Hints of the jet composition in gamma-ray bursts from dissipative photosphere models

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together with P Mészáros, J M Burgess, B-B Zhang, R Preece, F Ryde et al. on behalf of the Fermi LAT collaboration

名古屋市 (Nagoya)
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- Internal-external shocks
  - → synchrotron
  - → inverse Compton

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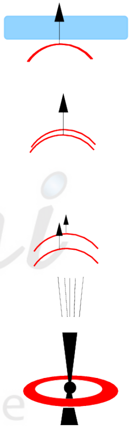
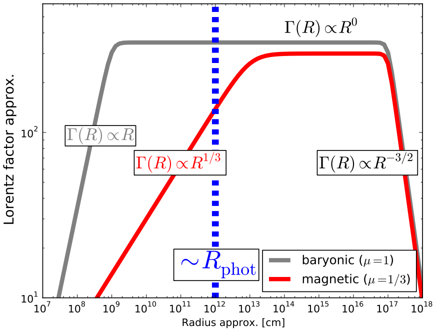
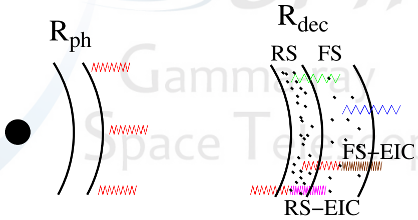


- Internal-external shocks
  → synchrotron
  → inverse Compton
- Problem: efficiency, spectra
- Dissipative/photospheric models
  - n-p heating (Beloborodov 2010)
    + magn. (Vurm et al. 2011)
  - magnetic reconnection (Giannios 2008)

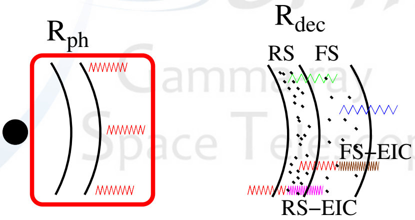
- Acceleration→saturation, coasting→deceleration
- Magnetic dynamics: $\Gamma \propto R^{1/3}$ (baryonic $\Gamma \propto R$)
- $t'_{\rm ex} \sim R/\Gamma$, $t'_{\rm reconn.} \sim \Gamma$. Self similar: $\gamma' \sim t'_{\rm reconn.}/t'_{\rm ex} \sim \Gamma^2/R$ (tot. energy per part.). $\gamma'\Gamma \sim$ const. during accel $\rightarrow \Gamma \sim R^{1/3}$ (Mészáros & Rees 2011)
- Photosphere in accelerating phase



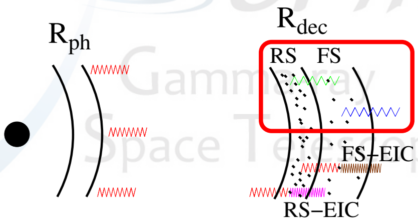

R_ph
R_dec
RS
FS
FS−EIC
RS−EIC

Radiation Sources- Two Zone Model

- Synchrotron peak from photosphere, BB (Mészáros & Rees 2011)



- Synchrotron peak from photosphere, BB (Mészáros & Rees 2011)
- FS/RS synchrotron
- FS/RS SSC (Sari & Esin 2001)



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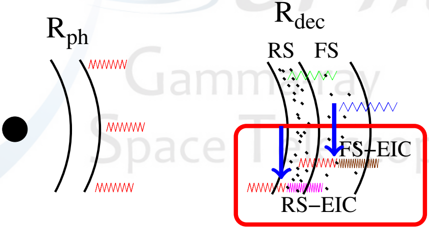
- Prompt up-scatters on FS/RS electrons (Beloborodov 2005, Murase et al., 2011)



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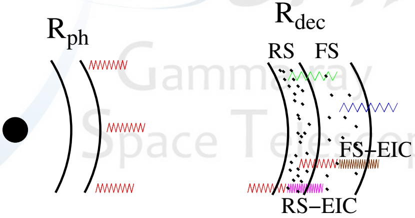
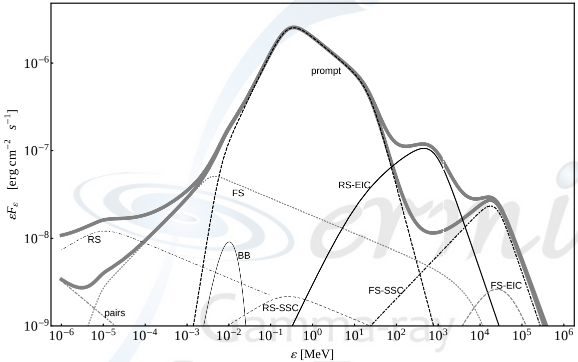
- Prompt up-scatters on FS/RS electrons (Beloborodov 2005, Murase et al., 2011)
- BB+FS, BB+RS (Ryde 2005; Ando & Mészáros 2008)
- p^+ sync., FS+RS, RS+FS (Razzaque et al., 2009, He et al. 2011)
- Max synch./KN cutoffs (Guetta & Granot 2003)



Prompt Emission from Magnetic Dissipation

- Here: $\Gamma \propto R^{1/3}$
- Magnetic energy dissipates at $\sim R_{\rm ph}$ (Giannios 2007; Mészáros & Rees 2011)
- Prompt phase is synchrotron radiation through $\Gamma_r \gtrsim 1$ shocks from close to photosphere
- $R_{ph} = 6.5 \times 10^{12}$ cm $L_{t,53}^{3/5} r_{0,7}^{2/5} \eta_{600}^{-3/5}$ pair creation may be important
- $\Gamma_{ph} = (R_{ph}/R_0)^{1/3} = 87 \; L_{t,53}^{1/5} \zeta_r^{1/5} r_{0,7}^{-1/5} \eta_{600}^{-1/5}$
- $\underline{\varepsilon^{\rm obs}_{\rm ph,syn} = 310 \;\; {\rm keV}} \;\; \zeta_r^{-1/2} (1-\zeta_r)^{1/2} r_{0,7}^{1/2} \epsilon_{B,0}^{1/2} \Gamma_r^3 \left(\frac{1+z}{2}\right)^{-1}$
- Subdominant thermal component
  $\underline{T(R_{ph}) = 2.7 \;\; {\rm keV}} \; L_{t,53}^{-1/60} \zeta_r^{-4/15} \eta_{600}^{4/15} r_{0,7}^{-7/30} \Gamma_r^{-1/2} \left(\frac{1+z}{2}\right)^{-1}$

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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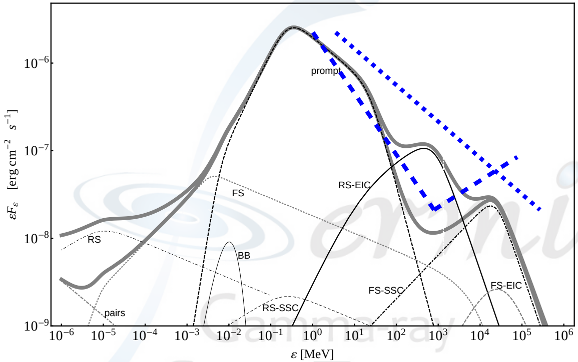

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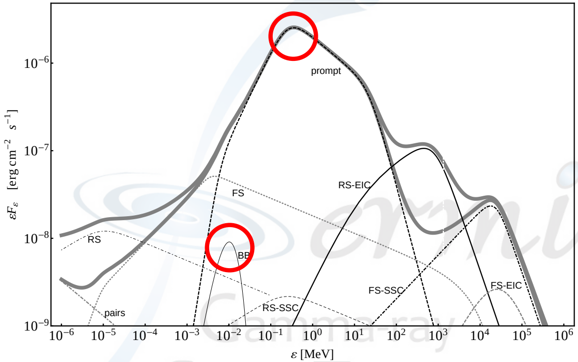

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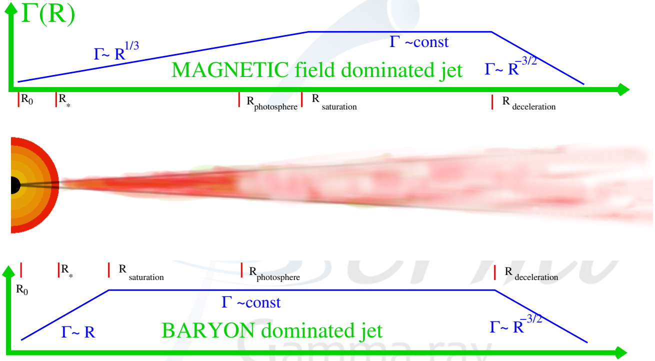
Mix of magnetic and baryonic



Veres, Zhang, Mészáros ApJ, **764**, 94 (2013)

Mix of magnetic and baryonic

- $\Gamma(R) \propto \begin{cases} R^{\mu} & \text{if} \quad R < R_{\rm sat} \\ \text{const.} & \text{if} \quad R_{\rm sat} < R \end{cases}$ $\qquad 1/3 \lesssim \mu \lesssim 1$
- $\eta_T = \left(\frac{L\sigma_T}{8\pi m_p c^3 R_0}\right)^{\frac{\mu}{1+3\mu}}$ Limiting Lorentz factor
- $\eta = \eta_T$ when $R_{\rm SAT} = R_{\rm PHOT}$
- $\eta > \eta_T \rightarrow$ "photosphere in **acceleration** phase"
- $\eta < \eta_T \rightarrow$ "photosphere in **coasting** phase"
- $\mu = 1/3$ MAGNETIC $\sim \eta_T < 100$ small
- $\mu = 1$ BARYONIC $\sim \eta_T > 1000$ high
- $\varepsilon_{\rm peak} \propto \begin{cases} L^{\frac{3\mu-1}{4\mu+2}} \; \eta^{-\frac{3\mu-1}{4\mu+2}} \; r_0^{\frac{-5\mu}{4\mu+2}} \; \Gamma_r^3/(1+z) & \text{if } \eta > \eta_T \\ L^{-1/2} \; \eta^3 \; \Gamma_r^3/(1+z) & \text{if } \eta < \eta_T. \end{cases}$
- $T \propto \begin{cases} L^{\frac{14\mu-5}{12(2\mu+1)}} \; \eta^{\frac{2-2\mu}{6\mu+3}} \; r_0^{-\frac{10\mu-1}{6(2\mu+1)}}/(1+z) & \text{if } \eta > \eta_T \\ L^{-5/12} \; \eta^{8/3} \; r_0^{1/6}/(1+z) & \text{if } \eta < \eta_T. \end{cases}$

Fit to bright LAT GRBs

- Can possibly tell us if:
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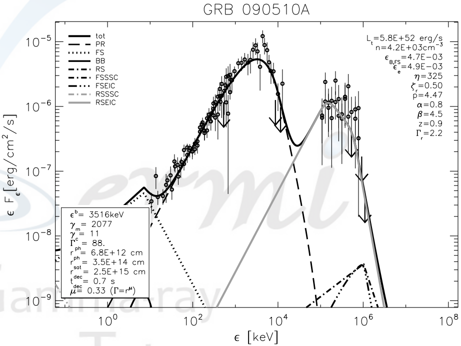

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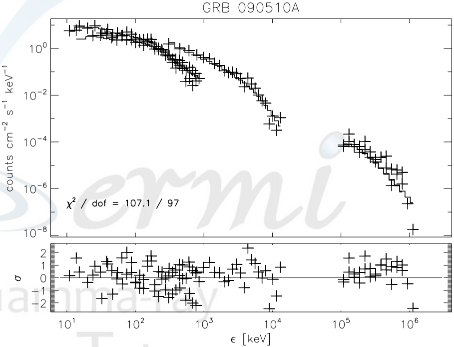

FIT TO BRIGHT LAT GRBs

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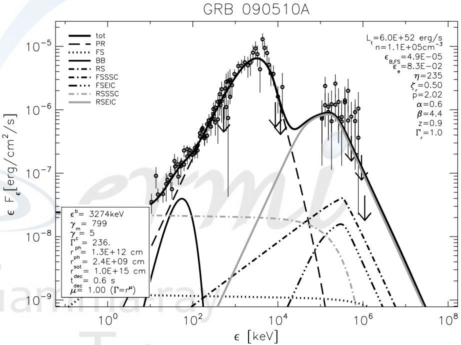
- GRB 090510, $\mu = 1$
- Problem: both fit.



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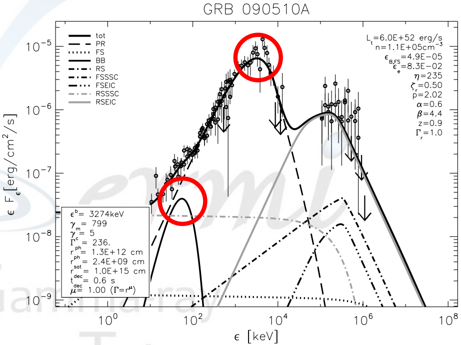
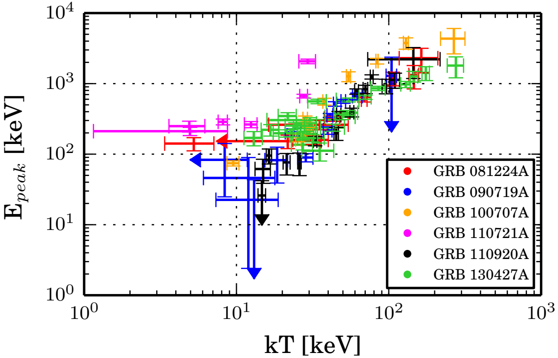
- Problem: both fit.
- Way out:
  $\varepsilon_{\mathrm{peak}} - T$ correlation
  → constrain μ
  → jet composition
  Burgess et al. ApJL **784**, 43, (2014)



$$\varepsilon_{\rm peak} \propto T^{\alpha}$$



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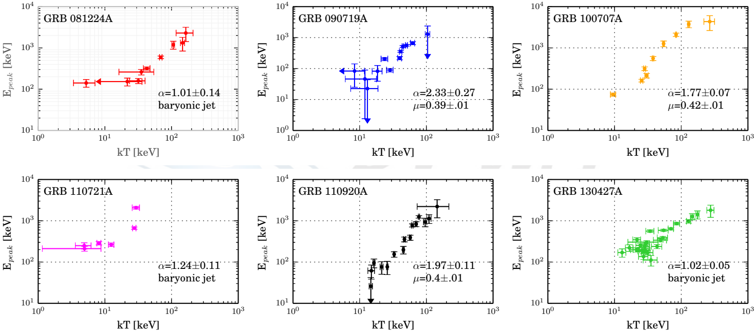

Burgess et al. ApJL **784**, 43, (2014)

$\varepsilon_{\rm peak}$-T correlation theoretical interpretation

- Take general acceleration model
- $\varepsilon_{\rm peak} \propto \begin{cases} L^{\frac{3\mu-1}{4\mu+2}}\ \eta^{-\frac{3\mu-1}{4\mu+2}}\ r_0^{\frac{-5\mu}{4\mu+2}}\ \Gamma_r^3/(1+z) & \text{if } \eta > \eta_T \\ L^{-1/2}\ \eta^3\ \Gamma_r^3/(1+z) & \text{if } \eta < \eta_T. \end{cases}$
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- use L, η (or r_0) to link $\varepsilon_{\rm peak}$ to T.

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- $$\varepsilon_{\rm peak} \propto \begin{cases} T^{\frac{6(3\mu-1)}{(14\mu-5)}} & \text{if } \eta > \eta_T \\ T^{1.2} & \text{if } \eta < \eta_T. \end{cases}$$

ε_p-kT correlation - Results

GRB Name	α	Jet Type	μ
GRB 081224A	1.01 ± 0.14	baryonic	–
GRB 090719A	2.33 ± 0.27	magnetic	0.39 ± 0.01
GRB 100707A	1.77 ± 0.07	magnetic	0.42 ± 0.01
GRB 110721A	1.24 ± 0.11	baryonic	–
GRB 110920A	1.97 ± 0.11	magnetic	0.4 ± 0.01
GRB 130427A	1.02 ± 0.05	baryonic	–

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Conclusion

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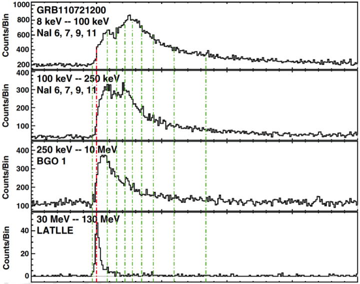
- Diss. phot., magn. dom. (+ EIC) $\Gamma \propto R^{1/3}$
- General treatment of acceleration $\Gamma \propto R^{\mu}$
- Fits bright LAT bursts, though ambiguous μ
- Through $\varepsilon_{\rm peak} - kT$ correlation:
  $\rightarrow$ hints of jet composition

Backup Slides

GRB 110721A (Axelsson et al. 2012)

Veres, Zhang, Mészáros ApJL, **761**, 18 (2012)

- Very high peak energy: 15 MeV
- Internal shocks not viable
- see also: Beloborodov (2013), Zhang et al. (2012)



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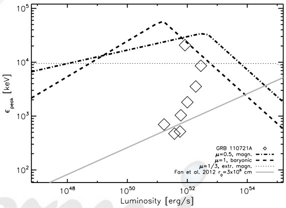

- Synchrotron from dissipative photosphere works
- $\varepsilon_{\rm peak} \propto$

$$\begin{cases} L^{\frac{3\mu-1}{4\mu+2}} \ \eta^{-\frac{3\mu-1}{4\mu+2}} \ r_0^{\frac{-5\mu}{4\mu+2}} \\ L^{-1/2} \ \eta^3 \end{cases}$$