

On P-GRBs

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Outline

In the next hour we will present some new results regarding the proper gamma ray burst (P-GRB). It occurs when photons coming from expanding photosphere, emitted when the average optical depth decreases to unity, reach the observer.

In what follows we will discuss:

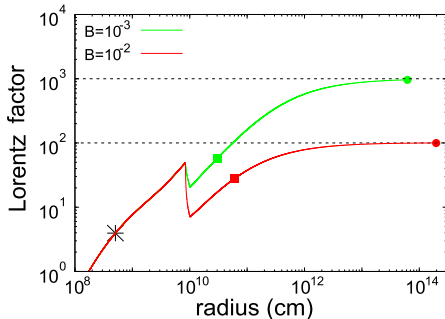
- the origin of P-GRB in the fireshell model;
- departure from thermal equilibrium during expansion in the optically thick phase;
- the form of the light curve of the P-GRB depends on initial conditions in the source of GRB (see De Barros's talk);
- deviations from the thermal spectrum of emission from the photosphere (see Akenov's talk);
- the duration of P-GRB (see Siutsou's talk).

The optically thick phase in the fireshell model

It is assumed that e^+e^- plasma is formed in the source of GRB with a fraction of baryons parametrized by

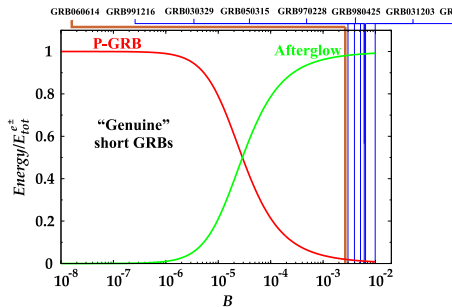
$$B = \frac{M_B c^2}{E_{\pm, \gamma}} \leq 10^{-2}.$$

It expands with acceleration in energy-dominated phase, and coasts in the matter-dominated phase. In the reference frame of observer most energy and matter is concentrated in the thin shell with the thickness R_0 .



The P-GRB

The optical depth of expanding plasma decreases with radius and eventually it becomes transparent to photons, which are emitted as a flash of quasi-thermal radiation with temperature in the keV range. P-GRB carries few percent of the total energy, but it lasts much shorter than the afterglow, and its luminosity can be similar or even larger than the peak of the afterglow.



Hierarchy of timescales

The validity of scenario described above, obtained in hydrodynamic approximation, is guaranteed by the following hierarchy of timescales in the problem. In chronological order:

- energy is injected on the timescale t_{in} ,
- kinetic equilibrium is reached on the timescale $t_{kin} = 1/(\sigma_T c n_{\pm})$,
- thermal equilibrium is reached on the timescale $t_{ther} = 1/(\alpha \sigma_T c n_{\pm})$,
- expansion starts at $t_{ex} = R_0/c$,
- plasma departs from thermal equilibrium at t_{ther}^* ,
- it departs from kinetic equilibrium at t_{kin}^* ,
- transparency is reached at t_{tr} ,
- plasma becomes collisionless at t_{cl} .

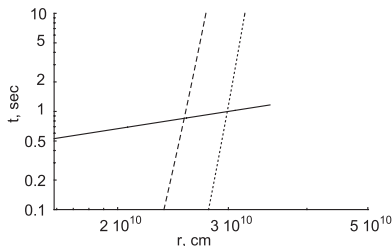
Departure from equilibrium during expansion

When expansion starts plasma is in complete thermal equilibrium, provided that $t_{ther} \ll t_{ex}$. However, when expansion rate exceeds the rate of three-body interactions such as $e^+e^- \leftrightarrow e^+e^-\gamma$ these reactions freeze out. Thermal equilibrium is no longer maintained.

Distribution functions will keep the form

$$f(\epsilon) \propto \exp\left(-\frac{\epsilon - \mu}{kT}\right),$$

since two-body interactions maintain kinetic equilibrium.

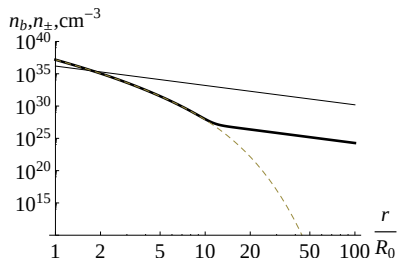


Rate equation

When expansion rate exceeds the rate of two-body interactions such as $e^+e^- \leftrightarrow 2\gamma$ these reactions freeze out as well.

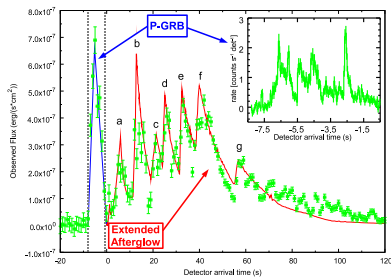
Then the number density of pairs can be determined by the following rate equation

$$(n_{\pm} U^{\nu})_{;\nu} = \langle \sigma v \rangle [n_{\pm}^2(T) - n_{\pm}^2] .$$



Light curve of P-GRB

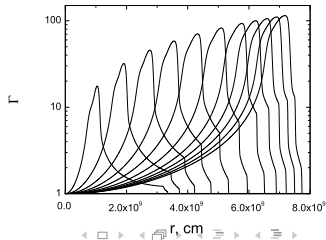
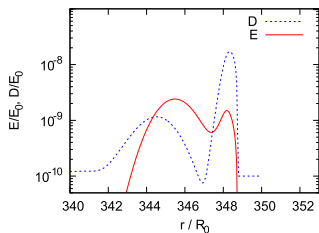
Based on the diagram for the fraction of energy emitted at transparency and duration of P-GRB it is possible to predict its average luminosity. However, the detailed structure of P-GRB light curve should be explained as well. We propose the idea that P-GRB light curve reflects the initial spatial distribution of plasma in the source of GRBs.



Lorentz factor distribution

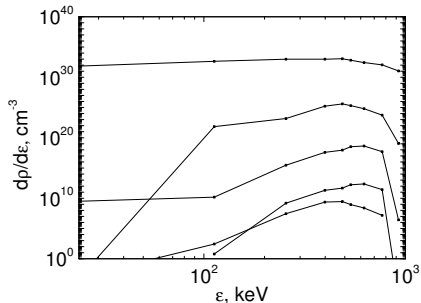
Indeed we find a nontrivial density distribution which can produce several spikes in the light curve.

As by-product of this idea we find also complex spatial distribution of the Lorentz factor, unlike the case of expansion into vacuum. This is a natural mechanism to generate internal shocks without action of inner engine.



Spectra at transparency

We computed for the first time the approach to transparency using kinetic one-dimensional code. We considered a test problem with the e^+e^- plasma having initial size 10^3 cm and temperature 1 MeV. The evolution of spectra shows hard to soft behavior.



Spreading of the expanding shell

From the point of view of hydrodynamics expanding shell has a constant thickness. It follows from the conservation laws such as $(n_B U^\nu)_{;\nu} = 0$. However, since at each radius particles have Maxwellian distribution of velocities, the shell will spread with time. The spreading is proportional to the velocity dispersion. An upper limit is $1 - \frac{\Delta v}{c} = \Gamma^{-2}$. However, the velocity dispersion is also a function of temperature, and the correct estimation gives

$$\Delta t_{obs} \simeq \frac{\Delta R_{tr} + R_0}{c} \simeq \left(2\sqrt{3} B^2 \sqrt{\frac{kT_0}{m_e c^2}} \sqrt{\frac{R_{tr}}{R_0}} + 1 \right) \frac{R_0}{c}.$$

Taking the typical values $\frac{kT_0}{m_e c^2} = 10$, $r_{tr} = 5 \times 10^6 r_0$, $B = 10^{-2}$ we have

$$\Delta t_{obs} \simeq 3.5 \frac{R_0}{c},$$

which is not sufficient to explain the observed P-GRB duration of the order of few seconds.

Conclusions

Kinetic effects play important role in our understanding of P-GRBs. Estimations based on hydrodynamic approximation such as those done by Goodman (1986), Paczynski (1986), Meszaros et al. (1993), Piran et al. (1993), Ruffini et al. (1999,2000) should be considered a first approximation. New observations reveal structured light curve of P-GRB as well as spectral evolution which should be explained by models of GRBs. The progress in understanding this phenomenon leads to the following conclusions:

- the structured light curves of P-GRB can be explained by the matter distribution in and near the source of GRBs;
- the spectrum in the comoving frame at transparency should deviate from the thermal one;
- the duration of P-GRB is not given by the light crossing time, computed with the initial size of plasma. There is a spreading of expanding shell due to velocity dispersion in the expanding plasma.