GRBs with Fermi - The implications of the high energy observations

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(E. Nakar, P. Kumar, R. Sari, Y. Fan, Y. Zou, F. Genet, D. Guetta, D. Wanderman, P. Biniamini)

- **Fermi’s new feature is the fantastic spectroscopic range.**

The Questions:

- **What is the emission mechanism of the prompt GRB emission?**
- **What is the origin of the high energy emission?**
- **What is the Lorentz factor of the emitting regions?**

The expectations

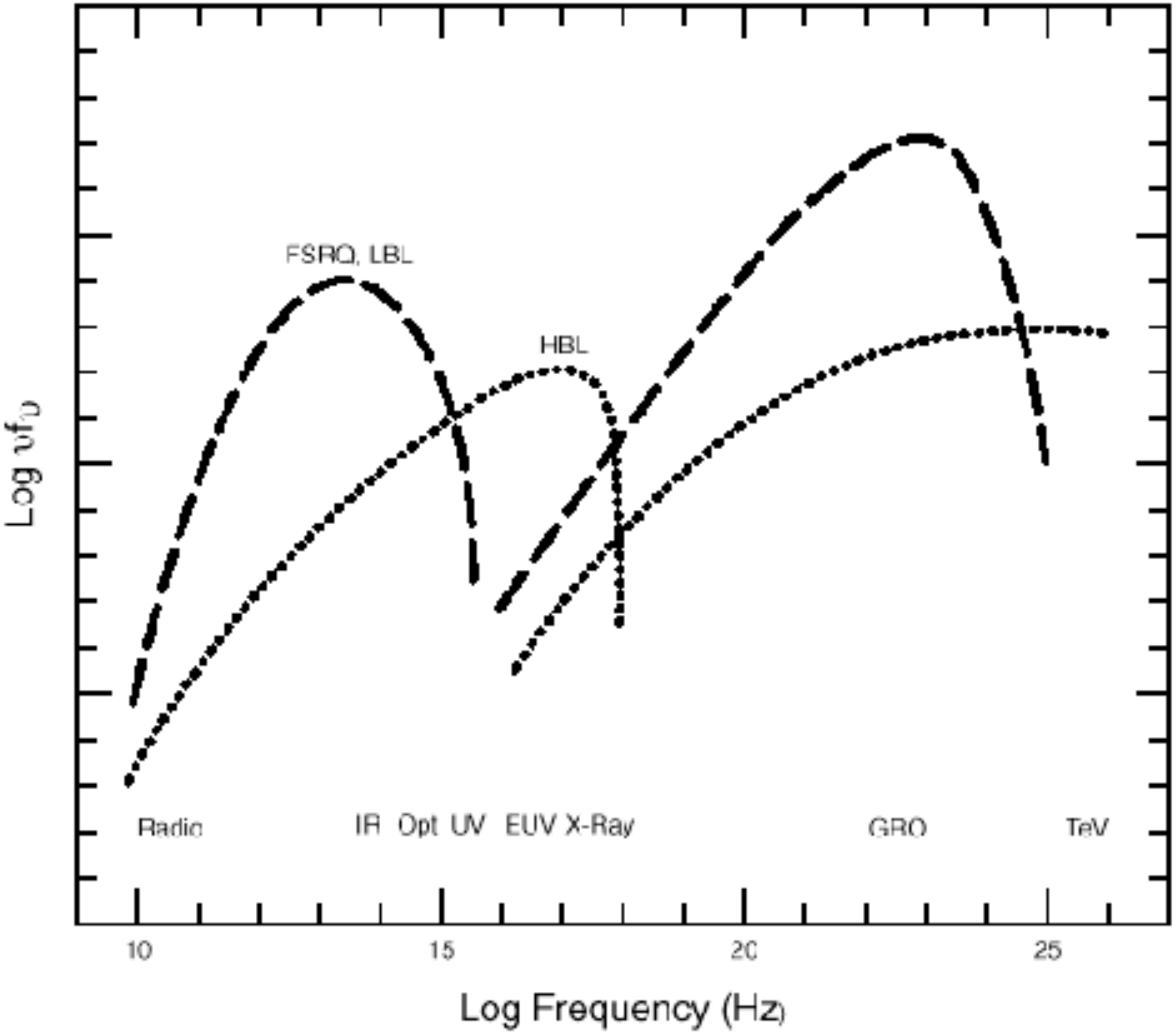
- We observe prompt (sub) MeV emission.
- We expect a second high energy Inverse Compton component.

$$\nu_{ic} = \gamma^2 \nu_{MeV} \quad \Leftrightarrow \quad 5GeV = (\gamma/100)^2 500keV$$

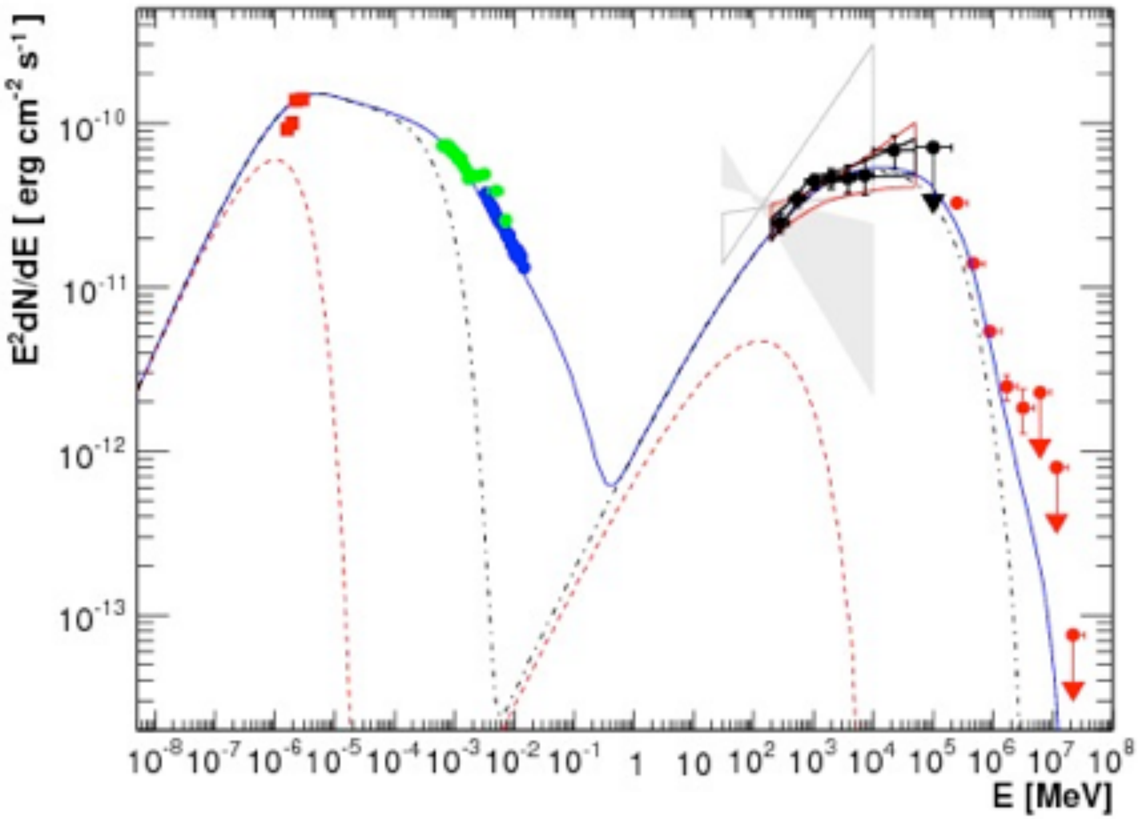
$$\nu_{ic} F_{ic} = Y \nu_{MeV} F_{MeV} \quad \Leftrightarrow \quad (\nu F)_{5GeV} = Y(\nu F)_{500keV}$$

$$Y = \gamma^2 \tau$$

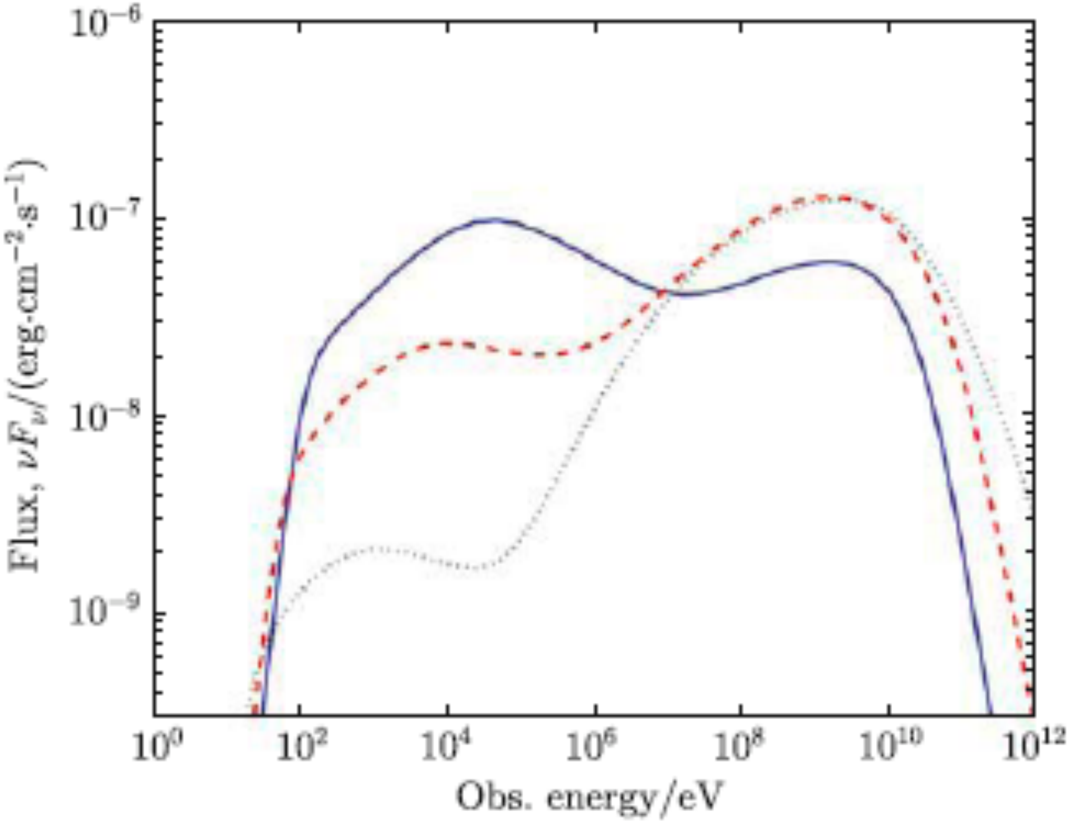
A Blazar spectrum



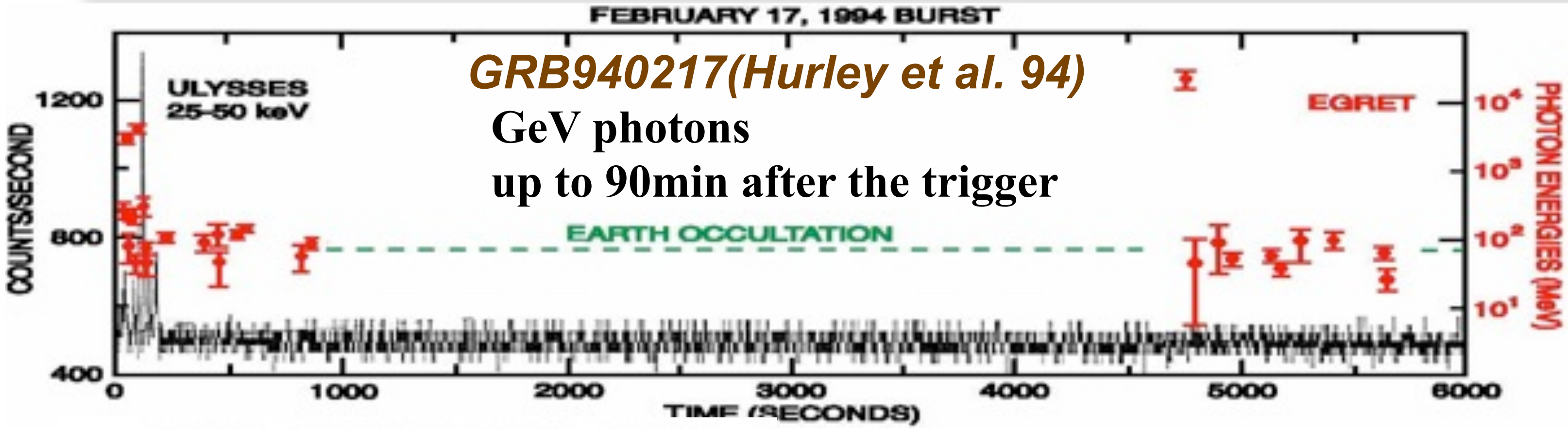
Fermi- H.E.S.S. Observations of a PKS 2155-304



Expectations for the prompt spectrum (e.g. Pe'er & Waxman 2004)

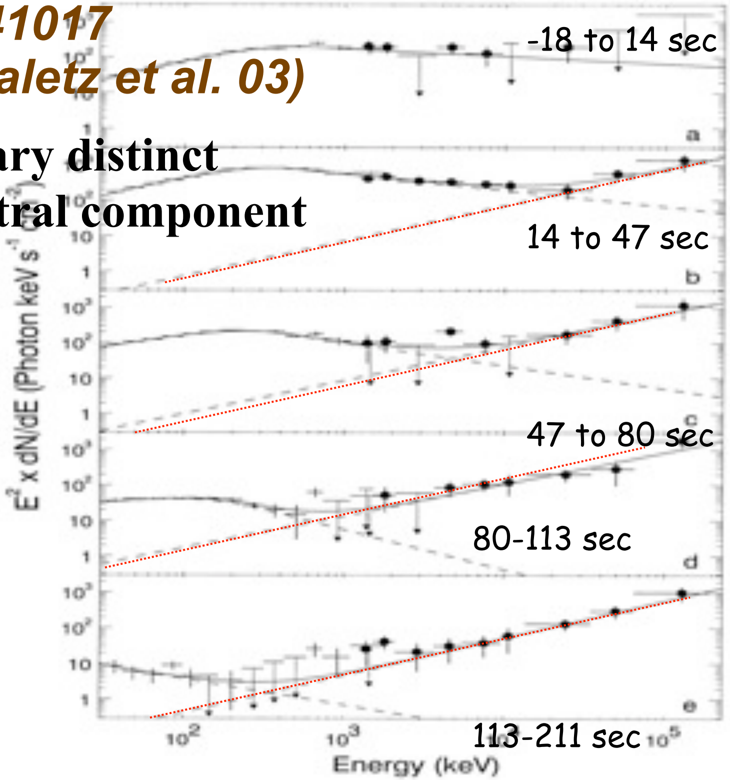


HE emission from GRBs : Pre-Fermi



GRB941017 (Gonzaletz et al. 03)

Temporary distinct HE spectral component

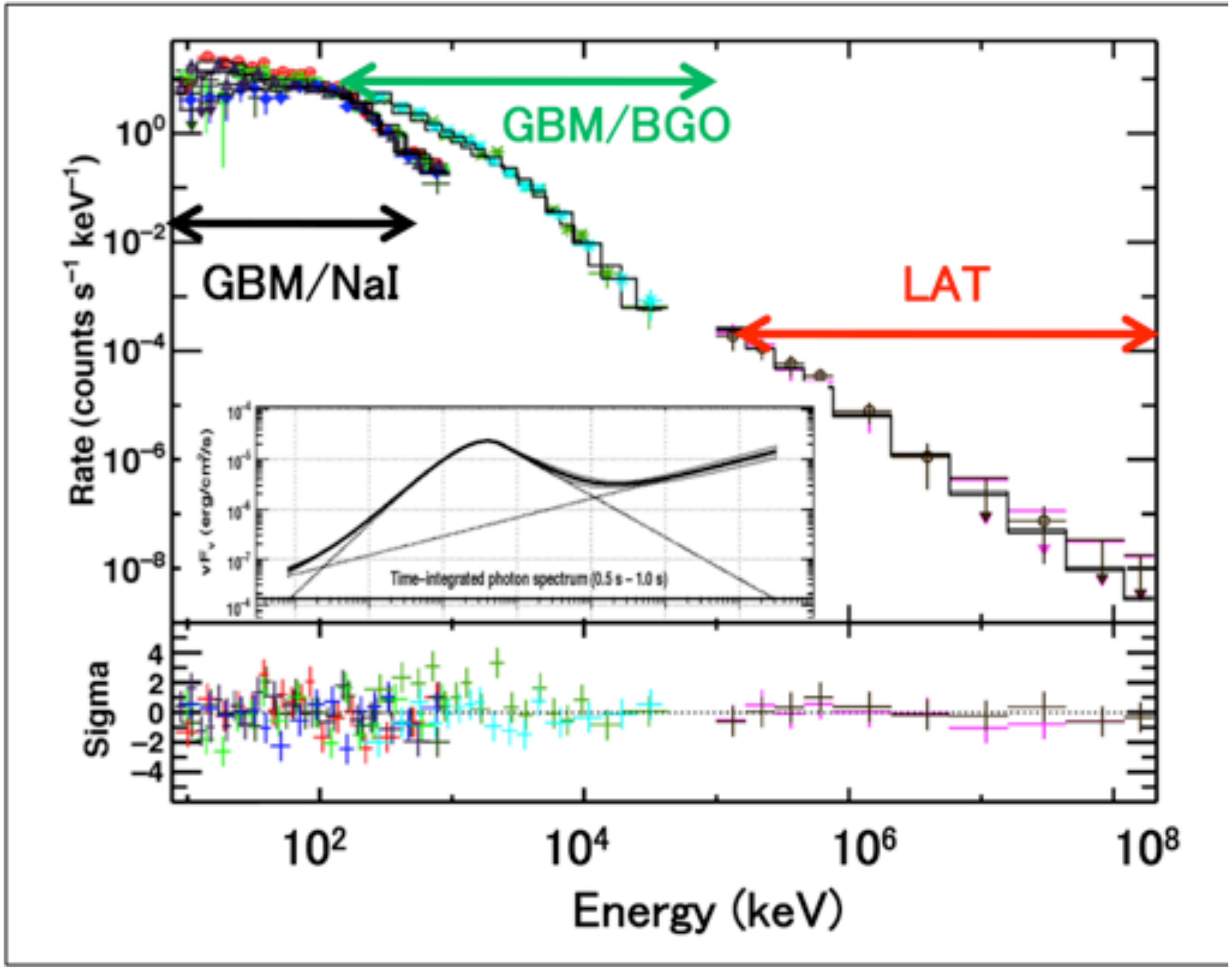


- Many observations in keV-MeV
- Little is known about HE (>100 MeV) emission from GRBs

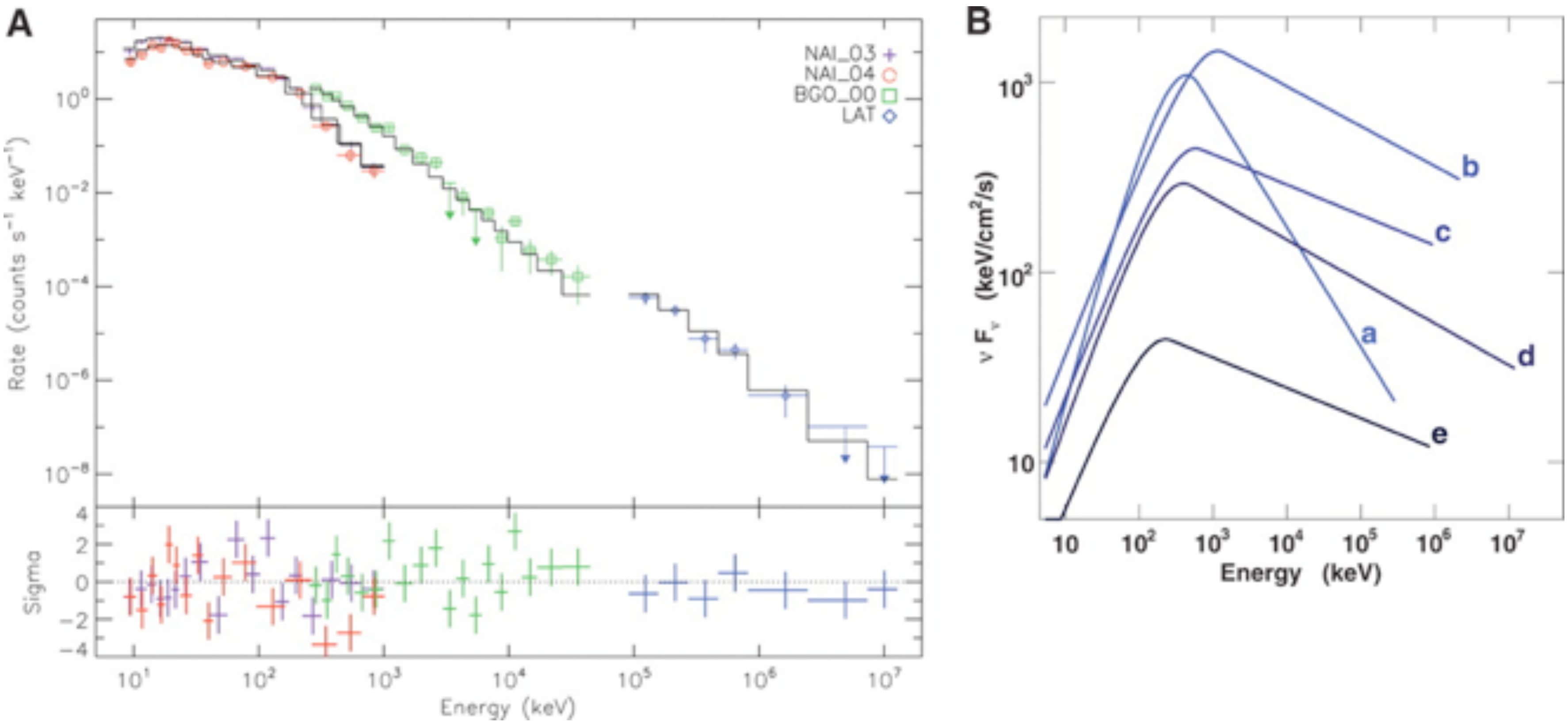
1) Distinct HE spectral component ?
2) Maximum photon energy (cut-off ?)
3) Long-lived HE emission ?

Important key for emission mechanism and environment of GRBs

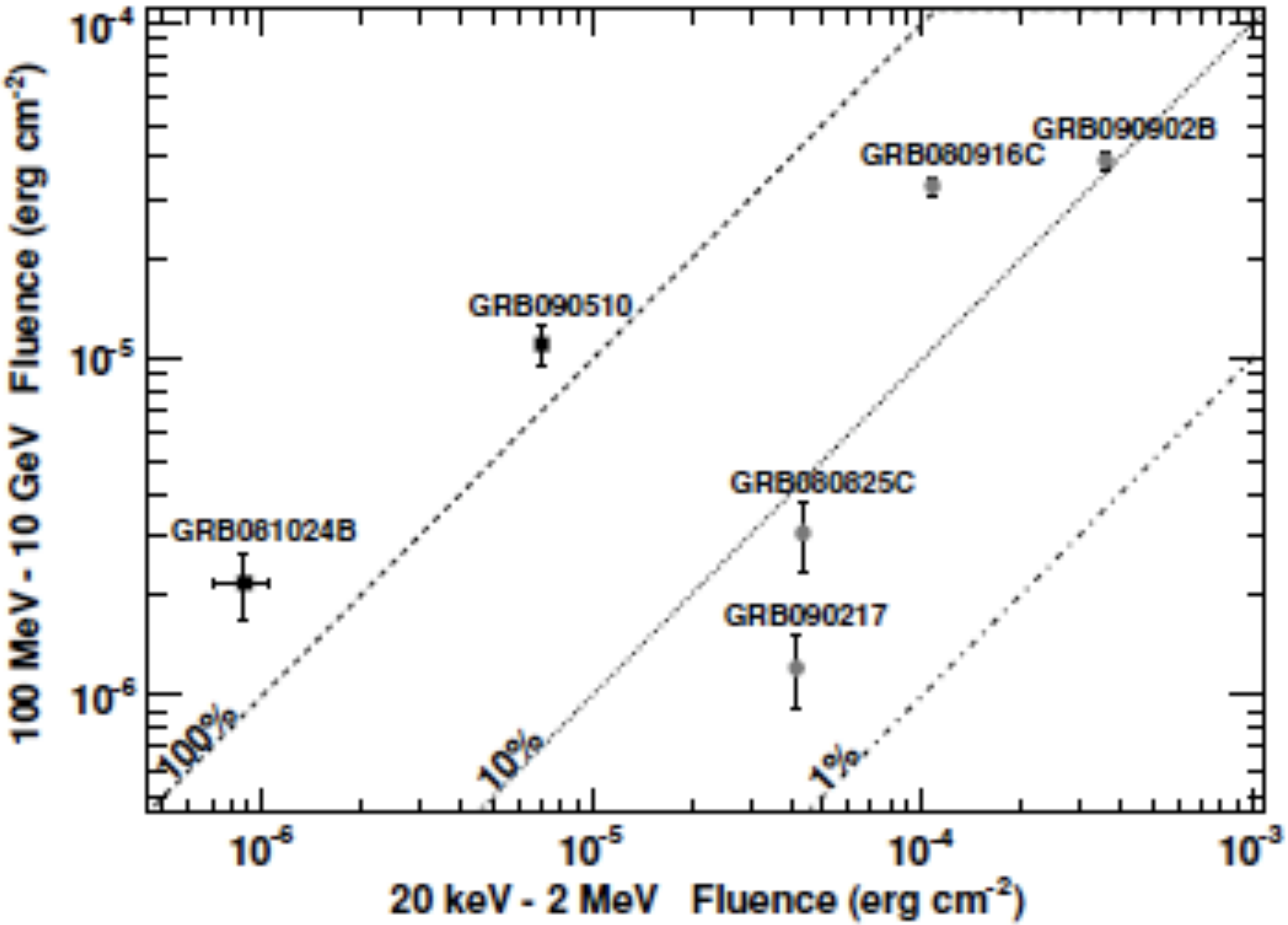
Fermi's observations GRB 090510



Fermi's observations GRB 080916c

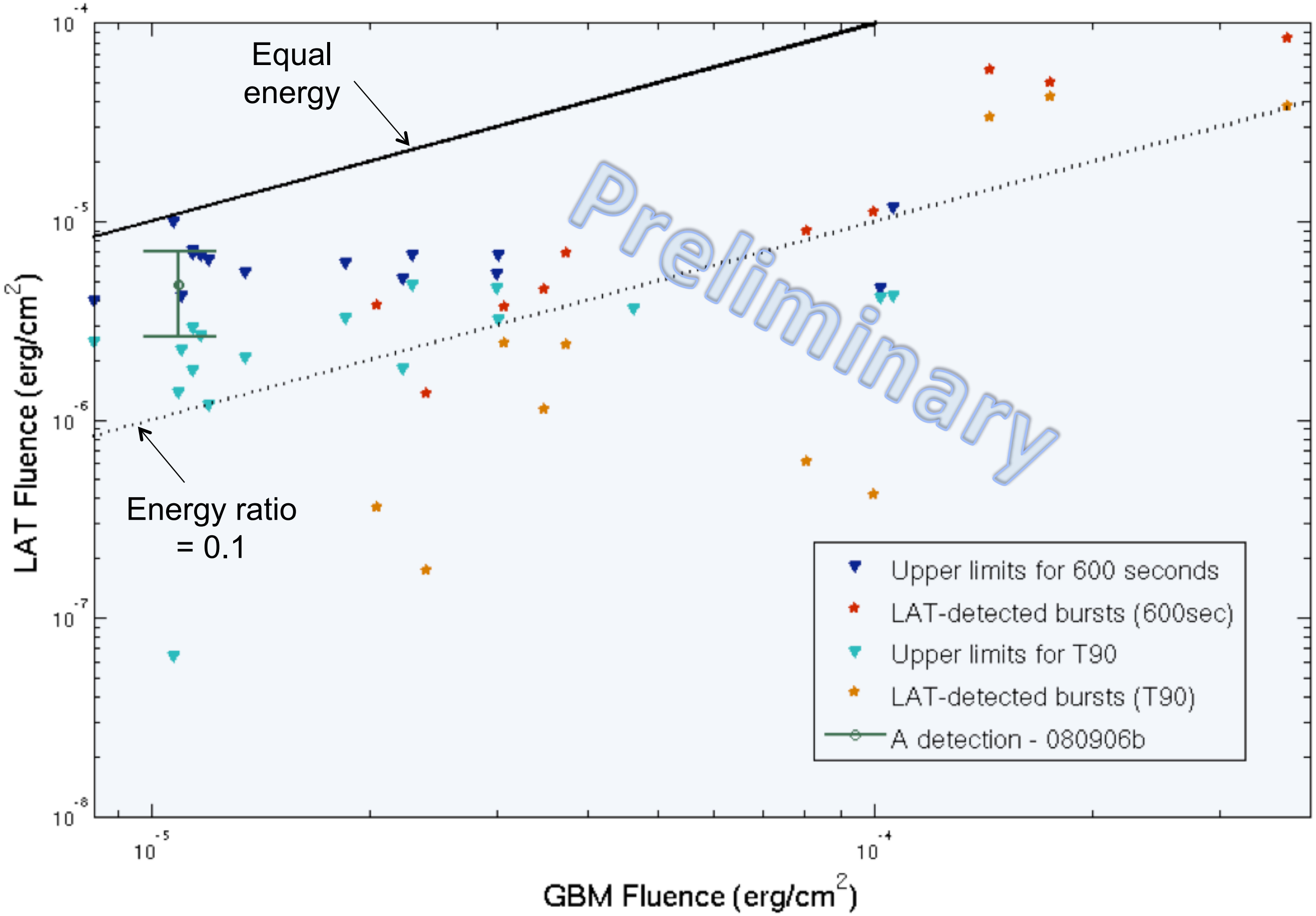


Strong upper limits on the GeV emission



Upper limits for LAT vs.GBM fluence

Paz Beniamini, Dafne Guetta, Ehud Nakar and Tsvi Piran (see poster 4.02)



See also Guetta, Pian Waxman, 10

What is the prompt emission mechanism?

The origin of the prompt (sub-MeV) emission is not clear:

- Synchrotron
- Synchrotron Self Compton
- Inverse Compton of external radiation field?
- $\tau \approx 1$ Comptonization

Limits on Synchrotron Parameters

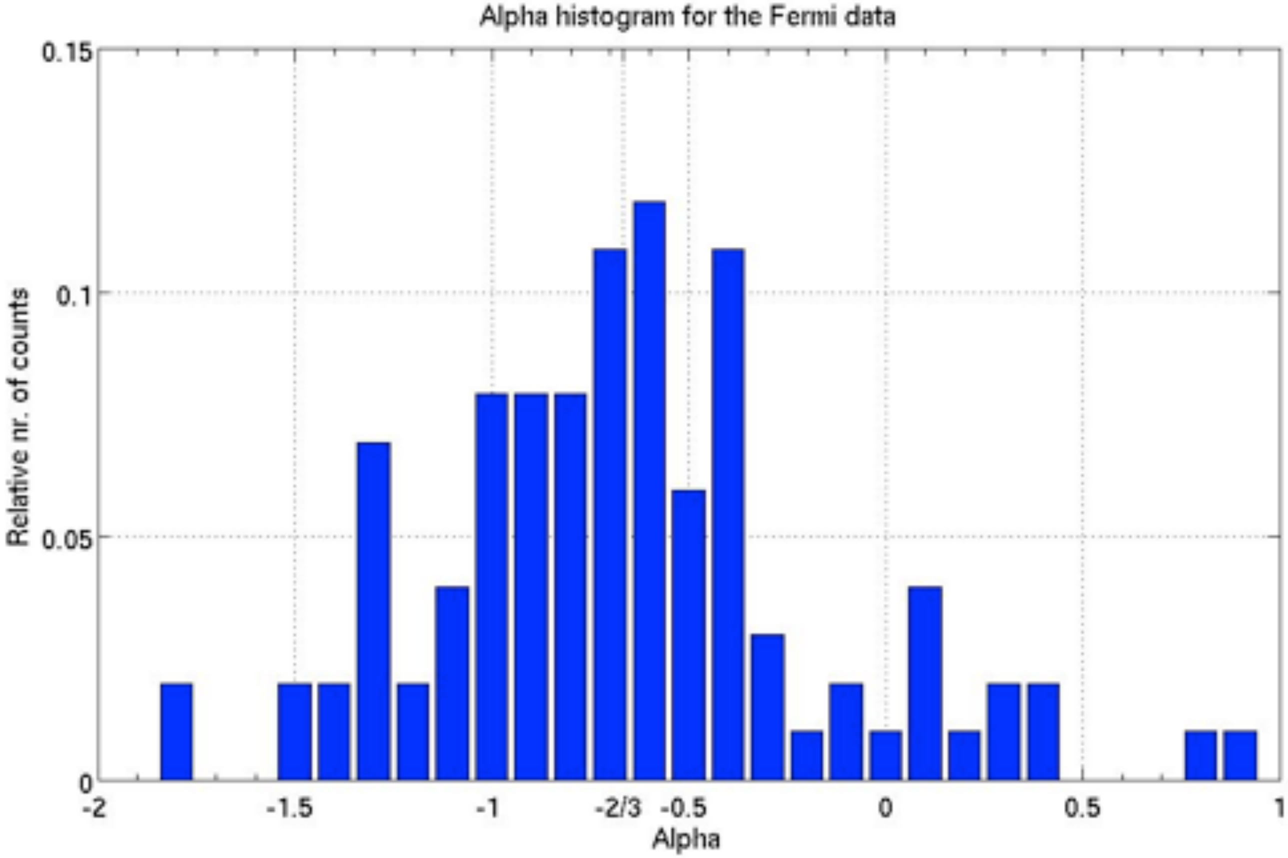
$$\nu_{ic} = \gamma^2 \nu_{MeV} \quad \Leftrightarrow \quad 5GeV = (\gamma/100)^2 500keV$$

$$\nu_{ic} F_{ic} = Y \nu_{MeV} F_{MeV} \quad \Leftrightarrow \quad (\nu F)_{5GeV} = Y(\nu F)_{500keV}$$

$$Y = \gamma^2 \tau$$

This rules out the $\gamma_e \approx 100$ electrons in the region that emits the prompt γ-rays
Or strong B

Fermi's α distribution (GCN parameters)



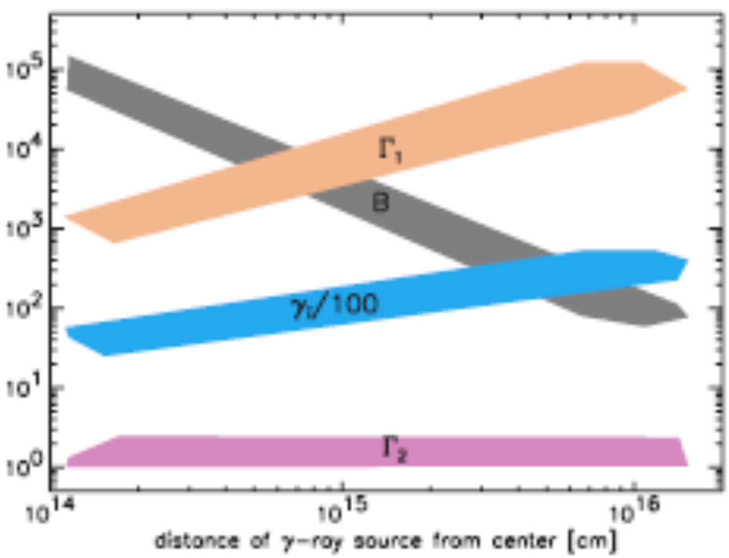
- The synchrotron "line of death" problem persists!

The origin of the prompt emission is not clear:

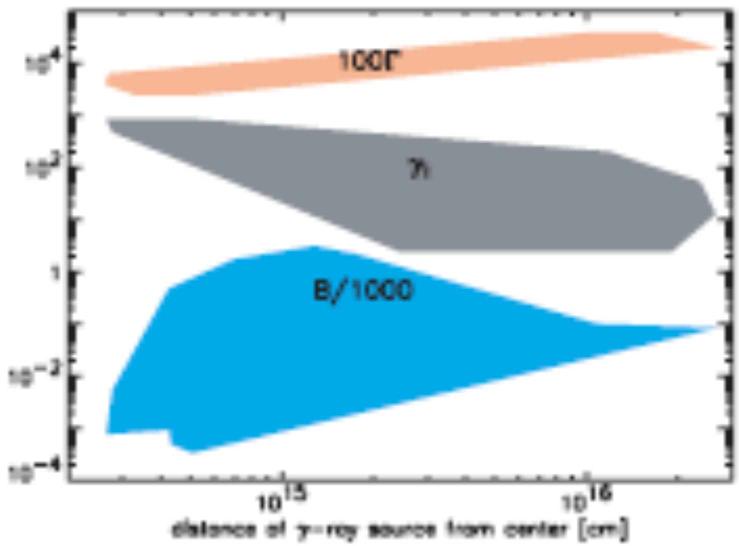
- Synchrotron – “line of death” + GeV limits (high B so that ν_{sa} is at the keV range - Granot, Piran, Sari 99 ?, Suppress IC component)
- Synchrotron Self Compton
- Inverse Compton of external radiation field?
- $\tau \approx 1$ Comptonization

SSC or IC ?

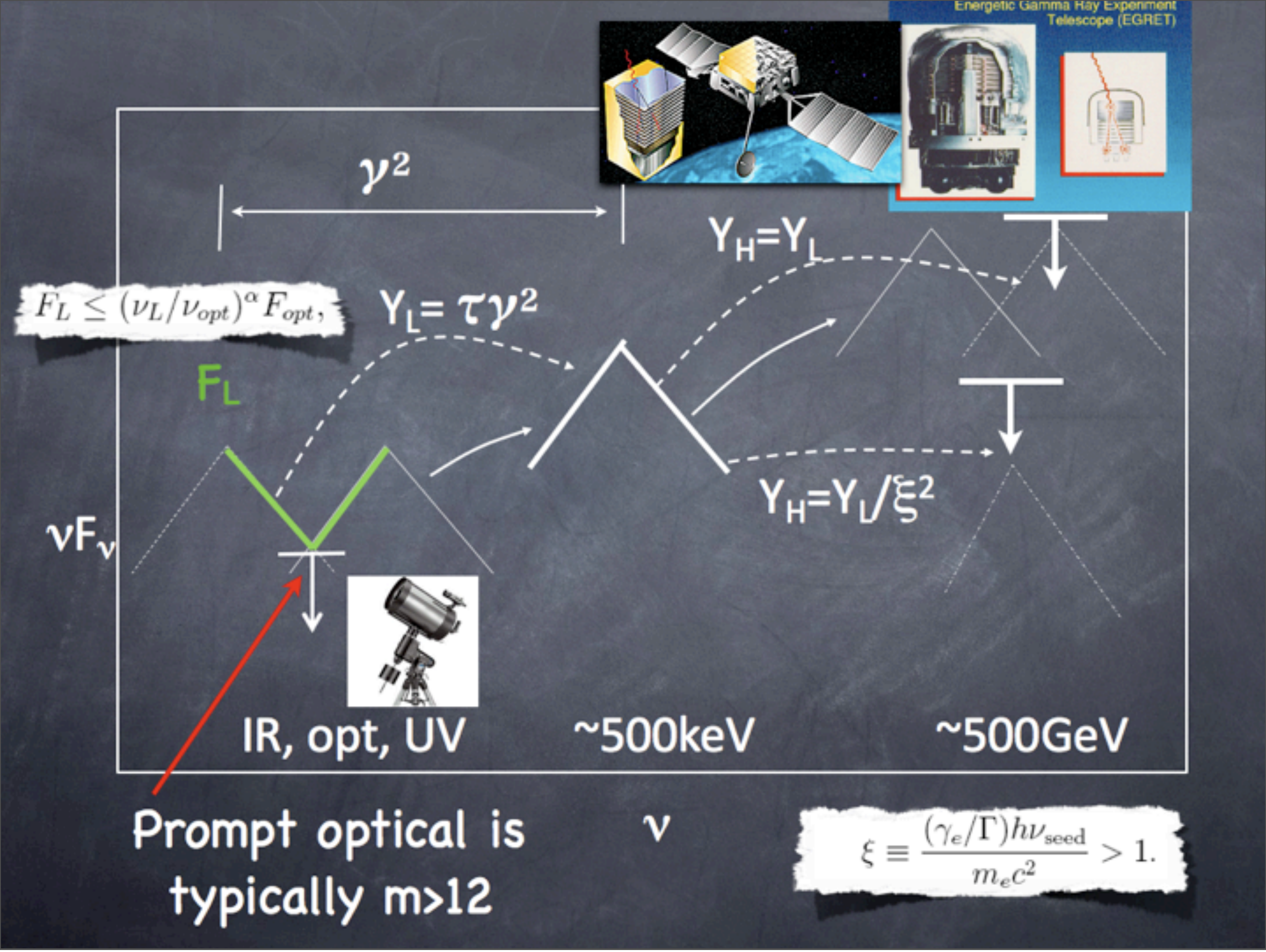
- P. Kumar E. McMahon, S. D. Barthelmy, D. Burrows, N. Gehrels, M. Goad, J. Nousek and G. Tagliaferri



Synch

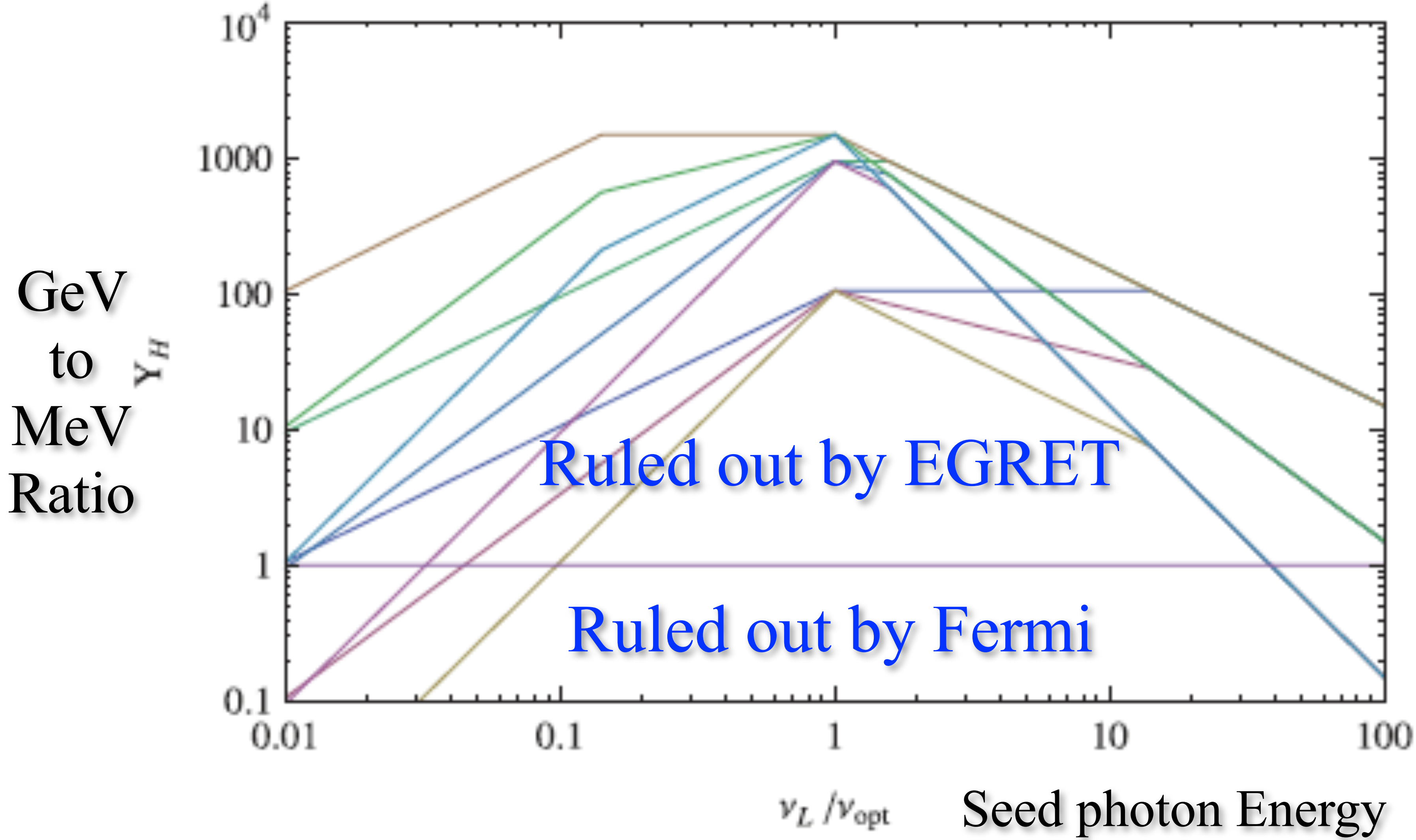


SSC

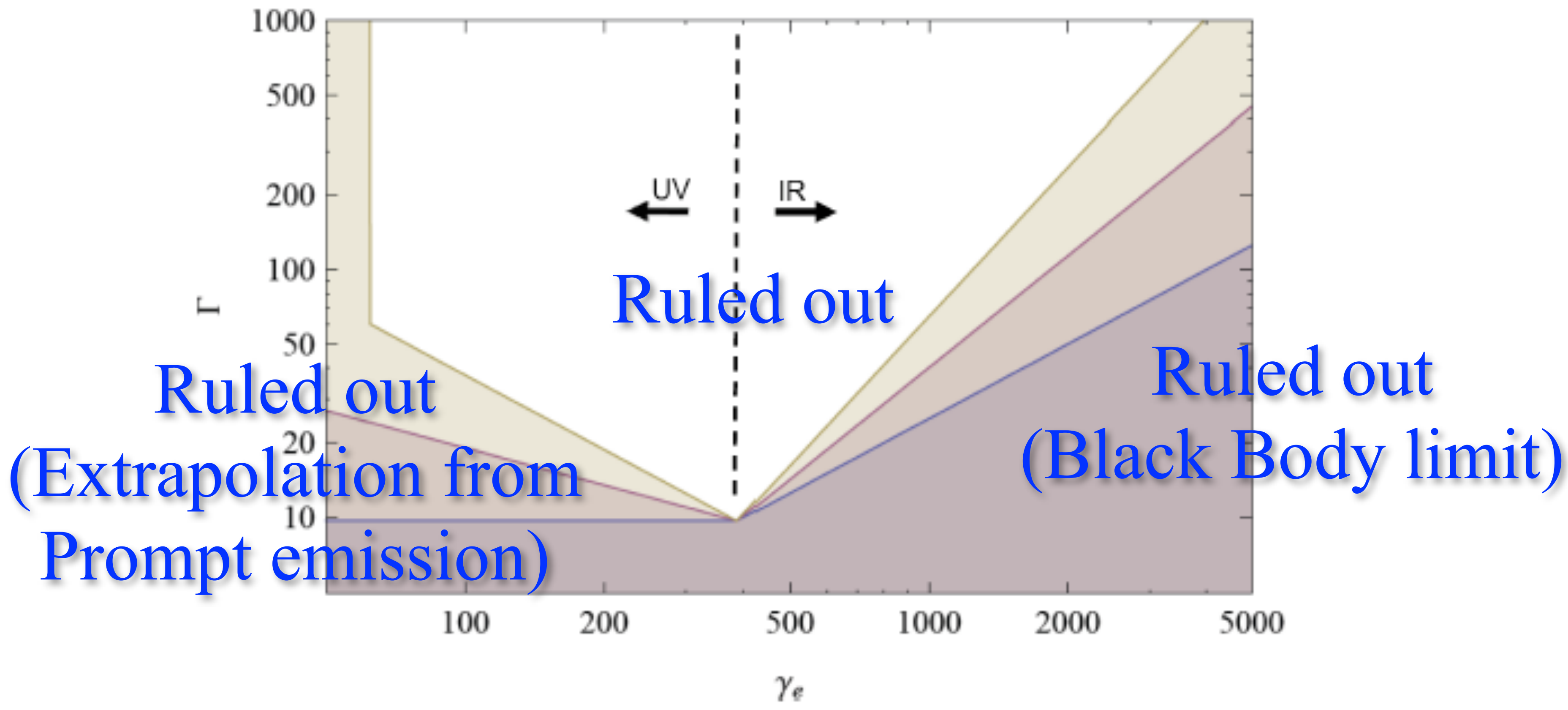


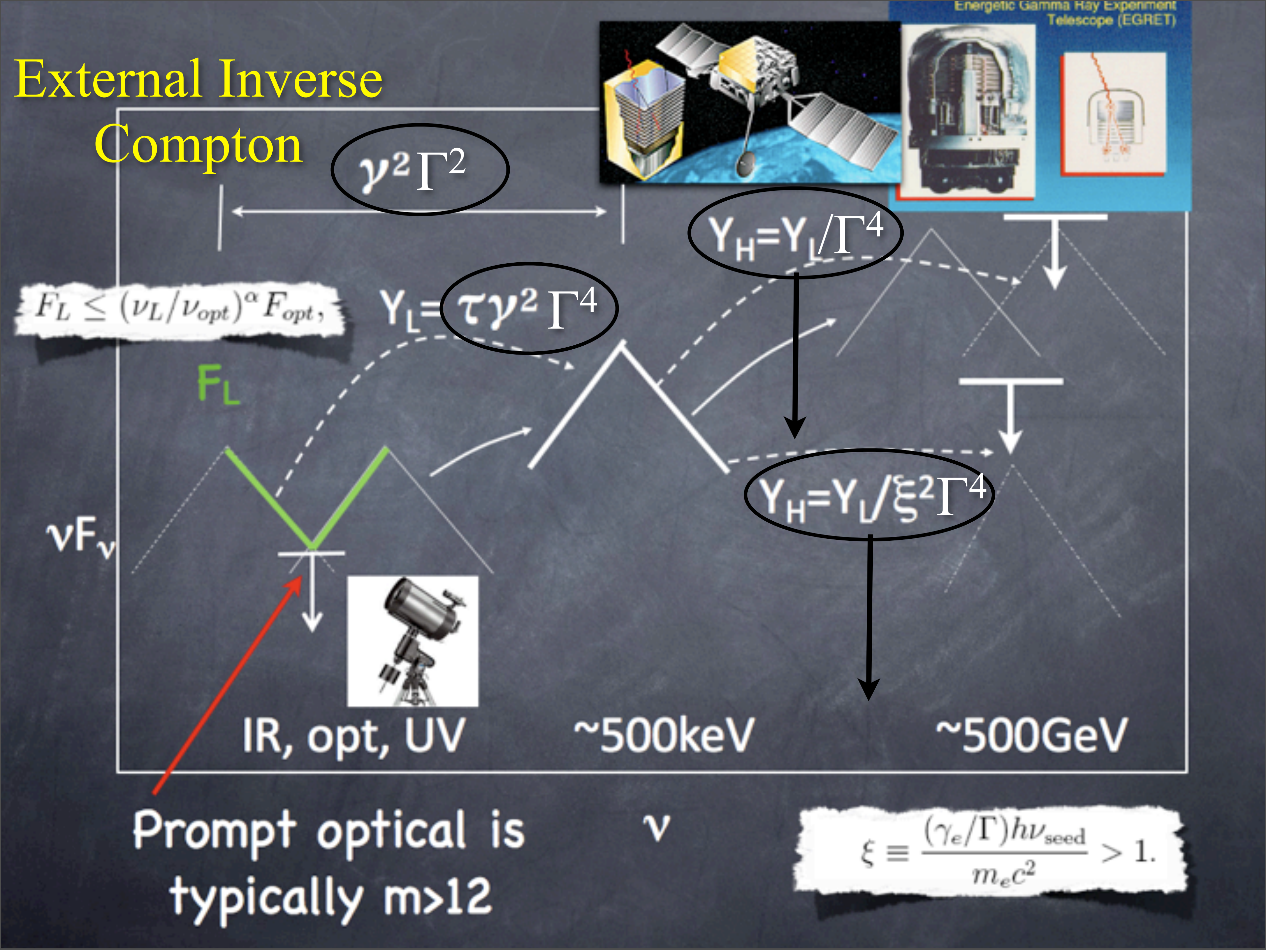
Energetic Gamma Ray Experiment Telescope (EGRET)
γ^2
$Y_H = Y_L$
$F_L \leq (\nu_L/\nu_{opt})^{\alpha} F_{opt},$
$Y_L = \tau\gamma^2$
F_L
$Y_H = Y_L/\xi^2$
νF_ν
IR, opt, UV
~500keV
~500GeV
Prompt optical is typically m>12
ν
$\xi \equiv \frac{(\gamma_e/\Gamma) h\nu_{\rm seed}}{m_e c^2} > 1.$

Limits on SSC prompt emission



Rules our regions in the Parameter phase space



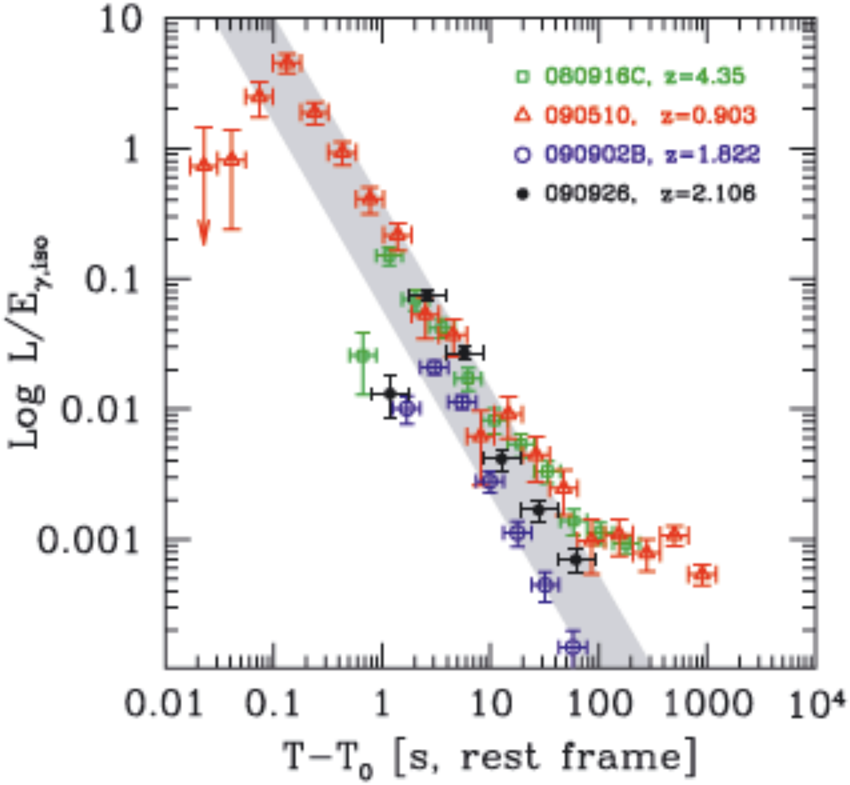


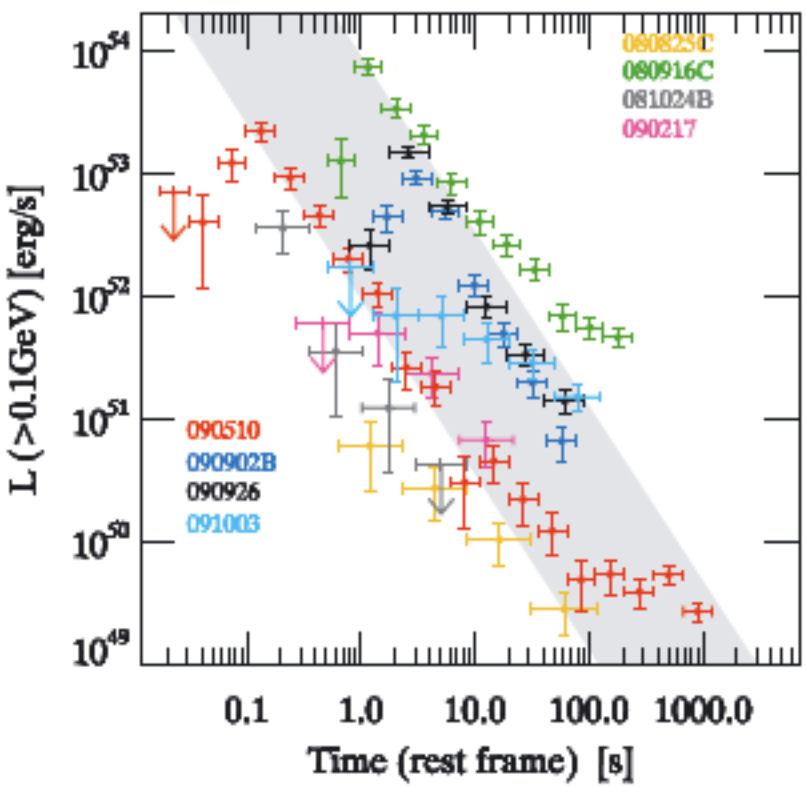
External Inverse Compton
Energetic Gamma Ray Experiment Telescope (EGRET)
$\gamma^2\Gamma^2$
$Y_H = Y_L/\Gamma^4$
$F_L \leq (\nu_L/\nu_{opt})^{\alpha} F_{opt},$
$Y_L = \tau\gamma^2\Gamma^4$
F_L
νF_ν
$Y_H = Y_L/\xi^2\Gamma^4$
IR, opt, UV
~500keV
~500GeV
Prompt optical is typically m>12
ν
$\xi \equiv \frac{(\gamma_e/\Gamma)h\nu_{\rm seed}}{m_e c^2} > 1.$

The origin of the prompt emission is not clear:

- Synchrotron – “line of death” + GeV peak
- Synchrotron Self Compton – GeV emission is too weak
- Inverse Compton of external radiation field? – No reasonable source of seed photons (Genet, Jacob & TP - see poster 2.06)
- $\tau \approx 1$ Comptonization thermal – What is the origin of the needed mildly relativistic electrons at the right location (see however Beloborodov)

The origin of the GeV emission?

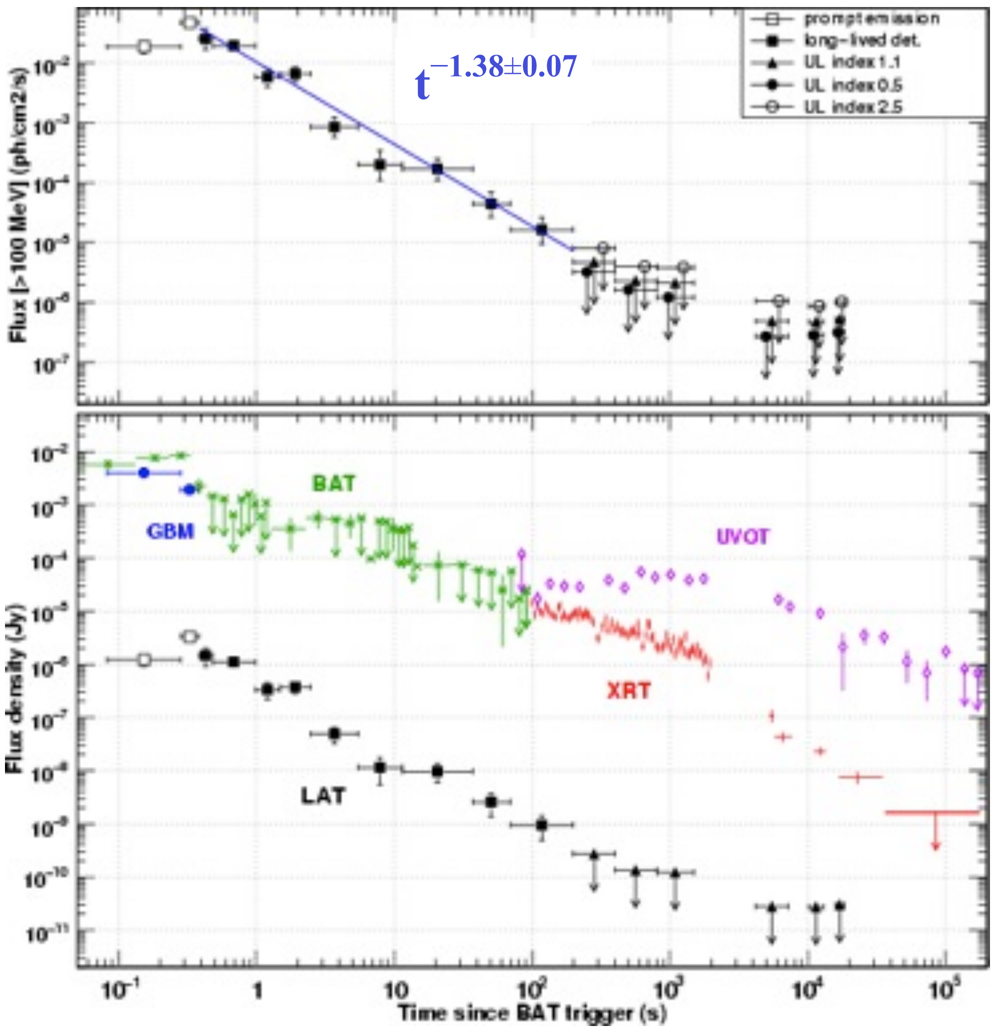




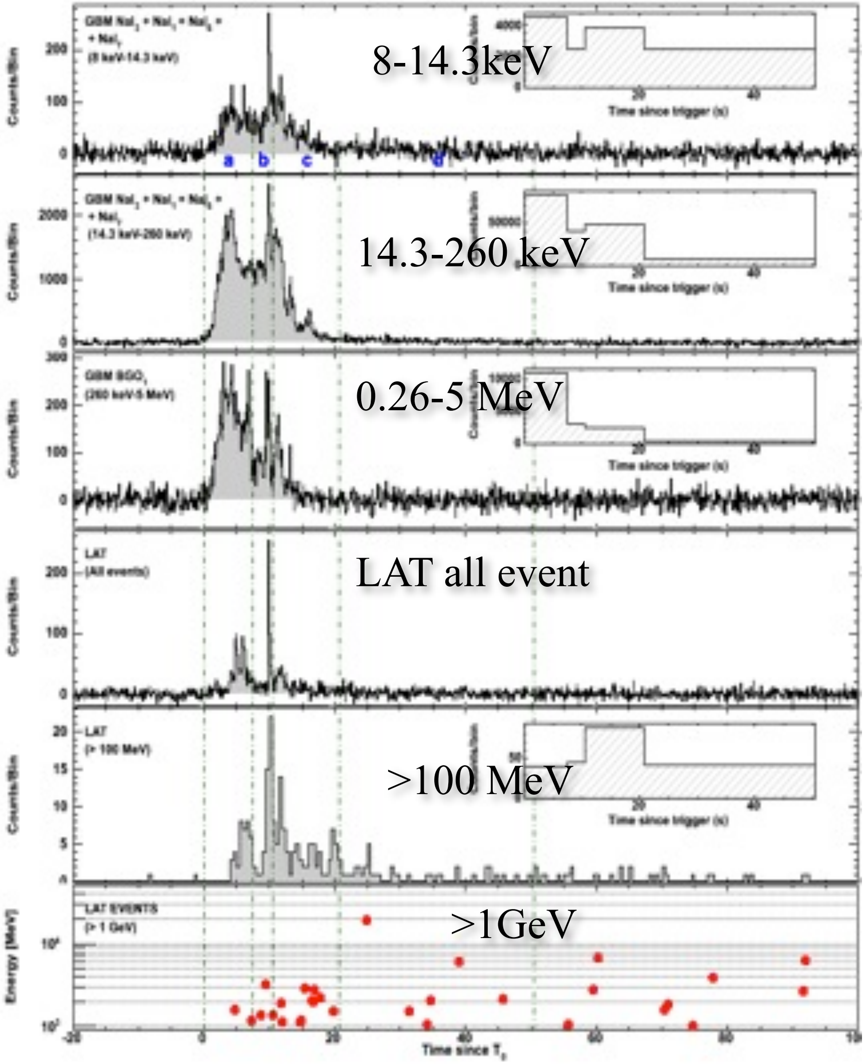
From Ghisellini et al 2010

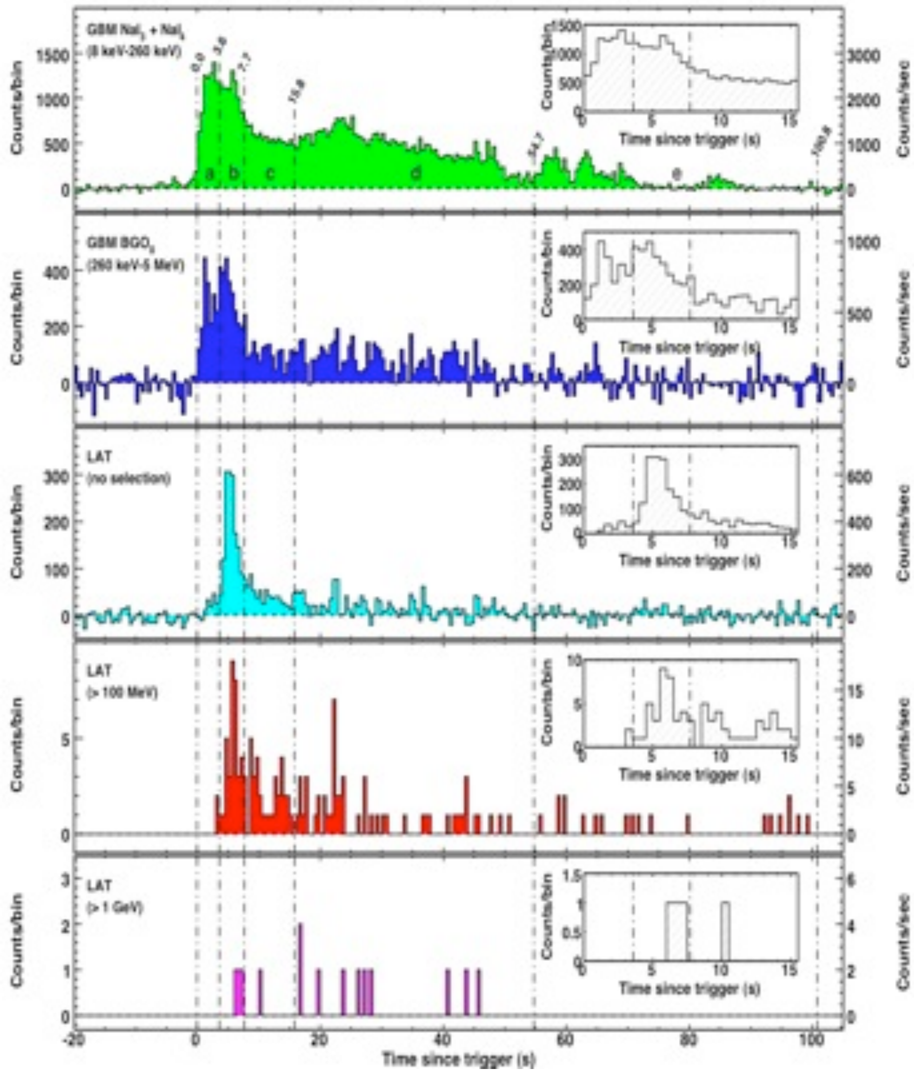
Long Lived GeV emission

De Pasquale et al., 2010



Delayed and long lived GeV emission

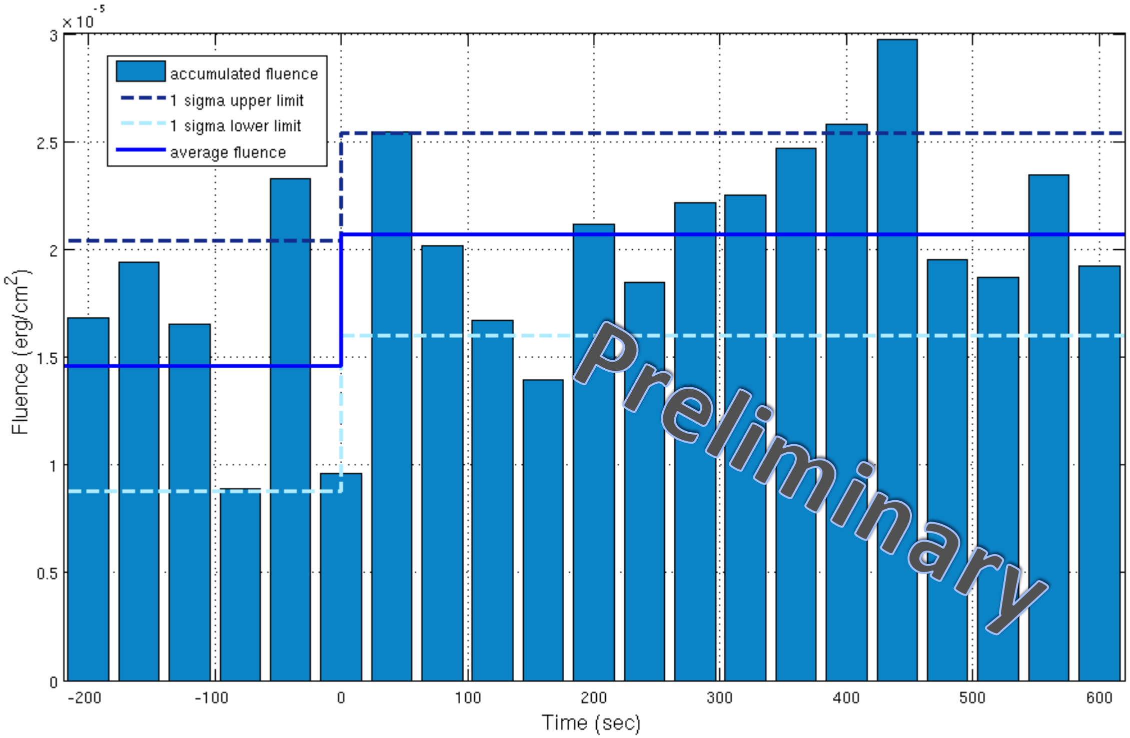




LAT bursts are the strongest GBM bursts!

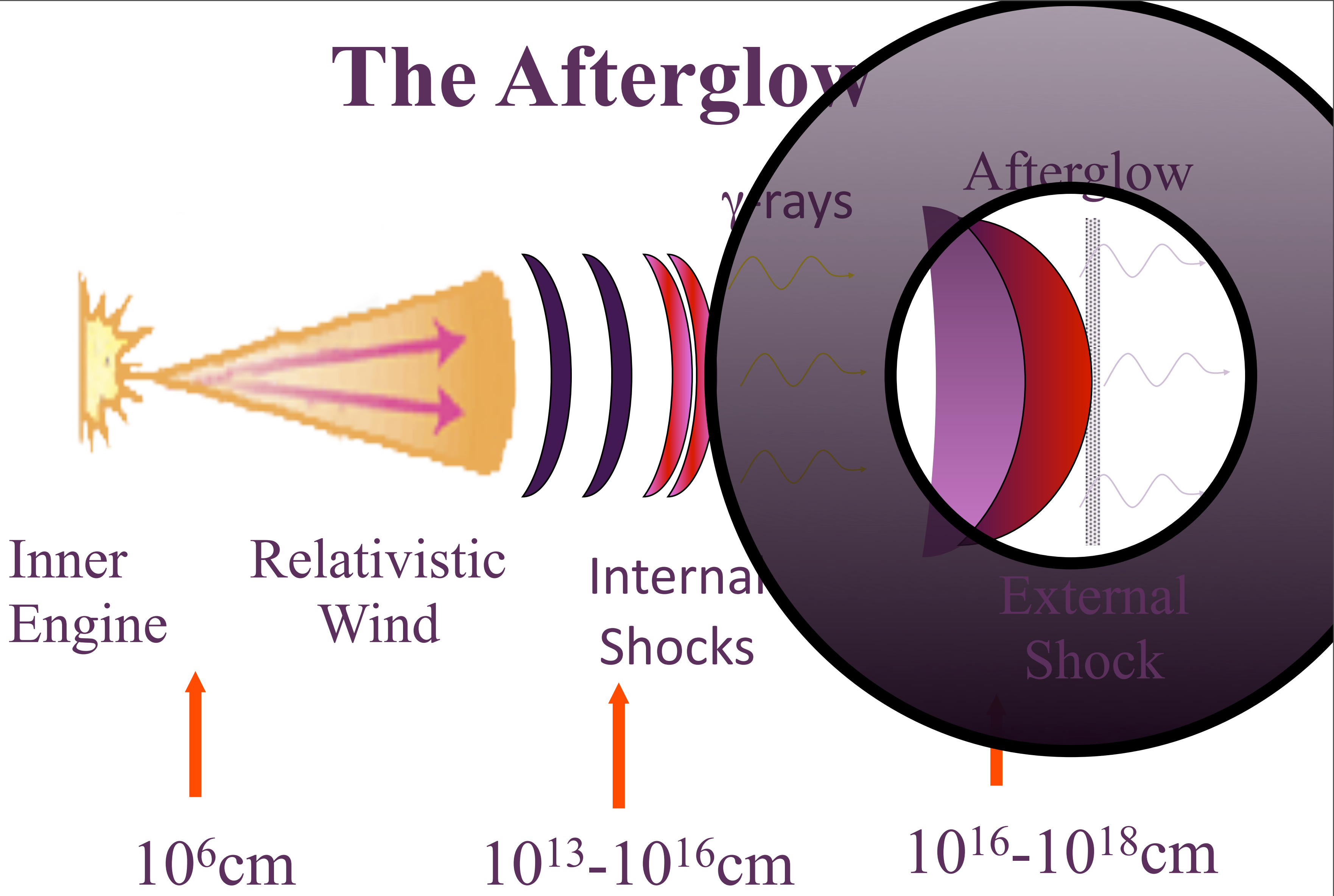
Stacked Fluence of 18 strong GBM Bursts

Paz Beniamini, Dafne Guetta, Ehud Nakar and Tsvi Piran (see poster 4.02)



- The average T90 fluence is insignificant above the noise.
- The average fluence between 0<t<600sec is $5.8 * 10^{-6}$ - a 5σ detection.

The Afterglow

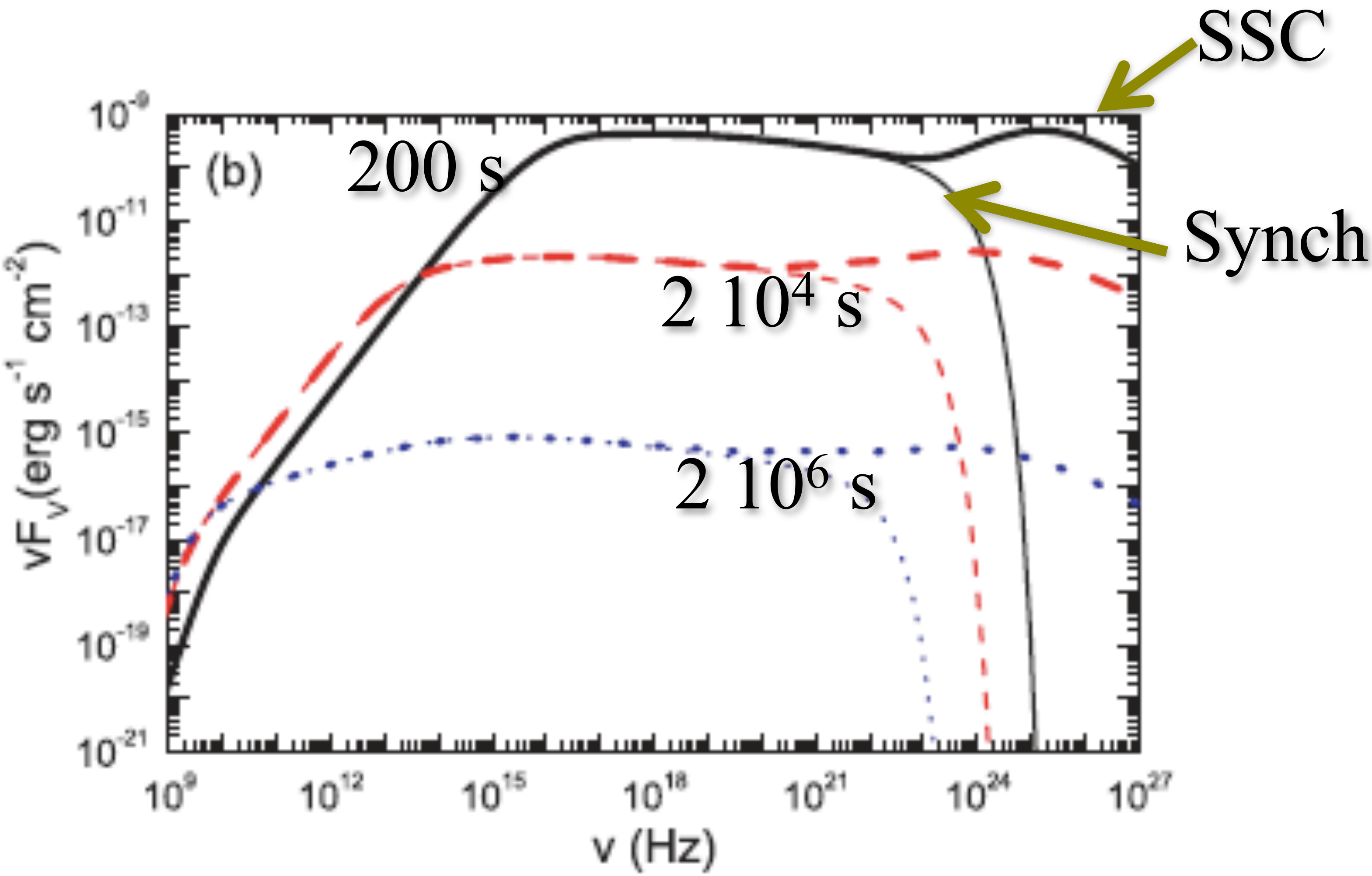


Can the forward shock synchrotron produce the observed GeV emission?

- Kumar and Barniol-Duran - Yes (adiabatic)
- Ghisellini, Ghirlanda, Nava, Celloti - Yes (radiative)

Standard External Shock Spectra

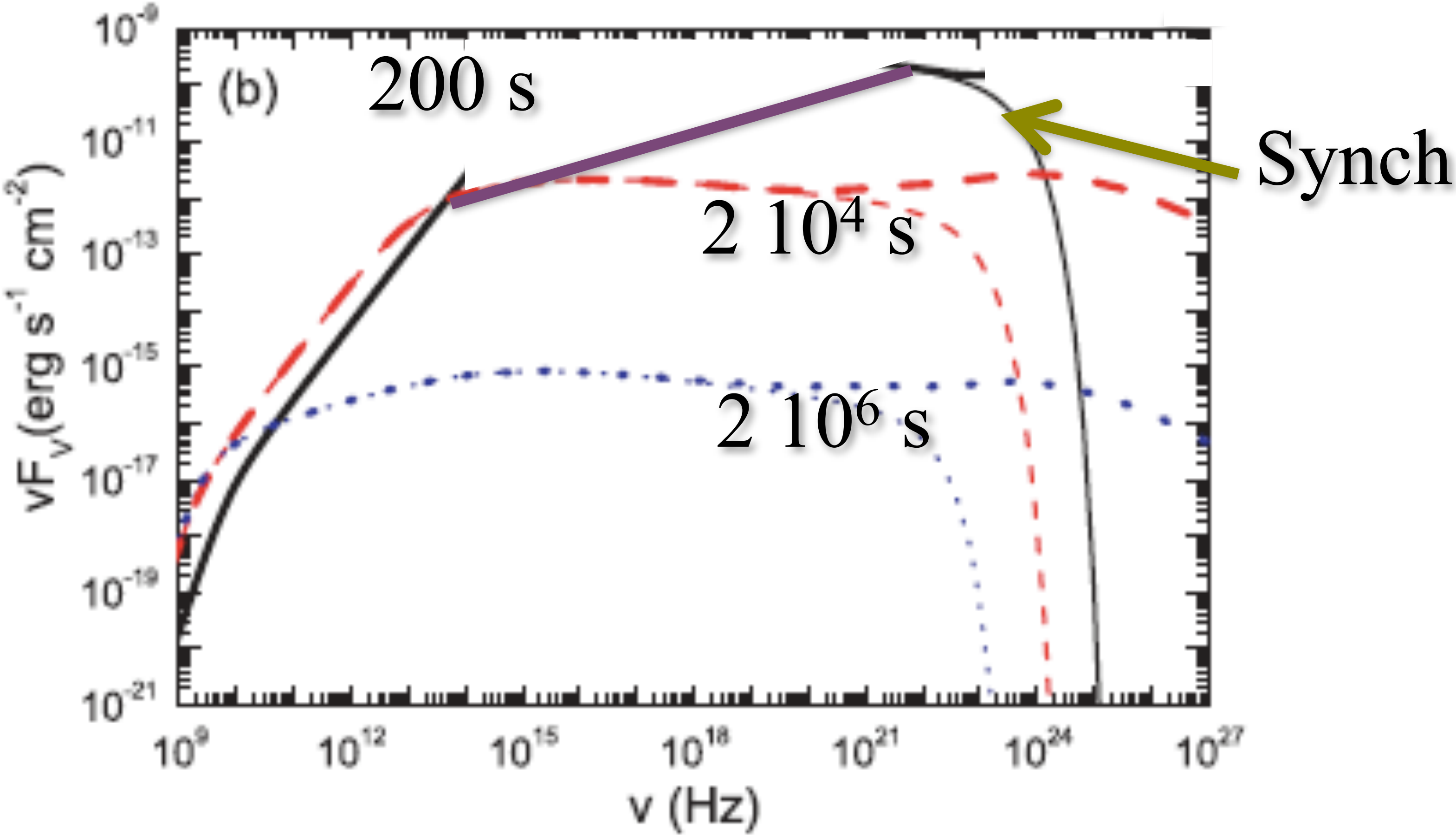
Fan, TP, Narayan & Wei, 2008



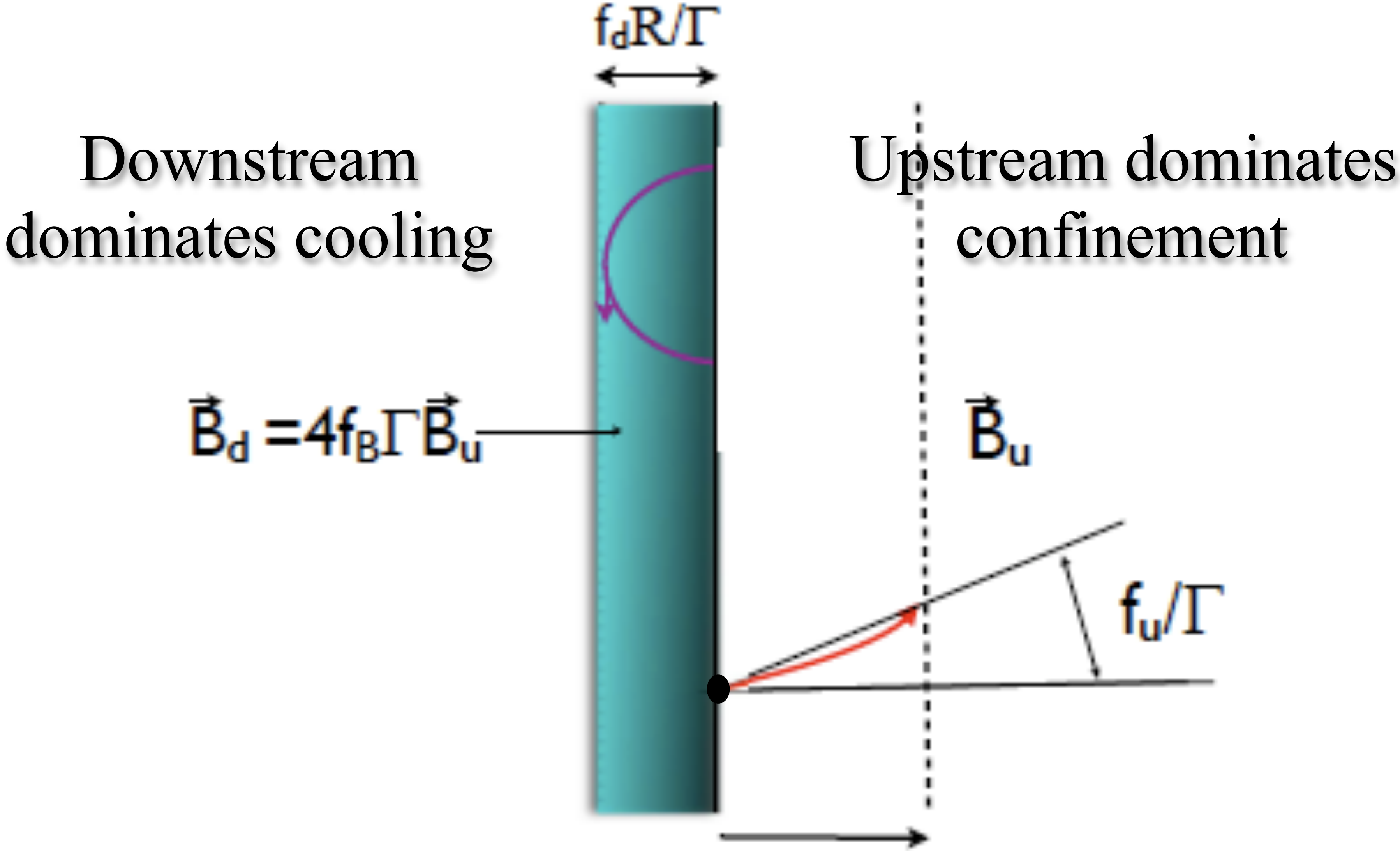
Standard External Shock Spectra

Fan, TP, Narayan & Wei, 2008

When we lower B



Shock Acceleration



But

TP & Nakar 2010, Kumar Barniol-Duran 2010

- **Cooling time = acceleration time**

=> Upper limit on synchrotron photons

$$\frac{m_e c^2}{\alpha} \approx 80\,\mathrm{MeV}$$

$$\Rightarrow h\nu_{\max} = 80\,\mathrm{MeV}\,\Gamma(t) \approx 9\ \mathrm{GeV}\left(\frac{t}{100\ \mathrm{s}}\right)^{-3/8}\left(\frac{1+z}{2}\right)^{-5/8}$$

- But 33 GeV photon at 82 sec from GRB090902B?
- Much worse in radiative cooling when $\Gamma(t)$ decreases much faster.

Cooling and Confinement constrains on the Low B solution

TP & Nakar 10, Kumar Barniol-Duran 10, Waxman & Zhou 06

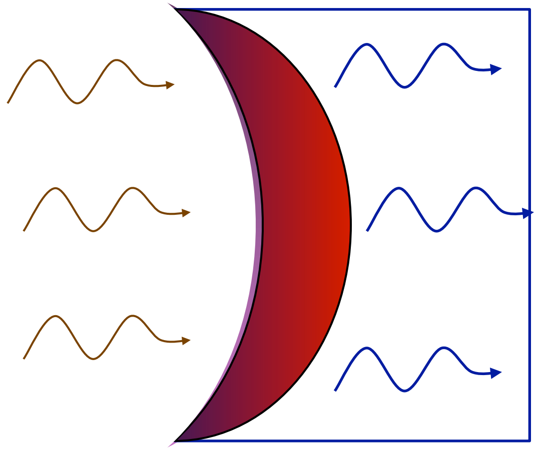
- Cooling - MeV $< h\nu_c <$ 100 MeV

  => $f_B\, B > 85\ \mu G\ (t/100)^{-1/6}$ for

- Confinement of the electrons producing 10GeV photon

  => $B > 20\ \mu G\ (t/100)^{-1/12}$

Oops - Cooling by IC



Even a modest (a few μJ) IR or optical flux will cool (via IC the GeV synch emitting electrons)

Limit on bulk Lorentz factor

Large luminosity and small emitting region, optical depth for the γ-γ -> e+e- pair production is too large to observe the non-thermal emission from GRB -> the compactness problem.

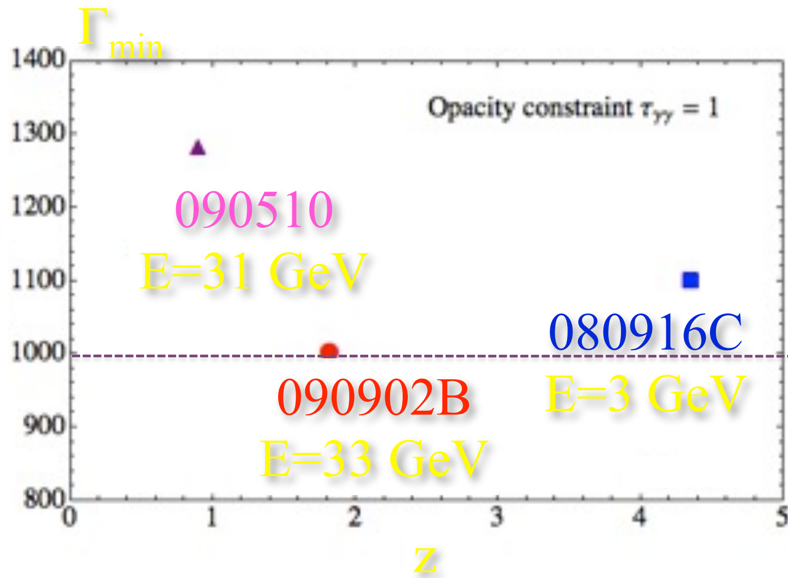
Relativistic motion (Γ>>1) is essential to avoid the compactness problem

$$\tau_{\gamma\gamma}(E) = \frac{3}{4}\frac{\sigma_T d_L^2}{t_v \Gamma}\frac{m_e^4 c^6}{E^2(1+z)^3}\int_{\frac{m_e^2 c^4 \Gamma}{E(1+z)}}^{\infty}\frac{d\epsilon'}{\epsilon'^2}\, n\left(\frac{\epsilon'\Gamma}{1+z}\right)\varphi\left[\frac{\epsilon' E(1+z)}{\Gamma}\right]$$

Γ_{min} can be derived using observed highest energy photon

$$\Gamma_{min}(E_{max}) = \left[\frac{4d_L^2 A}{c^2 t_v}\frac{m_e^2 c^4}{(1+z)^2 E_{max}} g\sigma_T\right]^{\frac{1}{2-2\beta}}\left[\frac{(\alpha-\beta)E_{pk}}{(2+\alpha)100\ \mathrm{keV}}\right]^{\frac{\alpha-\beta}{2-2\beta}} \times \exp\left(\frac{\beta-\alpha}{2-2\beta}\right)\left[\frac{2m_e^2 c^4}{E_{max}(1+z)^2 100\ \mathrm{keV}}\right]^{\frac{\beta}{2-2\beta}};$$

$$\text{for}\ \ \Gamma_{min} > \sqrt{\frac{(1+z)^2 E_{max} E_{pk}(\alpha-\beta)}{2m_e^2 c^4(2+\alpha)}},$$

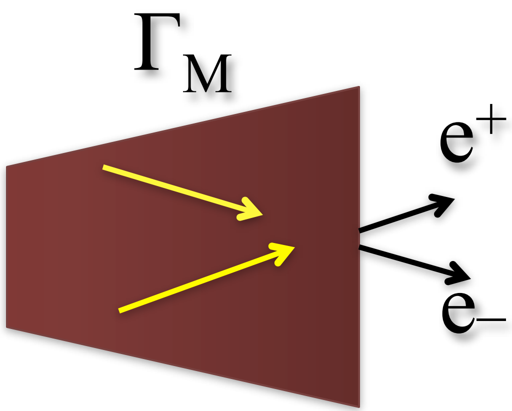


Γ_{min}~1000 for short and long GRBs

Two Zone Limits on the Lorentz factor

(Zou, Fan & Piran, 10)

- Opacity limits on Γ should take into account the possibility of a different origin of the prompt low energy γ-rays



- This reduces significantly the limits on Γ

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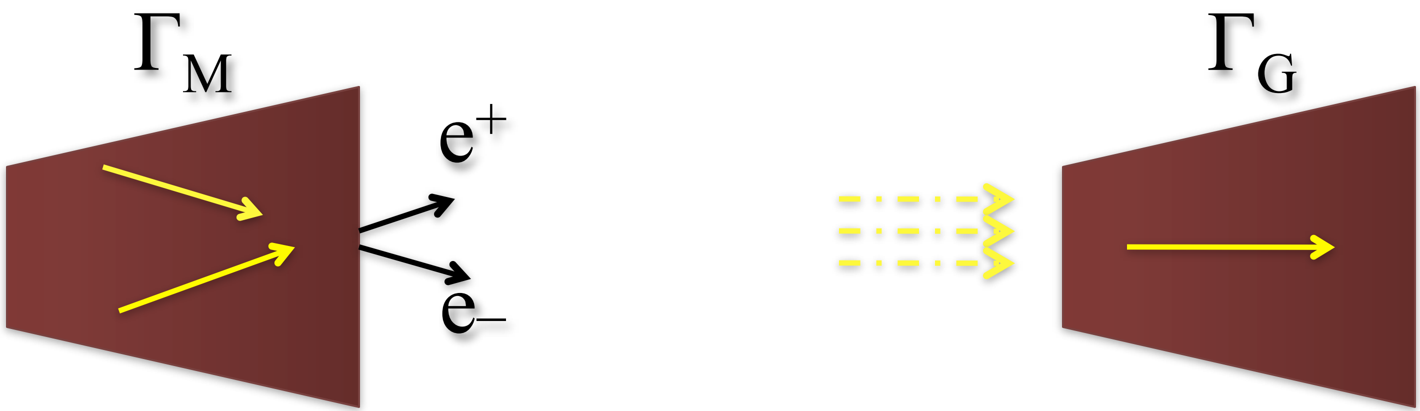

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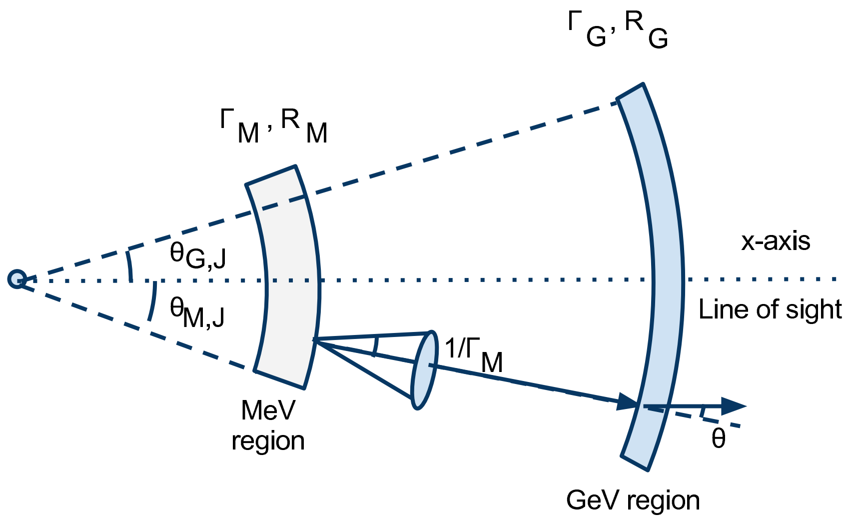
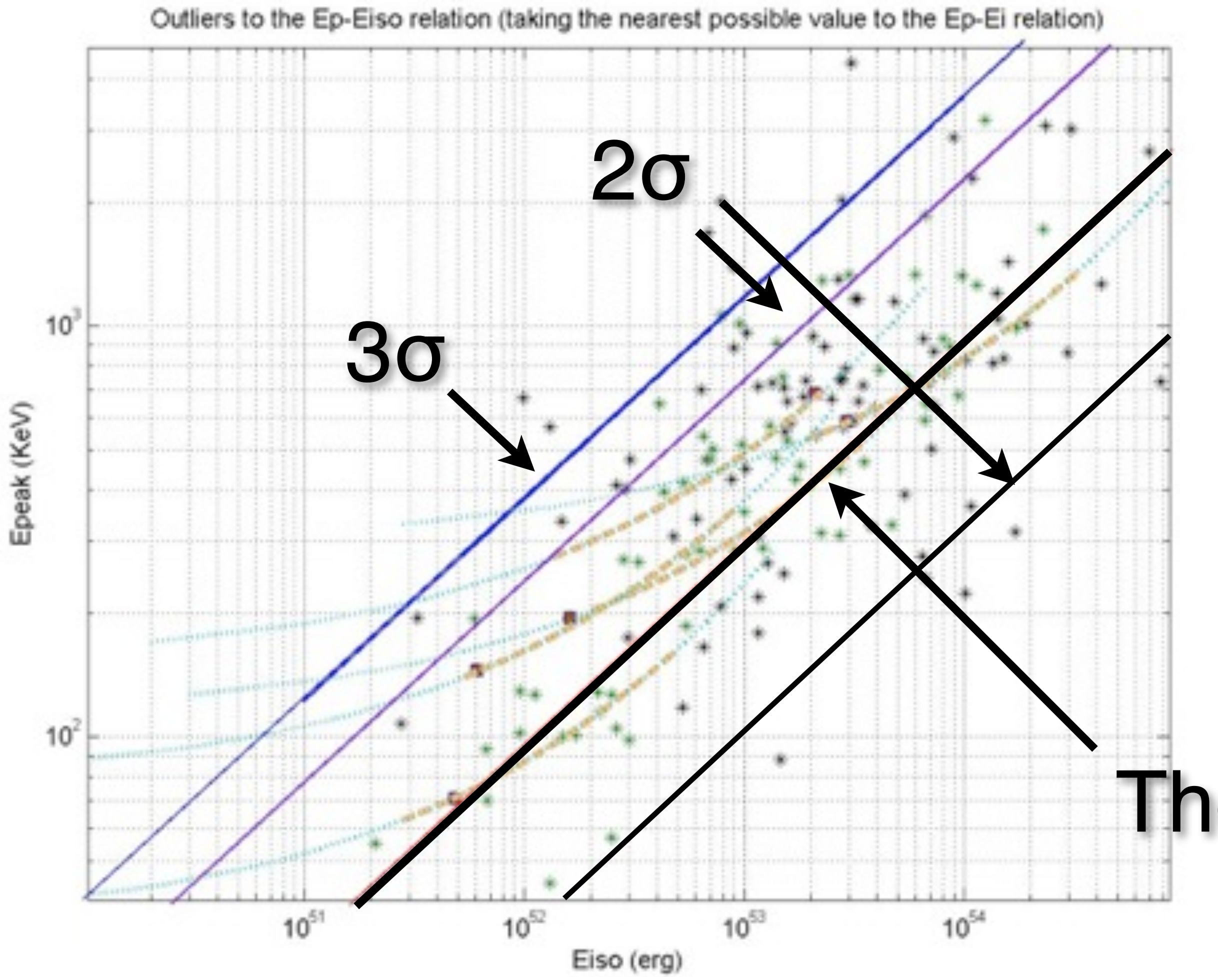


Table 1: Limits on Fermi LAT busts

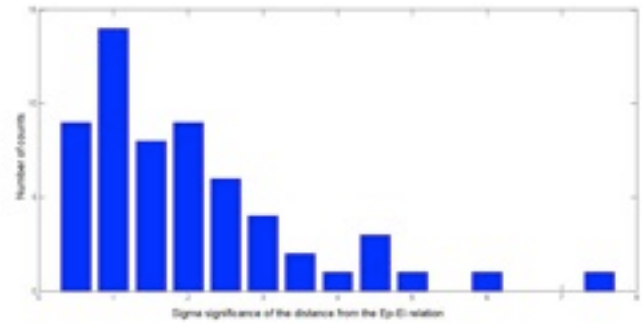
GRB	z	T_{90}(s)	α_M	β_M	E_P(MeV)	L_{iso} (erg/s)	E_G(GeV)	T_G	$\Gamma_{G,\min}$ *	$\Gamma_{\min}$	ref
080916C	4.35	66	1.02	2.21	1.17	7×10^{53}	13.22	40	**221**(488)	880	1
090510	0.903	0.5	0.48	3.09	5.1	4.6×10^{53}	3.4	0.5	**170** (324)	1200	2
090902B	1.822	30	0.61	3.87	0.8	3.2×10^{53}	33.4	82	**140** (253)	1000	3,4
090926A	2.1062	20	0.693	2.34	0.27	4.2×10^{53}	19.6	26	**174** (374)	1200	5

Shown are the low energy spectral parameters α_M, β_M and E_P as well as the luminosity, L_{iso} and the energy, E_G and time T_G of the highest energy GeV photon as well as the two zone, $\Gamma_{G,min}$, and the single zone, Γ_{min} ,limits.
(1) Abdo et al. (2009a); (2) Ackermann et al. (2010); (3) Abdo et al. (2009b); (4) de Palma et al. (2009); (5) Swenson et al. (2010)
* in bold face is the value for $\eta = 1$ and brackets is the value for $\eta = 0.01$

Fermi Ep-E_{iso} ?



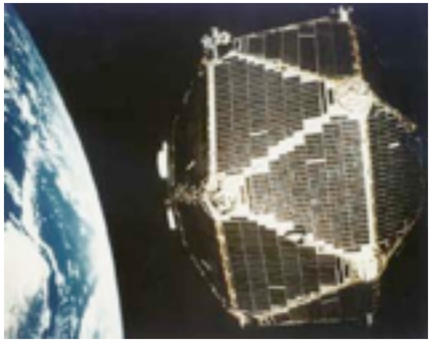
Green stars - bursts with known redshifts
Black stars are the Fermi bursts with no known redshift



One slide before last

- Vela
- BATSE
- BeppoSAX
- Swift
- Fermi

One slide before last



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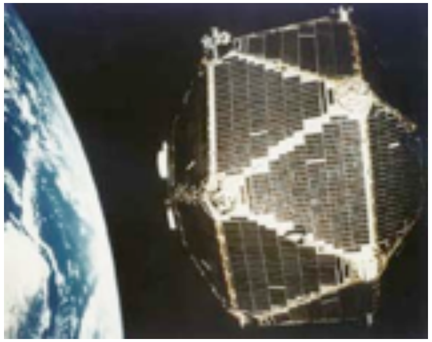

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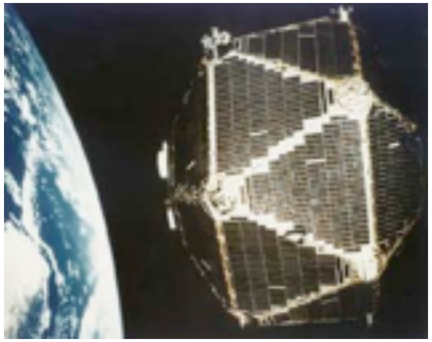

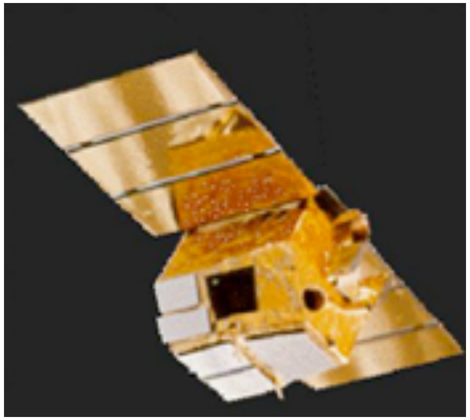

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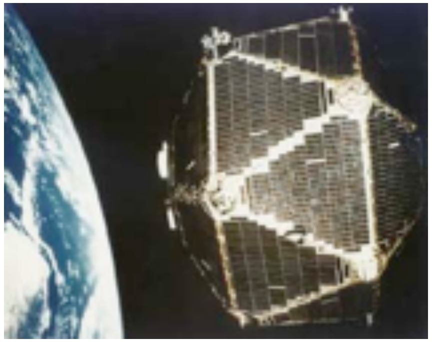

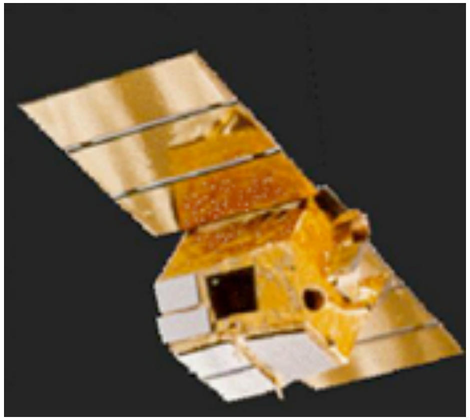
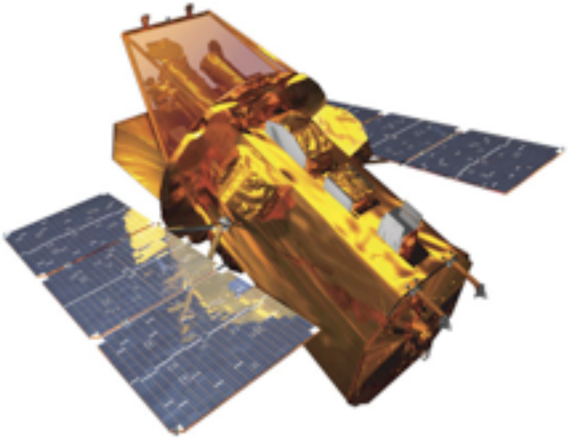

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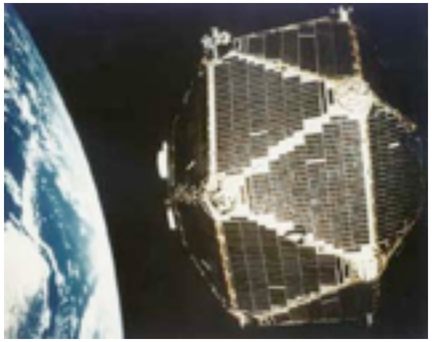

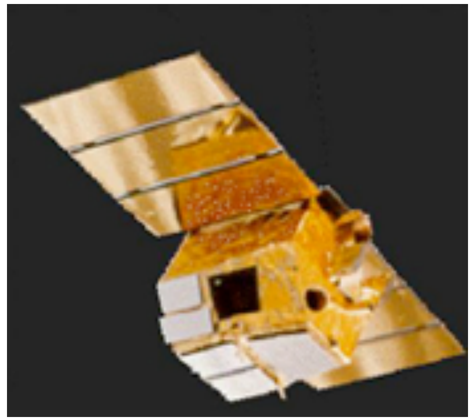
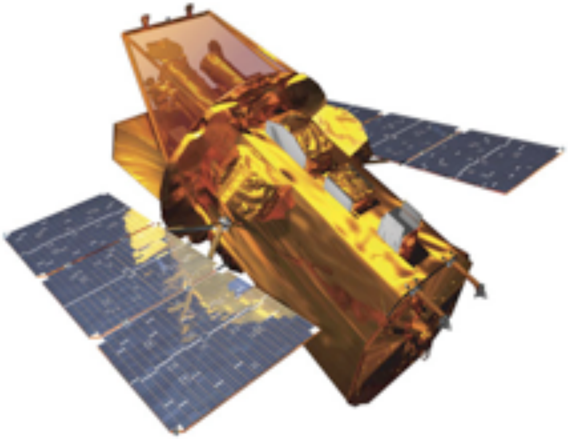
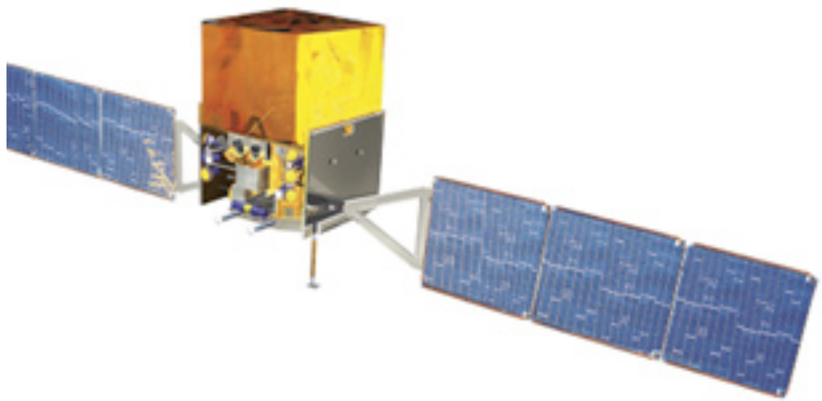

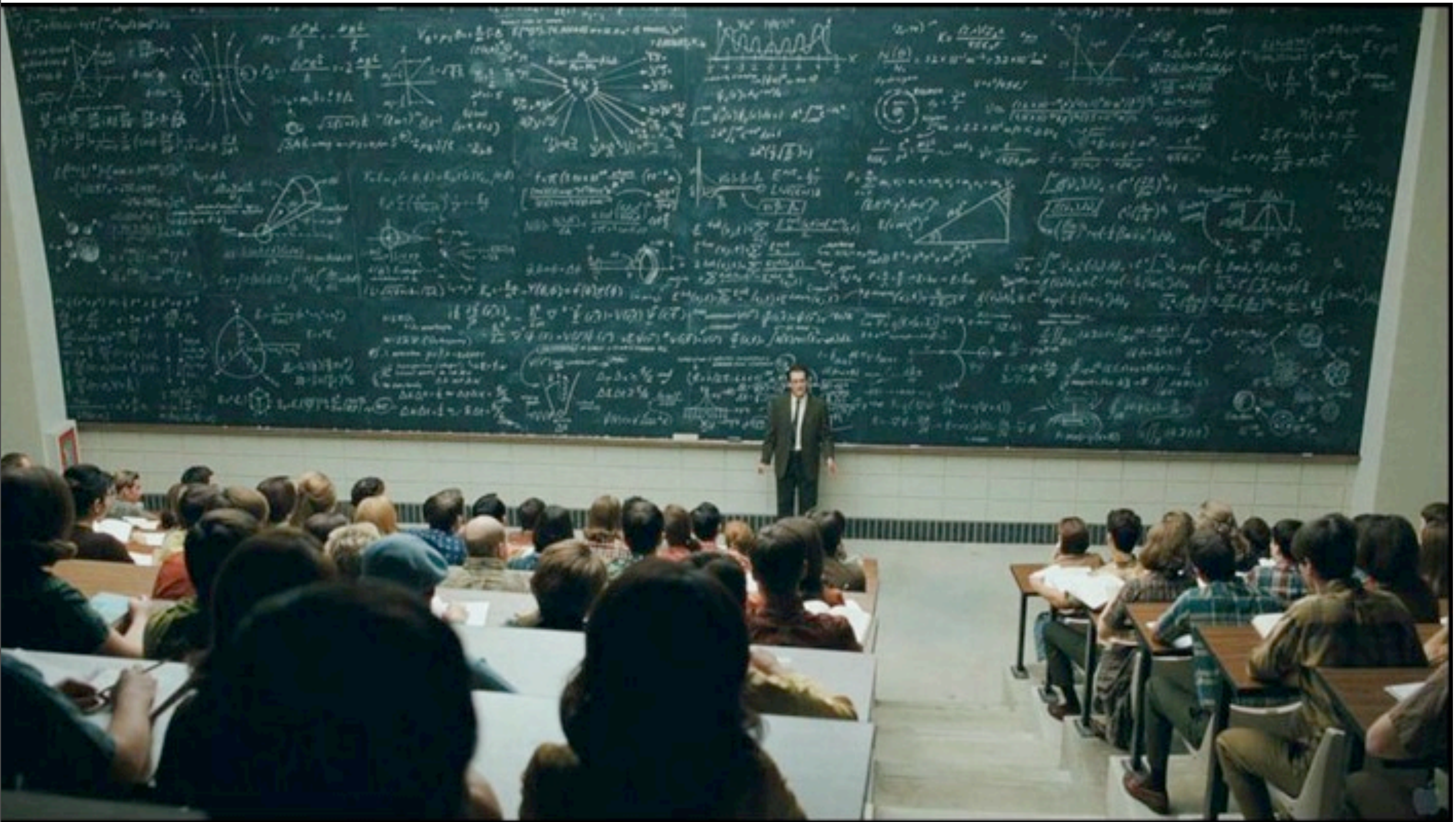

Conclusions

- Prompt emission mechanism
  - Not SSC (lack of high energy signature + not enough optical seed).
  - Not IC – no relevant seed source (may produce some GeV emission)
  - Synch – “line of death”+ Fermi limits on emitting elns Lorentz factor? - Very Strong B?
  - Mildly relativistic comptonization ?
- <u>The GeV emission</u>
  - Mostly external shocks
    - No late energetic photons - a prediction
    - No simultaneous strong IR or optical
- Revise lower Γ opacity estimates for LAT GRBs