Single- and Two-Component GRB Spectra in the Fermi GBM-LAT Energy Range

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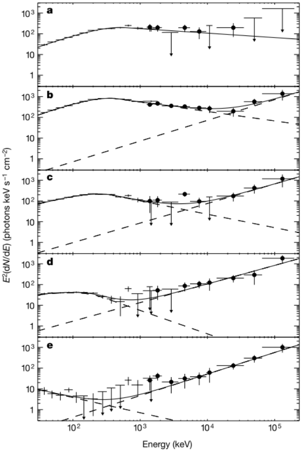
Overview

1. Introduction
2. Magnetic dynamics
3. Radiation components
    - Prompt emission
    - Radiation from $r_{\rm dec}$
4. Example spectra
    - Theoretical
    - Observed
5. Conclusions

Before Fermi - EGRET and projections for LAT

Extra component and/or cutoff

- Hints of extra PL component González et al. (2003)
- LAT GRBs predicted Band et al. (2009) -higher than observed
- Sign of tentative cutoff in prompt (Kocevski et al. 1201.3948)



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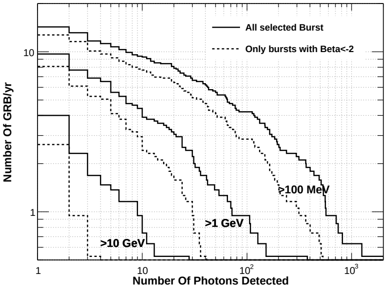

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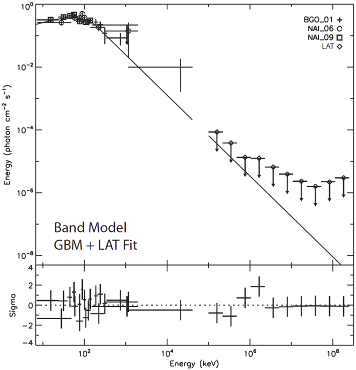
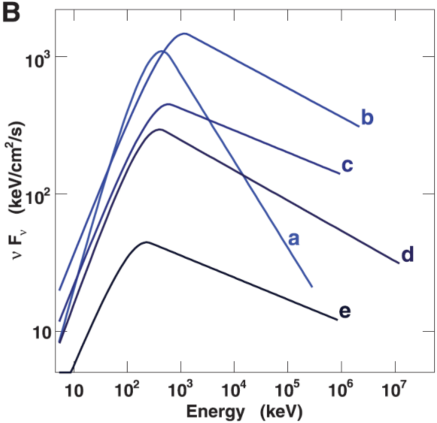


Fermi GBM/LAT observations

- GRB 080916C
  -smooth Band function
- GRB 090902B
  -extra power law comp.
- GRB 090926A
  -extra PL comp.+ break



goals: reproduce simple PL high energy behaviour, extra PL and cutoff

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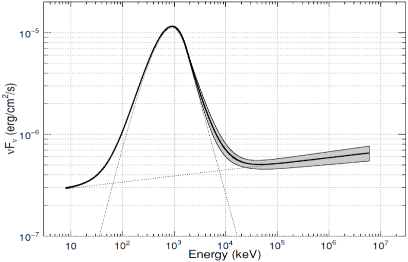

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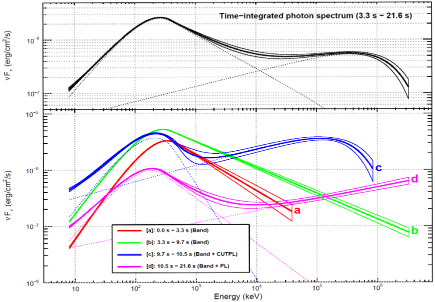

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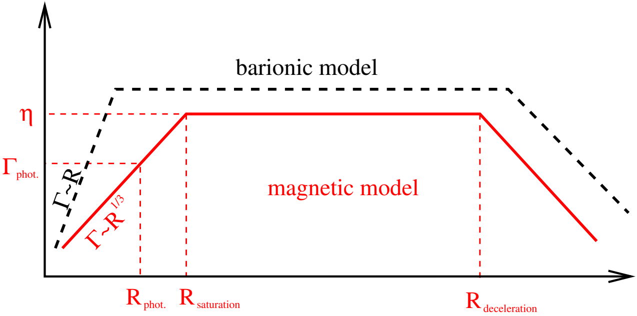
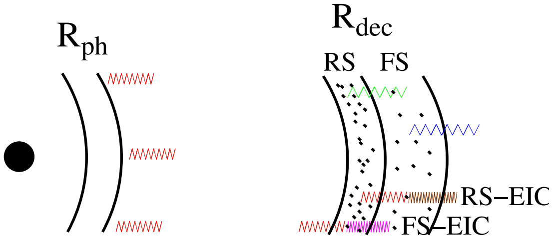
Magnetically dominated jets

- Magnetic dynamics: $\Gamma \propto r^{1/3}$ (baryonic $\Gamma \propto r$)
- ϵ_B goes from ≈ 1 in the prompt to $\lesssim 10^{-1}$ at $r_{\rm dec}$
- Dissipative photosphere: reconnection, weak shocks, turbulence
- Photosphere in accelerating phase
- Previous studies: Band-like prompt spectrum naturally arises -Vurm et al. 2011, Thompson 1994, Giannios and Spruit 2007



Radiation Sources- Two Zone Model

- Prompt component from photosphere (e.g. Beloborodov 2010)
- FS/RS synchrotron
- Prompt up-scatters on FS/RS electrons (Murase et al., 2011)
- FS/RS SSC (Sari & Esin, 2001)
- BB, BB+FS, BB+RS (Ryde, 2005; Ando & Mészáros, 2008)
- p^+ sync., FS+RS, RS+FS (Razzaque et al., 2009, He et al., 2011)
- Max synch./KN cutoffs (Guetta & Granot, 2003)

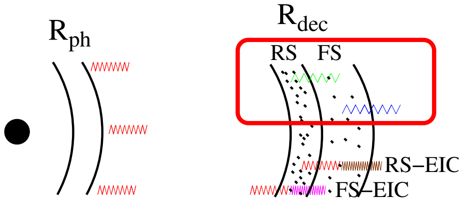


Prompt Emission from Magnetic Dissipation

- Magnetic energy dissipates at $r_{\rm ph}$ (e.g. semirelativistic shocks) (Giannios 2007, Lazzati & Begelman 2011, Mészáros & Rees, 2011, McKinney & Uzdensky 2011)
- E.g. Alfvénic turbulence naturally produces the Band function with $\alpha = -1$, $\beta = -2$ (Thompson, 1994)
- Prompt peak is synchrotron radiation from photosphere
- $r_{ph} = 6.5 \times 10^{12}$ cm $L_{t,53}^{3/5} r_{0,7}^{2/5} \eta_{600}^{-3/5} \sim 0.5$ AU
- $\Gamma_{ph} = (r_{ph}/r_0)^{1/3} = 87\ L_{t,53}^{1/5} \zeta_r^{1/5} r_{0,7}^{-1/5} \eta_{600}^{-1/5}$
- $\varepsilon_{\rm ph,syn}^{\rm obs} = 310$ keV $\zeta_r^{-1/2} (1-\zeta_r)^{1/2} r_{0,7}^{1/2} \epsilon_{B,0}^{1/2} \Gamma_r^3 \left(\frac{1+z}{2}\right)^{-1}$
- weak thermal component $T(r_{ph}) = 2.7$ keV $L_{t,53}^{-1/60} \zeta_r^{-4/15} \eta_{600}^{4/15} r_{0,7}^{-7/30} \Gamma_r^{-1/2} \left(\frac{1+z}{2}\right)^{-1}$
- Pairs at the photosphere? -consider both cases.

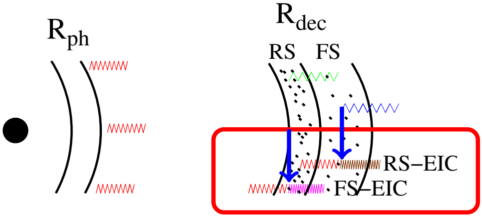
Forward- and Reverse Shock

- At $r_{dec} = 4.8 \times 10^{16}$ cm $\sim$ 3000 AU
- ϵ_B goes from ≈ 1 to $\lesssim 10^{-1}$
- $F_{max}^{FS}(\varepsilon_c) = 0.15$ Jy
  $\varepsilon_c = 3.7$ eV (UV) FAST cooling
- $F_{max}^{RS}(\varepsilon_m) = 92$ Jy
  $\varepsilon_m^{RS} = 1.1 \times 10^{-5}$ keV (FIR) SLOW cooling
- Cutoff at $\varepsilon(\gamma_{\rm MAX})$
- Does a RS develop?- take both cases

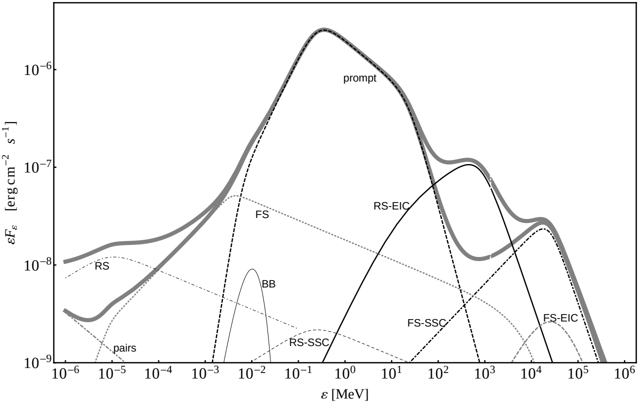


External inverse Compton

- $\tau_{RS} = 6.4 \times 10^{-6}$
- $\tau_{FS} = 1.1 \times 10^{-8}$
- cutoff and peak at $\varepsilon_{\rm KN}(\gamma)$
- $\varepsilon F^{\rm peak}_{\varepsilon,RSEIC} \approx \varepsilon_{br} N_{\varepsilon,p} \tau_{RS} \varepsilon^{RSEIC}_{KN} = 2.3 \times 10^{-8}$ erg cm^{-2} s^{-1}
- $\varepsilon F^{\rm peak}_{\varepsilon,FSEIC} \approx \varepsilon_{br} N_{\varepsilon,p} \tau_{FS} \varepsilon^{FSEIC}_{KN} = 7.2 \times 10^{-10}$ erg cm^{-2} s^{-1}



Example theoretical spectrum with pair cutoff



$L_t = 10^{53}$ erg/s, $\zeta_r = 0.6$, $n = 10$ cm^{-3}, $\eta = 600$, $\epsilon_{B,pr} = 1$, $\epsilon_{B,FS} = \epsilon_{B,RS} = 10^{-2}$, $\epsilon_{e,FS} = \epsilon_{e,RS} = 10^{-2}$, $r_0 = 10^7$ cm, $z = 1$, $\beta = 2.4$, $p = 2.4$

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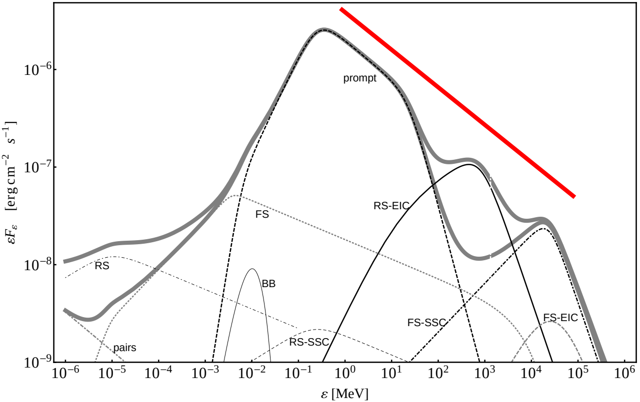

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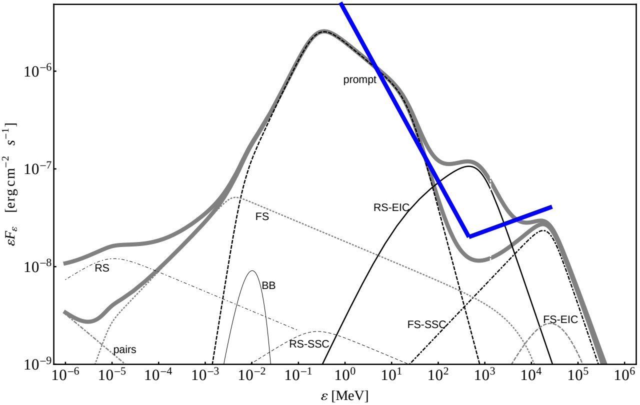

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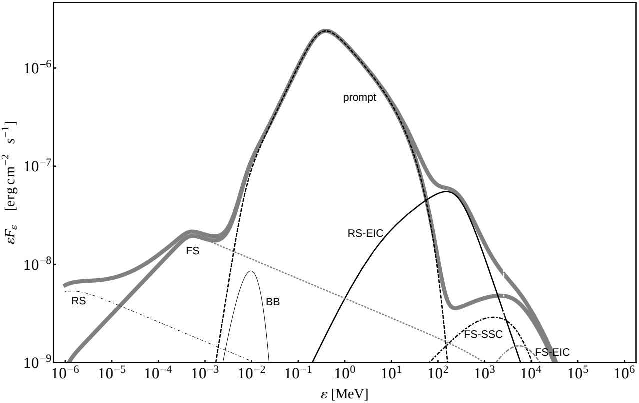
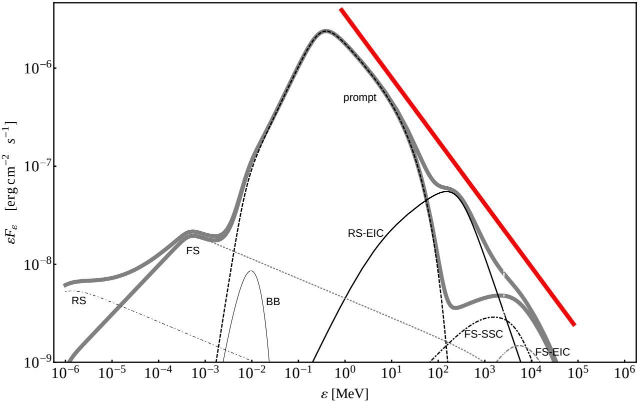
Example spectra: model with no pair cutoff 1.



$L_t = 10^{53}$ erg/s, $\zeta_r = 0.5$, $n = 30$ cm^{-3}, $\eta = 400$, $\epsilon_{B,pr} = 1$, $\epsilon_{B,FS} = \epsilon_{B,RS} = 2 \times 10^{-2}$, $\epsilon_{e,FS} = \epsilon_{e,RS} = 5 \times 10^{-3}$, $r_0 = 10^7$ cm, $z = 1$, $\beta = 2.5$, $p = 2.4$

Example spectra: model with no pair cutoff 1.



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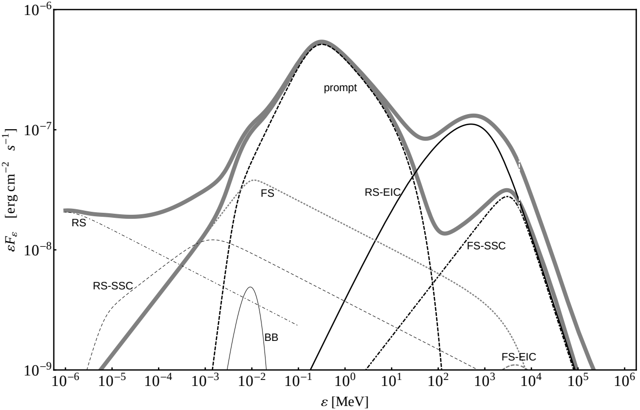
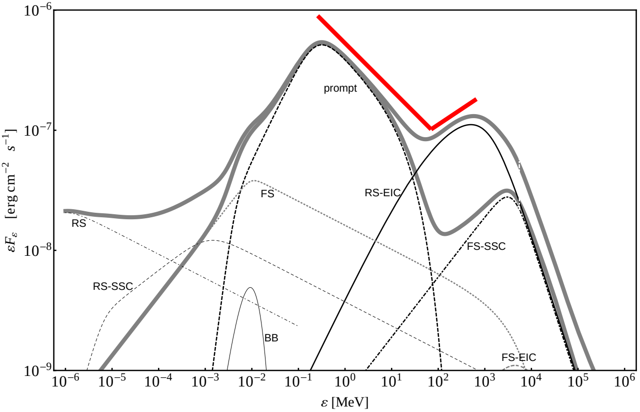
Example spectra: model with no pair cutoff 2.



$L_t = 5 \times 10^{52}$ erg/s, $\zeta_r = 0.6$, $n = 10^2$ cm^{-3}, $\eta = 400$, $\epsilon_{B,pr} = 0.9$, $\epsilon_{B,FS} = 10^{-2}$, $\epsilon_{e,FS} = 2 \times 10^{-2}$, $r_0 = 10^7$ cm, $z = 1$, $\beta = 2.4$, $p = 2.4$

Example spectra: model with no pair cutoff 2.



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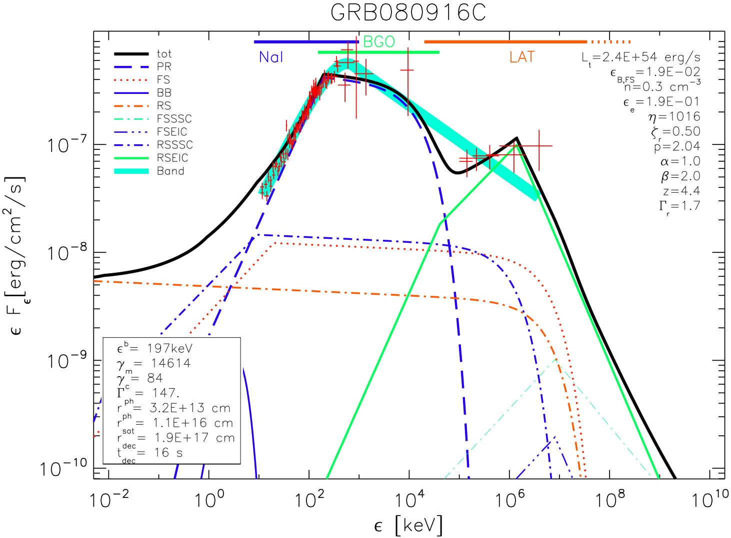
Example: fitting the model to Fermi measurements 1.

Data provided by Bin-Bin Zhang (Veres, Zhang and Mészáros in prep.)



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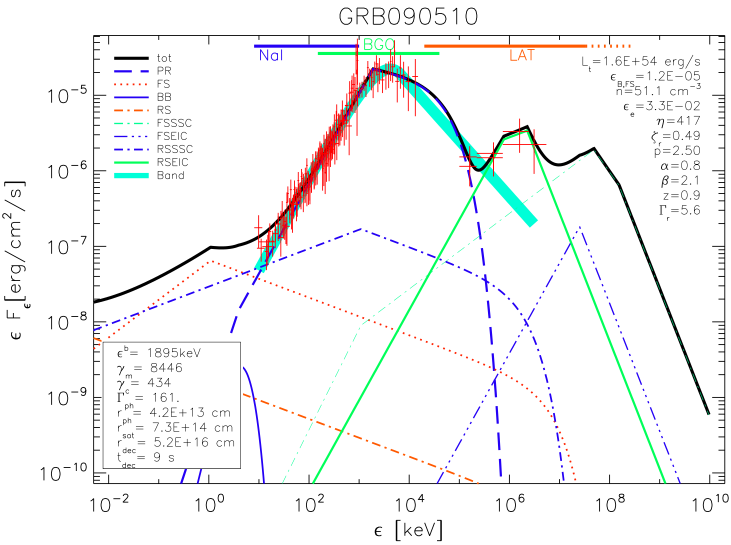
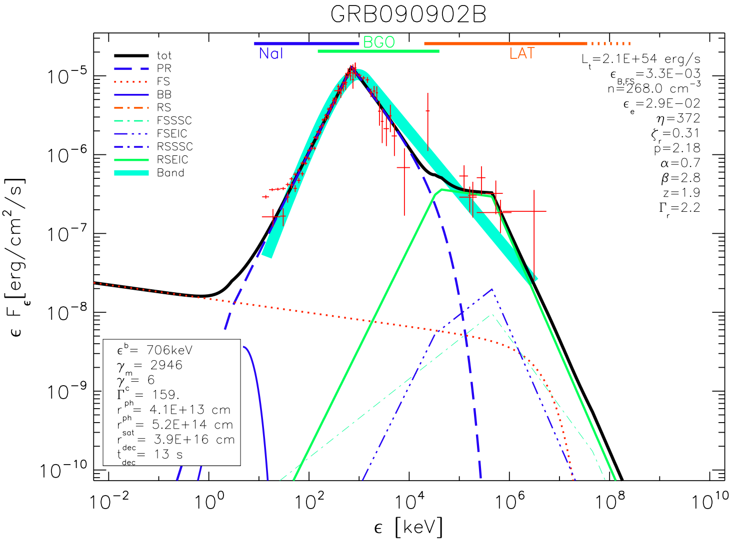


Example: fitting the model to Fermi measurements 3.



Conclusions

- Magnetic model fits well Fermi GBM/LAT data
- Good for inetrpreting observations
- External IC needed for additional PL comp.
- If RS is present, strong extra component
- Can reproduce:
  -smooth Band spectrum
  -Band spectrum + extra PL component + cutoff

for more, please see:
arXiv:1202.2821

Backup slides

Why we do not invoke internal shocks?

- Internal shocks are radiatively inefficient and also are typically expected at radii $r_{is} = ct\Gamma^2 \sim 3 \times 10^{13} t_{v,-3} \Gamma_3^2$ cm, too small for both showing small variability and to allow GeV photons to escape ($R_{\gamma\gamma} \geqslant 10^{15}$ cm).
- Dissipative photospheres can be 50% radiatively efficient; their spectrum reproduce the Band function, with a peak which is thermal (baryonic dyn) or synchrotron (mag.dyn), and where low and high energy slopes are due to scattering (baryonic) and or Synch/IC (magn dyn) - see Thompson 94, Rees, Mészáros05, Pe'er, Mészáros, Rees 06 and Beloborodov 11.
- Magnetic dynamics: useful because (a) suspect mag. fields dominant in high $E_{\rm iso}$ bursts (since need Blandford-Znajek), (b) dissipation very efficient due to reconnection, (c) spectrum is Band-like (Giannios 07, Thompson 94 or Vurm 11).

Time resolved spectra, e.g. 080916C work in progress