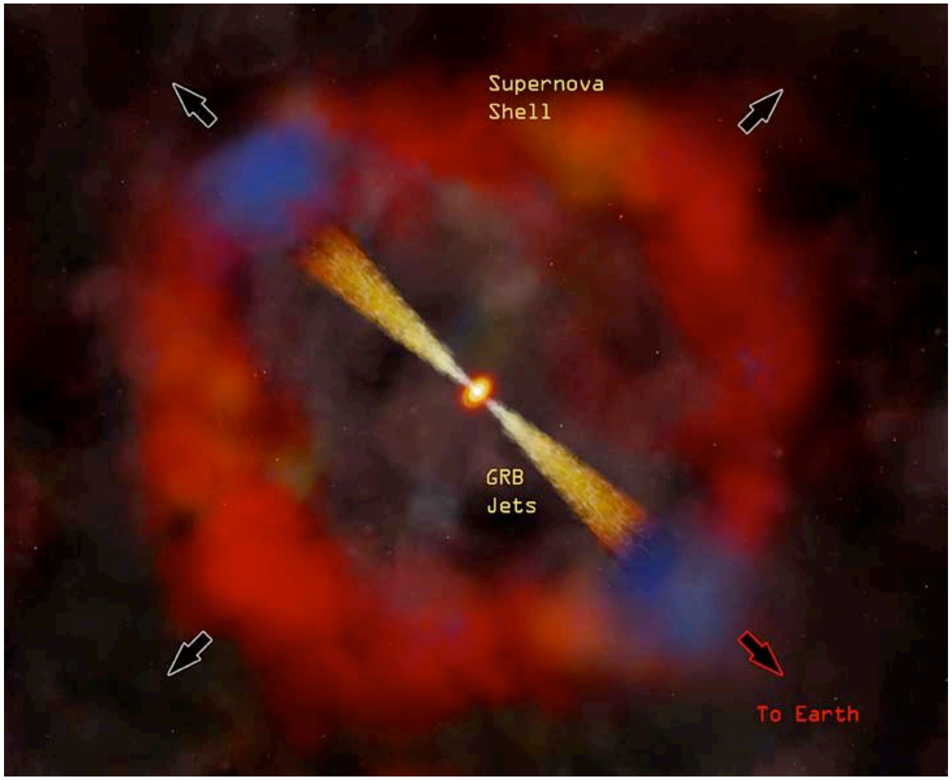
Relativistic interaction of a high intensity photon beam with a plasma: a possible GRB emission mechanism

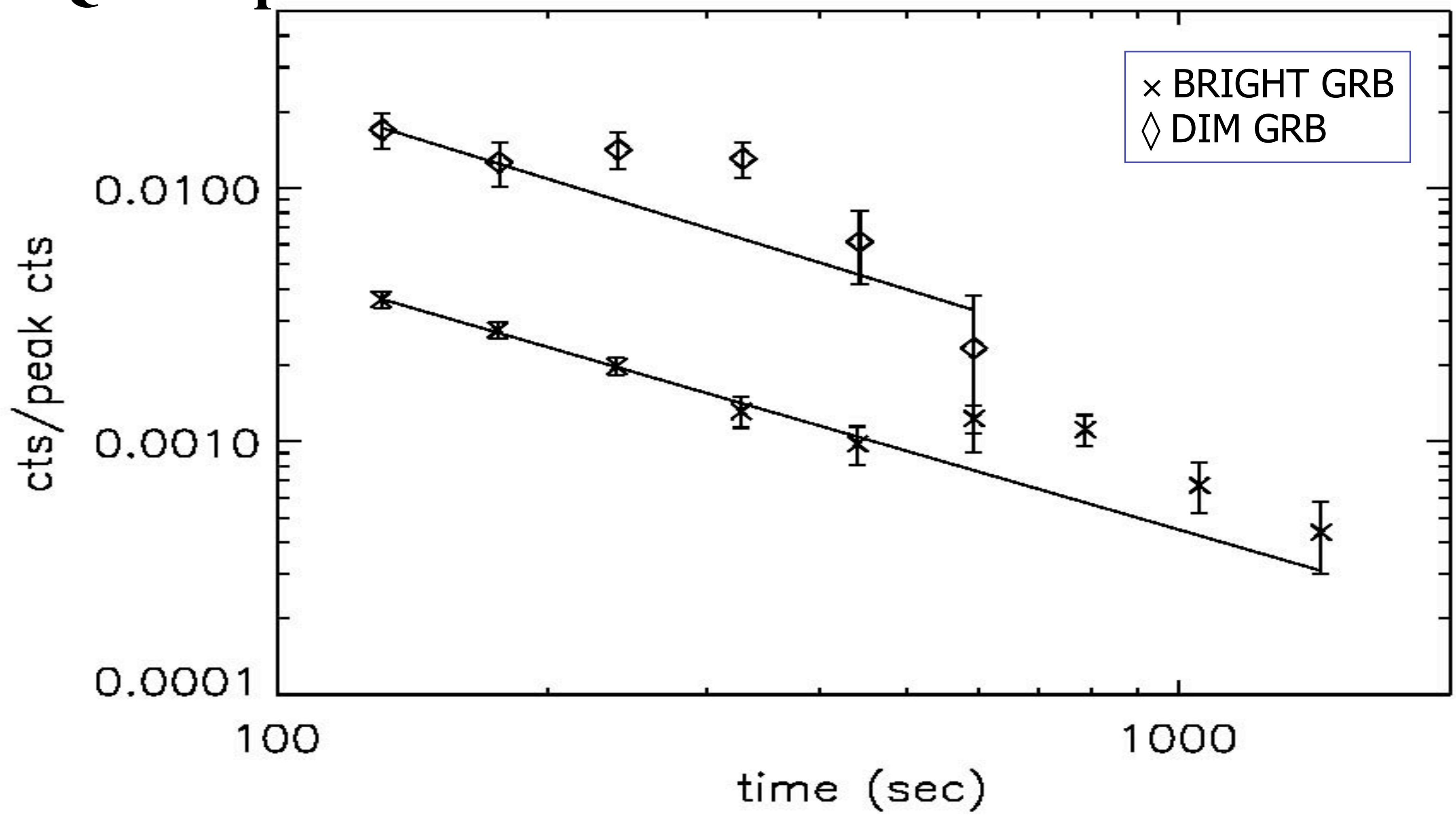


L. Amati, G. Barbiellini, A Celotti, A. Galli, R. Landi, F. Longo, N. Omodei, M. Tavani

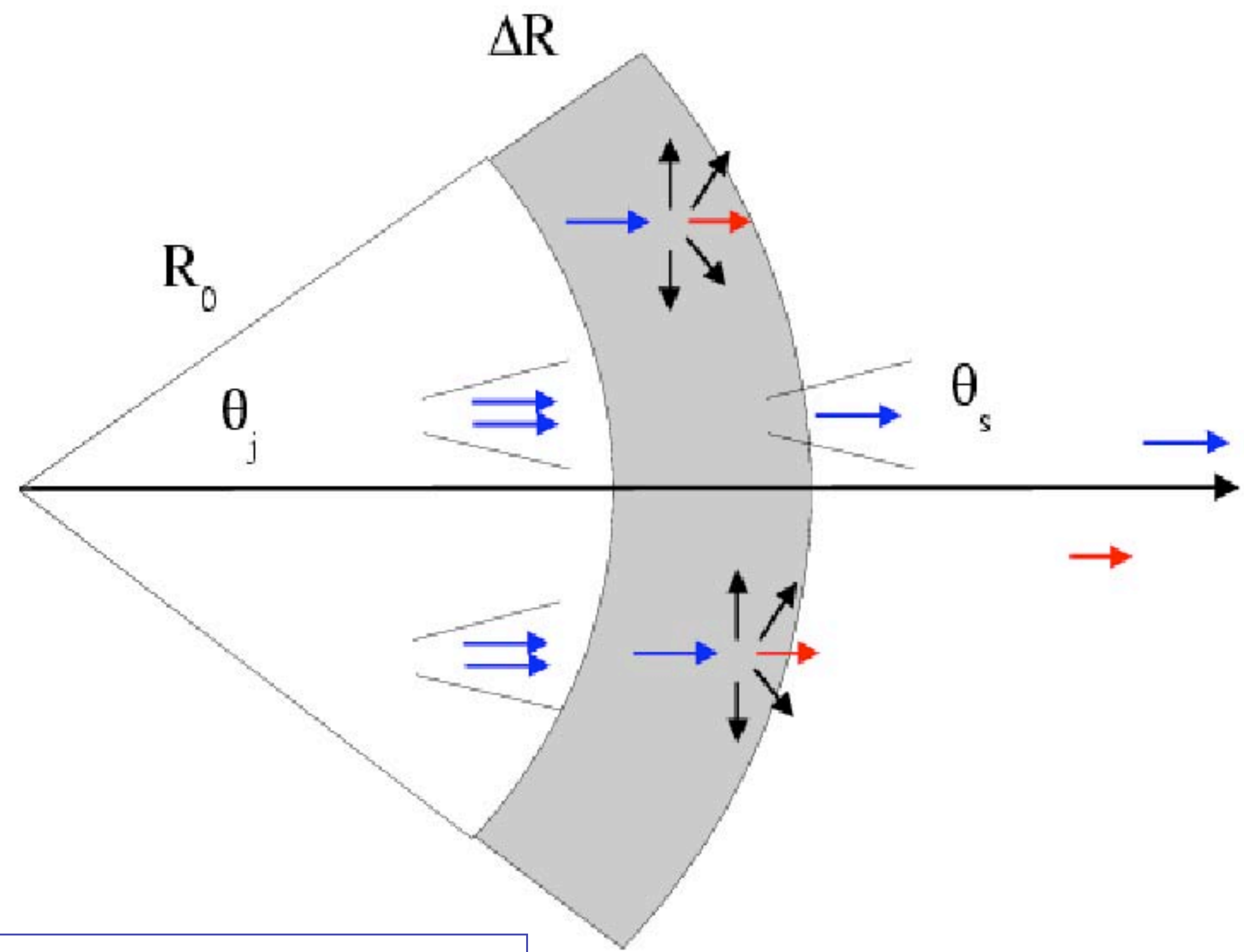
Bright and Dim GRB

(Connaughton 2002)

Q = cts/peak cts



The Compton Tail



Barbiellini et al. (2004) MNRAS 350, L5

The Compton tail

- "Prompt" luminosity

$$\langle L_{\rm s} \rangle = \langle \frac{dn_{\rm s}}{d\Omega\ dt} \rangle \simeq \frac{n_{\rm p}\ e^{-\tau}}{\pi\theta_{\rm s}^2\ t_{\rm grb}} \cdot \frac{\theta_{\rm s}^2}{\theta_{\rm j}^2}$$

- Compton "Reprocessed" luminosity

$$\langle L_{\rm c} \rangle = \frac{n_{\rm p}\ (1 - e^{-\tau})}{2\pi\ t_{\rm geom}} \qquad t_{\rm geom} \sim \frac{(R_0 + \Delta R)\theta_{\rm j}^2}{c}$$

- "Q" ratio

$$Q = \frac{\langle L_{\rm c} \rangle}{\langle L_{\rm s} \rangle} = (e^{\tau} - 1) \cdot \frac{c\ t_{\rm grb}}{(R_0 + \Delta R)}$$

Bright and Dim Bursts

- Bright bursts (tail at 800 s)
  - Peak counts >1.5 cm^{-2} s^{-1}
  - Mean Fluence 1.5 × 10^{-5} erg cm^{-2}
  - Q = 4.0 ± 0.8 10^{-4} (5 σ) fit over PL
  - τ = 1.3

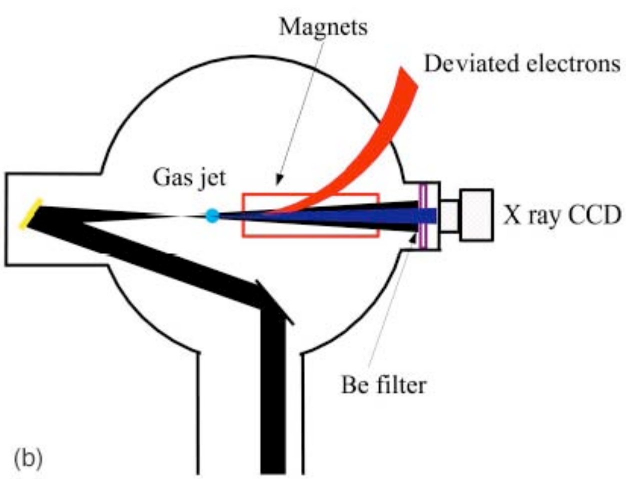
$R = 10^{15}$ cm
$\Delta R \sim R$
$\theta \sim 0.1$

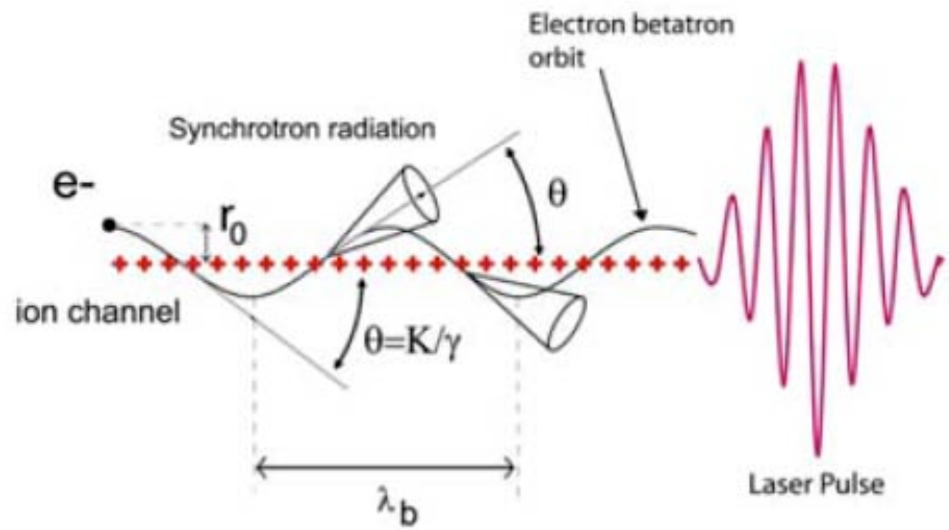
- Dim bursts (tail at 300s)
  - peak counts < 0.75 cm^{-2} s^{-1}
  - Mean fluence 1.3 × 10^{-6} erg cm^{-2}
  - Q = 5.6 ± 1.4 10^{-3} (4 σ) fit over PL
  - τ =2.8
- "Compton" correction

$$E = e^{\tau} E_{\rm obs}$$

WakeField Acceleration

(Ta Phuoc et al. 2005)

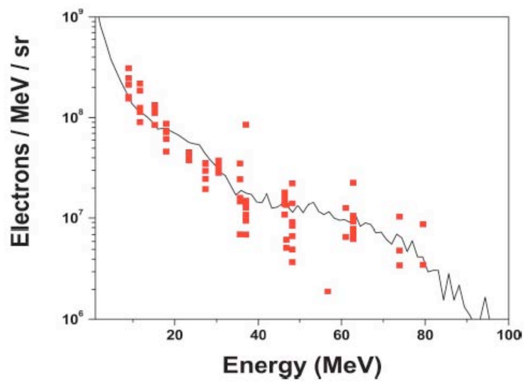




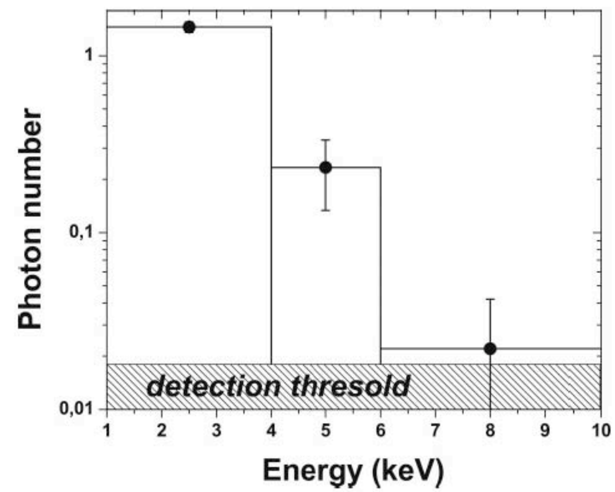
Laser Pulse $t_{laser} = 3\ 10^{-14}$ s
Laser Energy = 1 Joule
Gas Surface = 0.01 mm^2
Gas Volume Density = 10^{19} cm^3
Power Surface Density $\sigma_W = 3\ 10^{18}$ W cm^{-2}

WakeField Acceleration

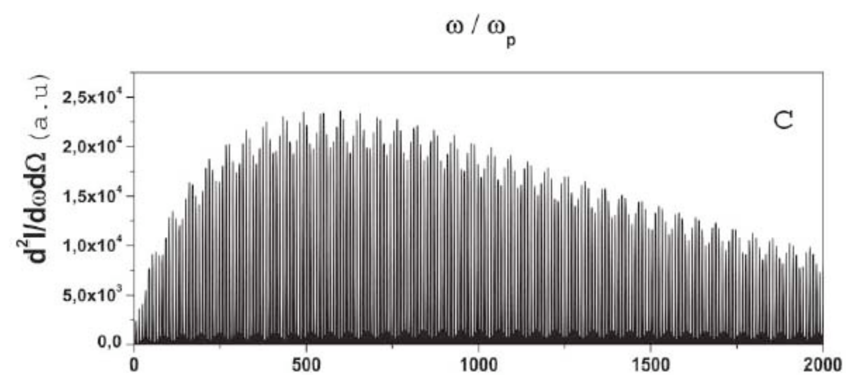
(Ta Phuoc et al. 2005)



Electron Spectrum

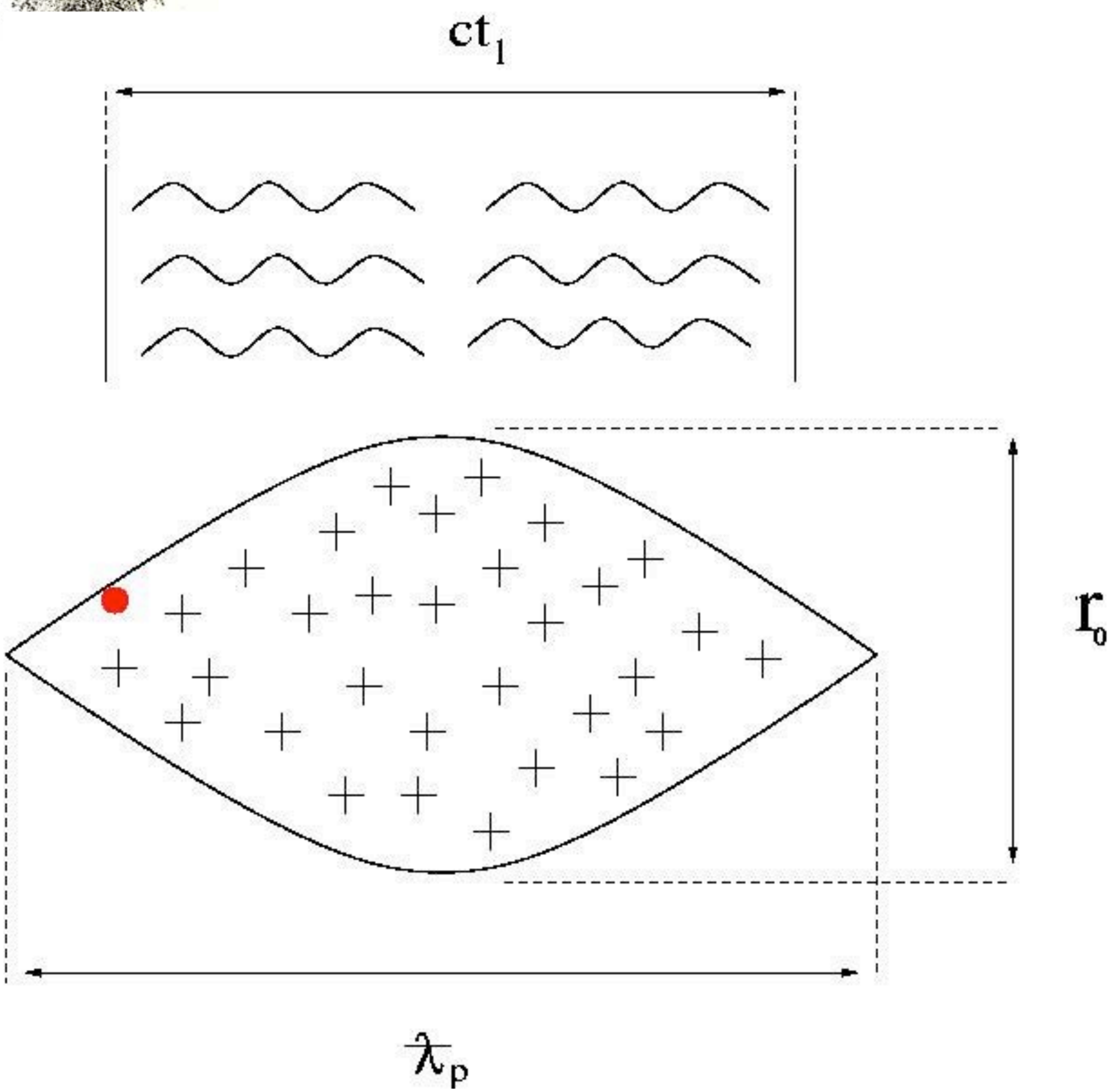


Emitted Photon Spectrum



Simulated Photon Spectrum

Scaling relations

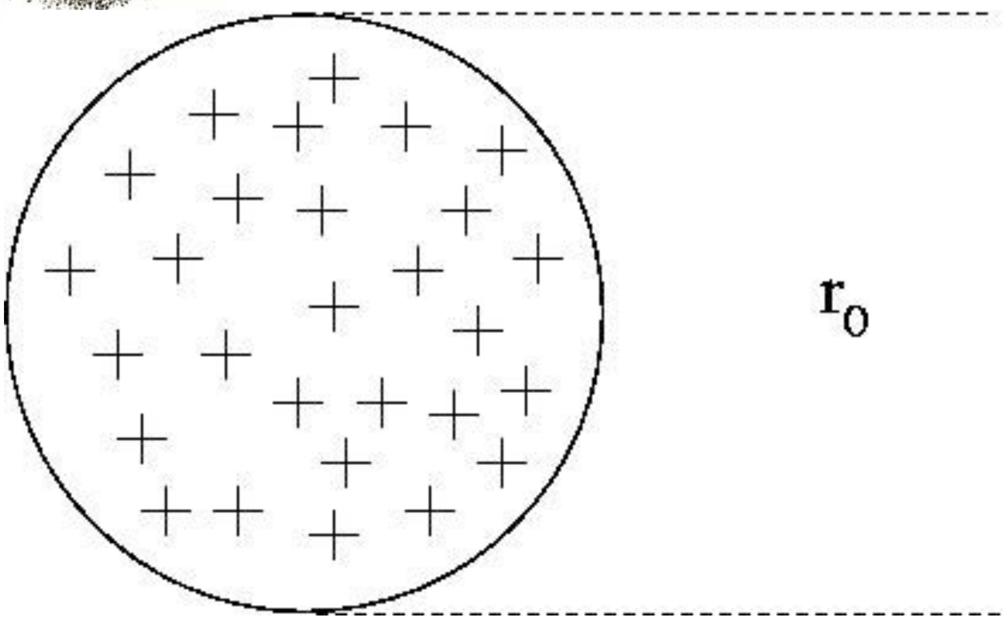


$\lambda_p \sim n^{-1/2}$

$\lambda_b \sim n^{-1/2}\gamma^{1/2}$

$r_0 \sim n^{-1/3}\,\gamma^{-1/2}$

Scaling relations



$V \sim r_0^3 \sim n^{-1}$

$Q_+ = enr_0^3 \sim n^0$

$\gamma(10^{19}) \sim 10^2$

$\gamma(10^9) \sim 2x10^5$

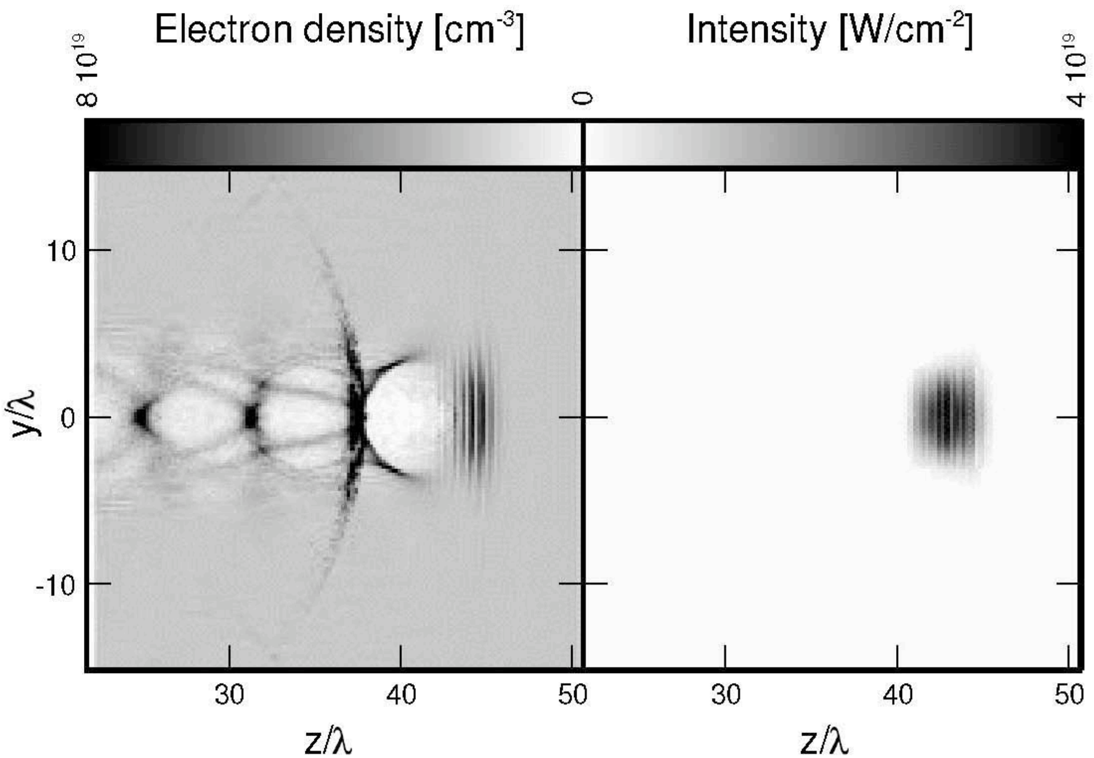
$\gamma(10^2) \sim 2x10^8$

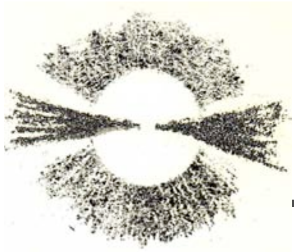
$\gamma \sim n^{-1/3}$

$E_p = 3/4\ hc\gamma^2\ r_0/\lambda_p^2$

3D PIC Simulation

- PhD Thesis Marco Galimberti 2003 Pisa





GRB Gamma Emission in the stochastic wake field acceleration regime

$$\theta_i = \frac{r_o}{\lambda_b}$$

$$\theta_{eff}^2 = \left(\frac{R}{\lambda_b}\right)\theta_i^2$$

$$R_\theta \frac{r_0^2}{\lambda_p^3}(2\gamma)^{-1.5} \le \theta_j^2$$

$$R_\theta(\gamma) = 2\sqrt{2}\lambda_p \theta_j^2 \gamma^{5/2}$$

From the equation of the electron energy loss we derive

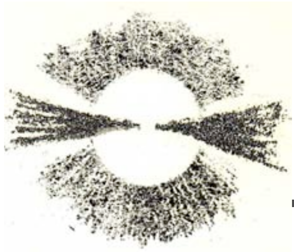
$$R_e \sim 4.1\lambda_p \left(\frac{\lambda_p}{r_e}\right)^{2/3}\gamma^{1/6}$$

Imposing $R_e = R_0$, we link the jet angle to an energy threshold γ_t

$$\gamma_t = 1.2\left(\frac{\lambda_p}{r_e}\right)^{2/7}\theta_j^{-6/7}$$

The previous relations allow the prediction of the typical energy emission

$$< E_{peak} >_{eff} \approx 25 \frac{n}{10^9}\theta_j^{-8/7} keV \approx 350 keV$$



Condition for the realization of the SWFA regime

$$\frac{N_\gamma(R)\sigma\lambda\sqrt{2}\Gamma}{ct_p R^2\theta^2} > 1$$

$$N_\gamma(R) = \left(\frac{E_\gamma(R)}{E_p}\right)_{prec}$$

Precursor Photon interaction condition

$$E_\gamma(R) = E_\gamma(R_0)F(R)$$

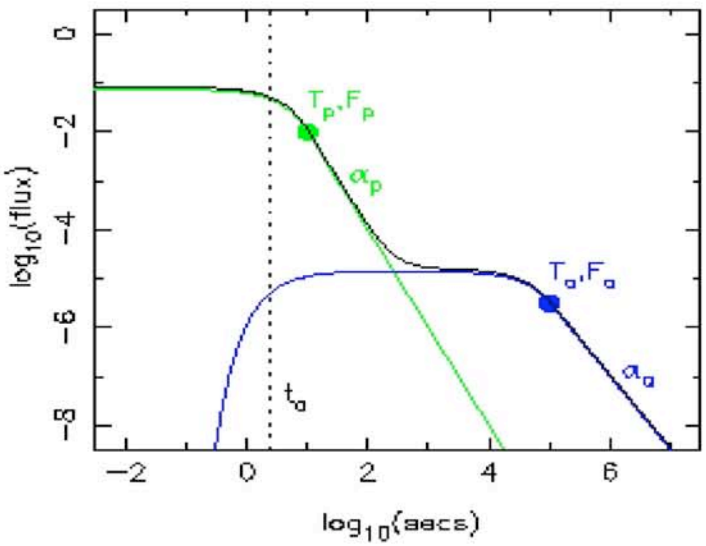
$$F(R) = \frac{e^{\sigma n_0 R_0\left(1-\frac{R\lambda_0}{R_0\lambda(R)}\right)}}{R_0^2\left(1+\frac{R\lambda_0}{R_0\lambda(R)}\right)^2}$$

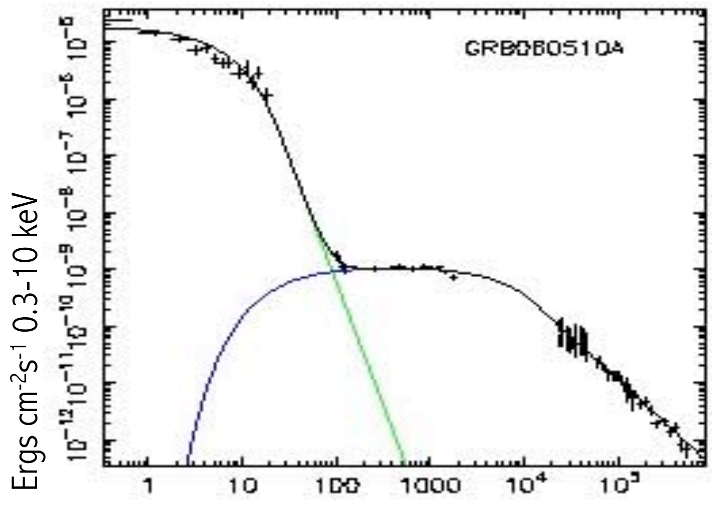
Energy Attenuation

Prediction (1)

- X-ray light curve for prompt and afterglow emission

(R. Willingale astro-ph/0612031)





i) $\alpha_p = n_0 R_0 \sigma_T$ $\quad \alpha_a = \frac{1}{2}\alpha_p$ $\quad T_p = \frac{R_0 \theta^2}{24c}$ $\quad \frac{T_a}{T_p} = \sqrt{\frac{n_0(R_0)}{n(R_a)}}$

ii) $n_0 = 1.6 \times 10^{14} \alpha_p^2 m^{-3}$ $\quad R_0 = 6 \times 10^{13} \alpha_p^{-1} m$ $\quad \theta^2 = 10^{-4} \frac{T_p \alpha_p}{1+z}$

Prediction (2)

- Spectral geometrical correlation:

$$E_p \propto \left(\frac{T\alpha}{1+z}\right)^{\frac{4}{7}} \qquad\qquad E_{iso} \propto \left(\frac{T\alpha}{1+z}\right)^{\frac{27}{28}}$$

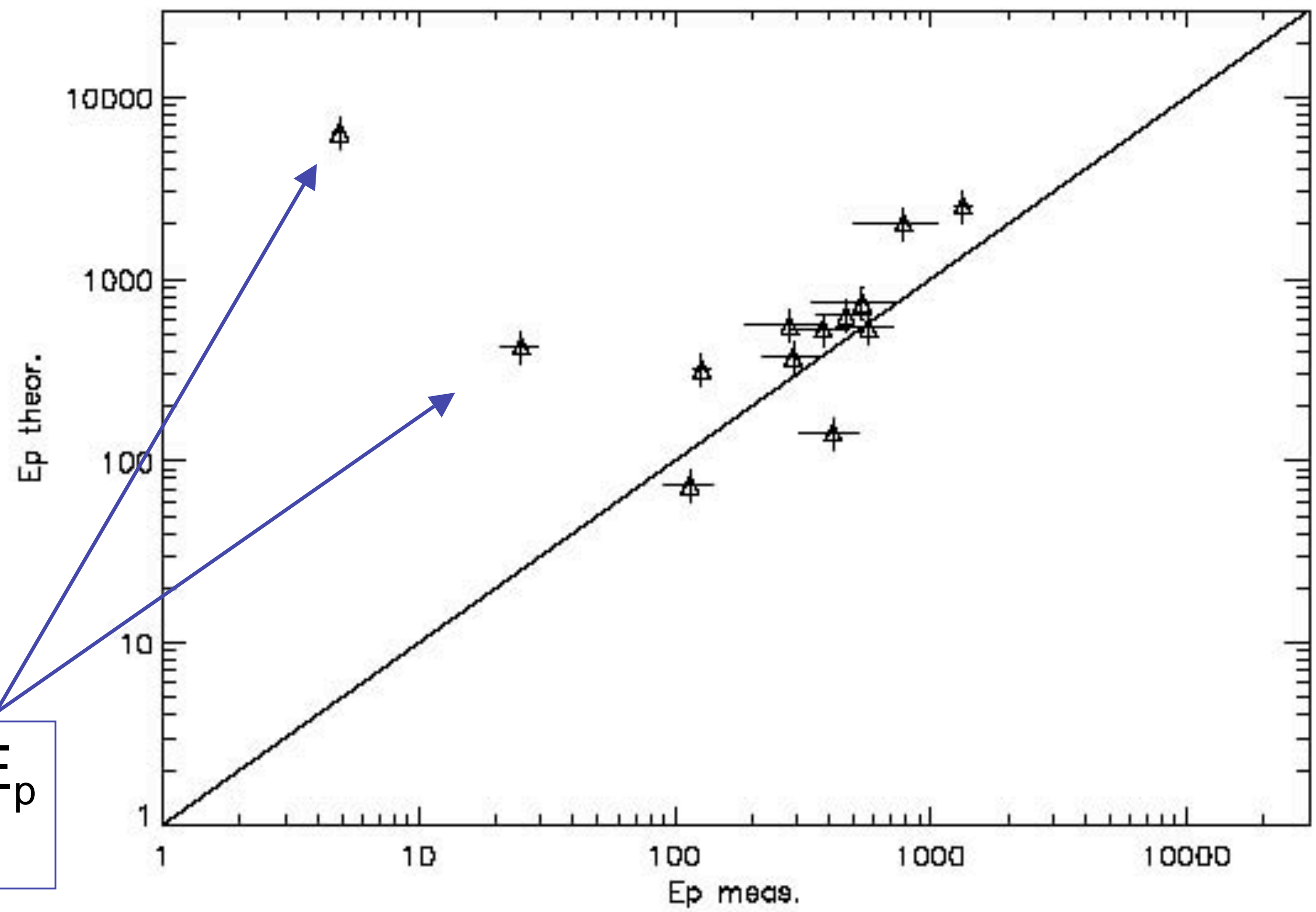
- Spectral-Energy correlation:

$$\frac{E_{iso}^{0.59}}{E_p} \propto \cos t$$

(Amati relation: $\frac{E_{iso}^{0.58}}{E_p} \propto \cos t$)

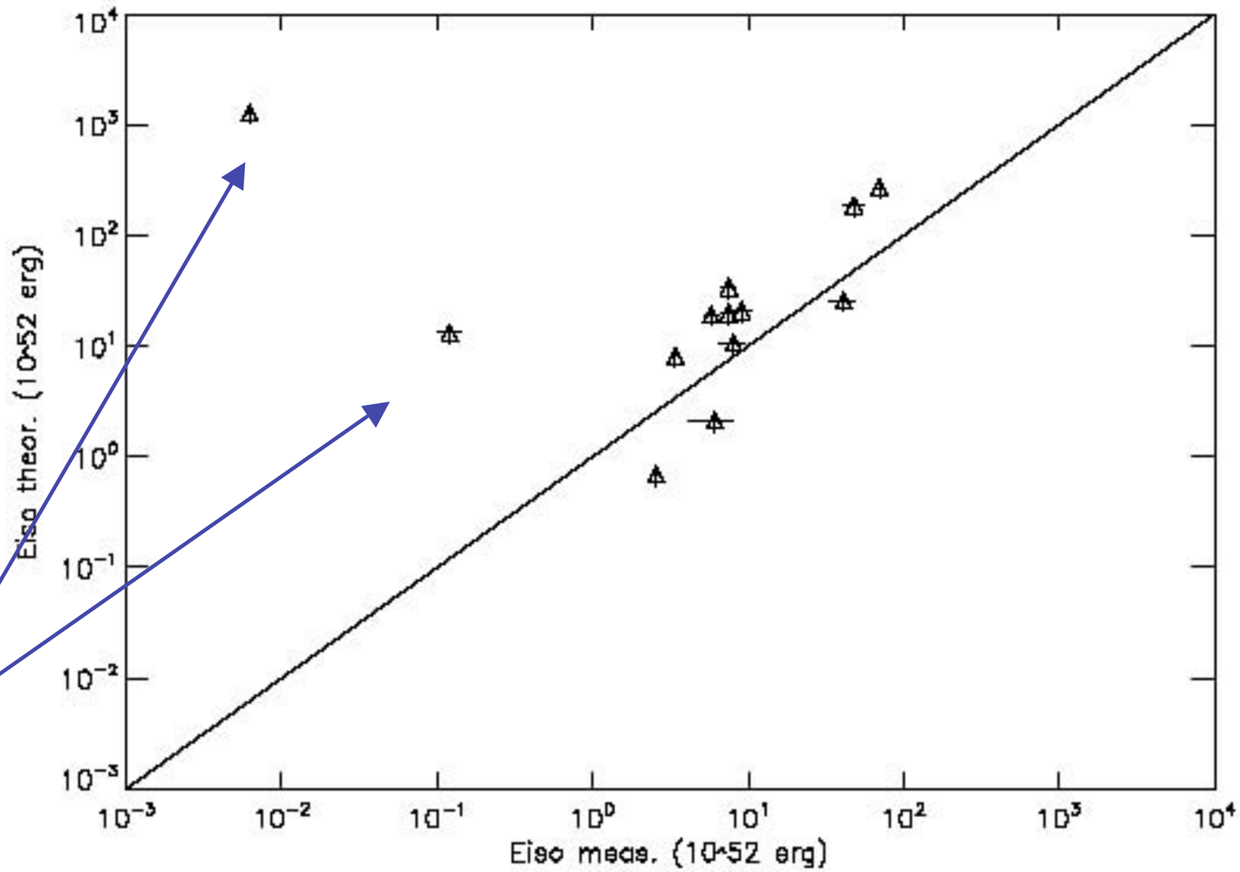
(L. Amati *Il Nuovo Cimento*)

Predictions (3)



Low E_p
GRB

Predictions (4)



Low E_p
GRB

Conclusions

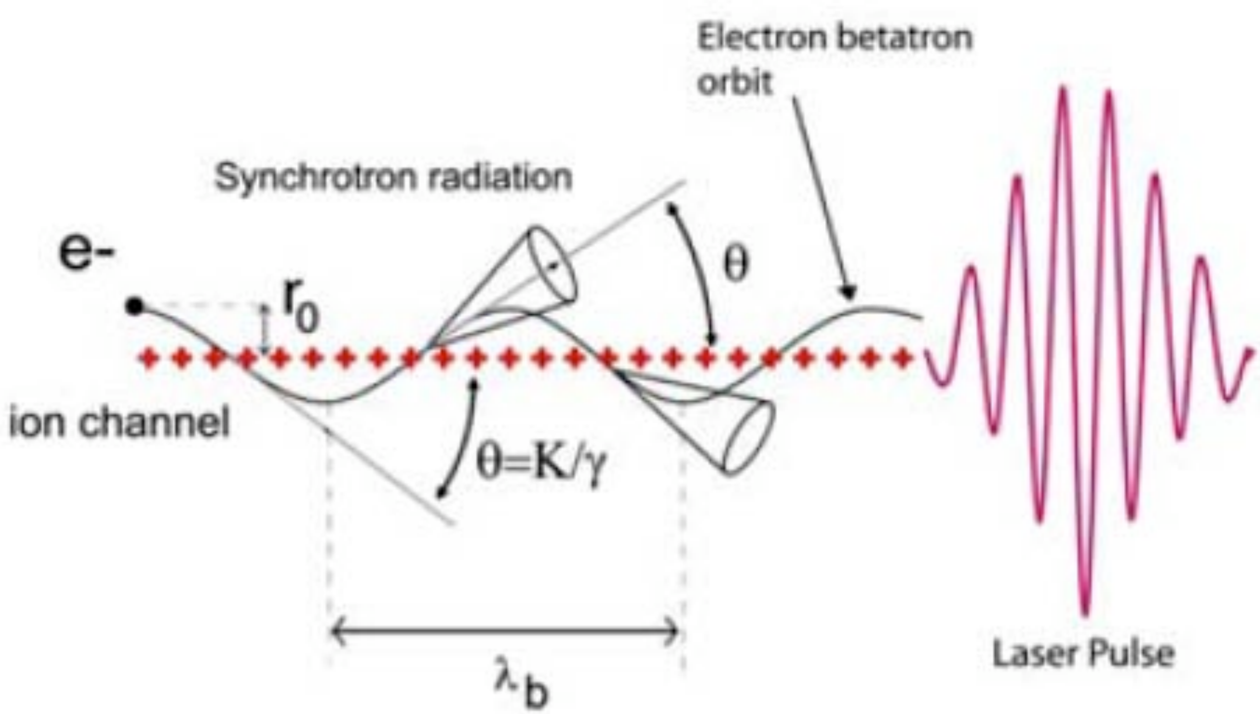
- Jetted structure of GRB
- Presence of Material around GRB
- Compton tail measurement
- Plasma acceleration mechanism
- Laboratory vs Astrophysics
- Cosmology with Spectral – Energy correlations?

Backup

GRB tails

- Connaughton (2002), ApJ 567, 1028
- Search for Post Burst emission in prompt GRB energy band
- Looking for high energy afterglow (overlapping with prompt emission) for constraining Internal/External Shock Model
- Sum of Background Subtracted Burst Light Curves
- Tails out to hundreds of seconds decaying as temporal power law $\delta = 0.6 \pm 0.1$
- Common feature for long GRB
- Not related to presence of low energy afterglow

WakeField Acceleration



(Ta Phuoc et al. 2005)