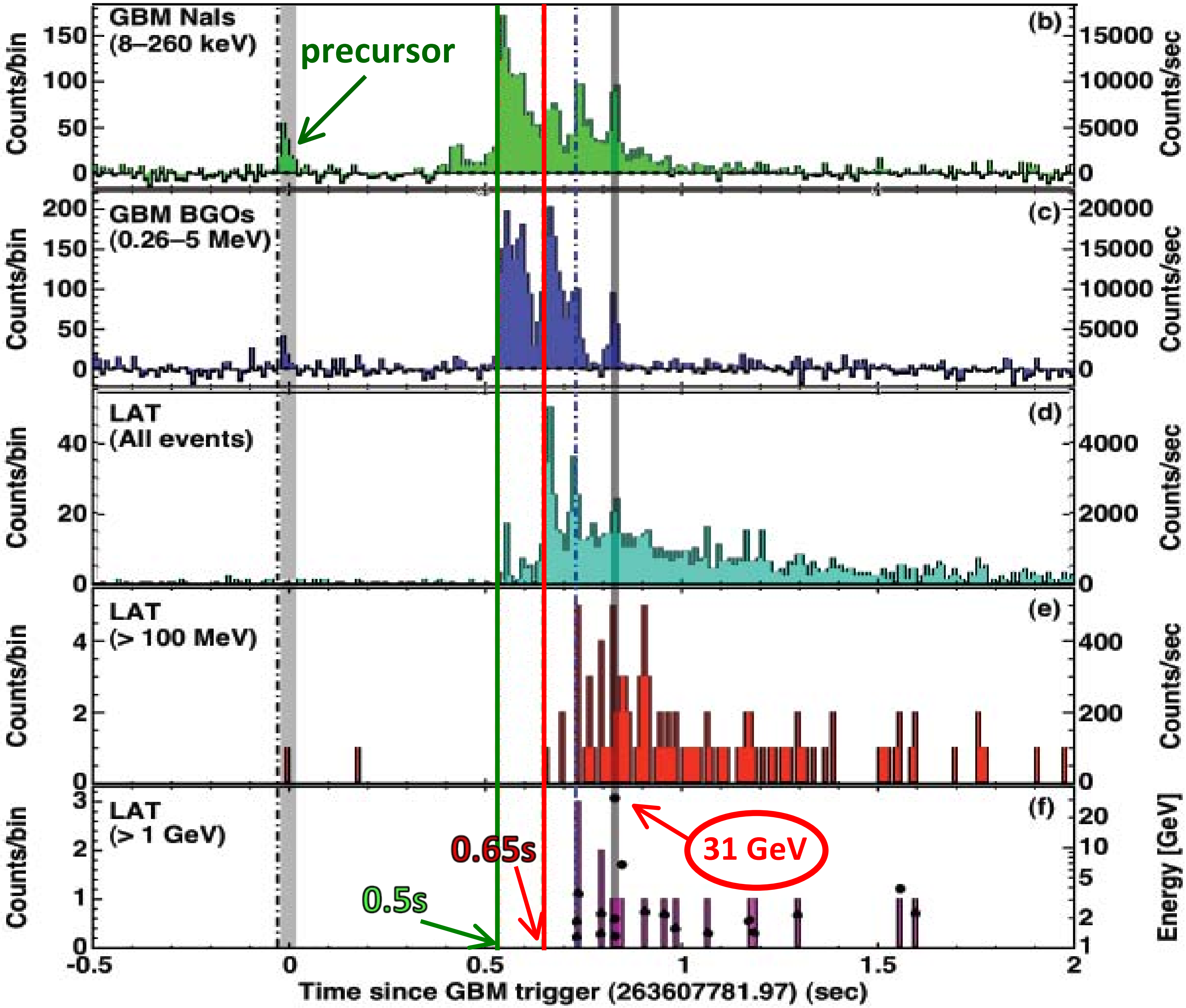
Simultaneous GBM-LAT spikes (Ackermann+ 2011; Zhang+ 2011
EC scattering of prompt photons? Numbers are ok

LAT spectra on the extrapolation of GBM spectra (Zhang+ 2011; with exceptions)
If fitted together (but LAT emission lasts longer…)

Highest energy photons that arrive after the peak of the LAT light curve are too energetic to be synchro (Piran & Nakar 2010).
Very few, possible additional component (SSC)?

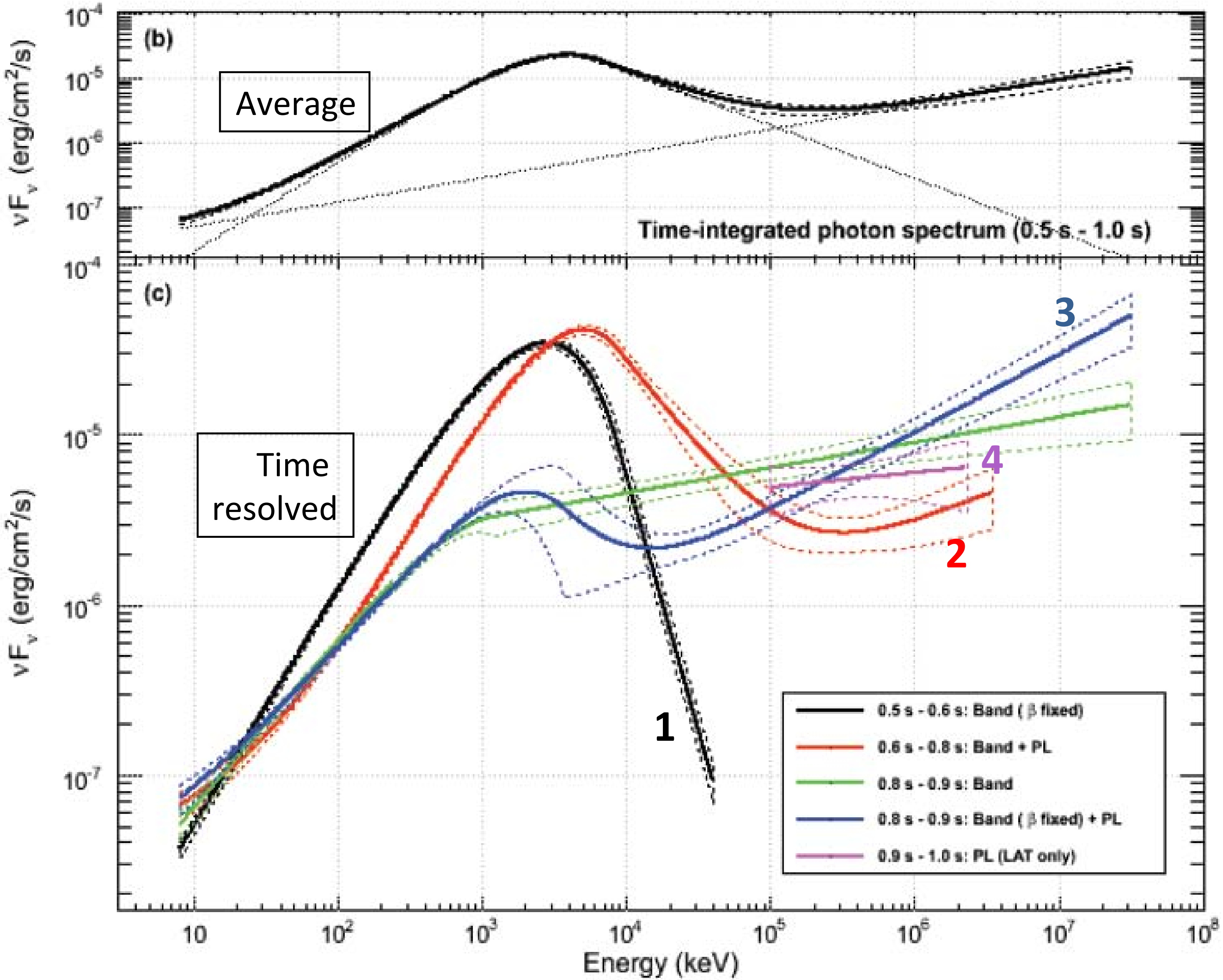
GRB 090510

- Short
- Very hard
- z=0.903
- Detected by the LAT up to 31 GeV!!
- Well defined timing
- Delay: ~GeV arrive after ~MeV (fraction of seconds)
- Quantum Gravity? Violation of Lorentz invariance?



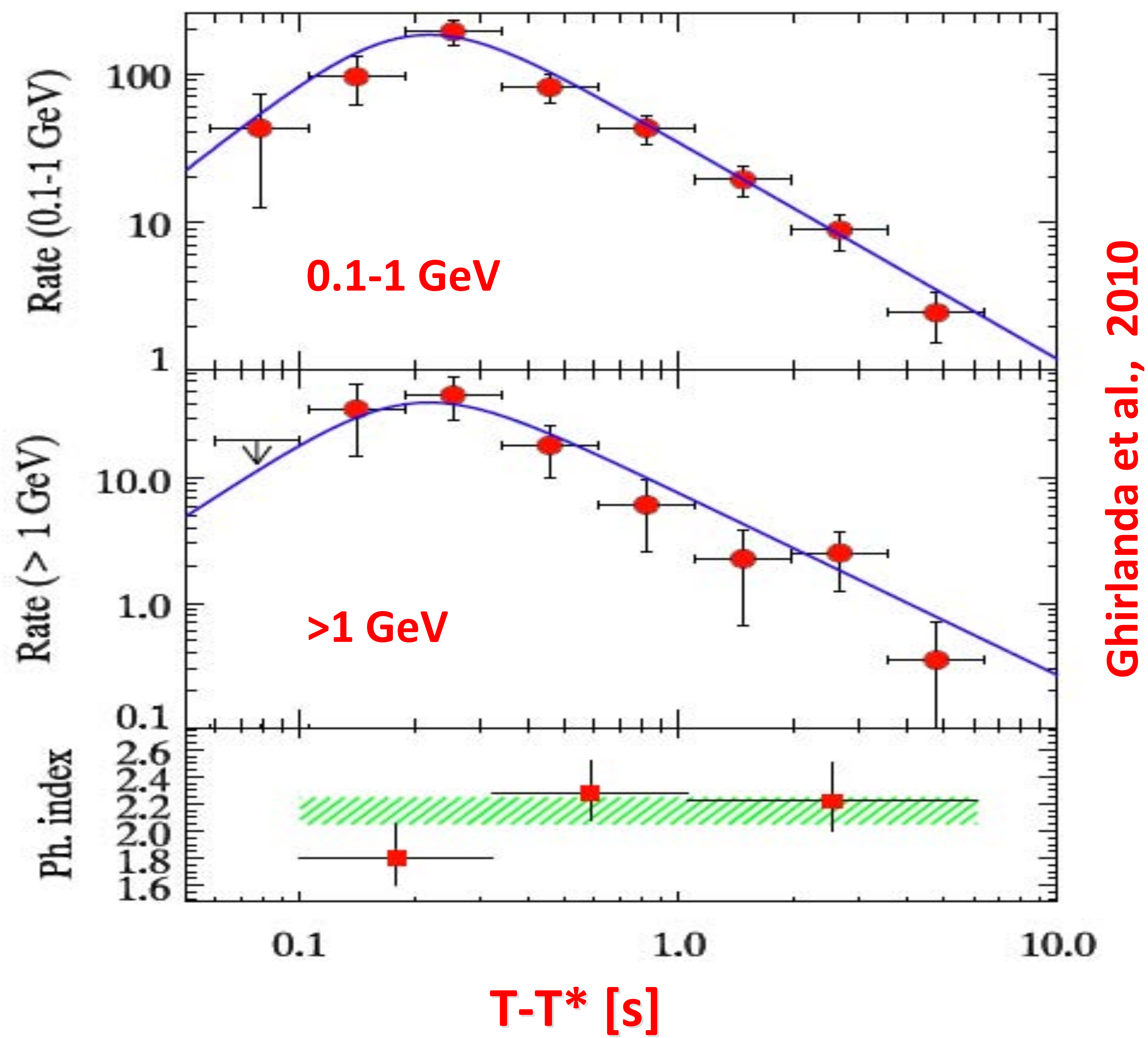
GRB 090510 lightcurve

Abdo et al., 2009

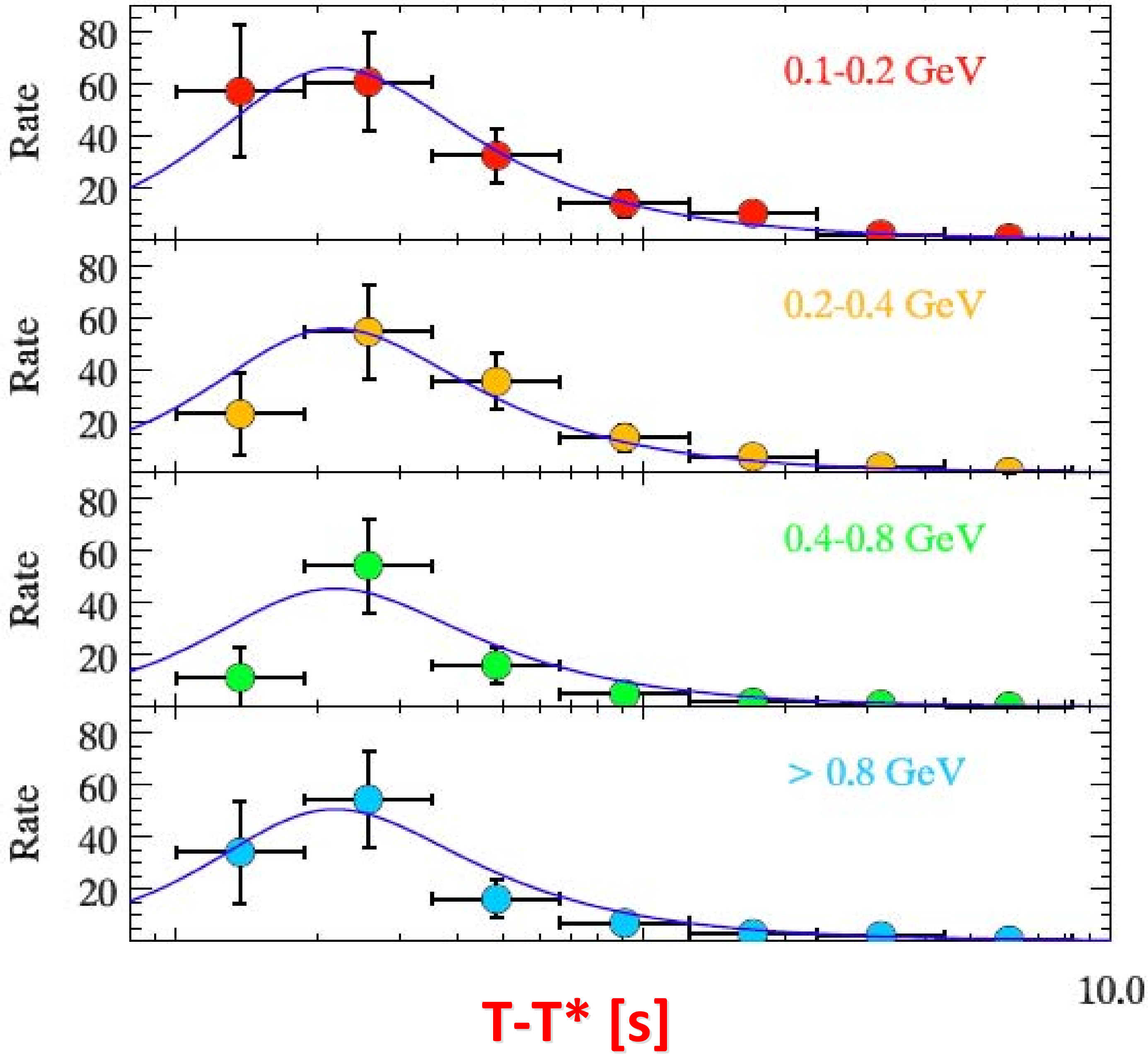


GRB 090510 spectrum

Abdo et al., 2009



Rate (0.1-1 GeV)
100
10
1
0.1-1 GeV
Rate (> 1 GeV)
10.0
1.0
0.1
>1 GeV
Ph. index
2.6
2.4
2.2
2.0
1.8
1.6
0.1
1.0
10.0
T-T* [s]
Ghirlanda et al., 2010



Ghirlanda+ 2010

If LAT and GBM radiation are cospatial: Γ>1000 to avoid photon-photon absorption

If Γ>1000: deceleration of the fireball occurs early → early afterglow!

If Γ>1000: large electron energies → synchrotron afterglow!

We expect an early, high energy afterglow!

~MeV and ~GeV emission are NOT cospatial

But the ~GeV emission is...

No measurable delay in arrival time of high energy photons: t_{delay}<0.2 s

Strong limit to quantum gravity →

$M_{QG} > 4.7\ M_{Planck}$

GeV detected GRBs should be the ones with the largest Lorentz factors

For smaller Γ:

$$t_{peak}^{rest} \approx 150 \left(\frac{E_{k,53}}{\Gamma_2^8 n} \right)^{1/3} seconds$$

A factor ~10^3 dimmer in luminosity, but if nearby…