

Numerical analysis of an optically thick plasma

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Introduction

Within the fireshell model, short GRBs are dominated by the emission when the expanding plasma becomes transparent for photons (P-GRB) see afternoon talks from : Izzo, Bernardini, Patricelli,

Bianco, Caito

We studied numerically an optically thick plasma with the focus on the issue how different possible initial spatial distributions of matter and energy may influence on the evolution of the plasma.

We developed a special relativistic hydrodynamic code (similar to Livermore code), with better spatial resolution, but without treating shocks.

Ruffini, Samolson, Wilson, Xue 1999, 2000

Assumptions

We consider a plasma formed initially by electrons, positrons, photons and baryons.

We analyzed its hydrodynamics expansion in a spherical symmetric system.

We analyze just smooth profiles.

Physical equations

$$T^{\mu\nu}_{;\nu} = 0,$$
$$(n_B U^\nu)_{;\nu} = 0,$$

$$T^{\mu\nu} = p g^{\mu\nu} + [\rho(1 + \epsilon) + p] U^\mu U^\nu$$

$$\epsilon = \epsilon_{nr} + \epsilon_r \simeq \epsilon_r,$$

$$\rho = \rho_{nr} + \rho_r \simeq \rho_b,$$

$$p = p_r + p_{nr} \simeq (\rho_r \epsilon_r)/3.$$

$$\frac{\partial D}{\partial t} = -\frac{\partial(r^2 D v)}{r^2 \partial r},$$

$$\frac{\partial E}{\partial t} = -\frac{\partial(r^2 E v)}{r^2 \partial r} - p \frac{\partial(r^2 u)}{r^2 \partial r} - p \frac{\partial \gamma}{\partial t},$$

$$\frac{\partial S}{\partial t} = -\frac{\partial(r^2 S v)}{r^2 \partial r} - \frac{\partial p}{\partial r},$$

$$D = \rho \gamma$$

$$E = \epsilon D$$

$$S = (D + E + \gamma p)u$$

Numerical approach

- one dimensional Eulerian code
- finite difference method

INTERACTION

$$\frac{\partial S}{\partial t} = -\frac{\partial p}{\partial r} = -\frac{\partial E/\gamma}{3\partial r},$$

$$u = \frac{S}{D + E + p\gamma},$$

$$\frac{\partial E}{\partial t} = -p \frac{\partial \gamma}{\partial t},$$

$$\frac{\partial E}{\partial t} = -p \frac{\partial(r^2 u)}{r^2 \partial r},$$

splitting

ADVECTION

$$\frac{\partial D}{\partial t} = -\frac{\partial(r^2 D v)}{r^2 \partial r},$$

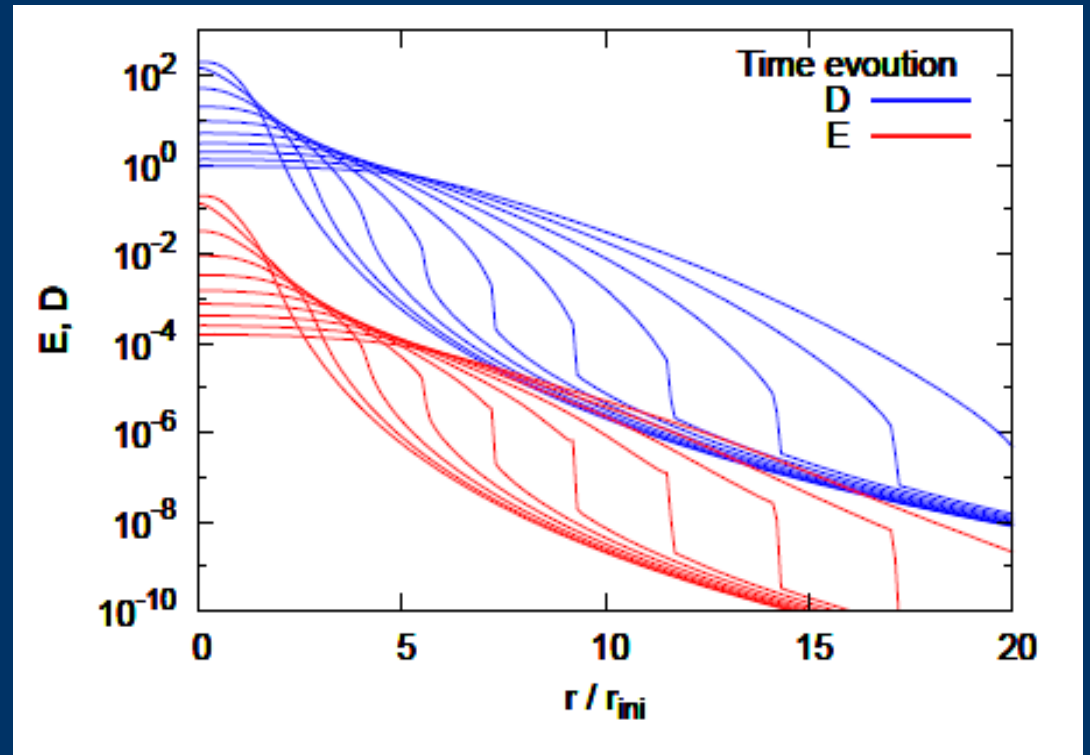
$$\frac{\partial E}{\partial t} = -\frac{\partial(r^2 E v)}{r^2 \partial r},$$

$$\frac{\partial S}{\partial t} = -\frac{\partial(r^2 S v)}{r^2 \partial r}.$$

Test-1

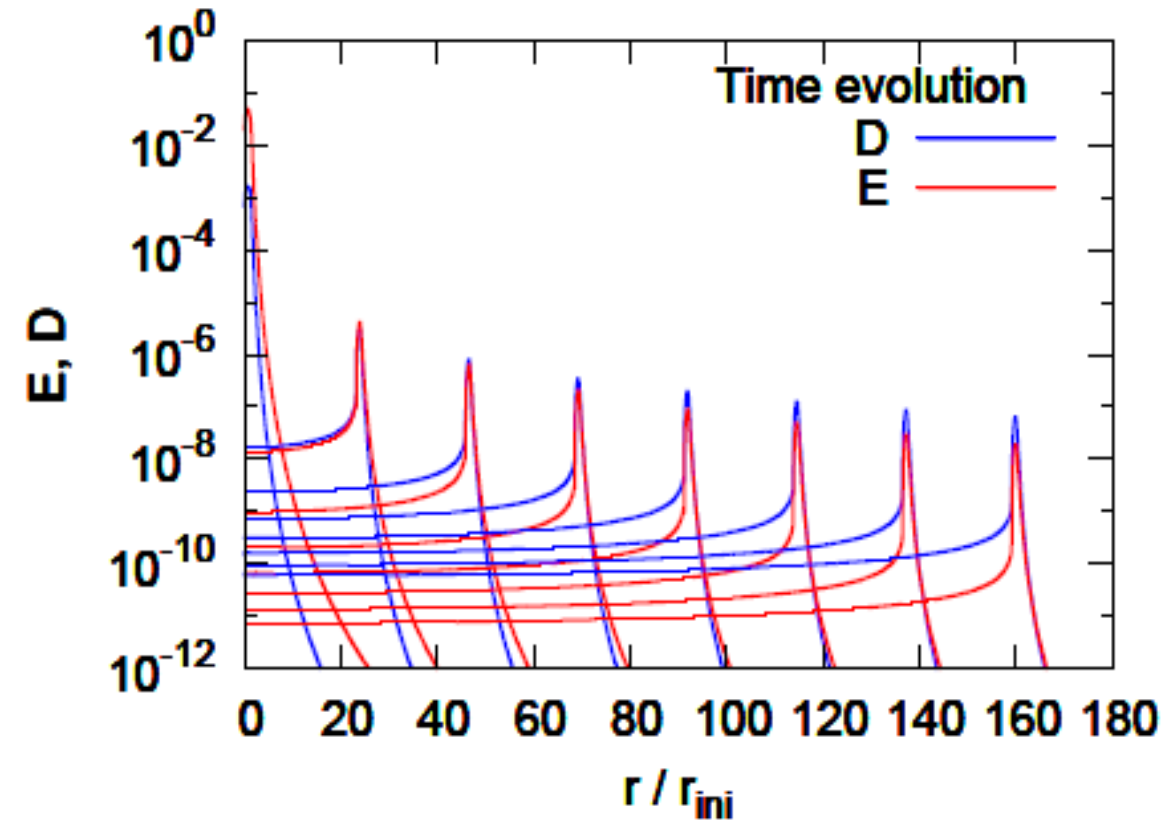
To test the code we reproduced the results of
Piran, Shemi, Narayan 1993

Non relativistic case



Test-1: Scaling laws

Relativistic case (frozen profile)



Energy dominated

$$\gamma \propto r,$$

$$n \propto r^{-3}$$

$$e \propto r^{-4}$$

Matter dominated

$$\gamma \rightarrow \text{constant}$$

$$n \propto r^{-2}$$

$$e \propto r^{-8/3}$$

$$\frac{1}{D} \equiv \frac{\gamma_0}{\gamma} + \frac{3\gamma_0}{4\eta_0\gamma} - \frac{3}{4\eta_0}$$

$$r = r_0 \frac{\gamma_0^{1/2} D^{3/2}}{\gamma^{1/2}}$$

$$n = \frac{n_0}{D^3}$$

$$\eta = \frac{\eta_0}{D}$$

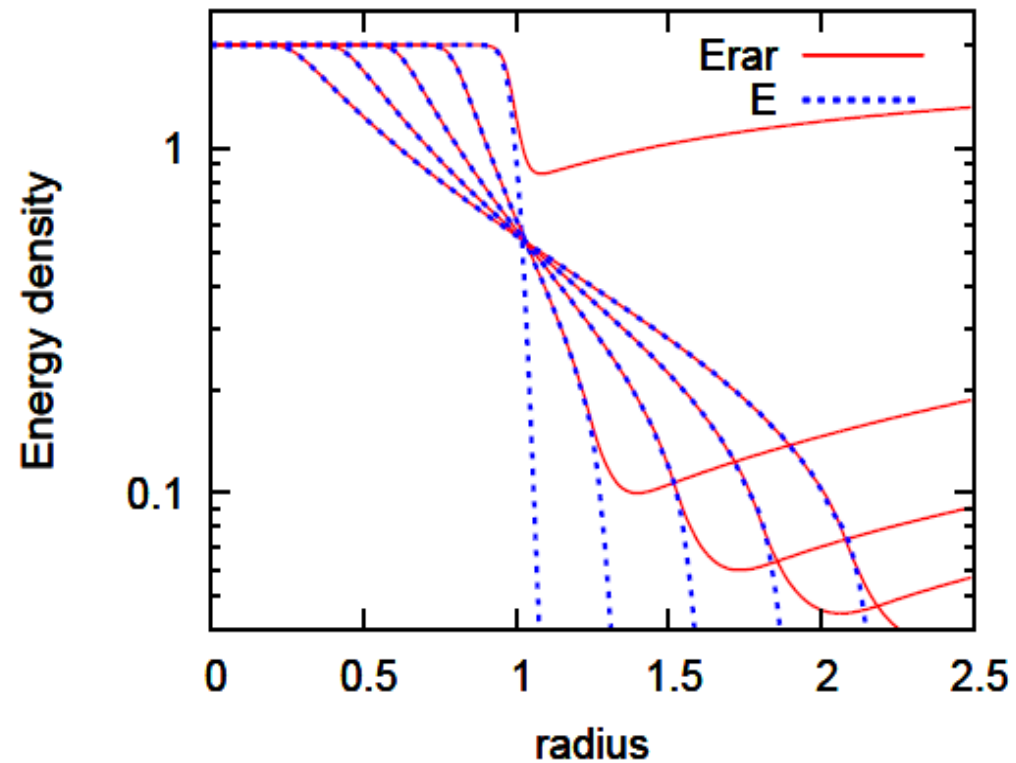
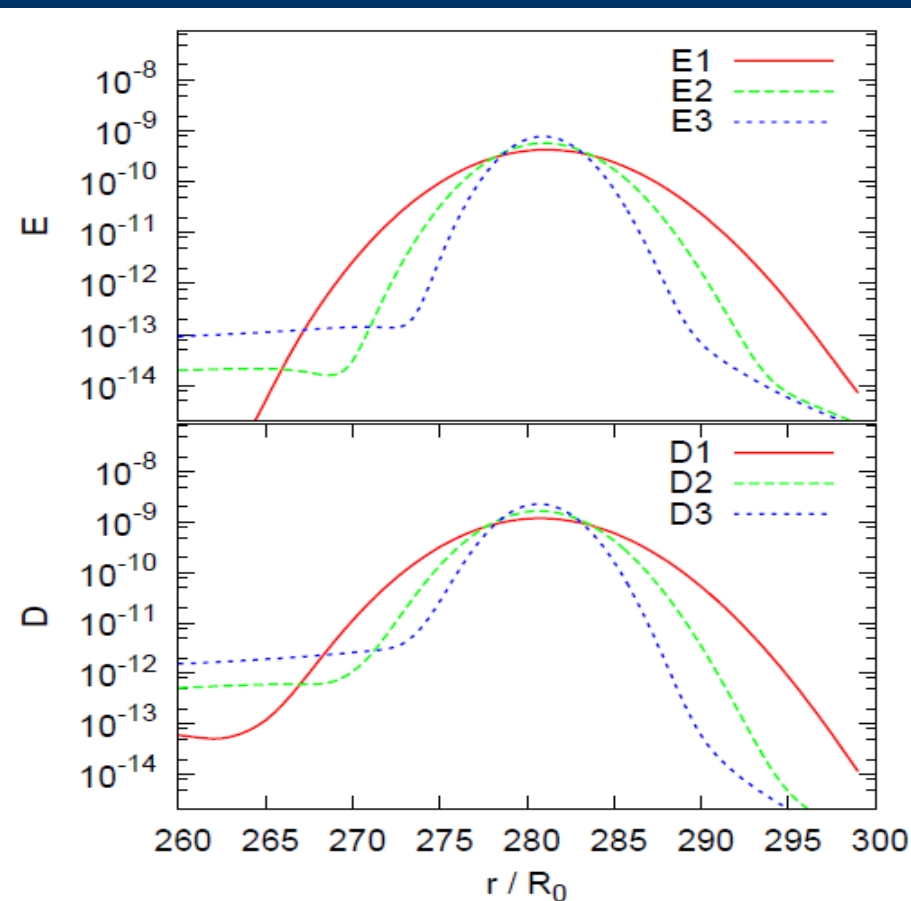
$$e = \frac{e_0}{D^4}$$

Test-2,3,4

2- Our advection test shows a result twice better than the one used in Bowers & Wilson 1991.

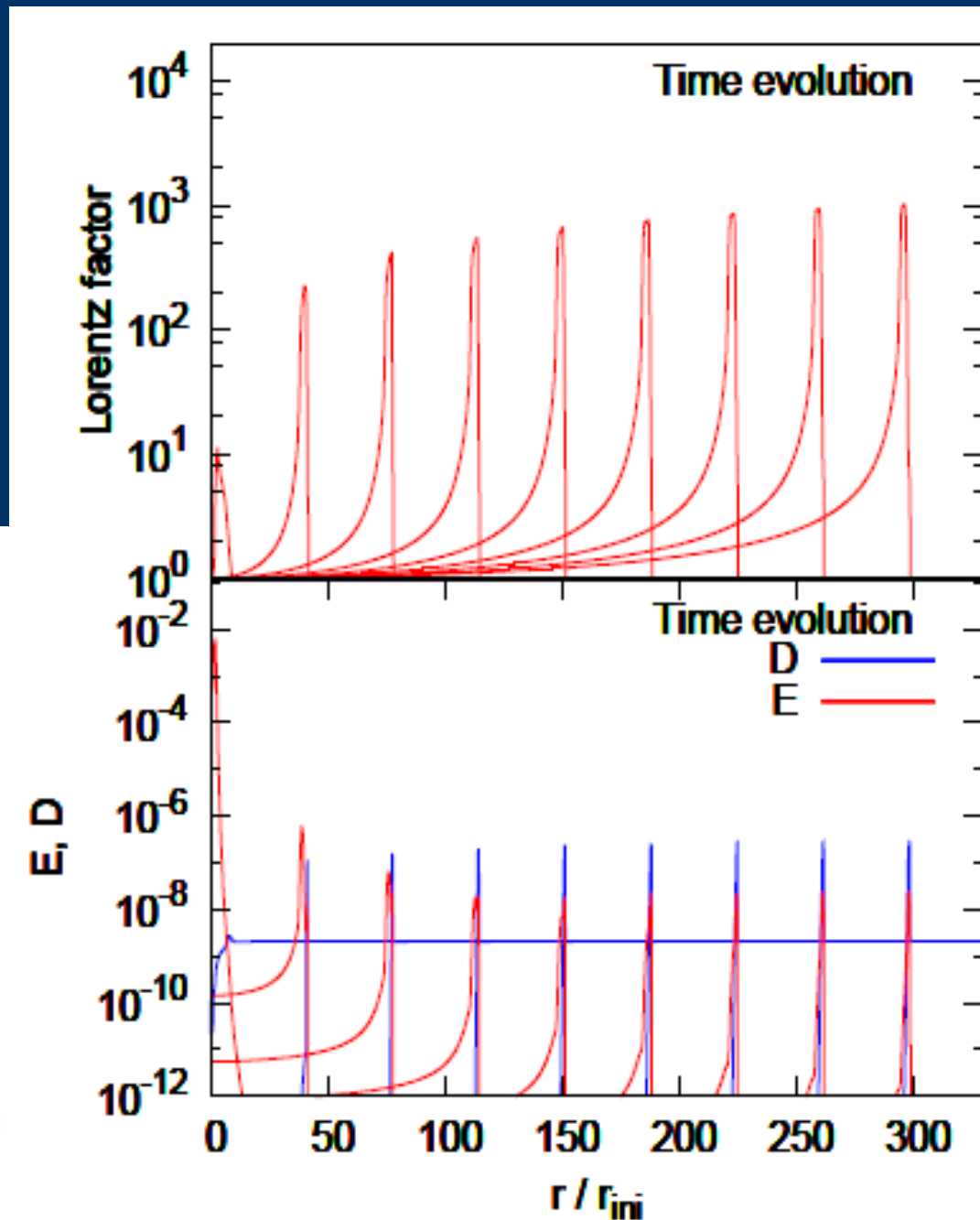
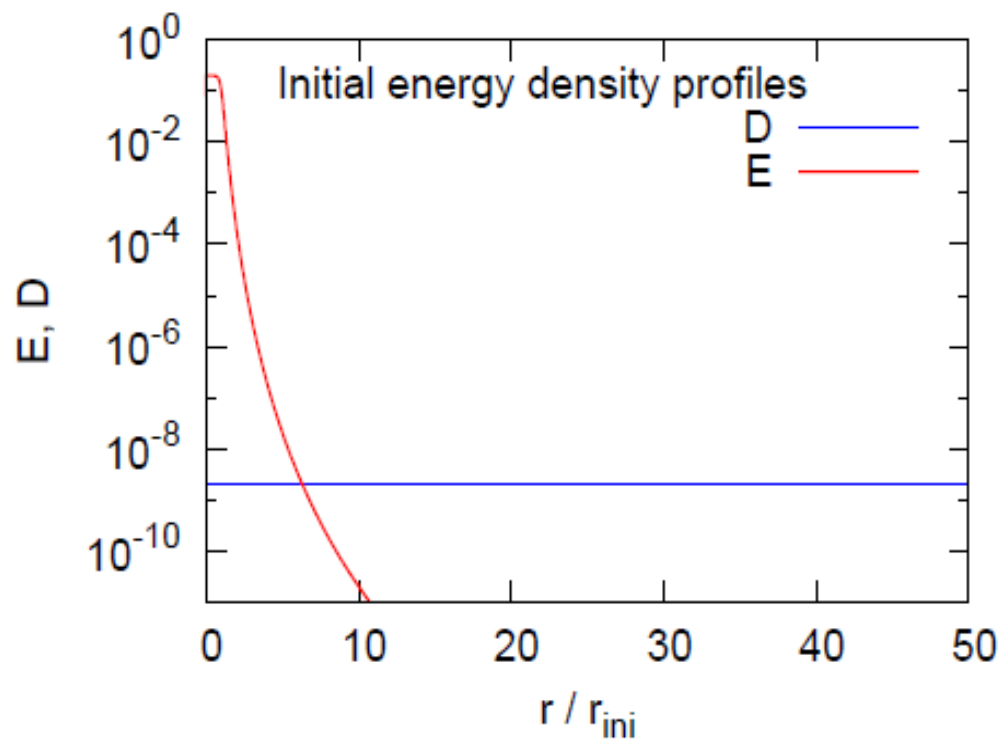
3- Radius step

4 - Rarefaction test
(Thompson 1986)

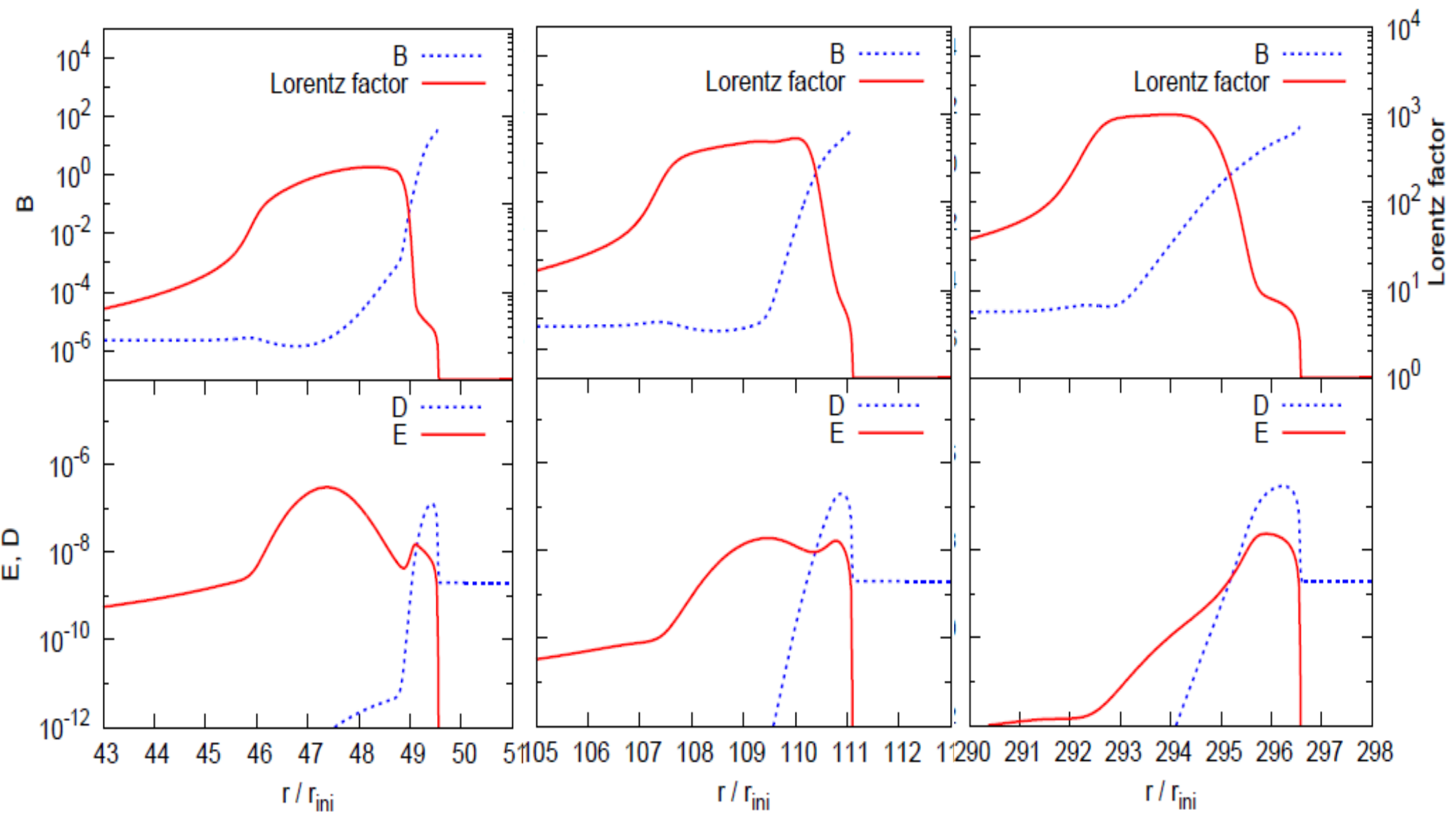


Results

Constant baryonic distribution

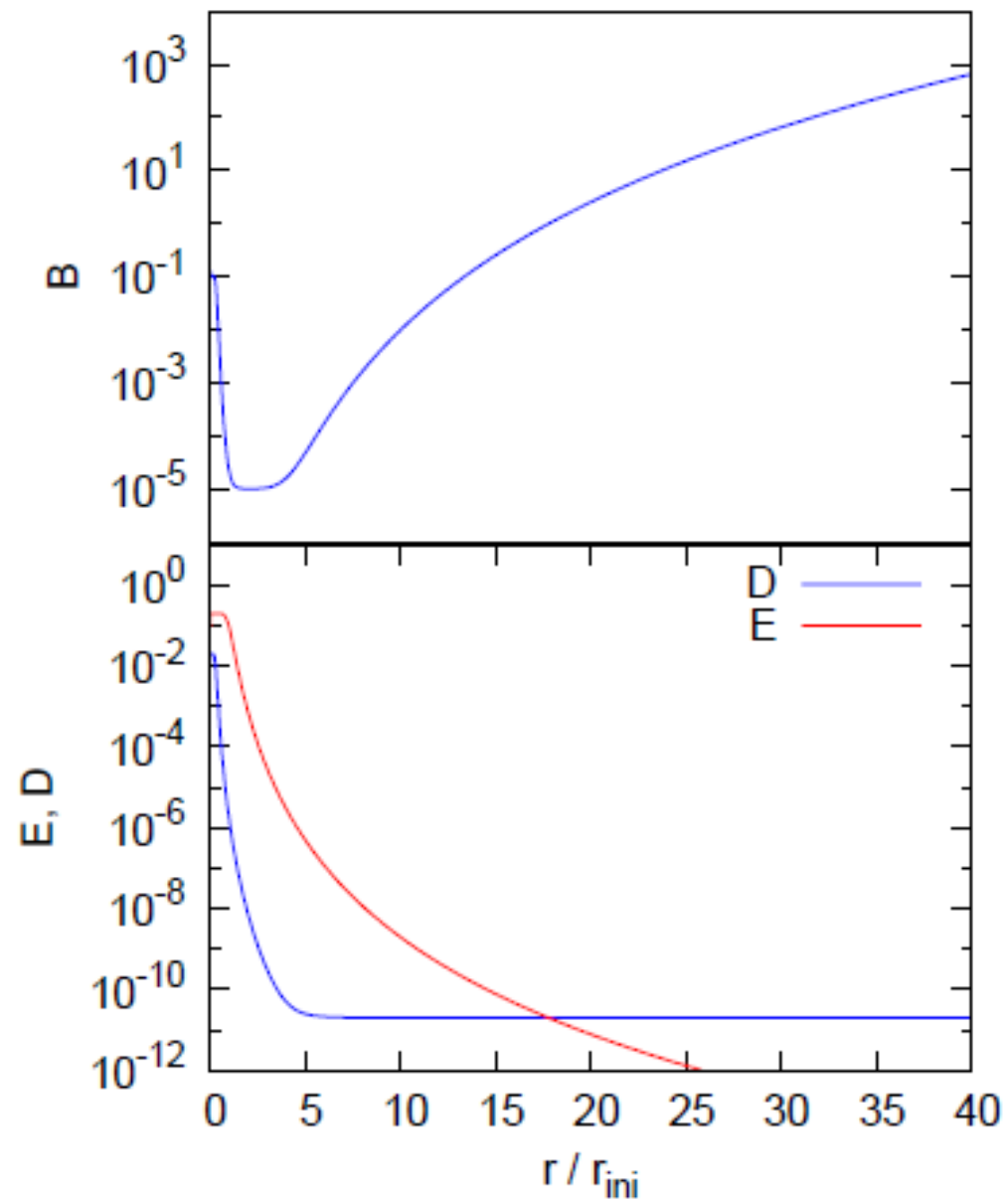
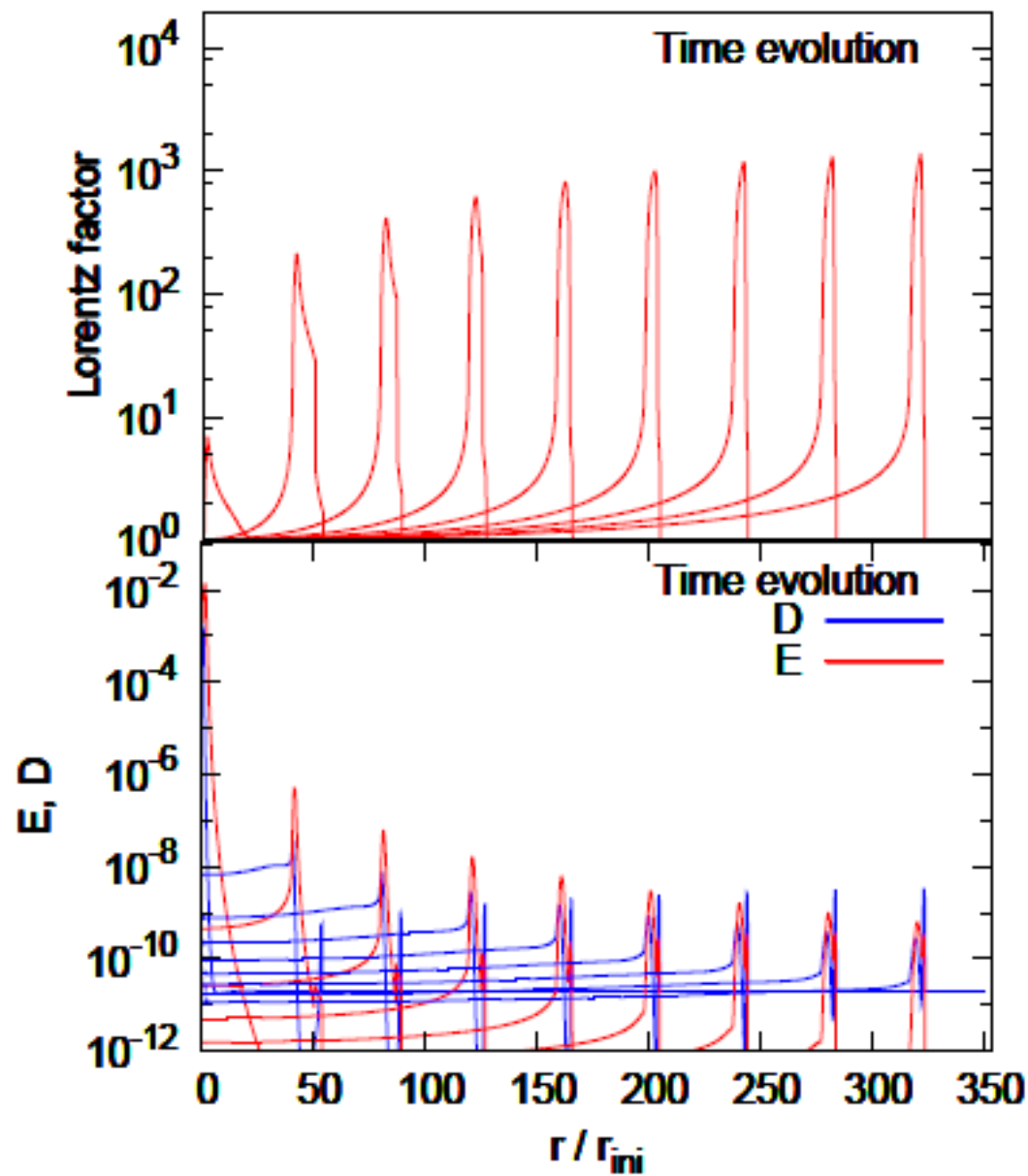


$$B=D/E$$



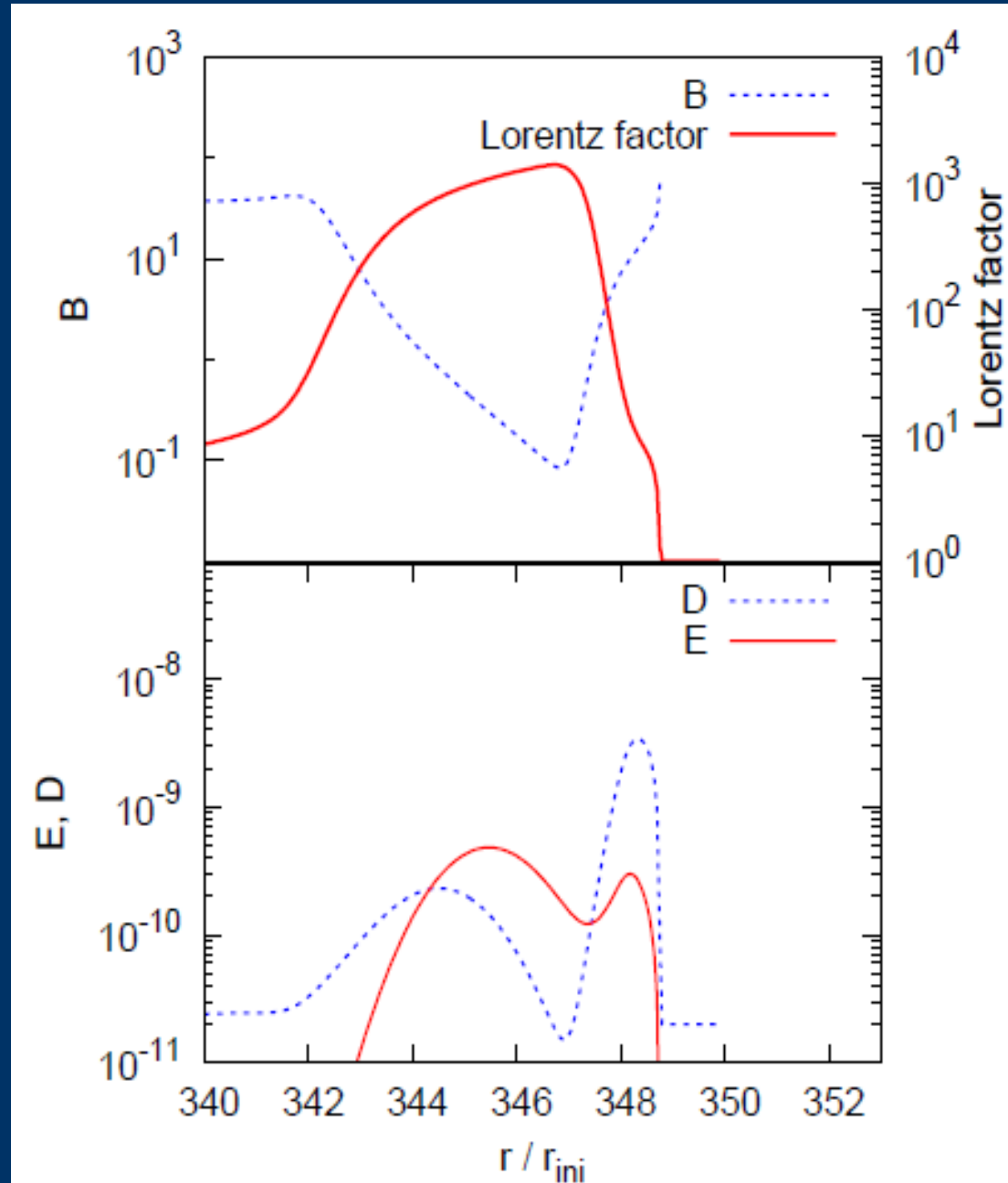
- there are two shells formed with different densities and Lorentz factors
- the inner shell has decreasing density, transferring energy to the baryons which are located in the external shell.
- the slope of the B parameter is changing, becoming less steep, because of the above reasons.

Hybrid profile



Double structured peak

- Here we have the formation of two shells, for both components: E and D. The outer shell comes from the interaction with external material; the inner shell comes from the source (peak D in the center)
- this is verified until more than 300 times the initial radius.
- the “frozen profile” is not the unique solution for all initial spatial distributions



Conclusions

- initial spatial distribution can influence the structure and evolution of the plasma. The “frozen profile” is not the unique solution for all initial distributions.
- when we have expansion in a medium with cold matter, it forms from the beginning a leading matter dominated shell.

Conclusions

- The structure at transparency is important for the balance of energy and matter distribution at transparency. The energy budget will be influenced.
- Since the Lorentz factor has a distribution with a peak in the middle of the shell, after transparency interaction is expected by variety of processes in collisionless regime.
- The double peak profile is our toy model to study the structure of the plasma at transparency.