The observable effects of a photospheric component on GRBs

(and a simple explanation to a peak energy clustering in GRBs)

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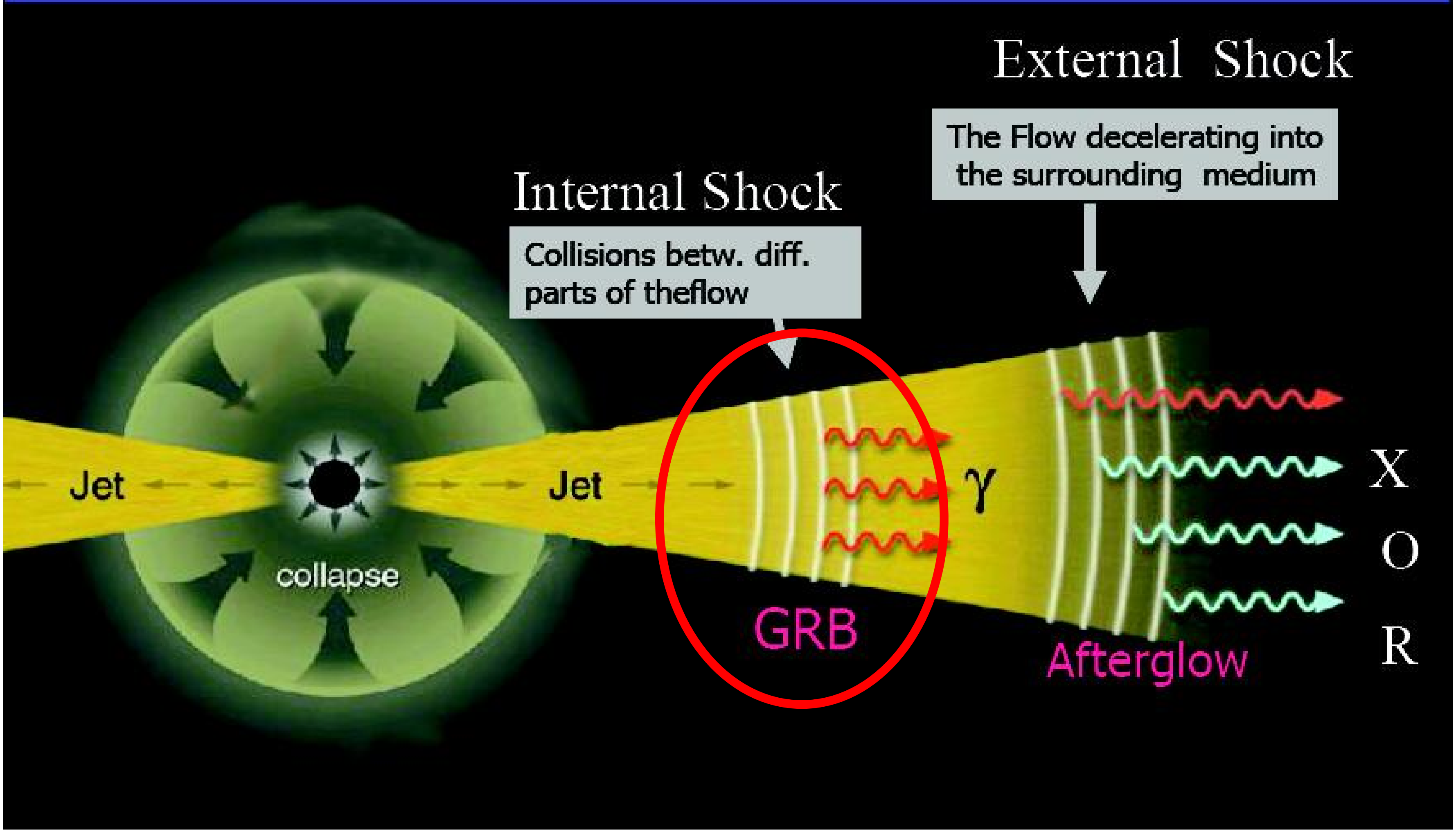
Outline

- Motivation: peculiarities in the prompt emission
- Electron energy balance: characteristic Lorentz factor
- Spectrum: high optical depth
- Spectrum: low optical depth

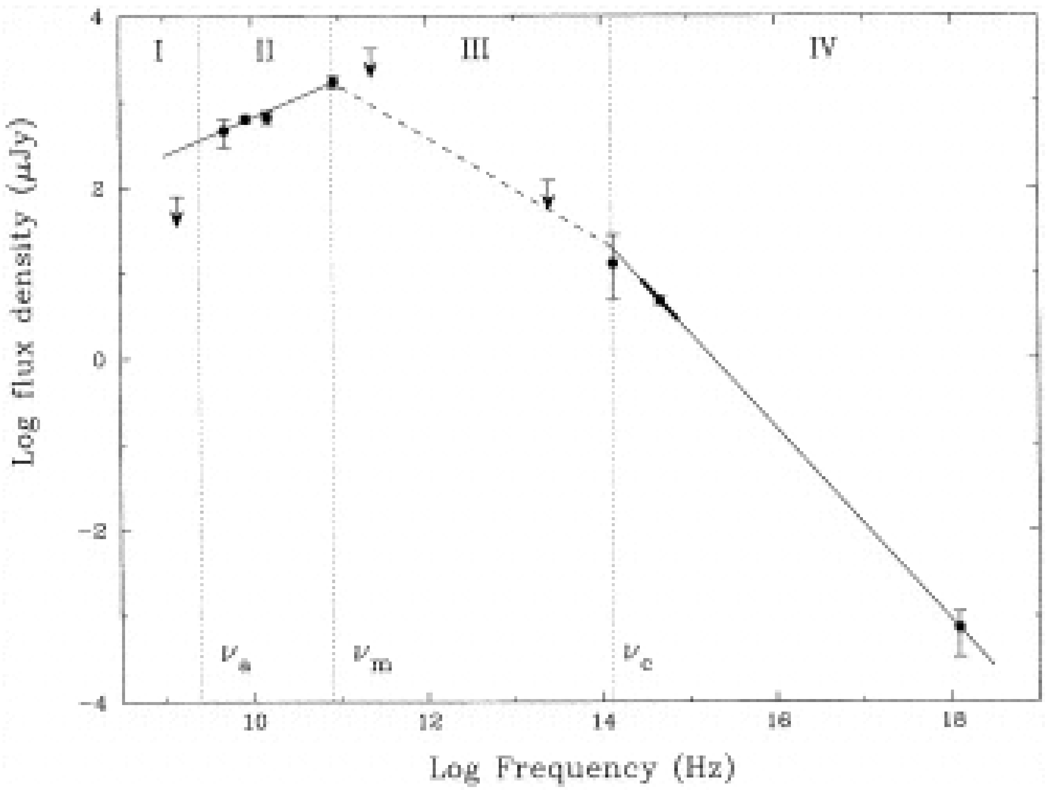
Fireball Model: long GRBs



Aim: to calculate the **<u>prompt emission</u>** spectrum

Motivation

Afterglow → well described by synchrotron emission

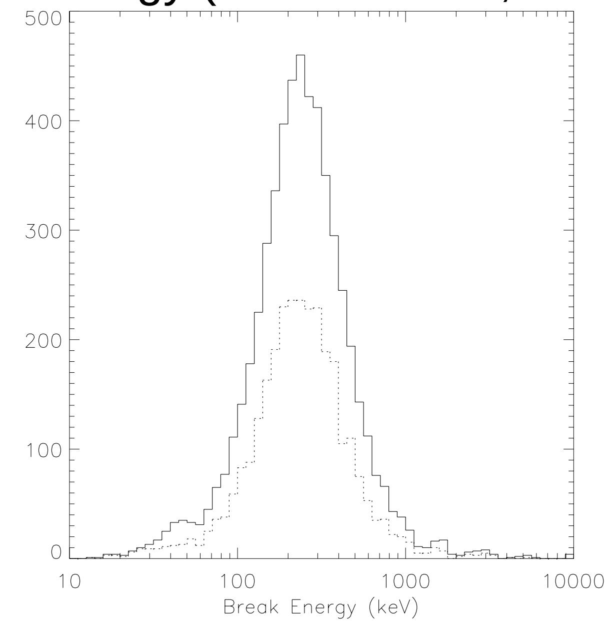


Fit of the spectrum of GRB970508 after 12 days by synchrotron emission (from Wijers & Galama, 1999)

Motivation (2)

Prompt emission:

Histogram of BATSE bright bursts peak energy (Preece et. al., 2000)



- Peak clustering at ~0.1-0.3 MeV;
  (Preece et. al., 1998, 2000; Kaneko et. al. 2006)

- Steep spectral slopes at low energies → difficult to account in Sync.
  (Preece et. al., 1998, 2002; Ghirlanda et. al., 2003; Ryde 2004; and more..)

- Existence of an advected thermal component
  (Rees & Mészáros 2005)
  $R_{dissipation} \leq R_{photospheric}$

Prompt emission scenario: definitions

- Think of a box of width Δ, (where dissipation occurs) with electrons and thermal photons.
Light crossing time: $t_{dyn} = \Delta/c$

- **<u>Define:</u>** photon temperature- $\theta \equiv \frac{kT}{m_e c^2} \sim 10^{-3}$

- Ratio of energy densities - $A \equiv \frac{u_{ph}}{u_e} \sim 1$

Assumption: Thompson scattering $\gamma_{char}\theta < 1$

Electron energy loss time

(don't panic!)

$$t_{loss} = \frac{E_{el}}{P} \times \gamma_{char} = \frac{\gamma_{char} m_e c^2}{(4/3) c \sigma_T \gamma_{char}^2 u_{ph}} \times \gamma_{char}$$

$$u_{ph} = A u_e$$

$$= \frac{m_e c^2}{(4/3) c \sigma_T \gamma_{char} A n_{el} m_e c^2}$$

$$\longleftarrow \quad u_e = \gamma_{char} m_e c^2 \times n_e$$

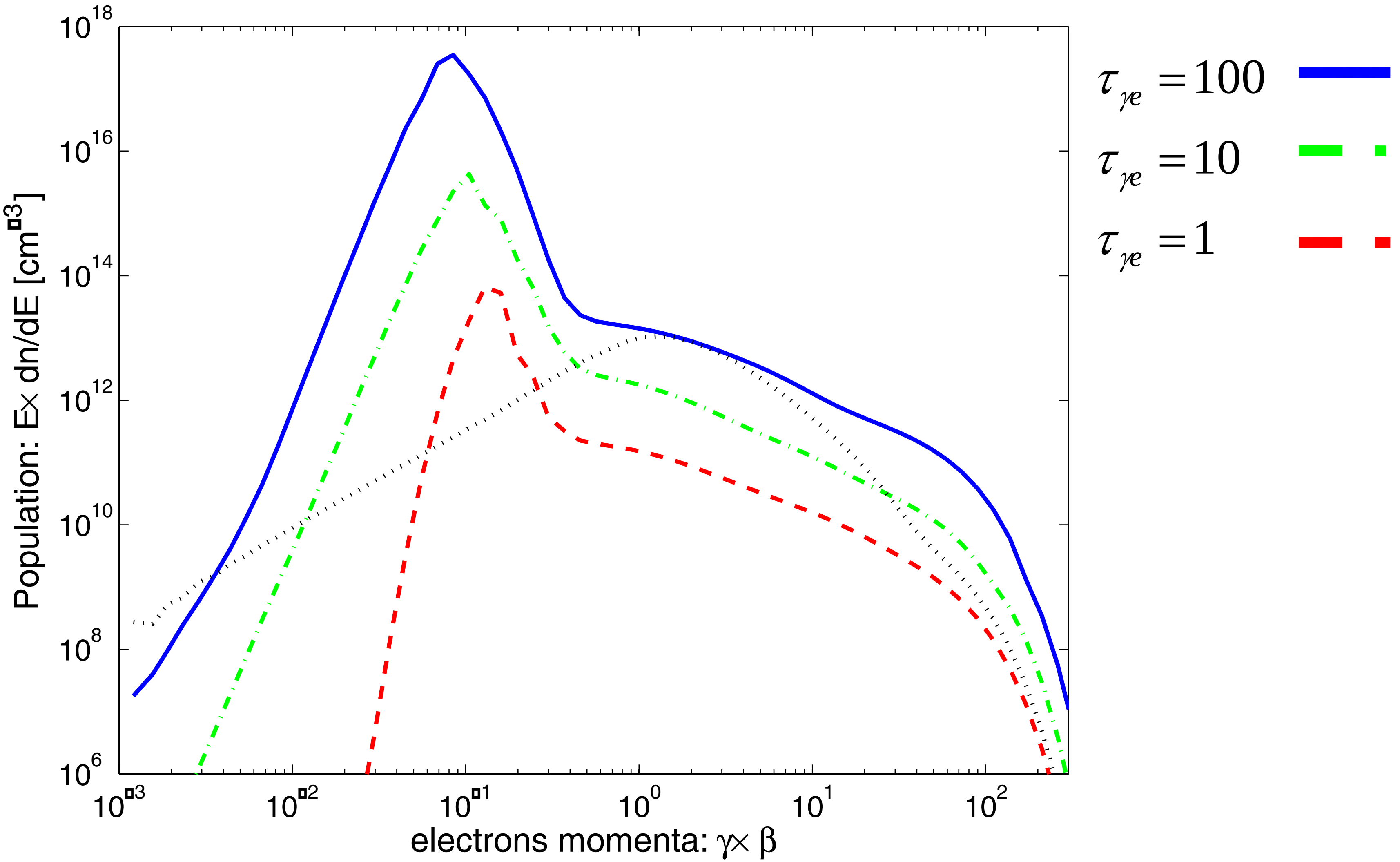
$$\frac{t_{loss}}{t_{dyn}} = \frac{1}{(4/3) c \sigma_T \gamma_{char} A n_{el} t_{dyn}} = \frac{3}{4 \gamma_{char} A \tau_{\gamma e}}$$

$$\tau_{\gamma e} = n_e c \sigma_T t_{dyn}$$

Conclusion: For A~1, $\tau_{\gamma e} > 1$ implies $t_{loss} < t_{dyn}$

→ Electrons lose all their energy within t_{dyn},
and are accumulated at $\gamma \sim 1$

Electron energy distribution



Estimate γ_{final} : balance between Compton and inverse Compton

- Electrons gain energy by down scattering energetic photons:

How many energetic photons there are ?

$$\frac{dn_{ph}(\varepsilon > m_e c^2)}{dt} \approx R(injection) - \frac{n_{ph}(\varepsilon > m_e c^2)}{t_{loss}}$$

-Energetic photons are at (quasi) steady state:

$$n_{ph}(\varepsilon > m_e c^2) \approx \frac{u_{el}}{m_e c^2} \frac{2}{\tau_{\gamma e}}$$

Energy gain rate of an electron:

$$\sigma(\varepsilon) \approx \sigma_T \varepsilon^{-1}$$

$$\frac{dE_+}{dt} \approx c\sigma_T \frac{m_e c^2}{2} \times n_{ph}(\varepsilon > m_e c^2) = \frac{c\sigma_T u_e}{\tau_{\gamma e}}$$

Energy loss rate of an electron:

$$\frac{dE_-}{dt} \approx (4/3) c\sigma_T (\gamma_f \beta_f)^2 u_{ph} e^{(4/3)(\gamma_f \beta_f)^2 n_{sc.}}$$

Estimate γ_{final} : balance between Compton and inverse Compton (II)

$$(\gamma_f \beta_f)^2 e^{(4/3)(\gamma_f \beta_f)^2 n_{sc.}} \approx \frac{3}{4A\tau_{\gamma e}}$$

(I): $\tau_{\gamma e}$~ few→ exp()~1

$$\gamma_f \beta_f (n_{sc.} \le 10) \approx \left(\frac{3}{4A\tau_{\gamma e}} \right)^{1/2} \approx 0.3 A_0^{-1/2} \tau_{\gamma e_1}^{-1/2}$$

(II) $\tau_{\gamma e}$~ few tens → exp()~$(\gamma_f\beta_f)^2/3\theta f$

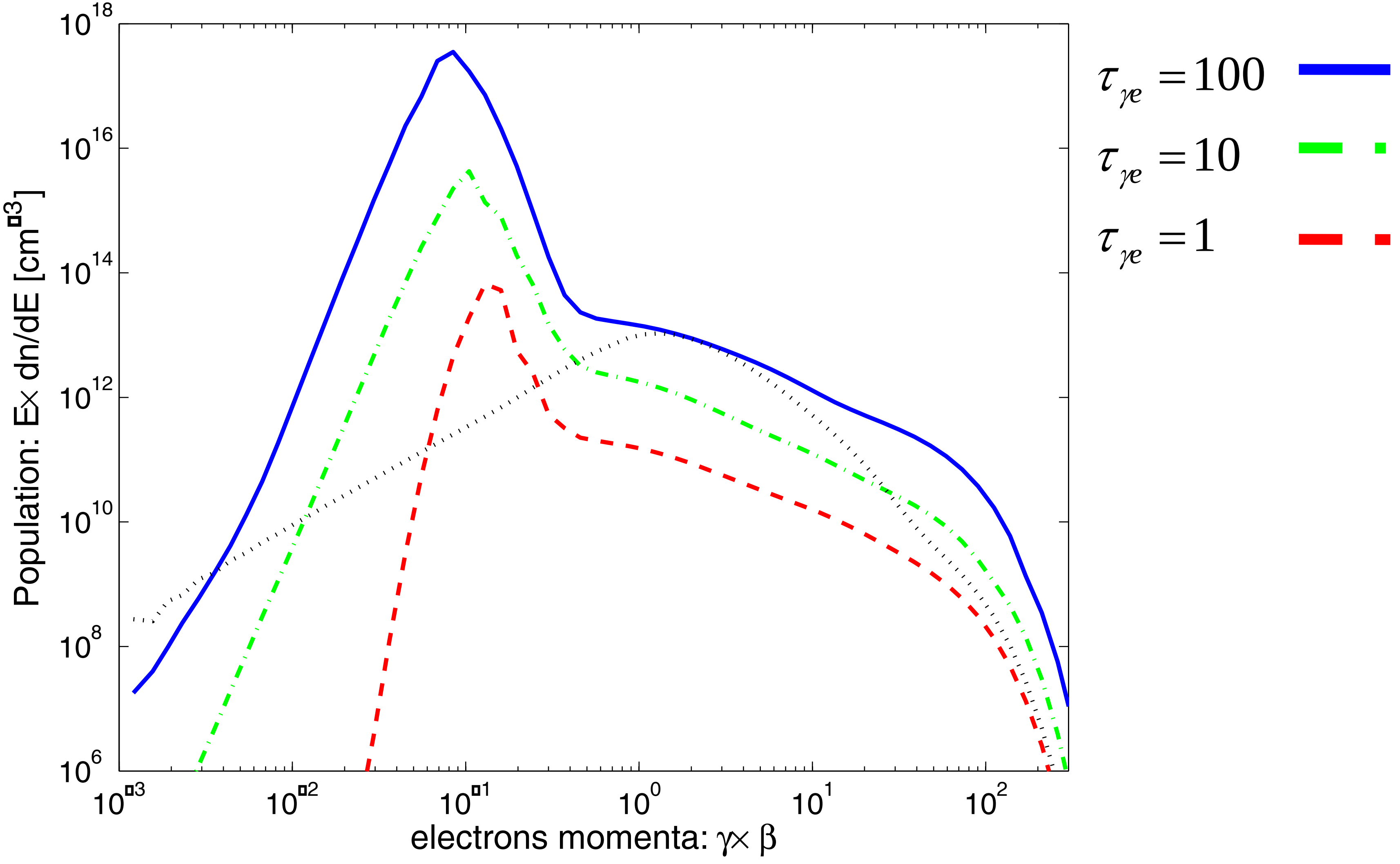
$$\gamma_f \beta_f (n_{sc.} \sim 10-100) \approx \left(\frac{9\theta f}{4A\tau_{\gamma e}} \right)^{1/4} \approx 0.1 \theta_{-3}^{1/4} A_0^{-1/4} \tau_{\gamma e_2}^{-1/4}$$

(III) $\tau_{\gamma e}$>few tens → Outside Thompson regime;
Compton equilibrium; Wien Peak

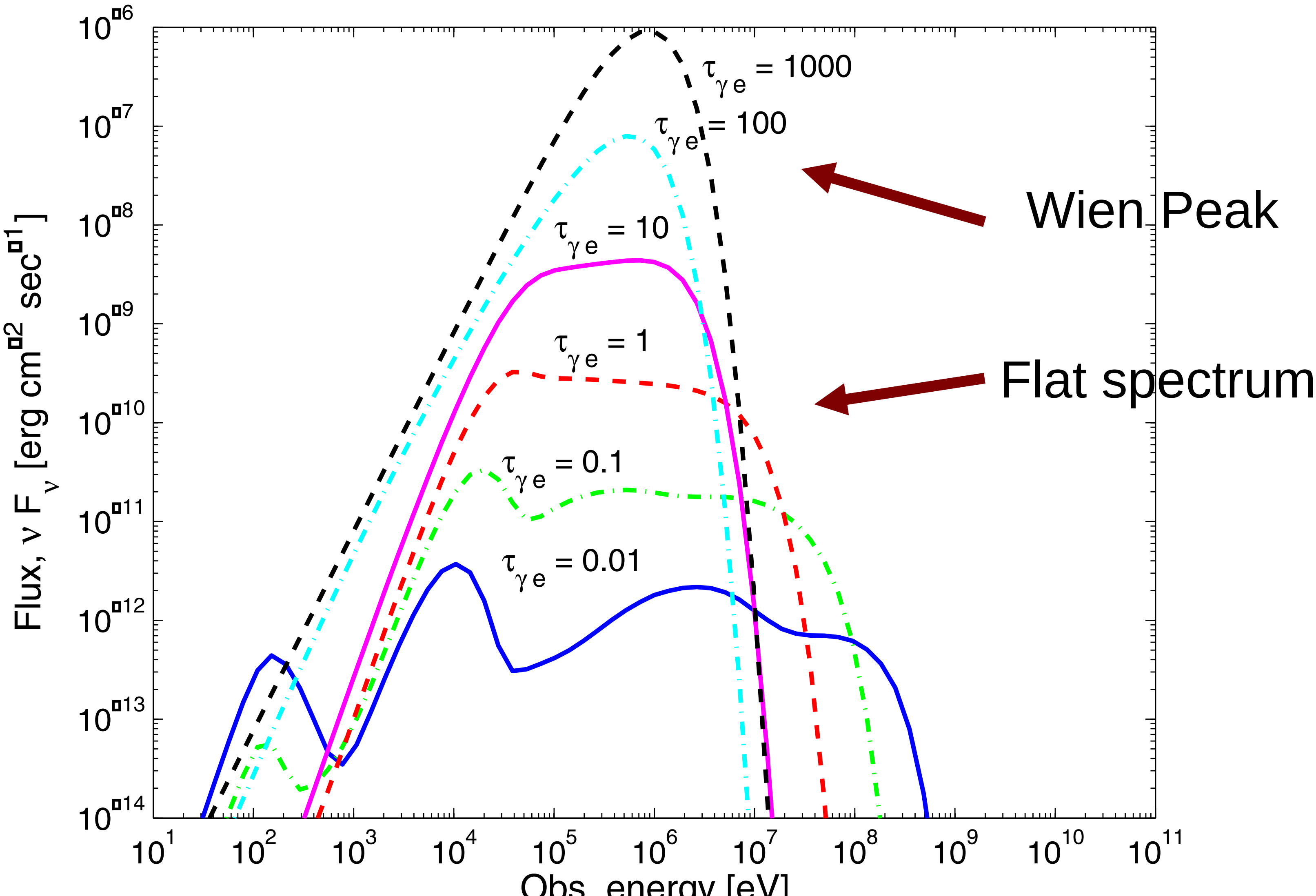
$$\gamma_f \beta_f (n_{sc.} > 100) \approx \left[3\theta(1 + A^{-1}) \right]^{1/2} \approx 0.08 \theta_{-3}^{1/2}$$

$$\varepsilon_{WP}(\text{plasma frame}) \approx 3\theta(1 + A^{-1}) m_e c^2 = 10\ \text{keV}$$

Electron energy distribution



Resulting spectrum



Spectrum: low optical depth - $\tau \leq 1$

$$\gamma_f \beta_f (n_{sc.} \leq 10) \approx \left(\frac{3}{4A\tau_{\gamma e}} \right)^{1/2}$$

- Number of photons with n_{sc} scattering:

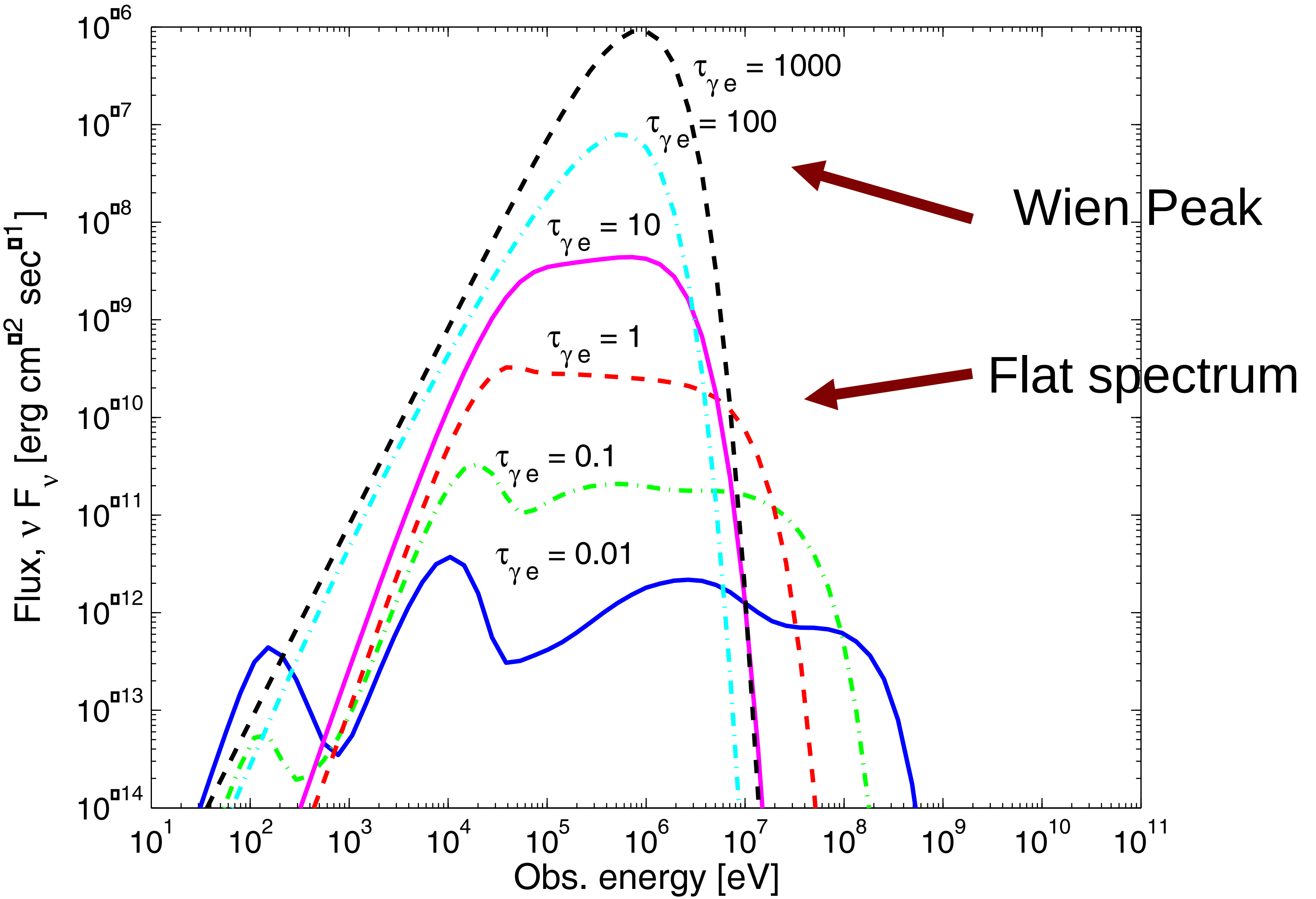
$$\frac{dn_{ph}}{dt} \approx n_{ph} c \sigma_T n_{el} \rightarrow n_{ph,n_{sc.}} \approx n_{ph,o} \times \tau_{\gamma e}^{n_{sc.}}$$

- Energy of a photon after n_{sc} scattering:

$$\varepsilon_{ph,n_{sc.}} \approx \varepsilon_{ph,o} \times (\gamma_f \beta_f)^{2n_{sc.}}$$

$$n_{ph,n_{sc.}} \equiv \varepsilon dn / d\varepsilon \propto \varepsilon^{-1} \rightarrow \nu F_\nu \propto \nu^0$$

Resulting spectrum



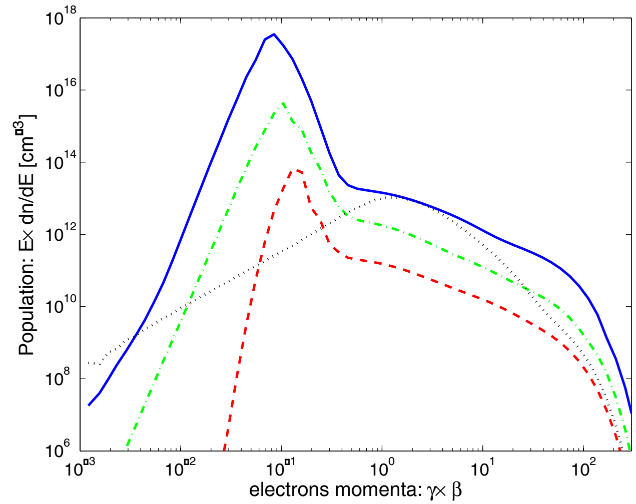
Summary

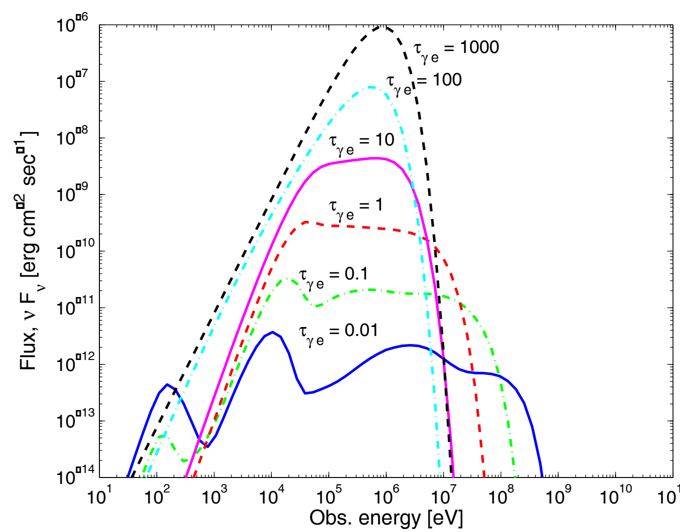
- A significant (A~1) photon component → $t_{loss} << t_{dyn}$; <u>Details of electron acceleration are not important</u>

<u>Compton scattering – main emission mechanism</u>

- $\tau_{\gamma e}$>few tens → Wien peak at $\varepsilon^{ob.}$ ~sub MeV

- $\tau_{\gamma e}$~few → Flat spectrum above the thermal component due to Compton scattering !





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$$n_{ph}(\varepsilon > f m_e c^2) \approx \frac{2u_e}{\tau_{\gamma e} m_e c^2}$$