Nuclear Composition in GRBs Disks and Jets

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OUTLINE

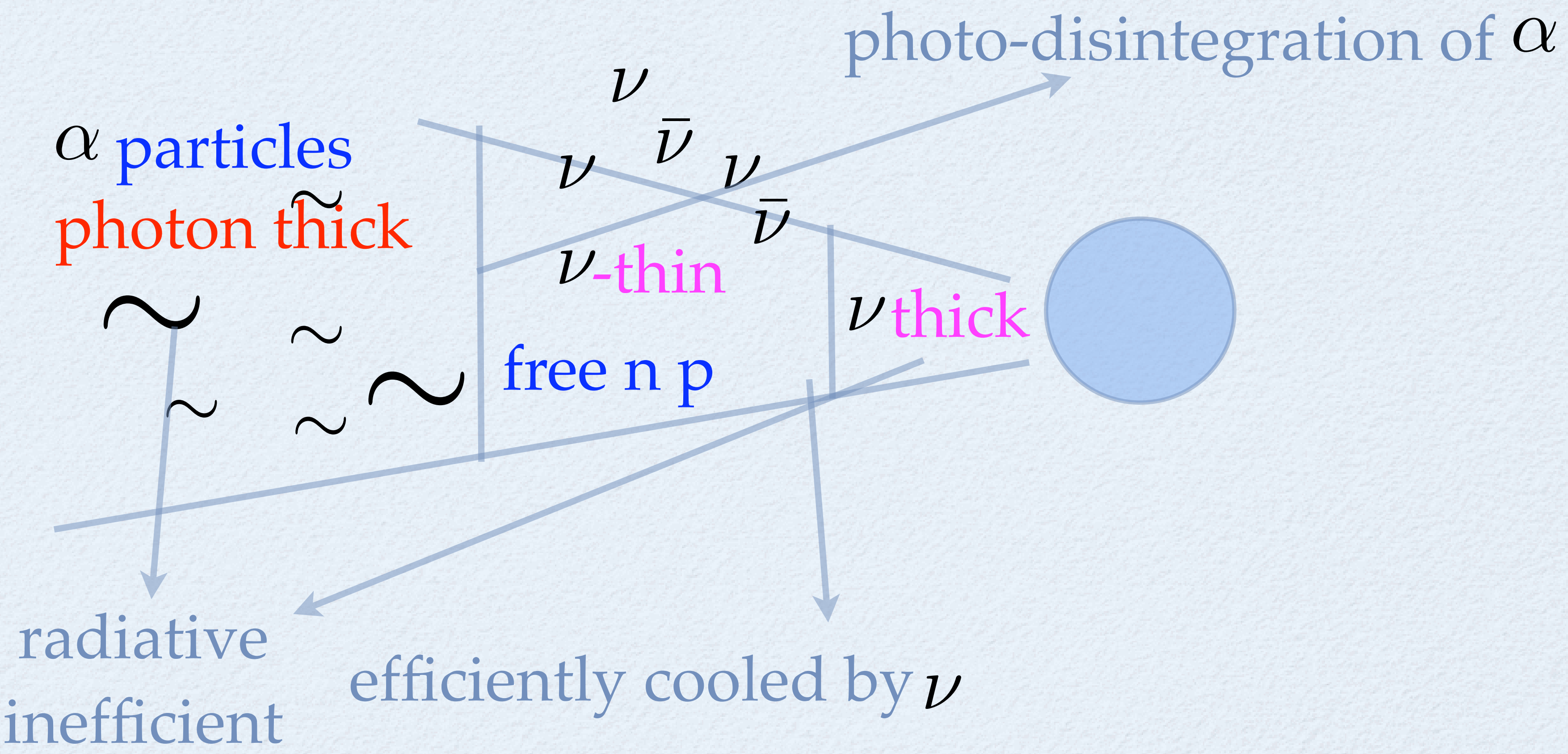
- HYPER-ACCRETING DISKS : NEUTRINO COOLING SHAPE THE RADIAL AND VERTICAL STRUCTURE
- NEUTRON LOADED OUTFLOW:DYNAMICS + THERMODYNAMIC

Hyper Accreting Disks

- GRB are powered by accretion disks of a 0.1-10 M_{sun} /sec onto a few M_{sun} black hole (Woosley 93,Janka et al 99&01,Fryer et al 99..)
- Pophan et al 99; Narayan et al 01

Energy Balance

$\rho \sim 10^{9}\text{-}10^{11}\ \mathrm{gr/cm^3}$ $\quad T \sim 10^{9}\text{-}10^{11}$ K

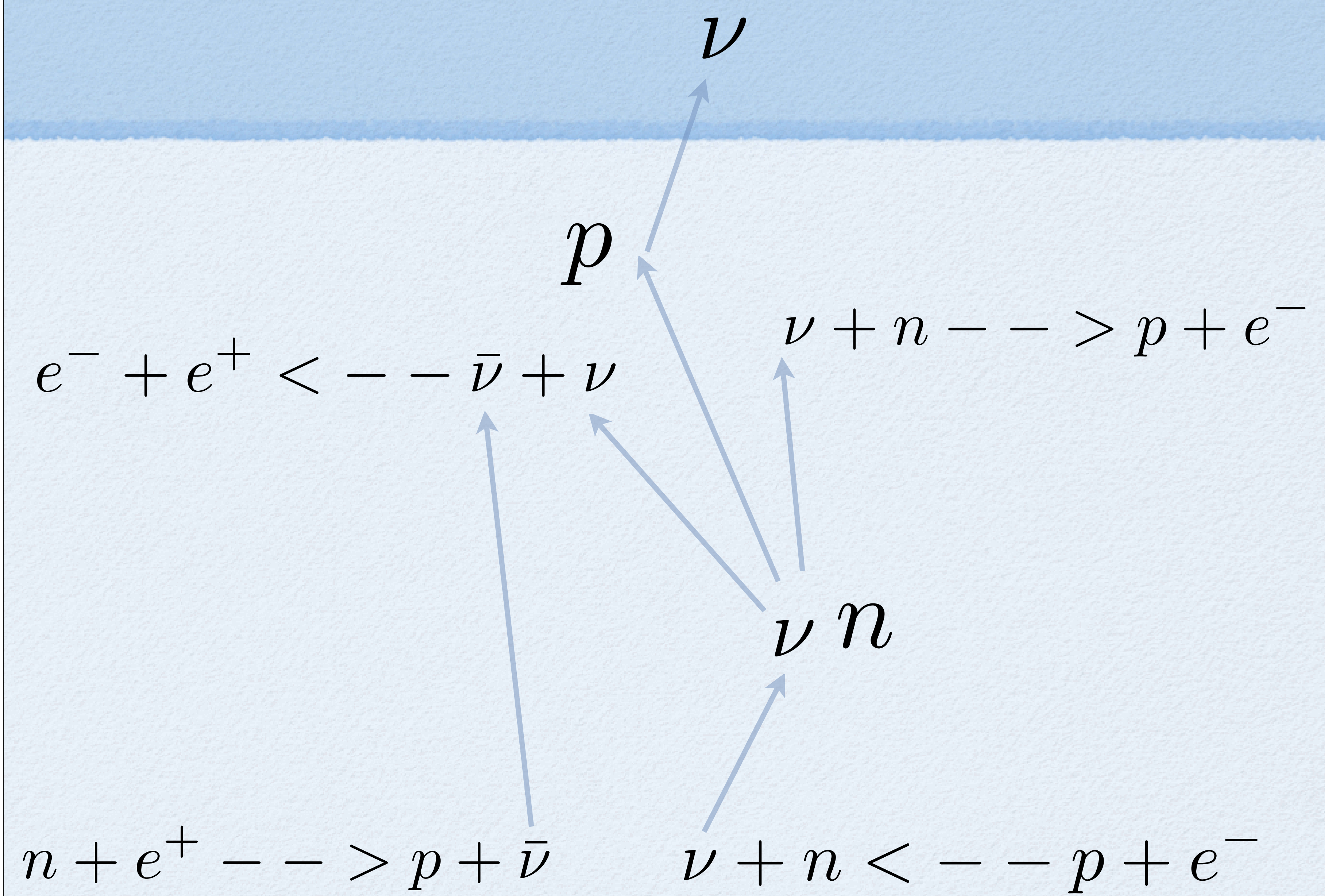


consistent calculation of nuclear composition and thermodynamical quantities:

for radial structure: Lee et al 05; Janiuk et al sub. & Chen and Beloborodov proc.

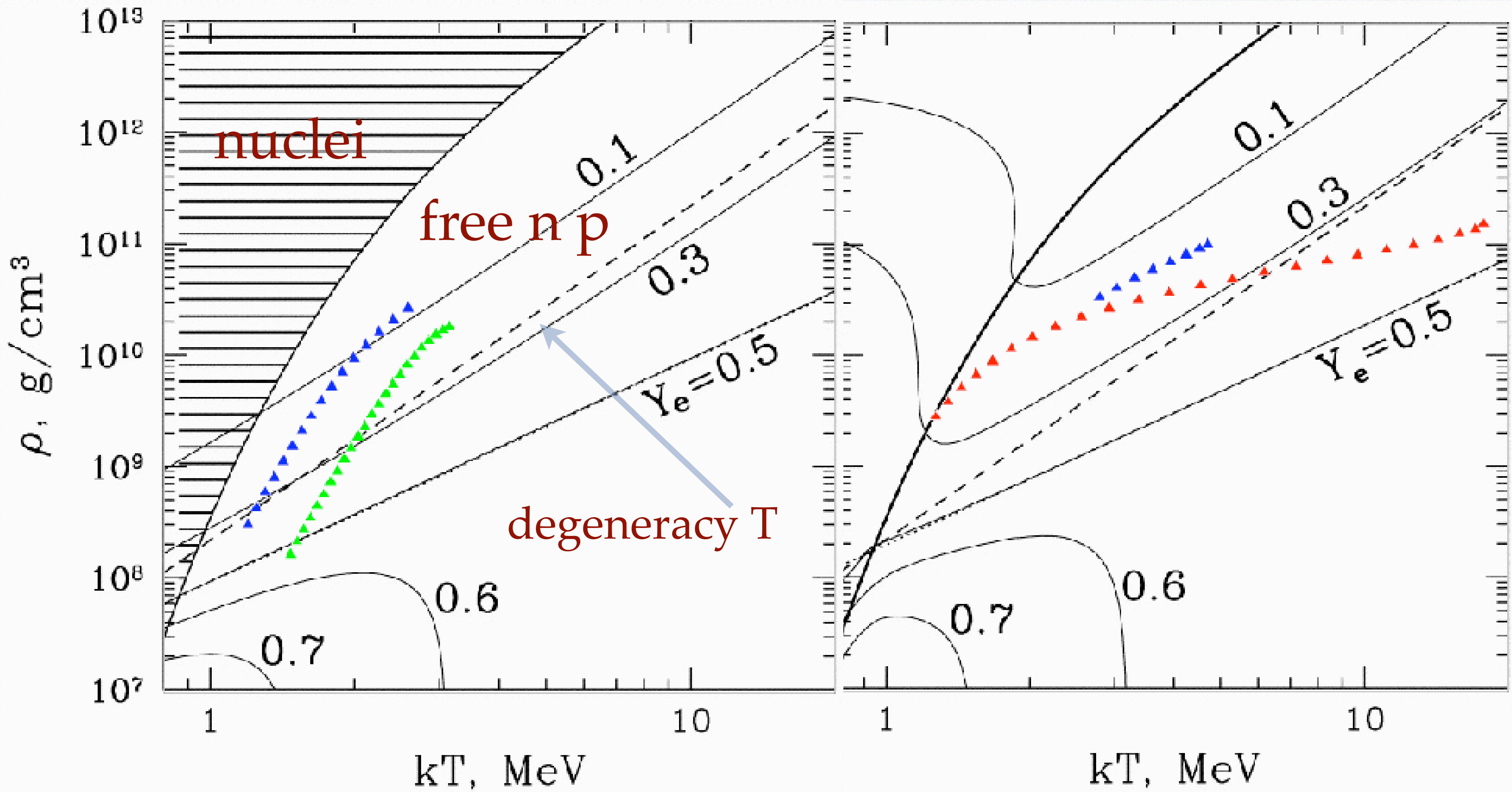
- thin disk dynamics: plane parallel atmosphere; no advection term: $$\frac{dP}{dz} = \rho \frac{GM}{r^3} z$$
- eq of state: gas pressure dominates
- Y_p Y_n X_{nuc} as function of ρ and T
- radiative transfer equations

Rossi, Armitage & Di Matteo in prep


ν
p
$\nu + n --> p + e^-$
$e^- + e^+ <-- \bar{\nu} + \nu$
$\nu\, n$
$n + e^+ --> p + \bar{\nu}$
$\nu + n <-- p + e^-$

NUCLEAR COMPOSITION

underlining figure from Beloborodov 02

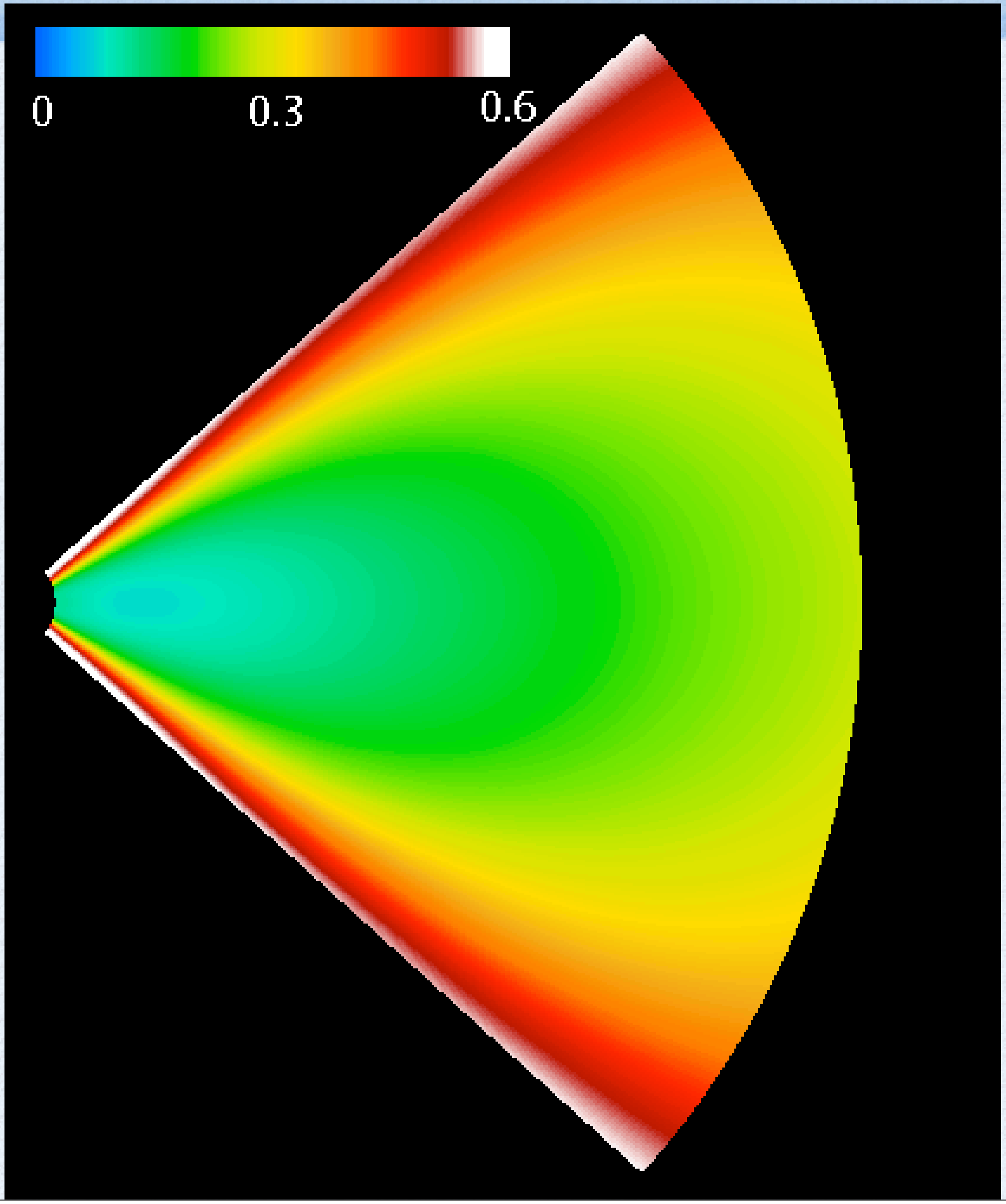


optically thin

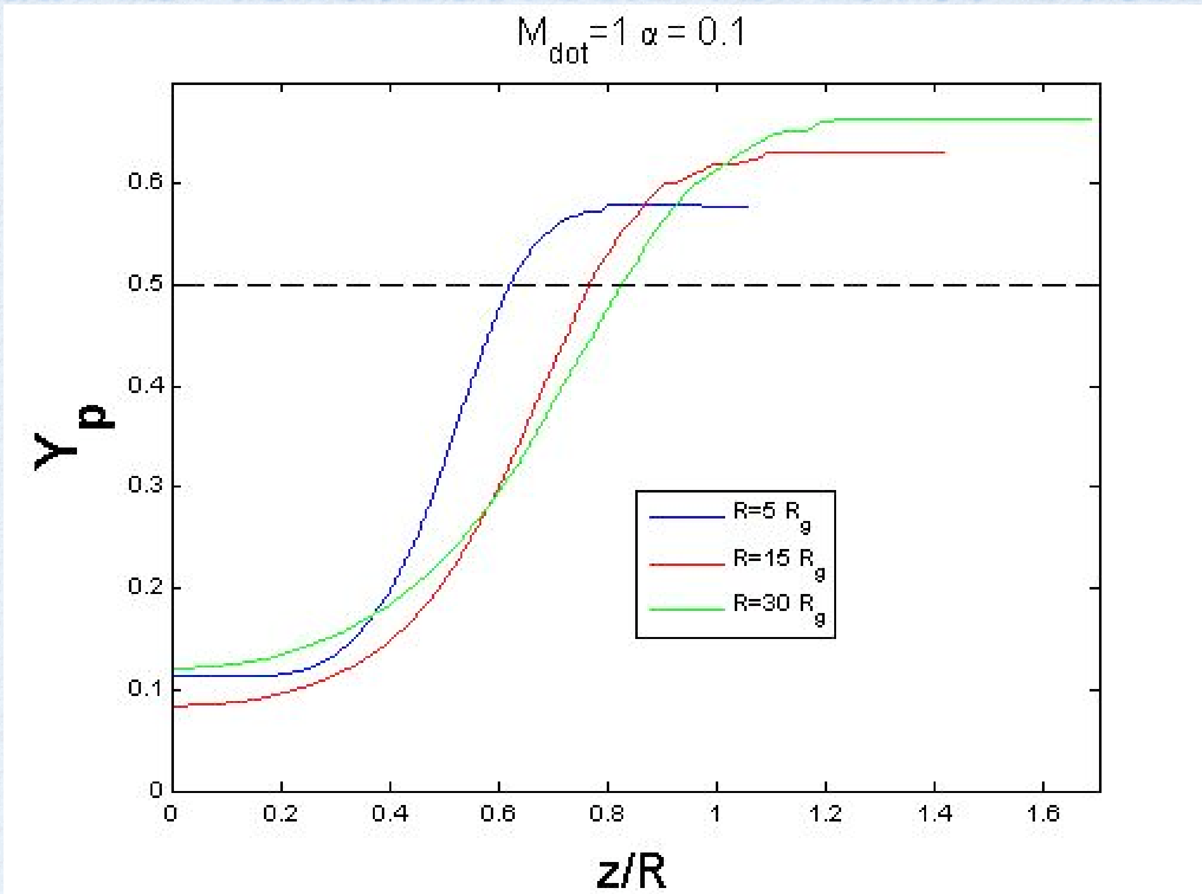
thick

2D Y_p MAP

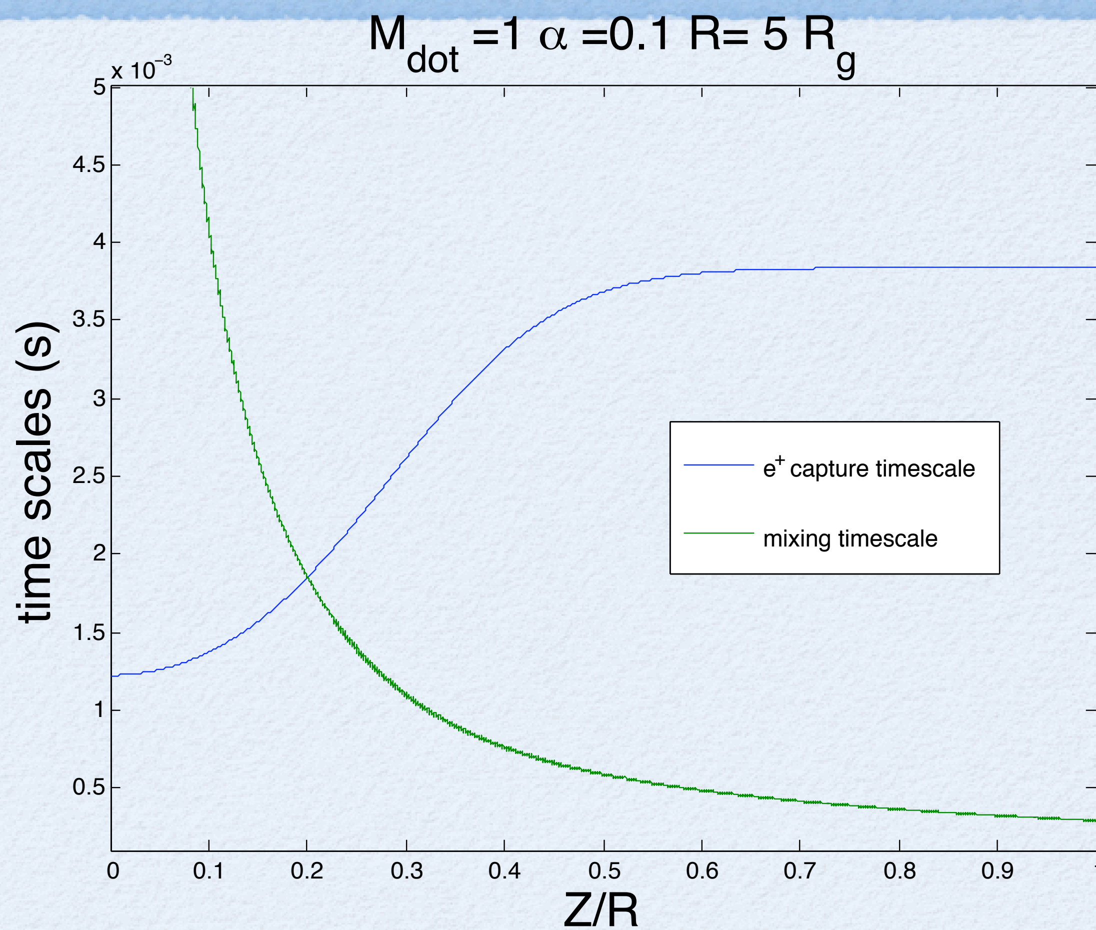
Y_p



Vertical Structure



No mixing: De-neutralisation time too long



most of matter as Yp<0.5 ---> neutron loaded jet

How do neutrons affect the outflow dynamics & thermodynamics ?

Standard matter dominated fireball:

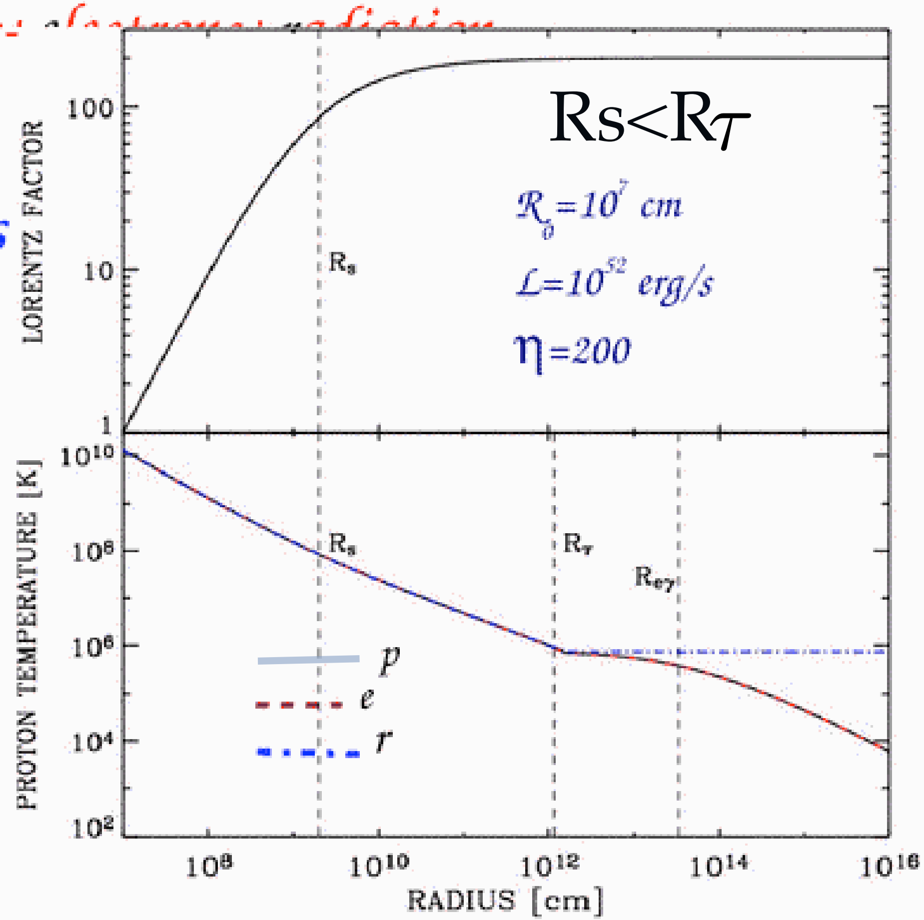
protons-

For most of the time is

a ***COLD***

COASTING

outflow



Rossi, Beloborodov, Rees 05

$$\eta = E/M_b c^2$$

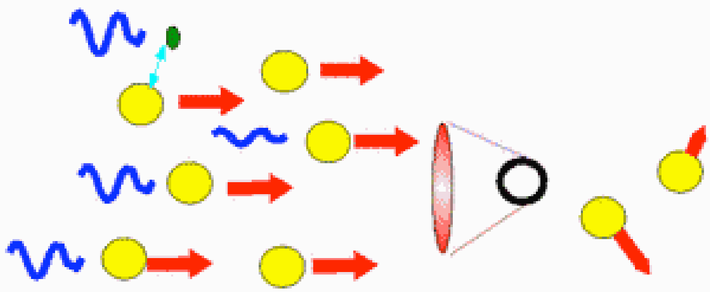
Fireball theory with neutrons

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

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

$t_\beta = 900\ s \dashrightarrow R_\beta = c\, t_\beta \Gamma_n$

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



n-p COLLISIONS AS MOMENTUM EXCHANGE AND FRICTION.

collision rate per n:

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

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

mean momentum gained per n (isotropic scattering):

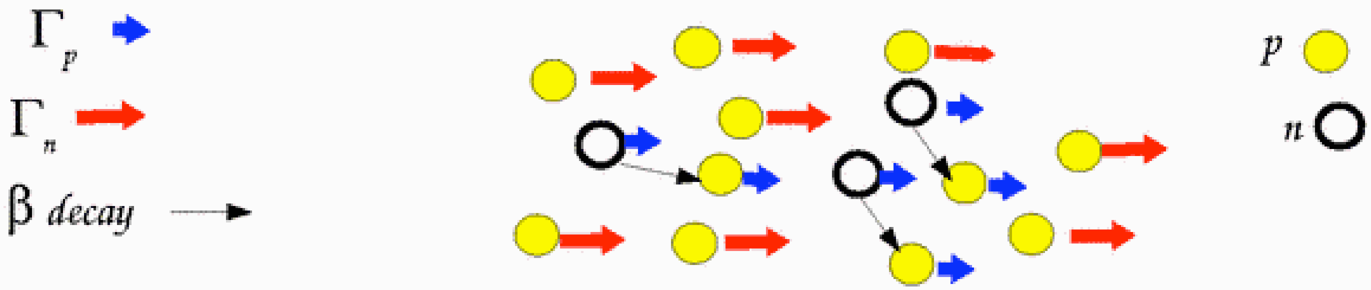
$$p_n = < p_p > = m_p v_{rel} \Gamma_{rel} 0.5$$

mean force on a n

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

Volume dissipation rate (proton rest-frame):

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



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

$$\frac{dq_p}{dt'}_\beta = \frac{n_n^p}{\Gamma_{rel}\,\tau_\beta}(\Gamma_{rel} - 1) m_p c^2 0.5$$

Solving for dynamics and thermodynamics

8 unknown : $\Gamma_n \Gamma_p T_n T_p T_e T_r n_p n_n$

8 coupled equations :

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

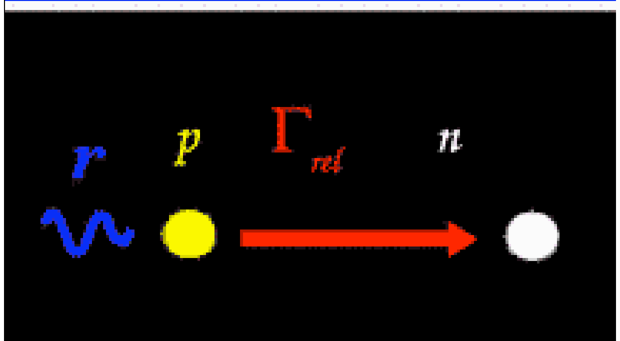
2) mass conservation ($F^{\nu}{}_{,\nu}=0$)

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

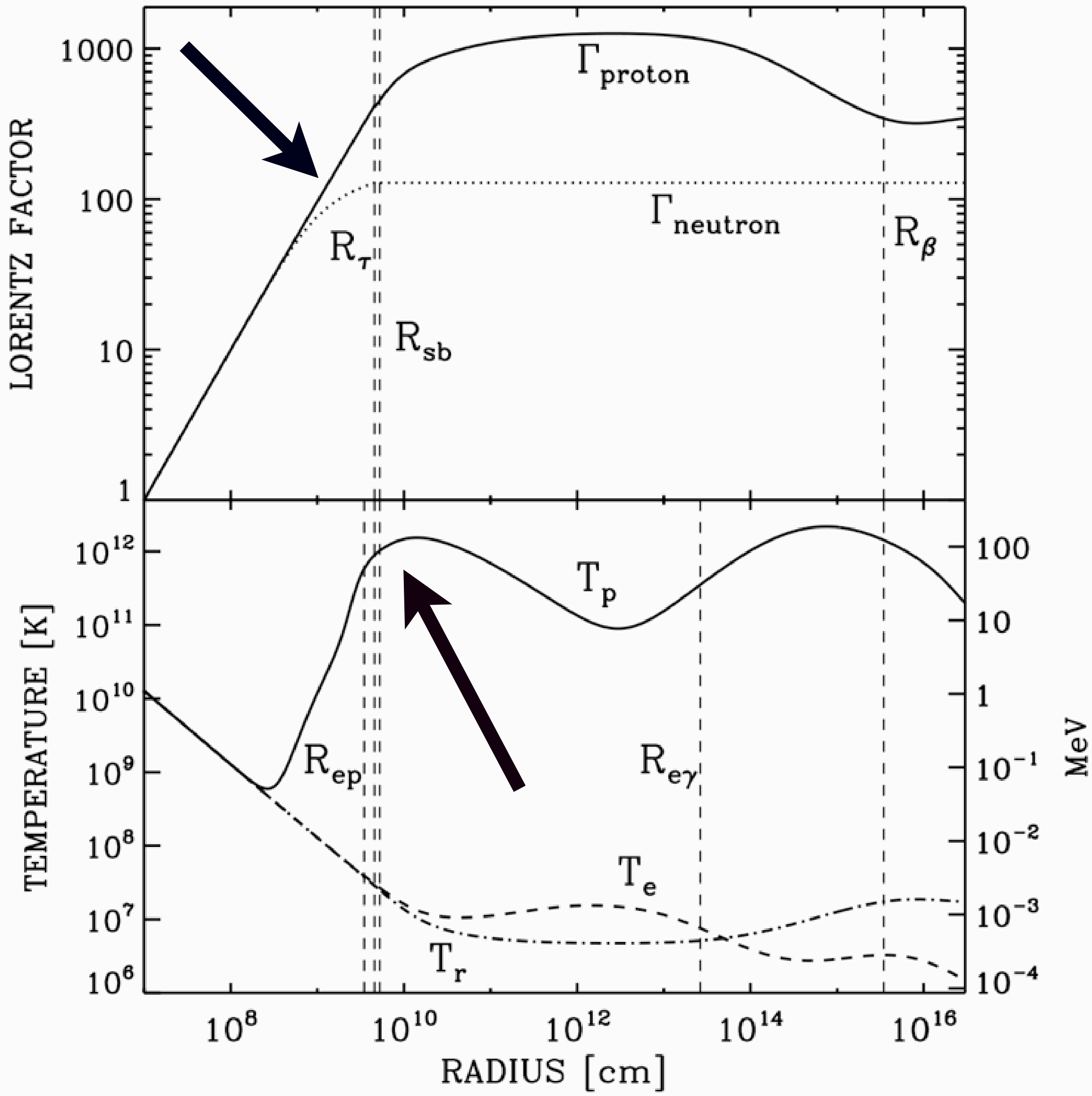
4) $\Gamma_n=f(\Gamma_p)$ accelerating force of p on n

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

STRONG COLLISIONS

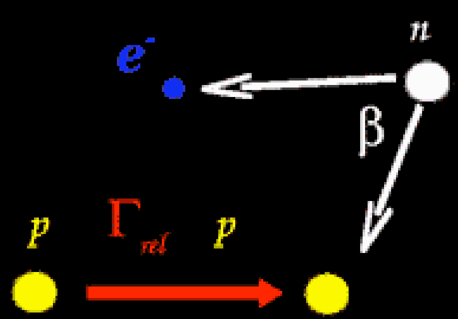


$$\eta = \frac{L}{\dot{M}c^2} = 10^3 L = 10^{52} erg/s$$

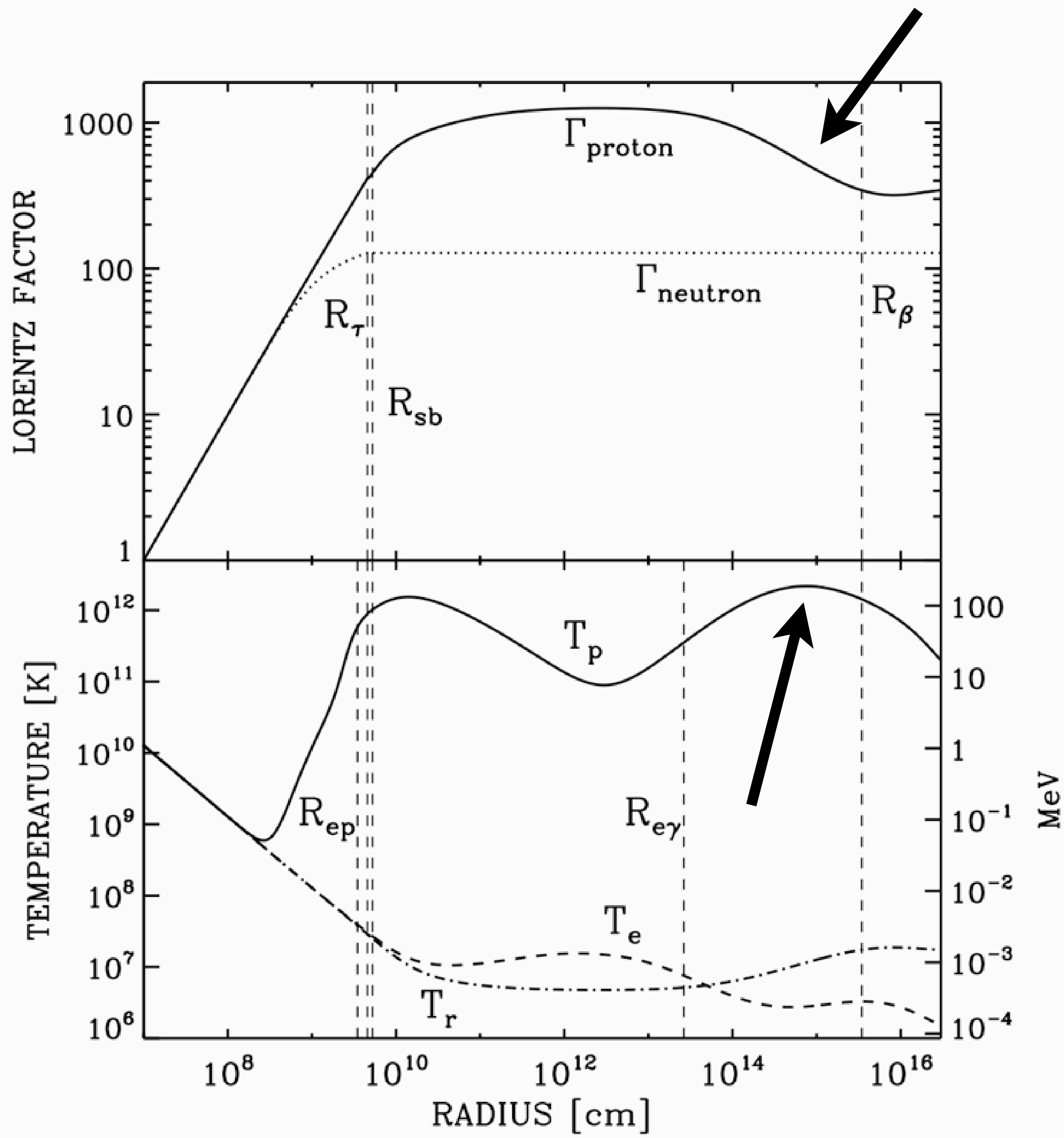


Rossi Beloborodov Rees 2005

β decay



e-
n
β
p
Γnel
p



LORENTZ FACTOR
1000
100
10
1
Γproton
Γneutron
Rτ
Rsb
Rβ
TEMPERATURE [K]
10^12
10^11
10^10
10^9
10^8
10^7
10^6
Tp
Rep
Reγ
Te
Tr
100
10
1
10^-1
10^-2
10^-3
10^-4
MeV
10^8
10^10
10^12
10^14
10^16
RADIUS [cm]

CONCLUSION

- GRB disks are neutron rich
- GRB jets are likely neutron loaded
- the nuclear composition affect the jet dynamics

Nucleosynthesis

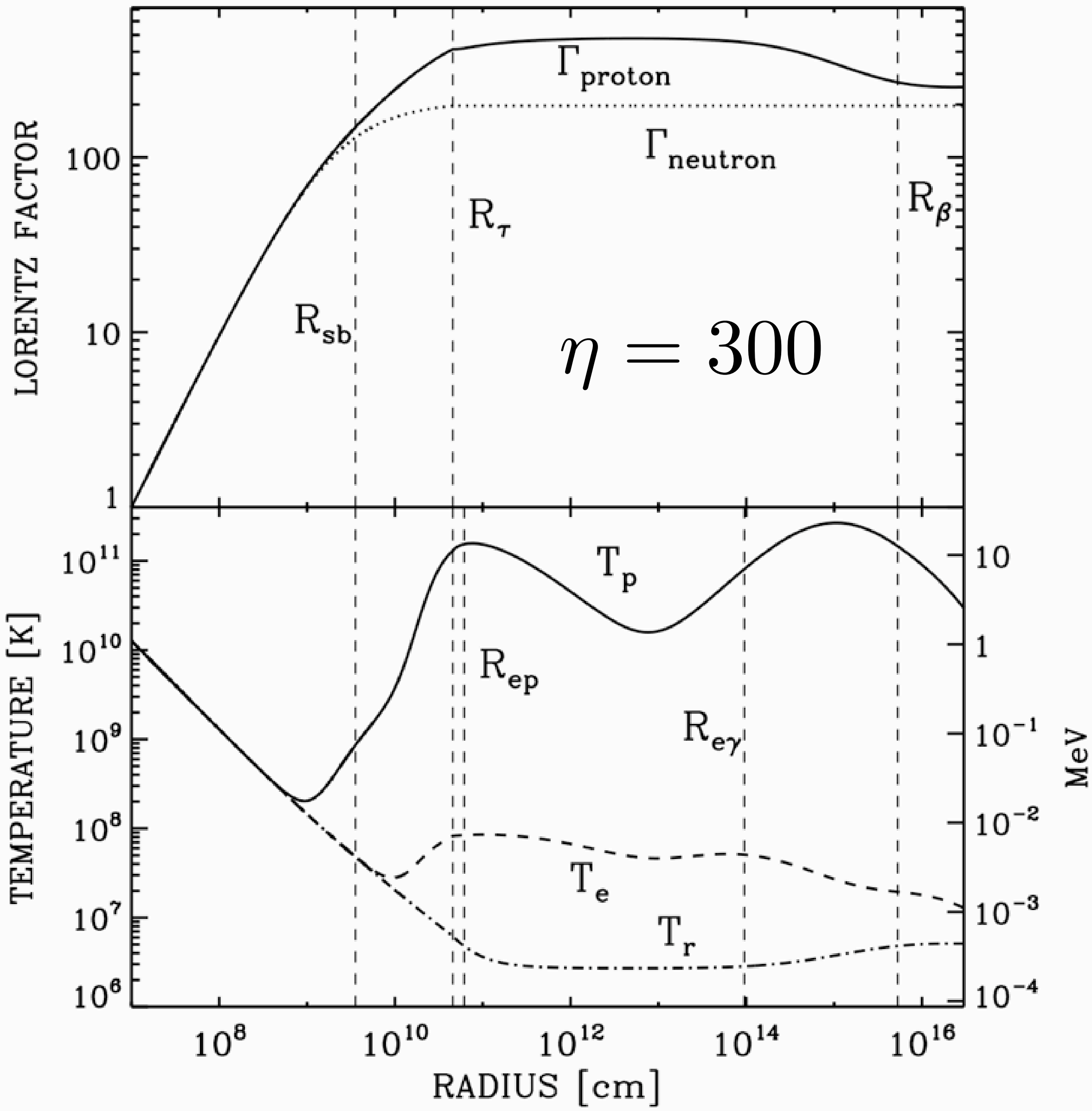
(Beloborodov 03, Lemoine 02, Pruet et al 03)

	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:	$n/p = 1/7$	$n/p > 1$

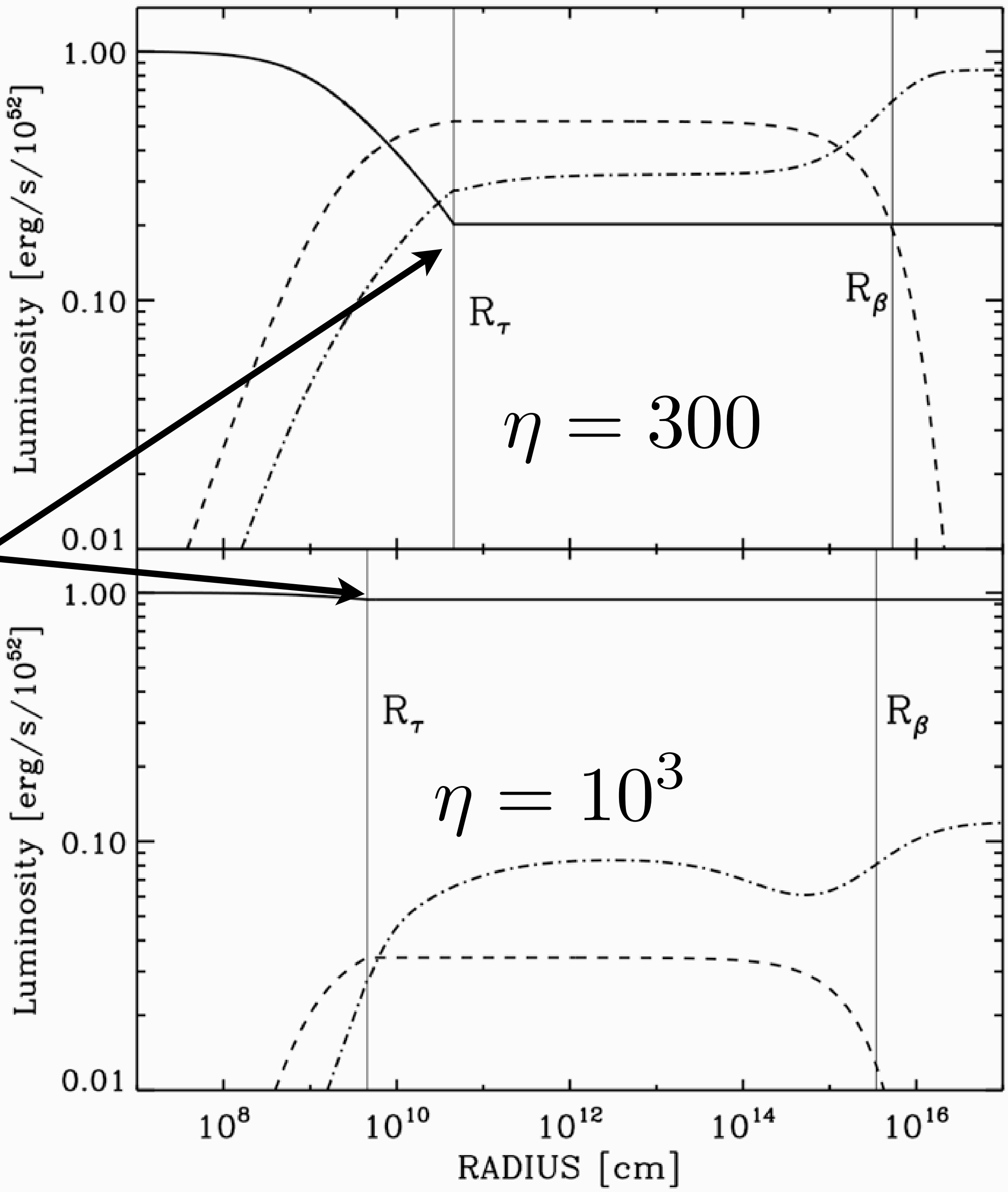
GRB has marginally successful nucleosynthesis

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

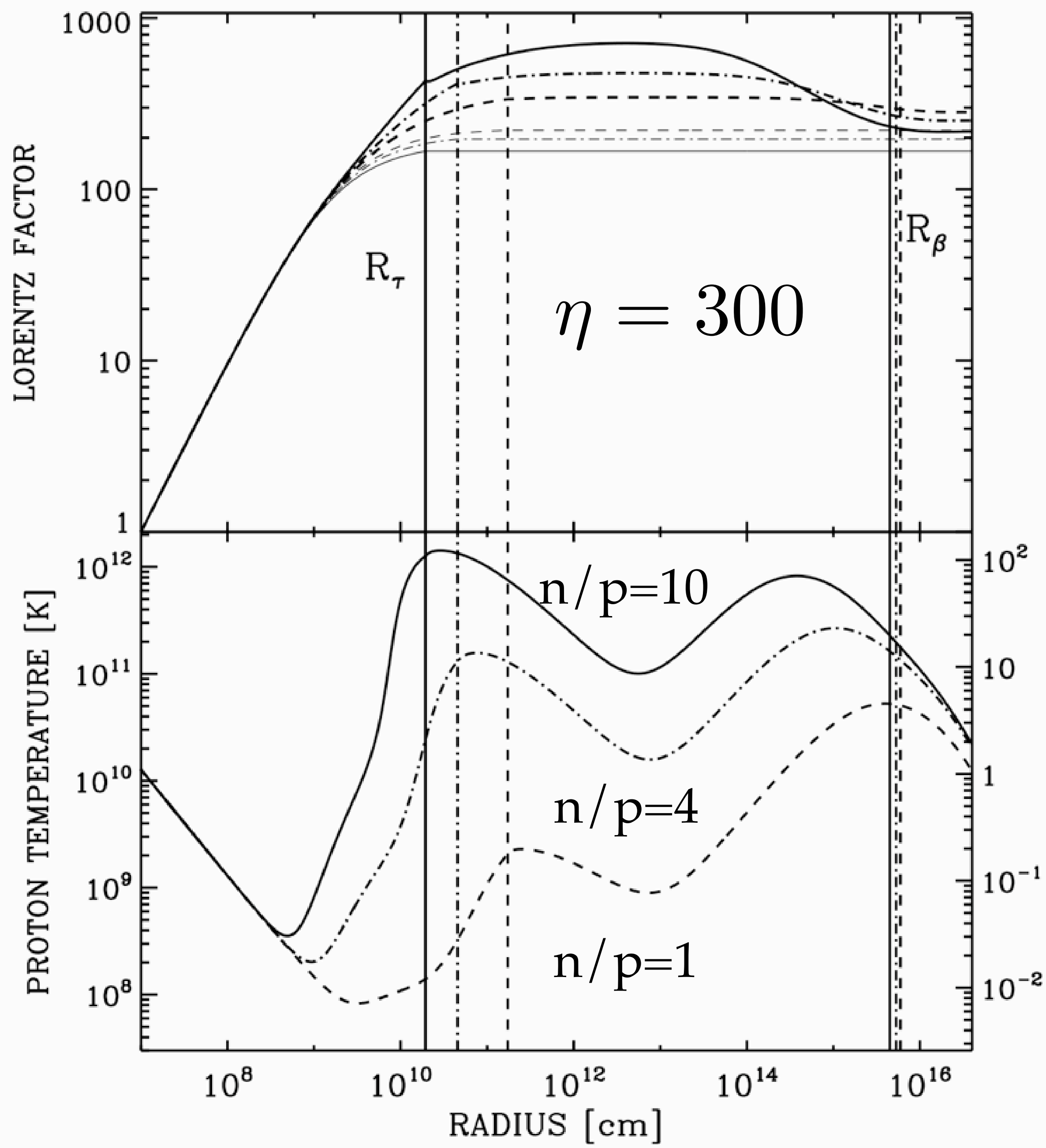
The larger the entropy per baryon the stronger the effects



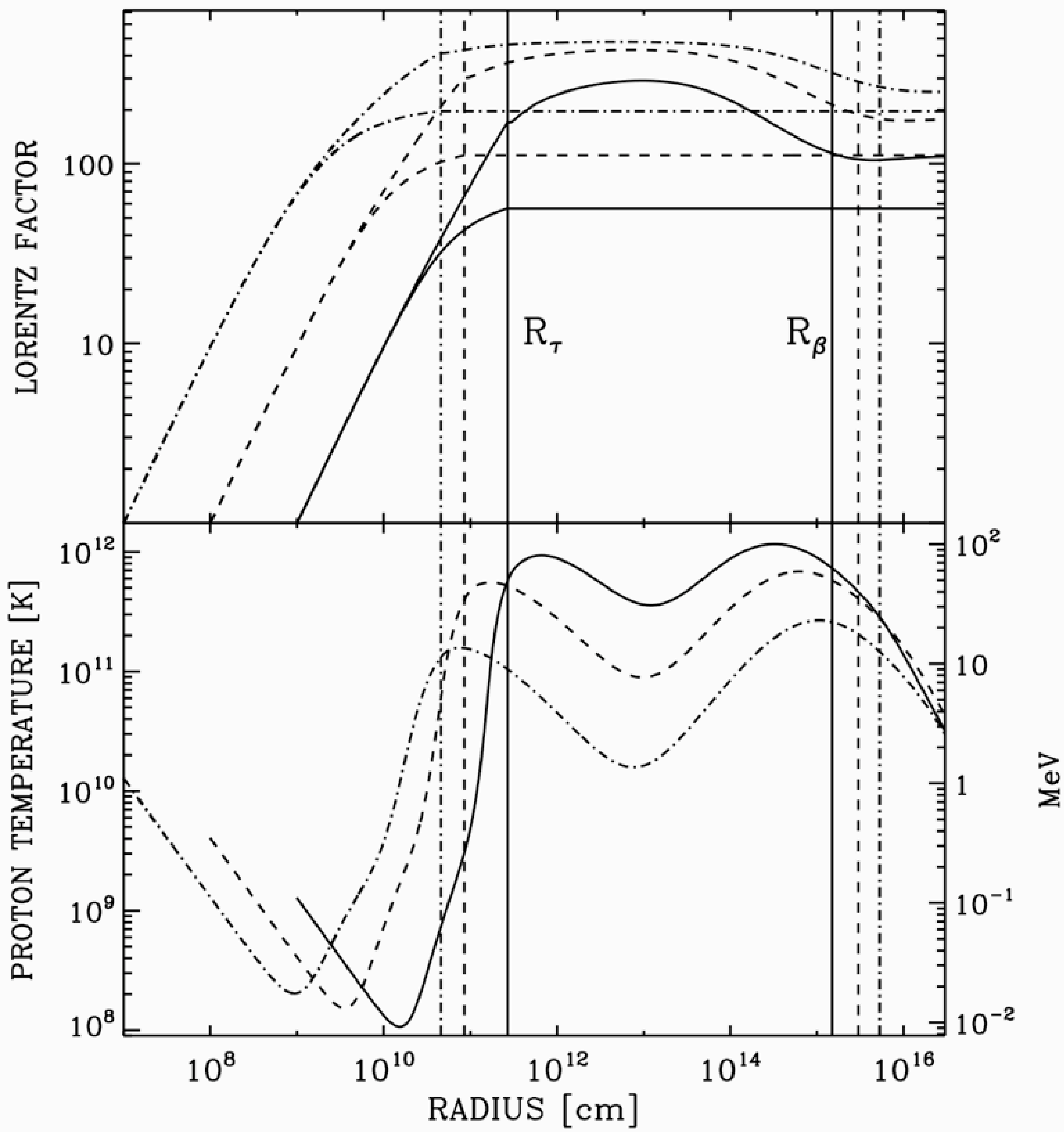
radiation energy escaped at the photosphere



More neutrons more deceleration and heating



spherical vs collimated outflows



Assumptions

- hydrodynamic evolution
- uniform outflow
- steady outflow
- spherical symmetry
- neglecting pairs (important only for r<50 r_0)
- neglecting neutrino losses

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*