GRB fireballs: neutron rich explosions

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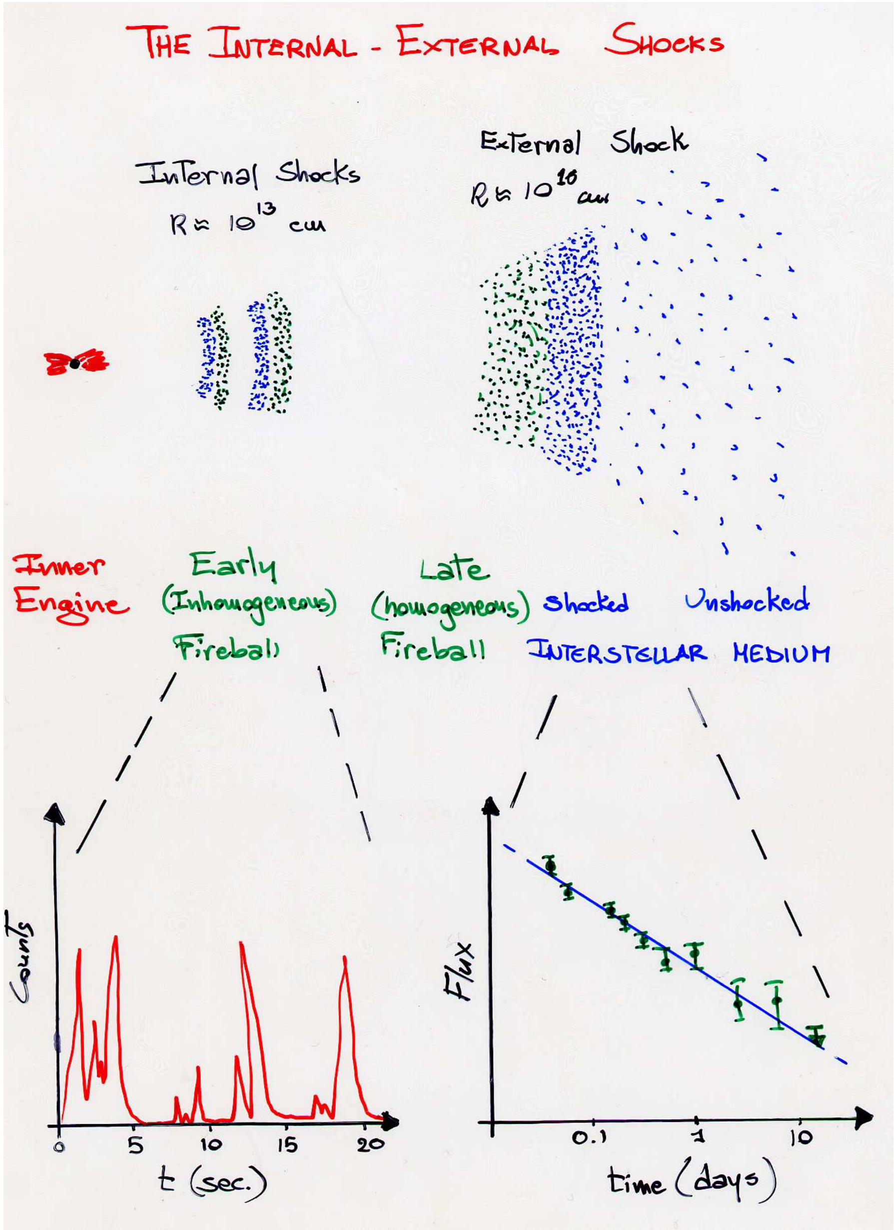
Outline

- ***Brief introduction on GRB***
- ***Nuclear composition of engine+jet: n/p>1***
- ***Theory of GRB outflows with neutrons***
- ***conclusions***

The internal-external shock scenario



- *Inner engine releases unsteady flow of ~10^{52} erg*
- *Shells with different Γ catch up at $R \sim R_0 \Gamma^2 \sim 10^{13}$ cm*
- *Shock waves (internal) accelerate electrons and generate magnetic fields: synchrotron emission*
- *At $R \sim 10^{16}$ cm an (external) shock is driven in the interstellar medium*
- *Synchrotron emission but at lower ν and decreasing -frequencies*

GRB outflows have neutrons

Current engine models naturally predict

$$n/p > 1 \quad (Y_e < 0.5)$$

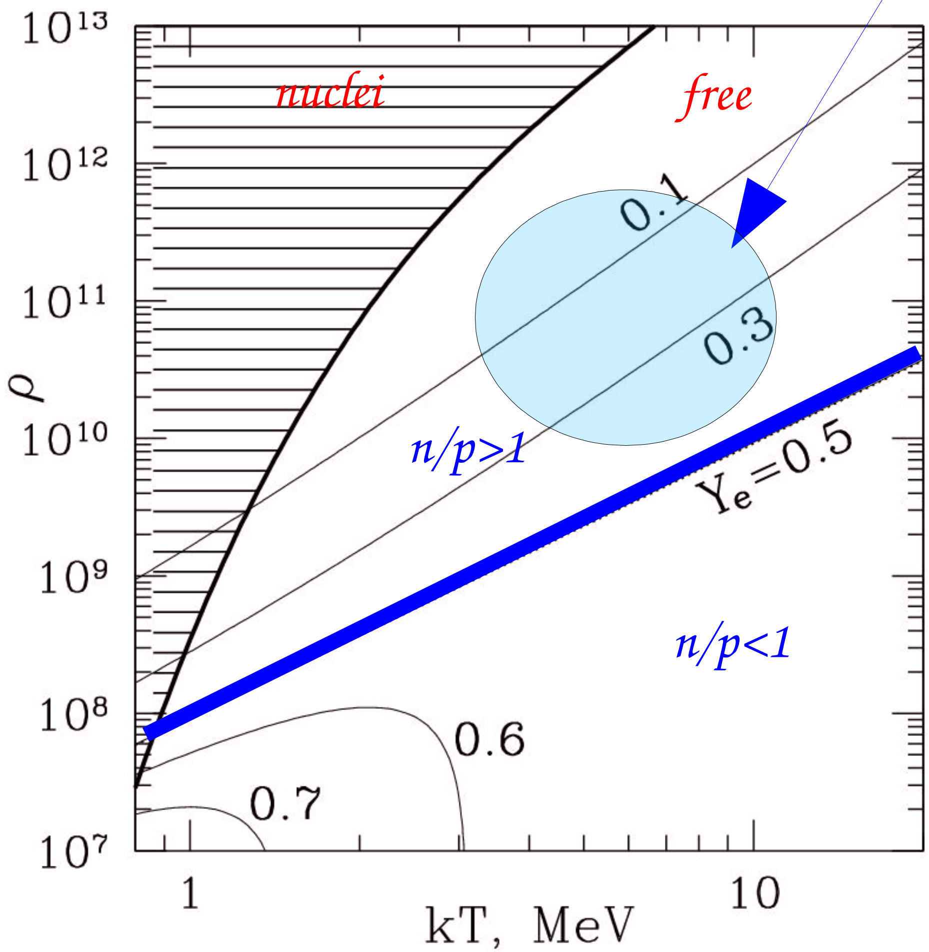
(Derishev et al 99, Beloborodov 03, Pruet at al 03)

GRB jets are powered by a high rate accretion disk of few M_{sun} per sec around a solar mass BH

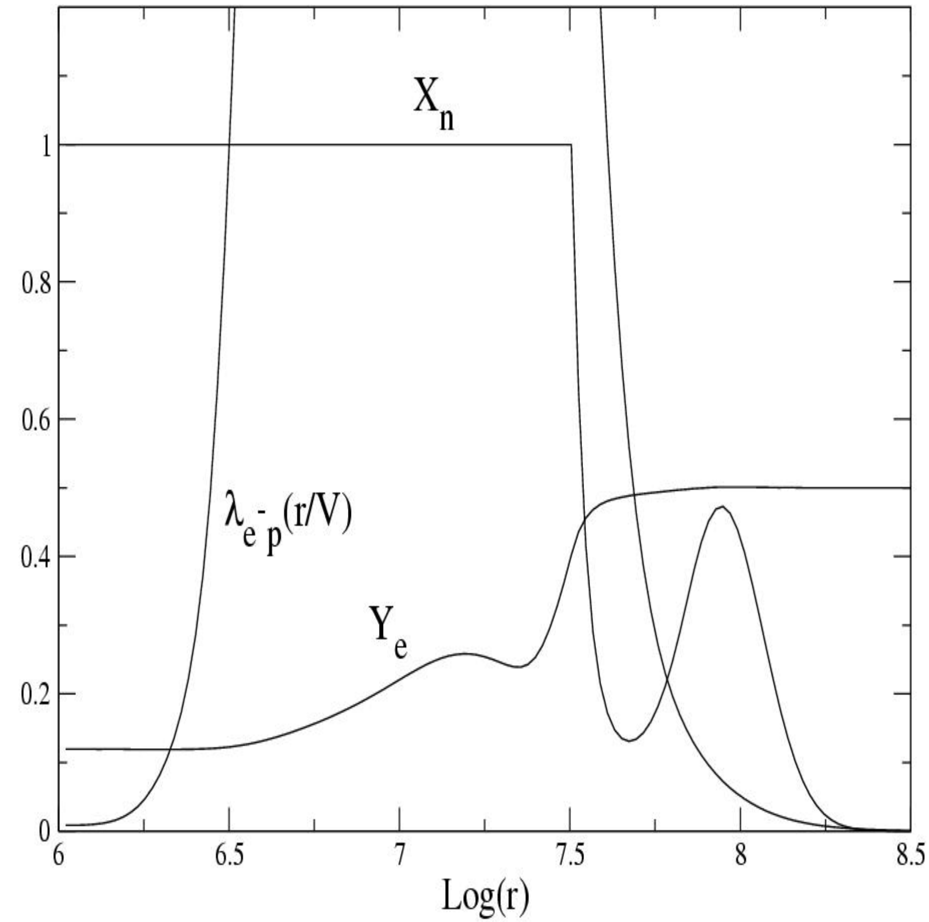
(Woosley 93, Eichler et al. 89, Janka et al. 99&01, Vietri&Stella 98, Zhang&Fryer 01 , Fryer et al. 99)

Jets are born in neutron rich sites **the inner accretion disk has:**

ρ ~10^{11} g/cm^3 and T~ few 10^{10} K

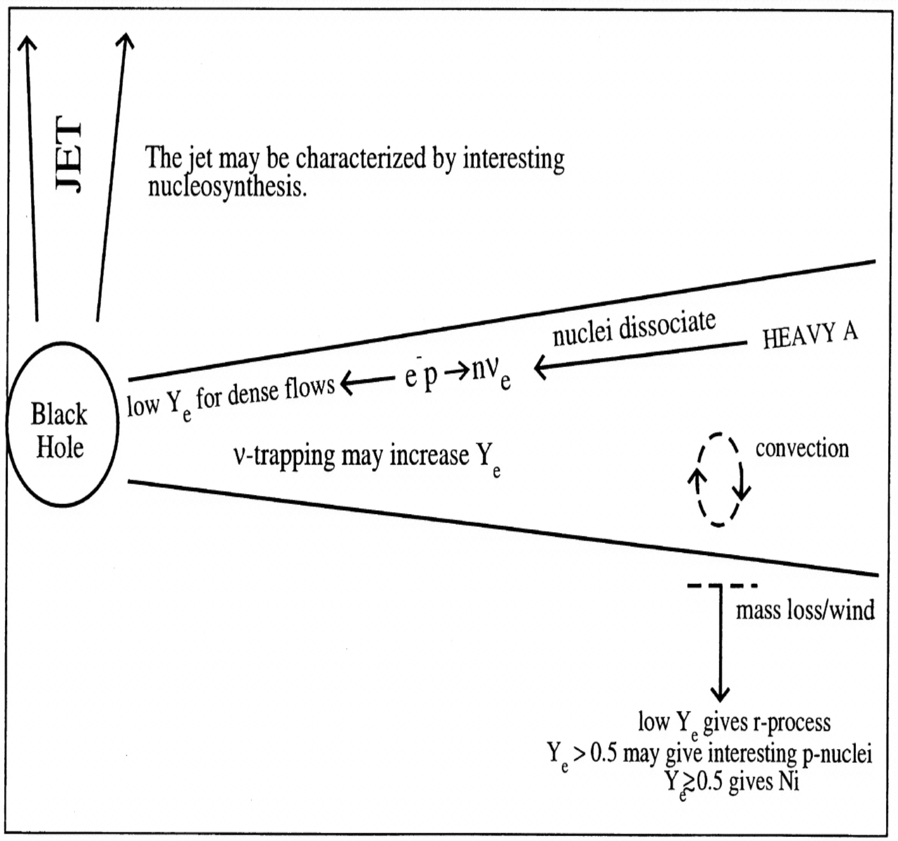


Beloborodov 03



Pruet, Woosley & Hoffman 03

Jet baryonic composition



From Pruet et al 03

- *Escape vs neutralisation timescale:*

  $t_{e+p} > t_{esc}$ *so*

  n/p jet = n/p engine

- *Little Nucleosynthesis:*

  free p & n with n/p>1

(Beloborodov 03, Lemoine 02, Pruet et al 03)

How do neutrons affect the fireball dynamics and thermodnamics of GRB fireballs?

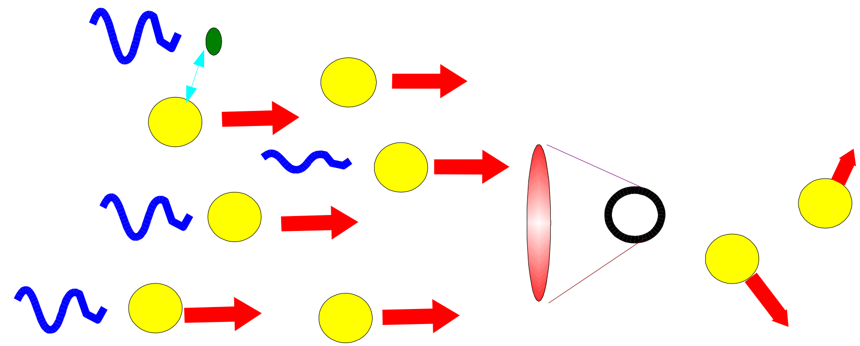
Fireball theory with neutrons

- Outflow with p+e+r+n
- r ⇔ e *by Compton Scattering*
- e ⇔ p *by Coulomb Collision*
- p ⇔ n *by strong collision*

$p \Leftrightarrow p_n \, (n \Rightarrow p_n + e + \; \bar{\;}_e)$ *by plasma instability*

t *=900 s --->* R *= c t* $_n$

$$\beta_{rel} = \tau_{np} / \tau_d$$



n-p COLLISIONS AS MOMENTUM EXCHANGE AND FRICTION.

collision rate per n:

$$\Gamma_{rel} n_p \sigma v_{rel} = \frac{\Gamma_{rel}}{\tau_{np}},$$

$$\sigma \approx \sigma_{np}(c/v_{rel}); \;\; \sigma_{np} = 3 \times 10^{-26} \mathrm{cm}^2.$$

mean momentum gained per n (isotropic scattering):

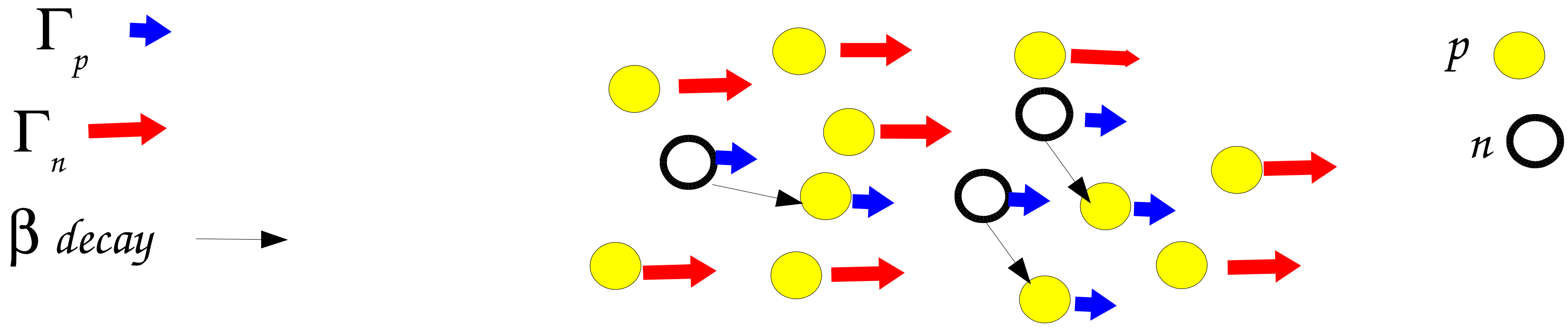
$$p_n = < p_p > = m_p v_{rel} \Gamma_{rel}$$

mean force on a n

$$\frac{dp_n}{dt} = n_p \Gamma_{rel}^2 \sigma_{np} \beta_{rel} m_p c^2; \qquad \frac{d\Gamma_n}{dr} = n_p \Gamma_{rel}^2 \beta_{rel} \sigma_{np}.$$

Volume dissipation rate (proton rest-frame):

$$\frac{dq_p}{dt'} = \frac{n_n^p (\Gamma_{rel} - 1) m_p c^2}{\tau_{np}}.$$



TWO STREAM-INSTABILITY AS HEATING MECHANISM:

decay rate

$$\frac{dN_n}{dt'} = -\frac{N_n}{\Gamma_{rel}\tau_\beta} = -\frac{dN_p}{dt'},$$

the volume heating

$$\frac{dq_p}{dt'}_\beta = \frac{n_n^p}{\Gamma_{rel}\tau_\beta}(\Gamma_{rel} - 1)m_p c^2$$

Solving for dynamics and thermodynamics

8 unknown : $_{n}$ $_{p}$ T_n T_p T_e T_r n_p n_n

8 coupled equations :

1) energy conservation $(T^{r}{}_{,}\ \ =0)$

2) mass conservation $(F_{,}\ \ =0)$

3) $M_p = f(M_n)$, decay changes n/p

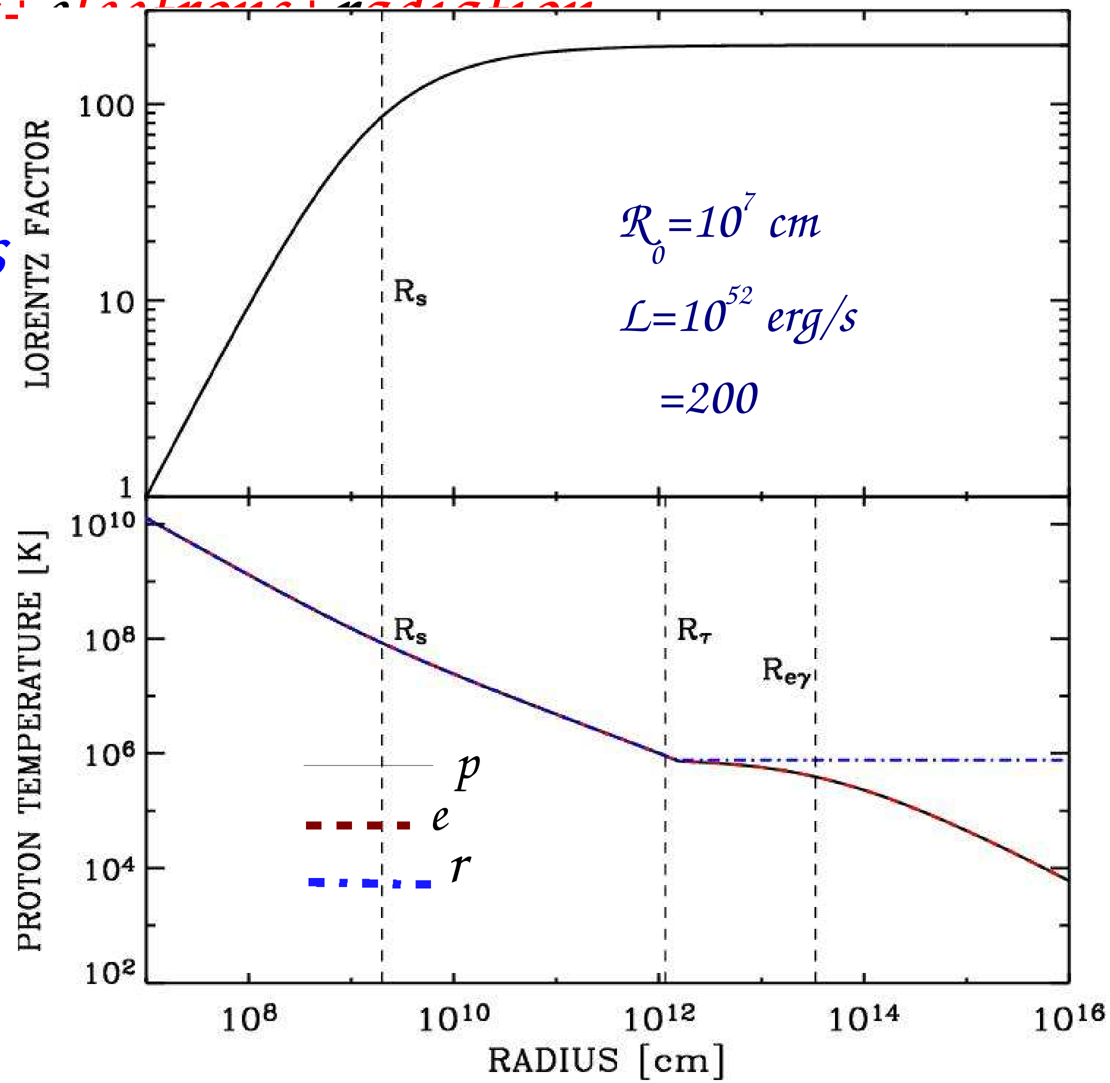
4) $_{n} = f(\ \ _{p})$ accelerating force of p on n

5-6-7-8) $dE_i = dQ_i - P_i\, dV$, i=r,e,p,n

Standard matter dominated fireball:

protons-

For most of the time is a **COLD COASTING** *outflow*



$=E/M_b c^2$

Rossi, Beloborodov, Rees 05

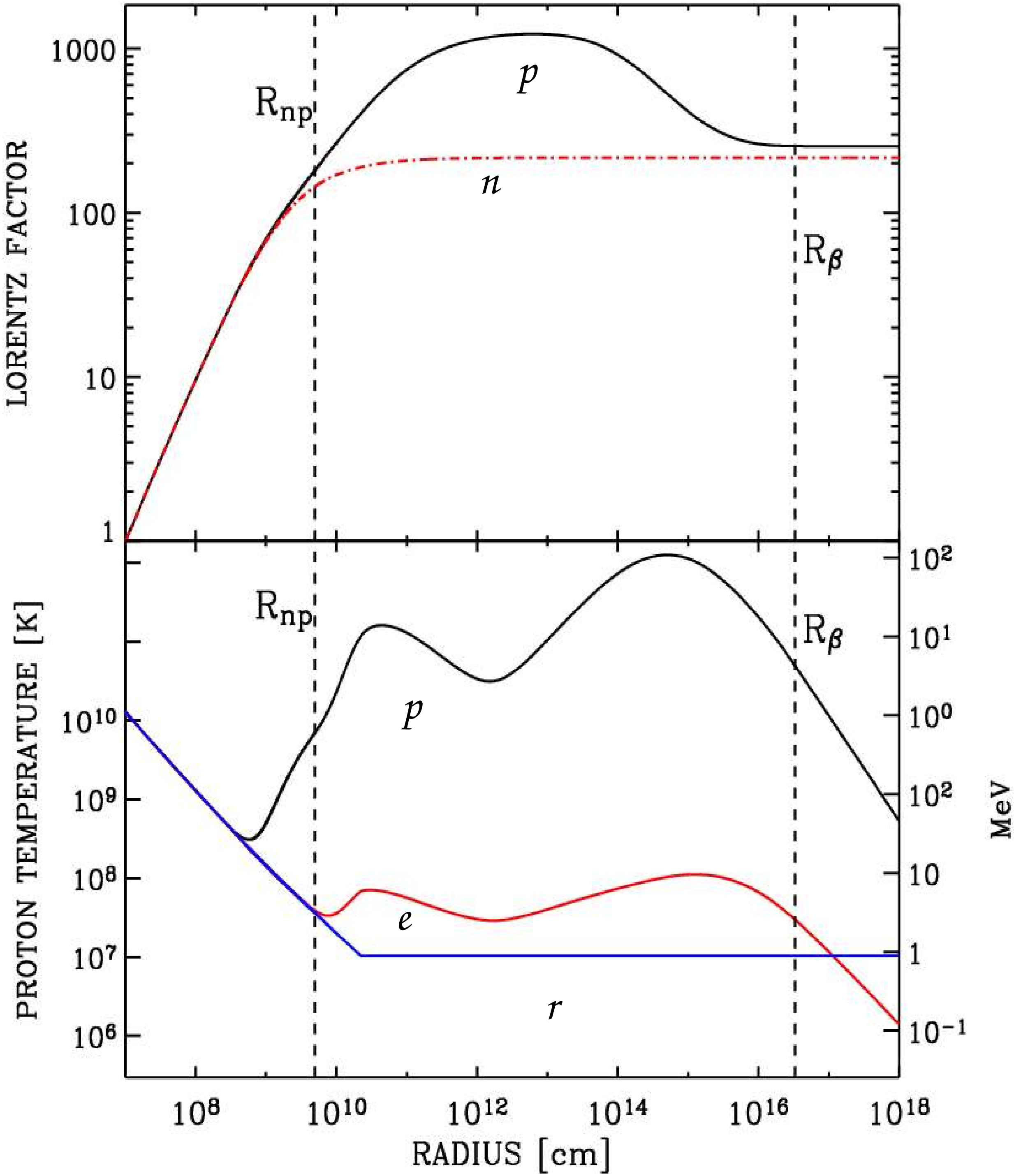
=300

n/p=10

L=10^52 erg/s

R0=10^7 cm

$R_{sep} \geq 2 \; {}^{2}{}_{n} \quad R \sim 2\ 10^{16}\ cm$



Rossi, Beloborodov & Rees 05

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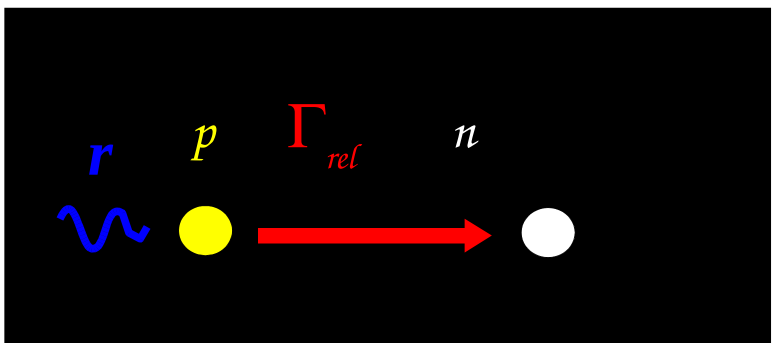
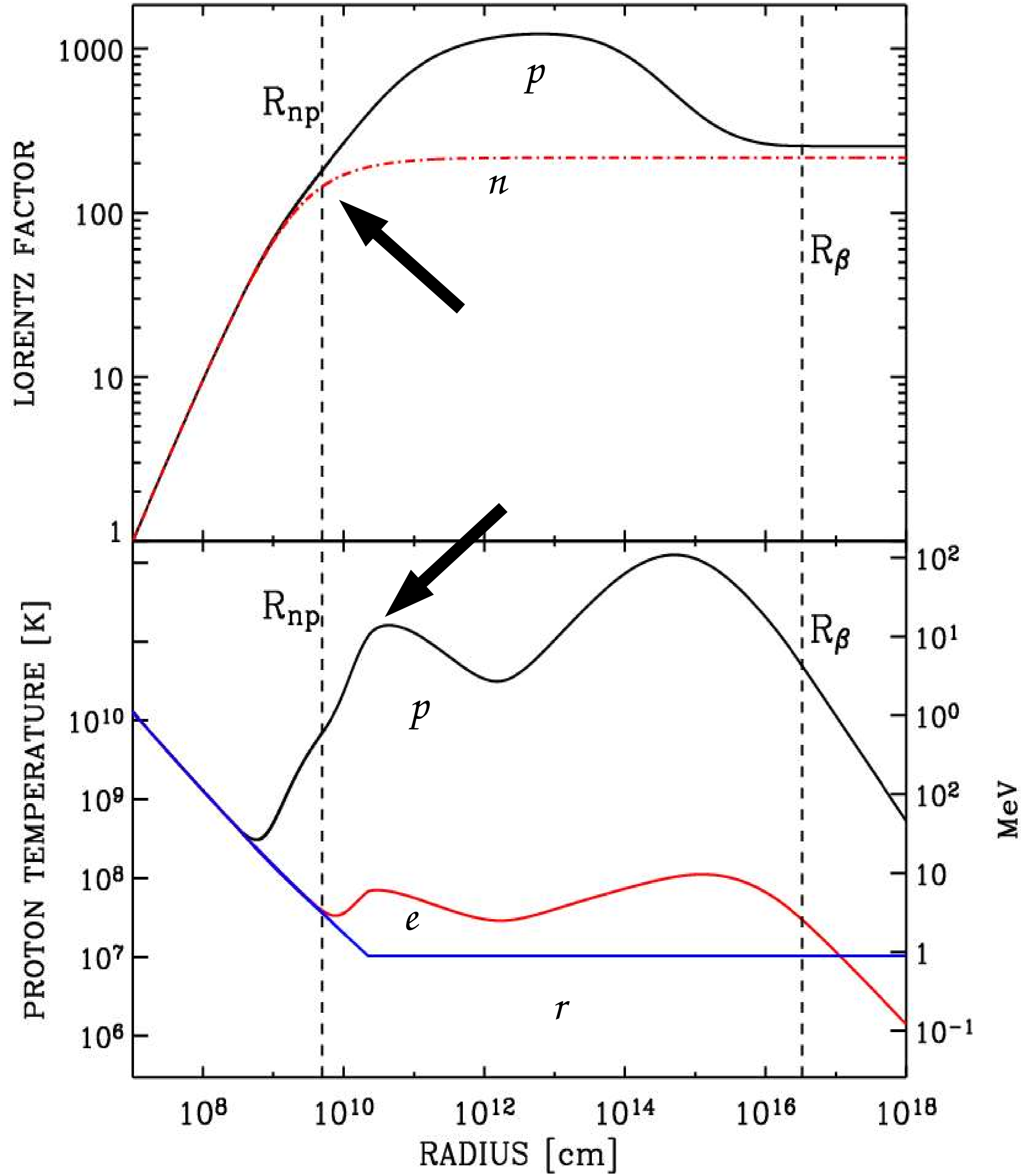




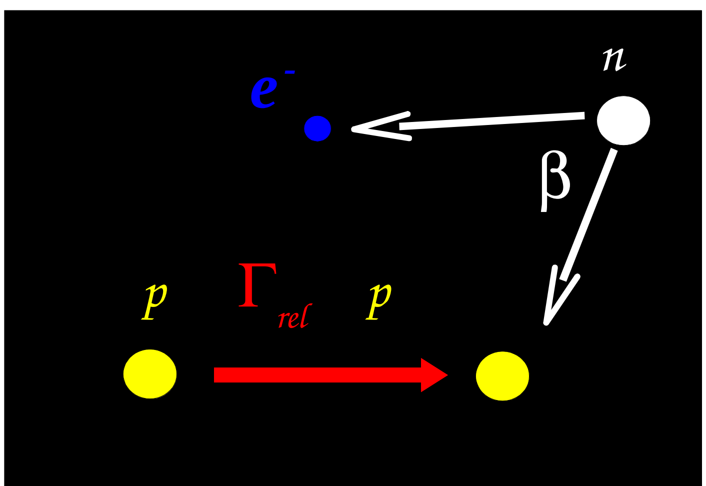
$=300$

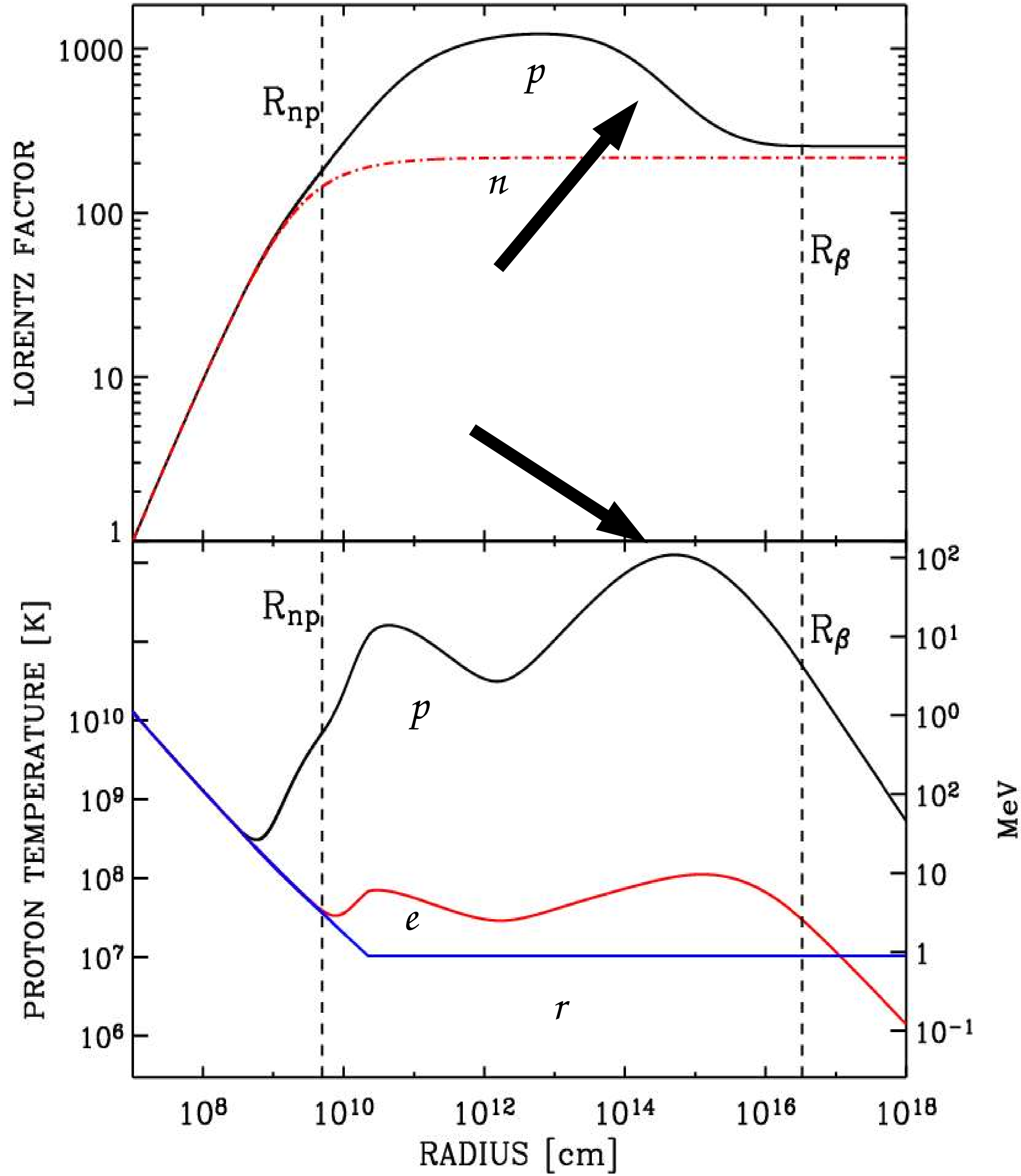
$n/p=10$

$L=10^{52}$ erg/s

$R0=10^{7}$ cm

$$n \propto e^{-R/R}$$





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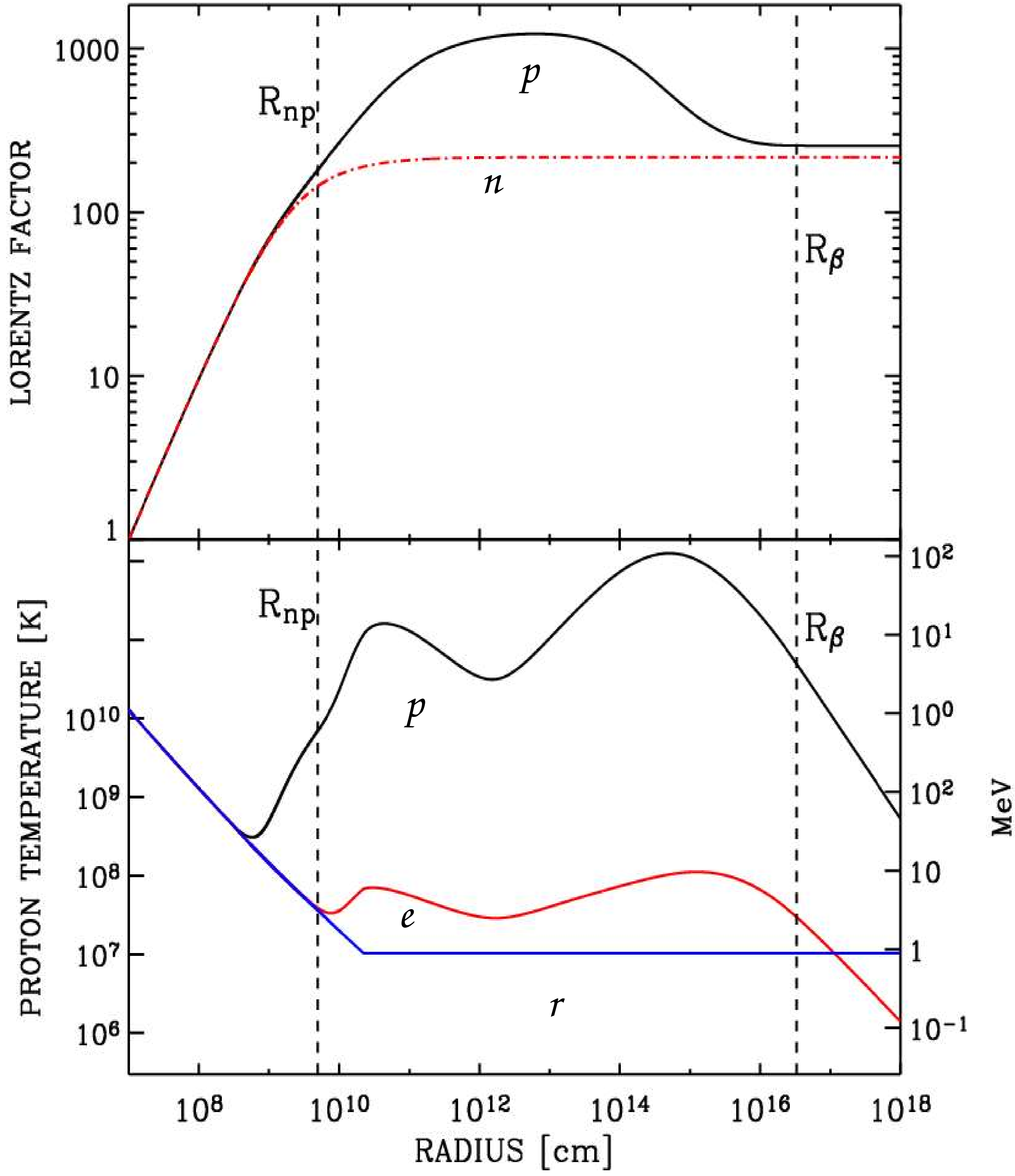
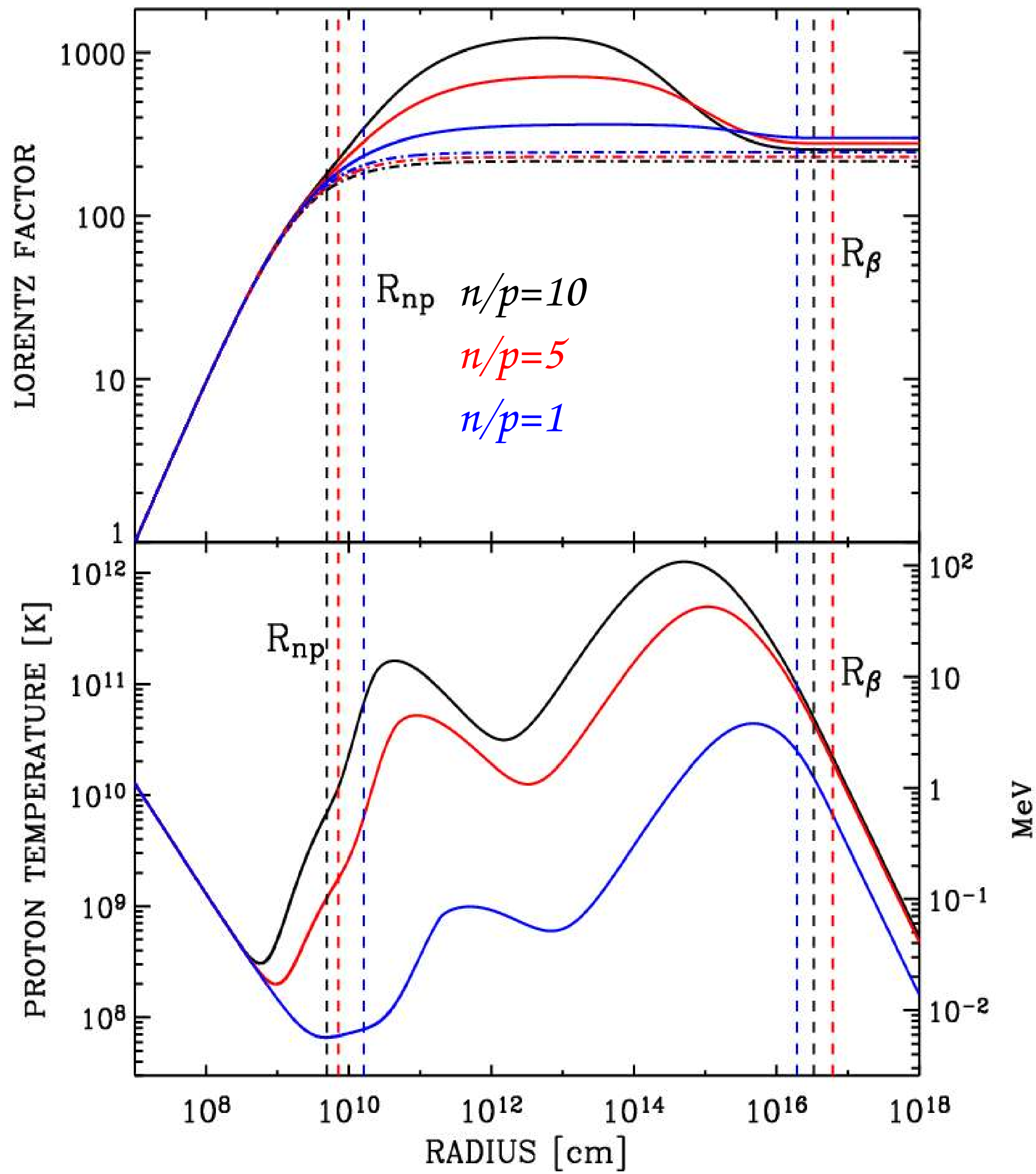
!! Protons are a decelerating relatively hot plasma !!



More deceleration and heating for larger n/p:

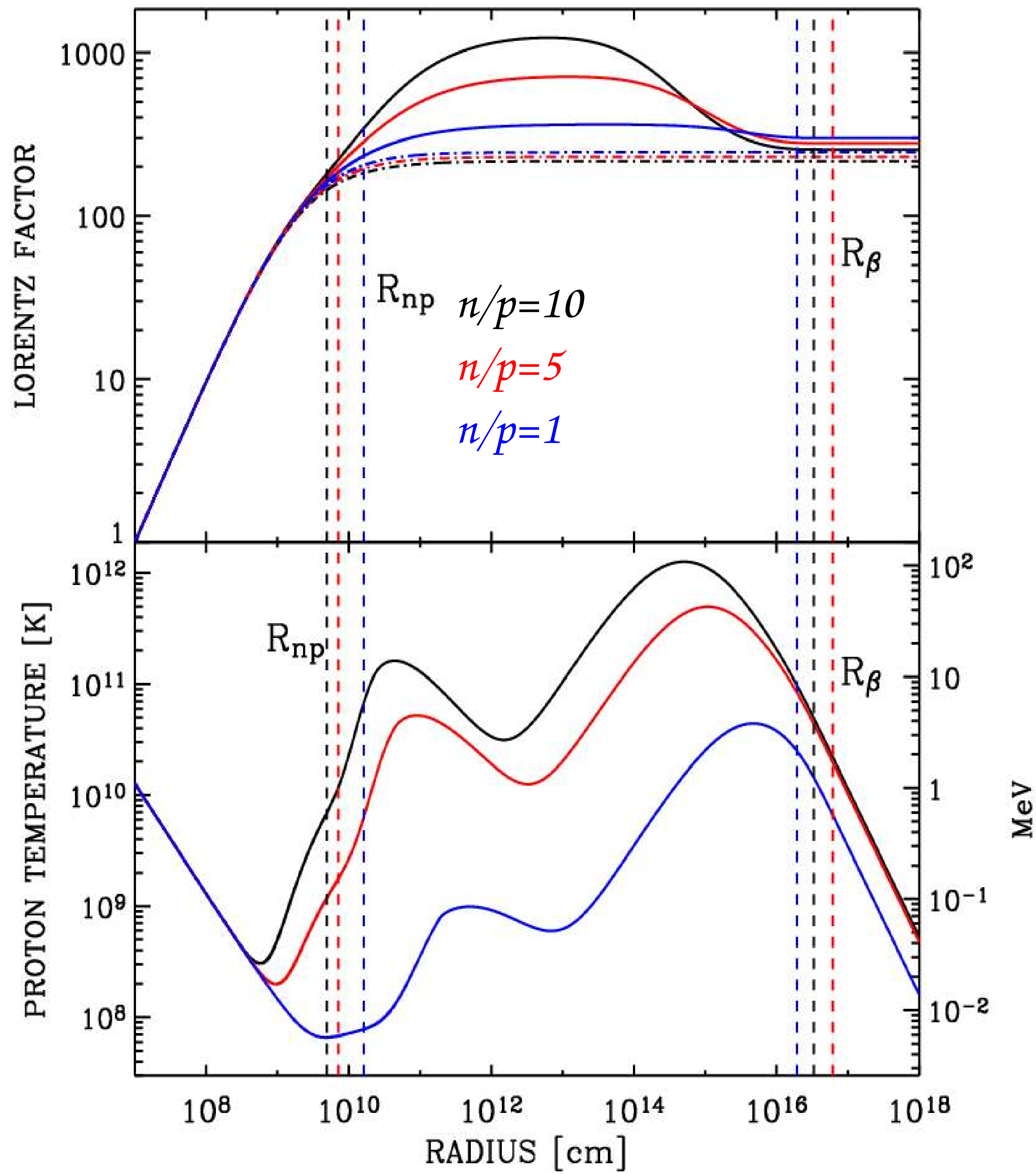
n/p ↑ n_p ↓ R_{np} ↓

---> $\mathcal{E}_{rel}$ ↑ T_p ↑



More deceleration and heating for larger n/p:

Dynamics and thermodynamic depend on the engine nuclear composition !



$=L/\dot{M}_b c^2$

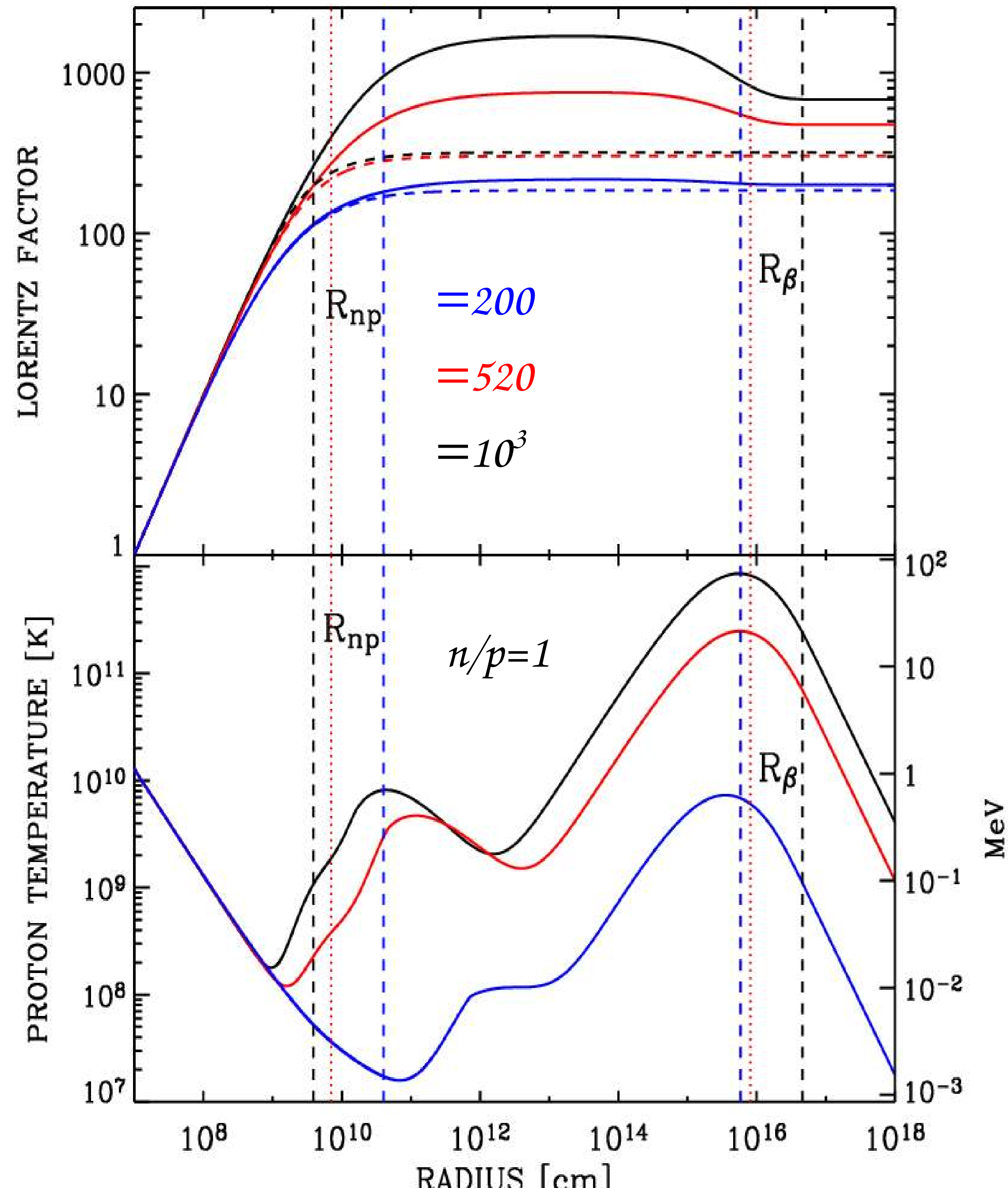
The higher

the stronger the p

p dec. & heating

M_b R_{np}

---> E_{rel} T_p



Conclusions

- *Fireballs are likely neutron loaded*

- *This influences dynamics and thermodynamics of the proton component*

- *The heating and deceleration depends on* η *and especially on n/p: link with the accretion disk*

Nucleosynthesis

(Beloborodov 03, Lemoine 02, Pruet et al 03)

	Big Bang	GRB
• Photon-to-baryon ratio:	$\sim 3\ 10^{9}$	$\sim 8\ 10^{4}$
• Exp. Timescale at NSy:	~100 s	$\sim 10^{-3}$ s
• n/p ratio prior to NSy:	n/p=1/7	n/p>1

GRB has marginally successful nucleosynthesis

$\alpha/(p+n)\sim 0.01\text{-}0.1$ ---> jet with free p & n with n/p>1