Poynting flux dominated jets challenged by photospheric emission

Based on work by

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University College Cork (UCC)

in collaboration with

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April 2015

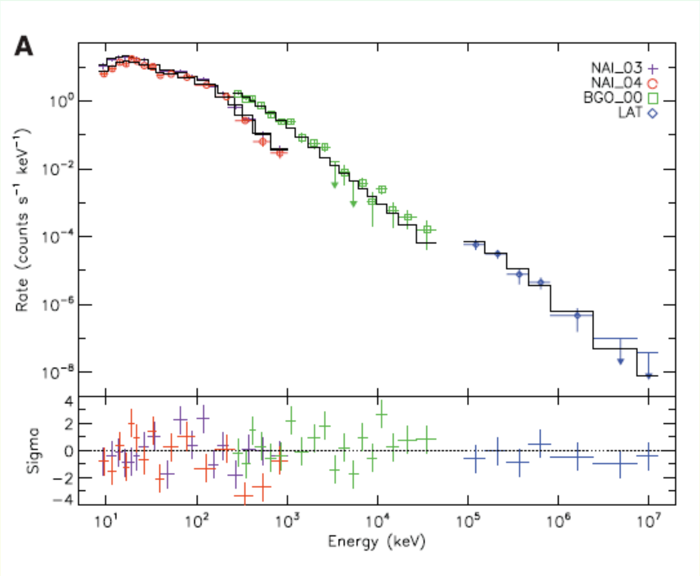
Begue & AP, 2015, Ap.J. 802, 134

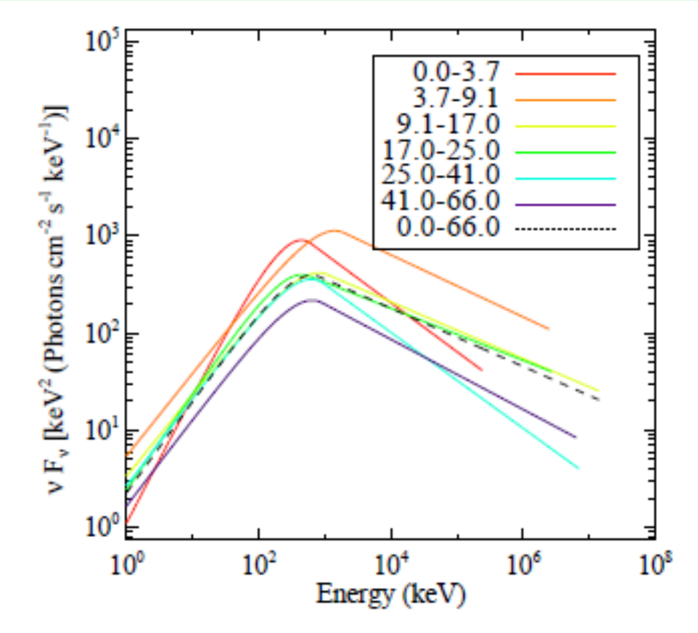
Motivation: "Photospheric revolution" in GRB prompt emission

Key spectral features:

"Broken power law";
E_{pk} <~ MeV

080916C(Abdo+09)



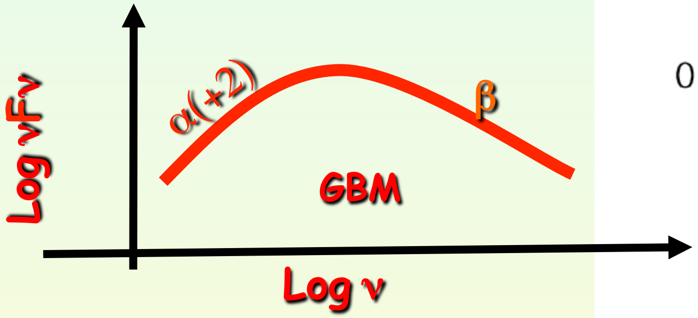


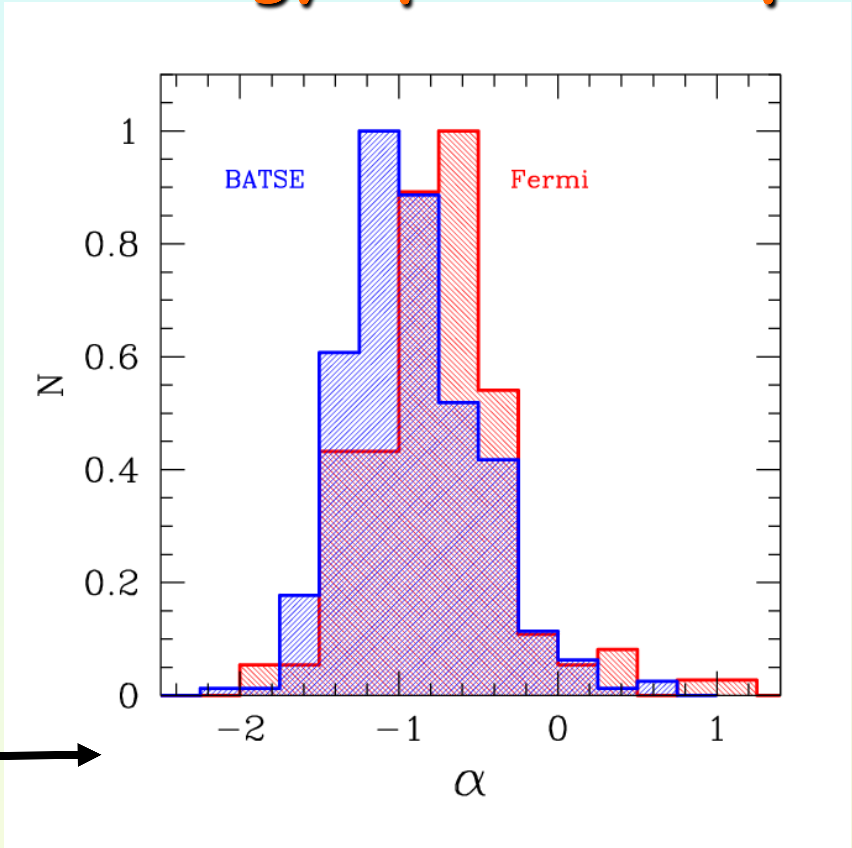
Main question:
What radiative processes produce the spectra ?
Initial suspect: synchrotron (?)

Fermi - GBM bursts

Most have low energy spectral slope <α>~-1

BATSE data: Kaneko+06





Nava+11; Goldstein+12

(picture taken from Ghisellini)

→Violate 'synchrotron line of death' (Preece98);
→Emission mechanism cannot be (only) synchrotron

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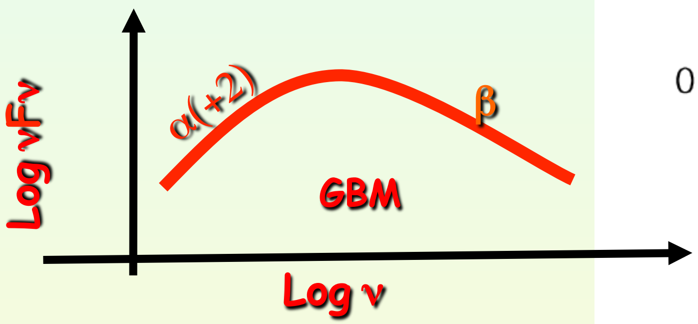

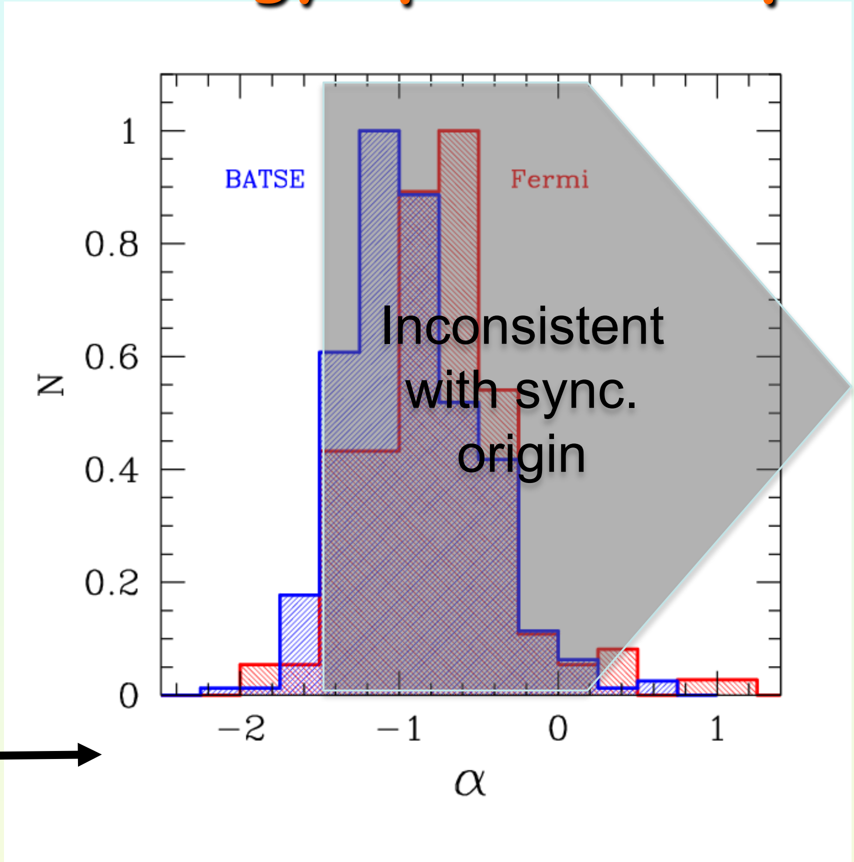

Photon spectral index

Nava+11;
Goldstein+12

(picture taken
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→Violate 'synchrotron line of death' (Preece98);

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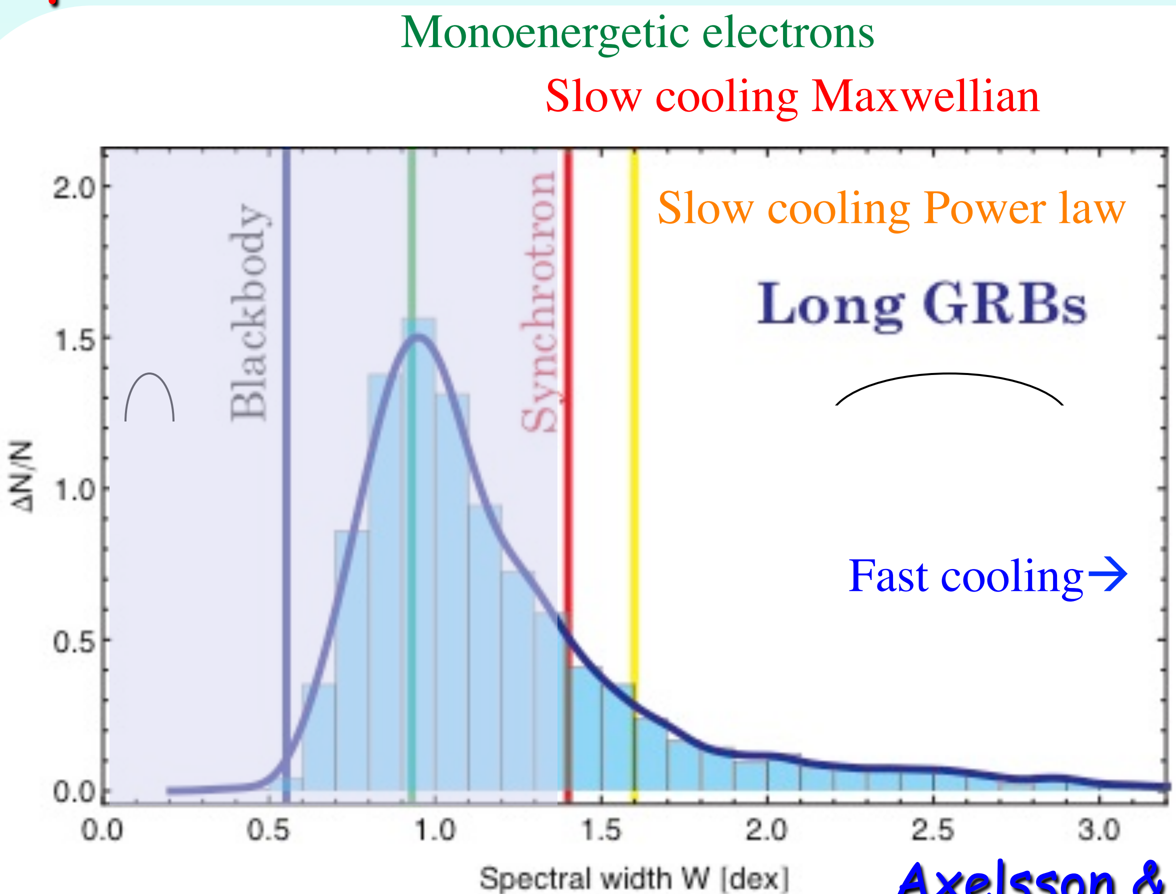
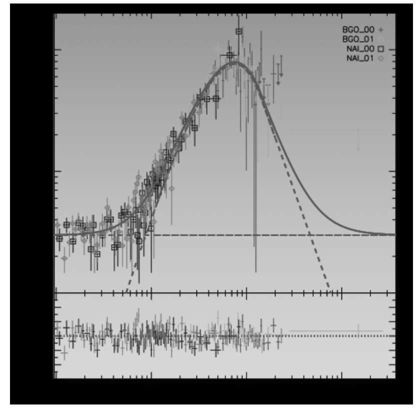
Main observational motivation to study alternatives (photospheric emission)

Same result: too narrow spectral width

Spectral width of 1611 CGRO/ BATSE and 681 Fermi/GBM





W=FWHM

$$W = \log\left(\frac{E_2}{E_1}\right)$$

Axelsson & Borgonovo, 2015, ApJ

→Violate 'synchrotron line of death' (Preece98);

→Emission mechanism cannot be (only) synchrotron

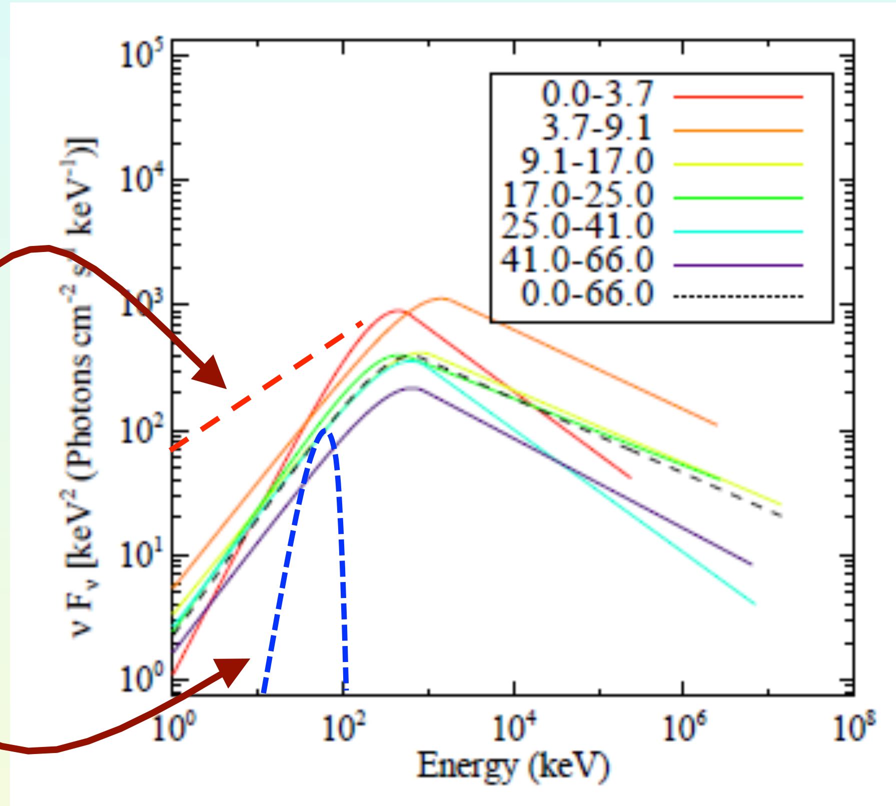
Main observational motivation to study alternatives (photospheric emission)

Key idea: broaden thermal (photospheric) emission

GRB080916C (Abdo+09)

Synchrotron – too flat

Planck – too steep



Idea: Broaden "Planck" !

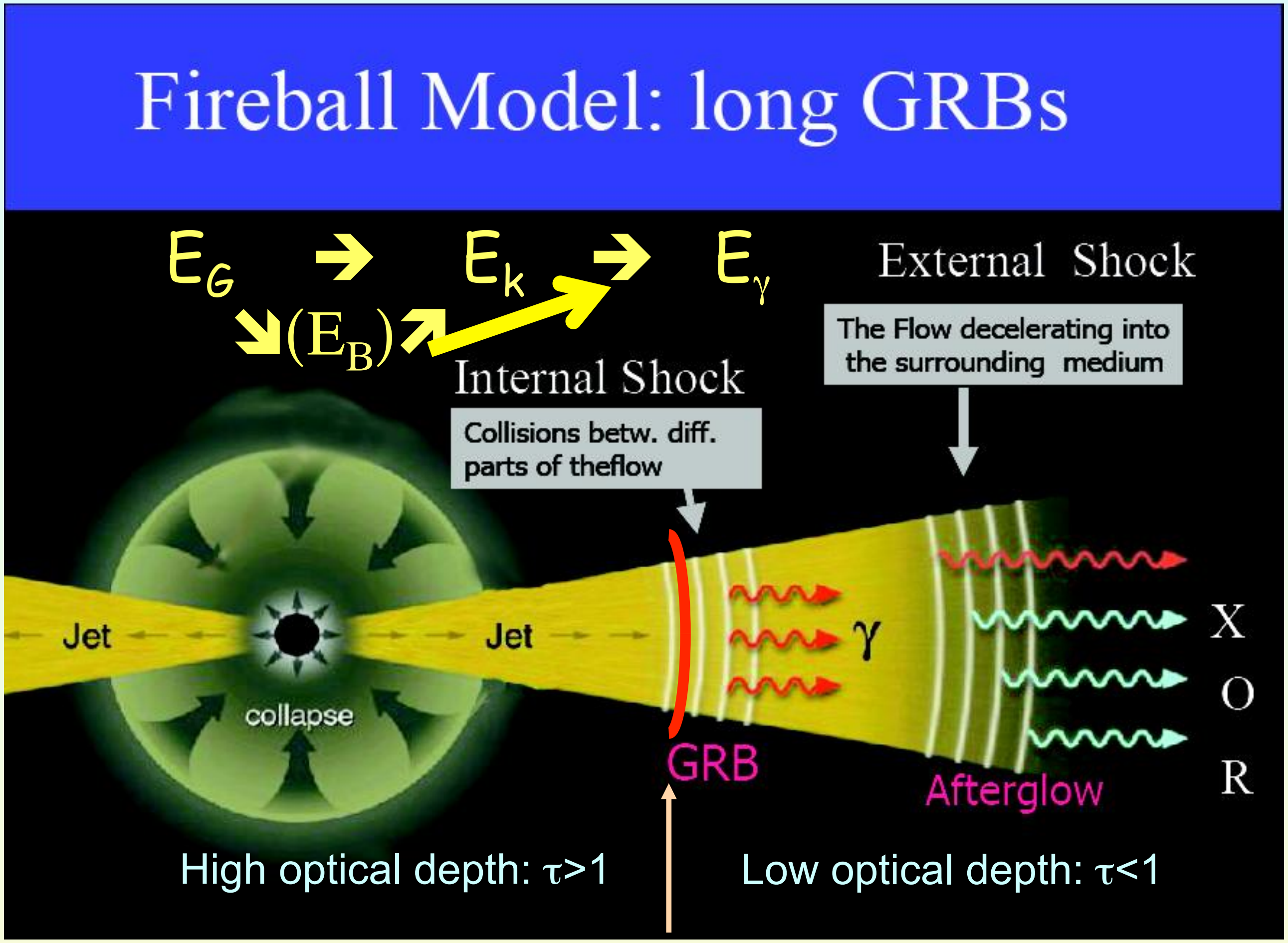
Photospheric ≠ Thermal

"Geometrical broadening":
(Light aberration)

"Physical broadening":
Sub photospheric energy dissipation

Photosphere: inherent in "fireball" model

- Paczynski (1986); Goodman (1986); Shemi & Piran (1990); Rees & Meszaros (1992, 1994);



Photosphere

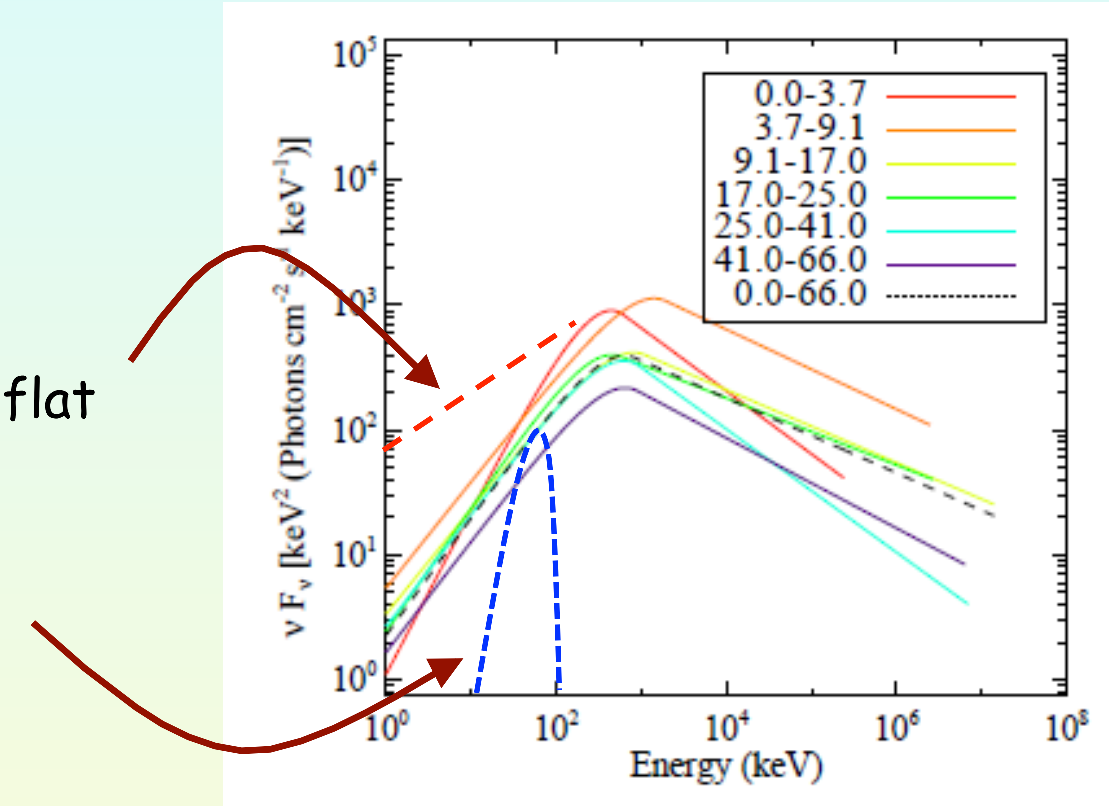
Variability -> ***several emission zones;*** ***(No predictivity !!)***

NOTHING tells what is the emission radius !!

Photosphere: inherent in all versions; (strong/weak B, high/low baryon load, etc.)

Key idea: broaden thermal (photospheric) emission

GRB080916C (Abdo+09)



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Idea: Broaden "Planck" ! | **Photospheric ≠ Thermal**

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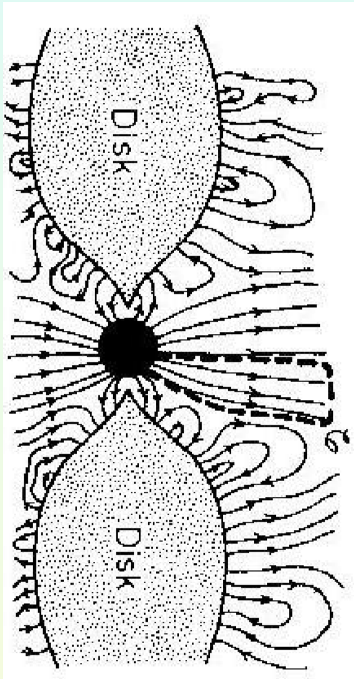
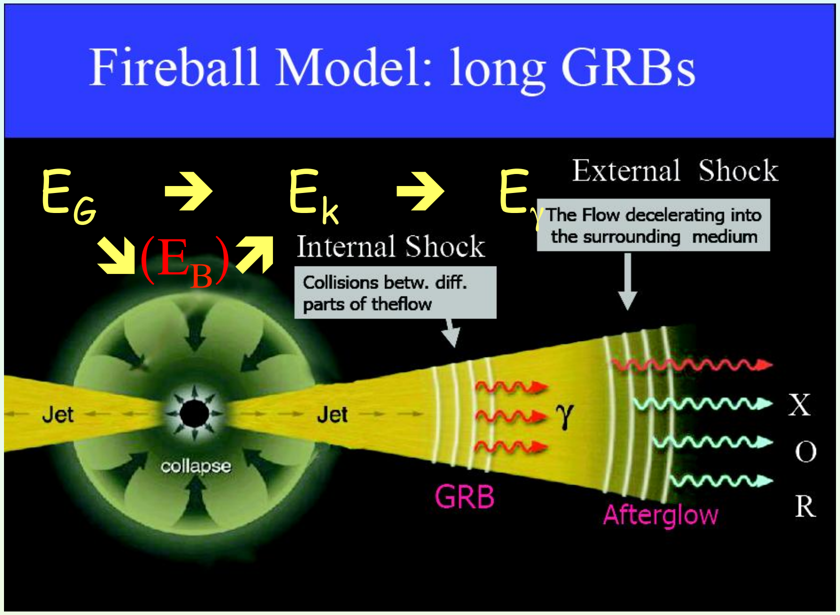
Jet magnetization: dynamical constraints



Blandford & Znajek 1977
Begelman & Li 1992
Meier et al. 2001
Koide et al. 2001
van Putten 2001
…
Barkov & Komissarov 2008
…



Begue & AP, 2015, Ap.J

$\Gamma_{(rph)}$>~100

$$r_{ph} = 6\times10^{11}\frac{L_{52}^{3/5}}{(\varepsilon\Omega)_3^{2/5}\sigma_2^{3/2}}\,\mathrm{cm}$$

Basic scenario:

Continuous reconnection & steady B-field decay rate

~50% of $\dot{E}$ → acceleration,

~50% → heating

→ Gradual acceleration, $\Gamma(r) \sim r^{1/3}$ (Lyubarski's talk)

Dynamics >>

Drenkhahn & Spruit, 2002; Giannios 2006

Can thermal emission explain the spectra ?

Basic idea: *photon production rate*

- As long as $\dot{n}_\gamma > n_{\gamma,th} / t_{\exp} \leftrightarrow$ full thermalization.

$$t_{\exp} = \frac{r}{\Gamma(r)c}$$

- Photon production processes:

  - double Compton $\dot{n}_{DC} \sim T'^2 n_e' n_\gamma$
  - Brem. $\dot{n}_B \sim T'^{-1/2} n_e'^2$
  - cyclo-Synch. $\dot{n}_{sync} \sim T'^2 n_e'$

Vurm, Lyubarski & Piran (13)

Magnetized flows:

→ Condition fulfilled only for $r < r_{supp} \sim 5*10^9$ cm

Begue & AP (15)

Can thermal emission explain the spectra ?

Photon production rate: $\dot{n}_\gamma > n_{\gamma,th} / t_{\exp}$

- At r > r_{supp} ~ 5*10^9 cm photon emission suppressed.
  → **Full thermalization impossible**

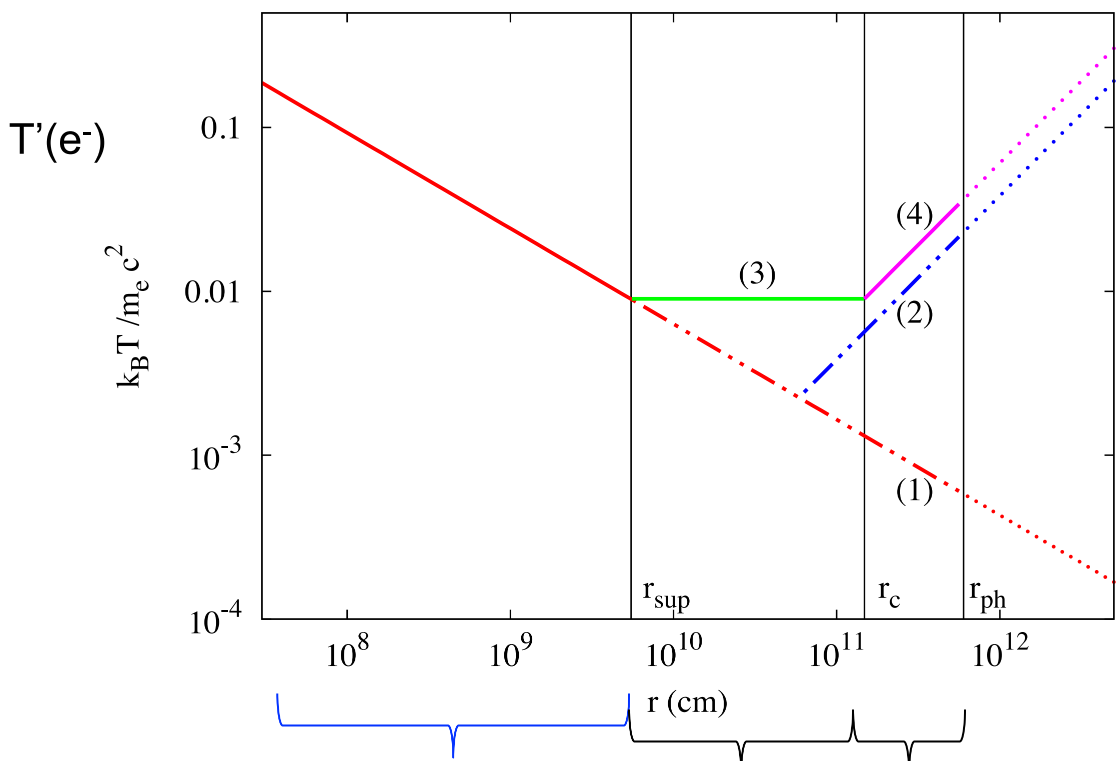
- At r< r_{ph}~6*10^{11} cm photons are coupled to the plasma
  → photon # is conserved by multiple IC

- Continuous reconnection → continuous electron heating
  At r< r_c ~ 2*10^{11} cm Efficient radiative cooling
  → Energy is divided between e^-, γ
  → photon temperature increase

- At r_c ~ 2*10^{11} cm < r < r_{ph}~6*10^{11} cm → inefficient cooling,
  T_e increases

→ Photons: **Wien spectrum**, with T'~ u'/<n_γ>

Electron temperature



$$L_{52} = 1; \sigma_2 = 1; (\varepsilon\Omega)_3 = 1$$

$$r_{ph} = 6 \times 10^{11} \frac{L_{52}^{3/5}}{(\varepsilon\Omega)_3^{2/5} \sigma_2^{3/2}} \text{cm}$$

Efficient photon production

$T' \sim r^{-7/12}$

Efficient e^- cooling

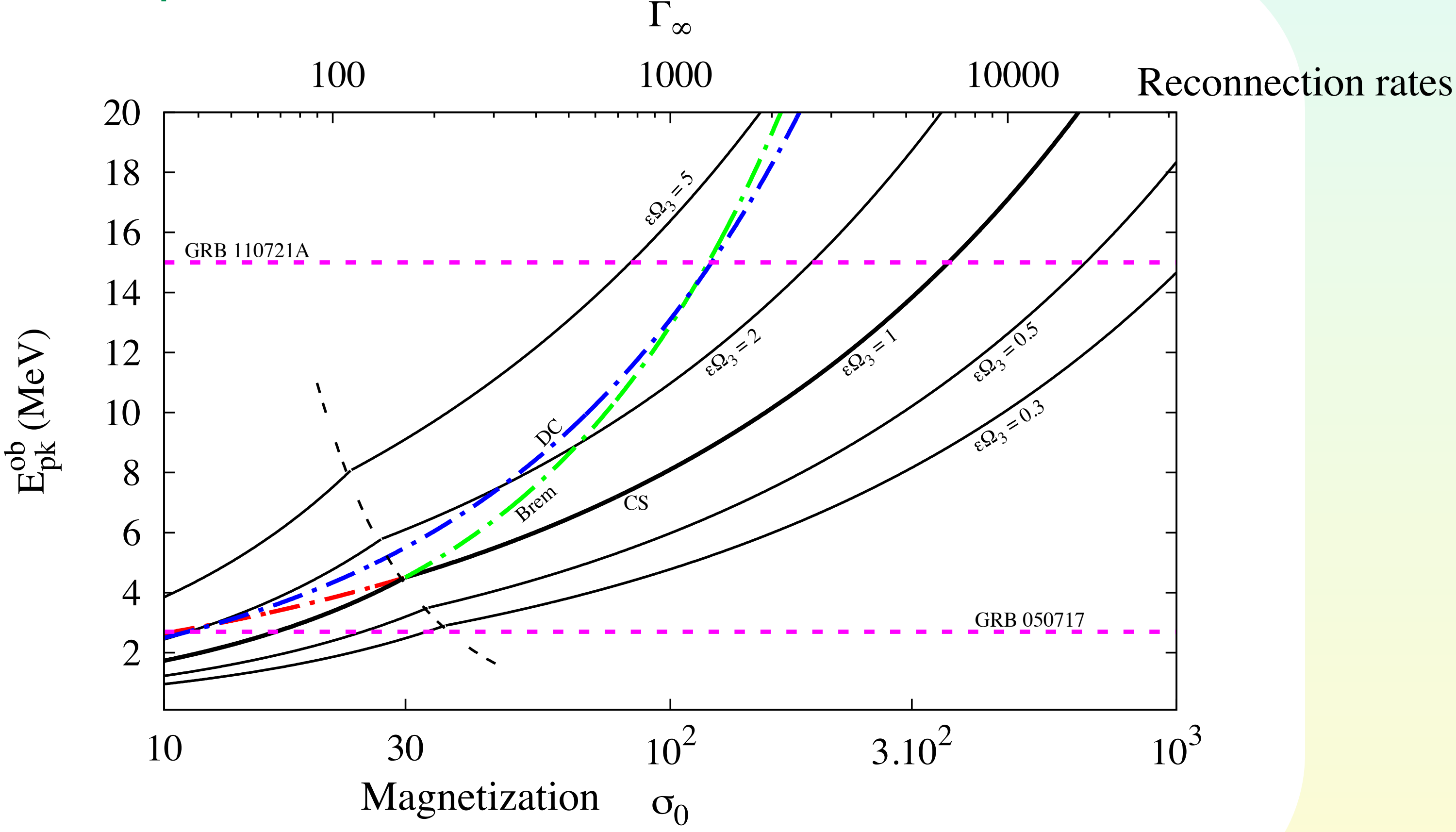
Inefficient e^- cooling

Inefficient photon production

Using thermal emission to constrain jet magnetization

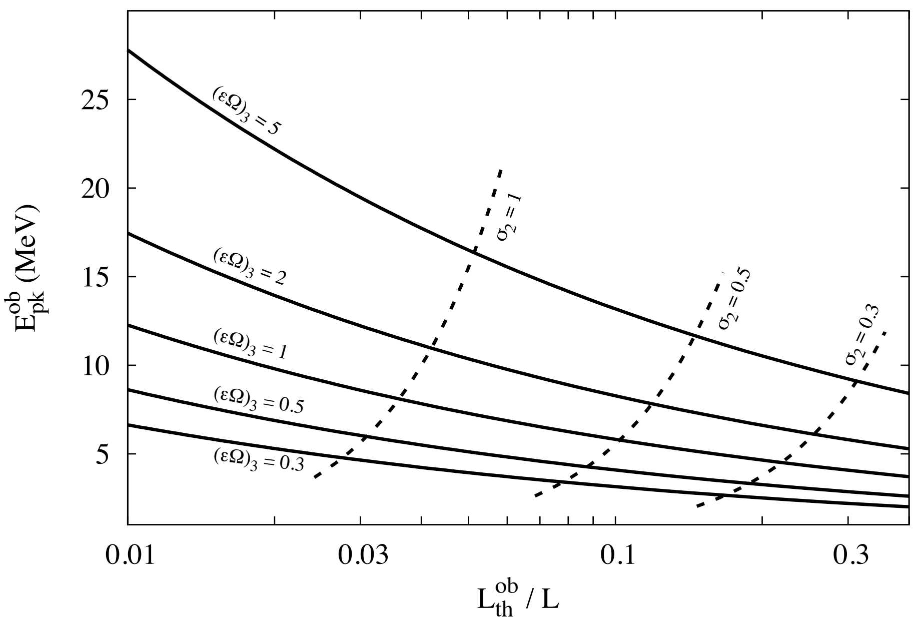
Photon starvation → Wien spectrum with

$T^{ob} = T' \Gamma(r_{ph})$ >~3 - 5 MeV



Using thermal emission to constrain jet magnetization

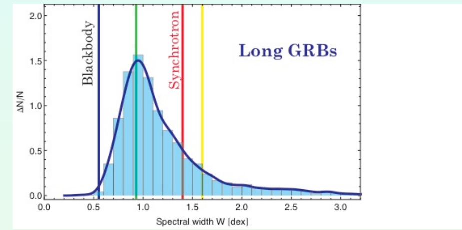
E_{pk} vs. L_{th}



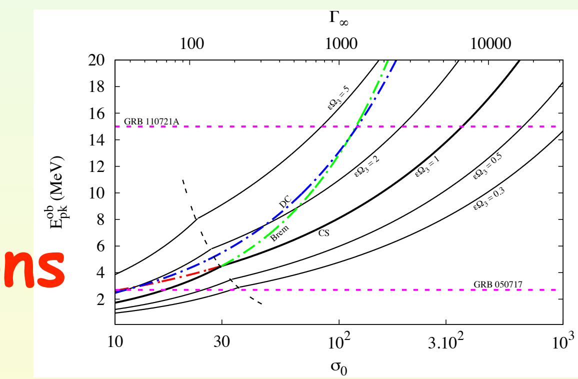
High σ → high E_{pk}, low L_{th}
High reconnection rate → High E_{pk}

Summary

★ Thermal component: a natural way of overcoming the steep slopes in GRBs
(after broadening)



★ Highly magnetized flows & constant reconnection rate:
photon production rate suppressed,
Wien spectrum with E_{pk}>~few MeV
→ inconsistent with (most) observations



Begue & AP, 2015, Ap.J. 802, 134