Gravitational collapse as the source of gamma-ray bursts

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Abstract: If the threshold for e^-e^+ pair production depends on an angle between photon momenta, and if the г-rays are collimated right *in* gamma-ray burst (GRB) source then another solution of the compactness problem is possible. The list of basic assumptions of the scenario describing the GRB with energy release $< 10^{49}$ ergs is adduced: the matter is about an alternative to the ultrarelativistic fireball if *all* long-duration GRBs are physically connected with core-collapse supernovae (SNe). The questions about radiation pressure and how the jet arises on account of even a small radiation field asymmetry in a compact GRB source of size $< 10^8$ cm, and observational consequences of the compact model of GRBs are considered.

1. Introduction: the root of the problem

Gamma-ray bursts (GRBs) are the brief (~0.01-100s), intense flashes of г-rays (mostly sub-MeV) with enormous electromagnetic energy release up to $\sim 10^{51}$ - 10^{53} ergs. The rapid temporal variability, дT </~10 msec, observed in GRBs implies *compact* sources with a size smaller than сдT </~3000 km.

But a problem immediately arises for distant GRB sources (e.g. [1, 2]): too large energy ($>10^{51}$ ergs) is released in the observed (for the most GRBs) soft г-rays (< 511 keV and up to 1 MeV) in such a small volume for the sources at cosmological distances (> 1 Gpc). For a photon number density $n_г \sim (10^{51}$ ergs/ $(m_e c^2))/(c\,дT)^3 \sim 10^{57}/(3000\ \mathrm{km})^3 \sim 10^{32}\mathrm{cm}^{-3}$ two г-ray photons with a *sum energy* larger than $2m_ec^2$ could interact with each other and produce electron positron pairs. The optical depth for pair creation is given approximately by $ф_{e\text{-}e+} \sim n_г r_e^2 (c\,дT) \sim 10^{16}$, where r_e is the classical electron radius $e^2/(m_ec^2)$ (the cross-section for pair production is $\sim r_e^2$ or $\sim 10^{-25}\mathrm{cm}^2$ at these semirelativistic energies). It is the essence of a so-called "compactness problem": the optical depth of the relatively low energy photons (~ 511 keV) must be so large that these photons could not be observed.

In the popular ultrarelativistic fireball GRB model [3, 4] in this definition a role of the high-energy photons is emphasized: the г-ray photons with energies much larger than $m_e c_2$ (or >> 1 MeV) could interact with lower energy (< 511 keV) "target" photons and produce e^-e^+ pairs (e.g. [4]). In the ultrarelativistic fireball model it is supposed that the "heavy"/hard (or high-energy) photons *must be present* in all GRB spectra as high energy tails which contain a significant amount of energy. So (see e.g. [5]), the optical depth *of the high-energy photons* (>> 1 MeV) would be so large that these photons could not be observed. In this theory the size of the region where the GRB prompt emission arises must be $\sim 10^{15}$ - 10^{17} cm [6], if it is supposed that radiation (with 100 MeV and 10 GeV photons) is generated by ultrarelativistic jets moving with huge Lorentz factors ~ 100-1000.

Below we will try to understand the *observational soft* (in the meaning of photon energies) GRB spectrum in a compact GRB model implies the GRB source with the size of с дT < /~ 10^8 cm, i.e. without involving huge kinematical motions of the radiating plasma, or without so enormous Lorentz factors. It concerns with another attempt of solving the compactness problem, namely, the dependence of the threshold for e^-e^+ pair production on the angle between photon momenta, a photon collimation *in* the source and the dependence of this collimation on GRB photon energy. Taking into consideration the compactness of the source and the fact that all long-duration GRBs are physically connected with core-collapse supernovae (SNe), it may be supposed that when observing these GRBs we directly observe the gravitational collapse of a massive and compact star nucleus.

2. Typical GRB spectra and typical photon energies

The GRB spectra are described in a review by Fishman and Meegan [7], see also the catalogue of the spectra by Preece et al. [8]. Typical observational GRB spectra turned out to be very diverse, but yet these are mainly soft (but not hard) г-ray quanta. It has been known since the moment of GRBs discovery, when their spectra were presented in energy units: e.g., see a review by Mazets and Golenetsky [9], and many authors [10-14] point to the same again. Almost all GRBs have been detected in the energy range between 20 keV and 1 MeV. *A few* г-ray quanta have been observed in GRBs above 100 MeV. In a review by Piran [3] also has paid attention to a puzzle of the origin of narrow distribution for the typical energy of the observed GRB radiation ($E_p < 511$ keV, [8]). More, by 2000 it was clear that there were other two GRB classes: X-Ray Flashes (XRF) and X-Ray Rich Gamma Ray Bursts (XRR GRB) [15, 16]. These are GRBs either *without* (XRFs) or almost without (XRR GRB) г-ray quanta.

Thus, for usual (mostly sub-MeV) GRBs, still there are too many lower energy г-ray photons in a small volume R^3 with R ~ с дT </~3000 km. The observed fluxes give an estimate of a total GRB energy release to be of ~ 10^{51} ergs in the form of just these *low-energy* photons, or this “standard” estimation (~ 10^{51} ergs) was obtained from typical observational GRB spectra of just these, most frequently observed low-energy photons with the *semirelativistic* energies, up to 1 MeV, basically. (It is natural that the photon density was estimated using the simple assumption of spherical symmetry – see below.)

Nevertheless, if these theoretical (rather than observational) statements [17] on the possibility that *as though* (1) all GRB spectra have high energy tails and (2) the observed GRB spectra are non-thermal, are true indeed, the fireball theory [4, 18] with huge Lorentz factors is the only possible theoretical alternative for GRBs. It should be admitted though that the standard optically thin synchrotron shock emission model explains everything, except the observational spectra of GRBs themselves [19]. But for all that, it was left out of account that these (“target”) photons with $E_p < 511$ keV are just the observed typical GRBs. So, it turns out that the main task, according to the standard fireball model, is not the explanation of this observed soft GRB spectrum in terms of photons' energy/frequency, but the investigation of rare cases of release of hard quanta with energy of more than or ~ 1 GeV.

As a result, the origin of the *observed* and substantially soft GRB spectra with a big number of photons </~1 MeV remains not properly understood. It is especially incomprehensible against the background of conjurations about the huge gamma factor that is supposed to solve the compactness problem. But the question remains: why are mainly soft GRB spectra observed at ultrarelativistic motions of radiating plasma supposed in the fireball model? And what is more, as was noted above, sometimes the GRB spectra do not contain г-ray quanta at all, as, for example, XRFs known already before 2000 [20]. Thus, when solving the compactness problem, we somehow imperceptibly incurred another problem of strong contradiction between the ultrarelativistic Lorentz factor Г ~ 100-1000 (in the fireball model with 100 MeV and 10 GeV photons) and observed soft (</~ 1 MeV) г-ray (GRB, XRR GRB) and X-ray (XRF) radiation of the most classical GRBs. Moreover, it is also important to point out here that the observed *black-body* prompt GRB radiation with a temperature kT ~ 100 keV [21, 22] is inconsistent with the Lorentz factor ≈ 10^2 - 10^4 for the reason that the mean observed temperature can easily exceed kT=MeV in cosmological fireballs [23].

3. The threshold for e^-e^+ pair production

The compactness problem was mentioned (before 1992, i.e. before the BATSE/EGRET mission) in connection with the famous burst of 1979 March 5 in the Large Magellanic Cloud. Already then a possibility of a *photon collimation right in the source* for explanation of observed soft spectra was not excluded [1] because the cross-section of electron-positron pair production y_{e-e+} (and annihilation also) depends not only on energy, but on the angle between momenta of colliding particles. For the first time in the paper by Aharonian and Ozernoy [1], and than later by Carrigan and Katz [2], a lot of interesting was said in connection with collimation of г-rays leaving GRB source with high photon density in it.

It seems that just the collimation in GRB source solves the notorious compactness problem indeed. The paper by Carrigan and Katz [2] tells about modeling the observed GRB spectra allowing for the electron-positron pair production effects. These effects could produce effective collimation of the flux because of kinematics of the two-photon pair production: the opacity (ф$_{e-e+}$) is also a sensitive function of the *angular* and *spectral* distribution of the radiation field *in the source*.

The argument proceeds as follows: *two* photons with energies E_1 and E_2, which are above the threshold energy $E_1 + E_2 > 2 \cdot E_{th}, E_{th} = \sqrt{E_1 E_2}$ for electron-positron pair production

$$E_{th}^2 = E_1 \cdot E_2 \geq 2(m_e c^2)^2 / (1 - \cos\theta_{12}) \qquad (1)$$

may produce a pair, where $2(m_e c^2)^2 = 2(511 \text{ keV})^2$ and и$_{12}$ is the angle between the directions of the two г-rays. The cross section for pair production reaches the maximum at a finite center-of-momentum photon energy: e.g. $E_1 + E_2 > 2 \cdot E_{th} = 2 \cdot 511$ keV for $и_{12} = 180°$, or $E_1 + E_2 > 2 \cdot E_{th} \approx 2 \cdot 700$ keV for $и_{12} \approx 90°$), or $E_1 + E_2 > 2 \cdot E_{th}$ going to infinity (>> 1 MeV) for $и_{12} \approx 0°$.

If the source photon spectrum is not sharply peaked, the relatively high-energy photons ($E > E_{th}$) will, therefore, form pairs predominantly with relatively low-energy photons ($E < E_{th}$). It means that the observed (or the emergent) GRB spectra will be soft, since the high-energy photons will be held by the threshold of pair production. Thus, because any *reasonable* source spectrum will contain much more low- or moderate-energy photons (</~511 keV) than high-energy photons, the emergent spectrum will differ most markedly from the source spectrum at high photon energies (>/~1 MeV) at which it (the emergent spectrum) will be heavily depleted. In other words, the observed (emergent) spectrum becomes softer. Then, the e^-e^+ pairs eventually annihilate to produce two (infrequently 3) photons, but usually not one high- and one low-energy photon.

The result is that high-energy photons are preferentially removed from the observed spectrum. The observation of a measurable amount of quanta with $E_1 > E_{th} = \sqrt{E_1 E_2}$ is not expected unless the optical depth $ф_{e\text{-}e+}$ to pair production is equal to 1 or less, because the threshold for electron-positron pair production (1) is also a sensitive function of the angular distribution of the radiation field in the very source (see below). Thus, the observation of a considerable number of quanta with E > 1 MeV due to the filter effect (1) is not expected, if only the optical depth for the e^-e^+ pair production is not proved </~1 indeed for various reasons, for example, because of anisotropy of the radiation field in the GRB source itself.

As is seen from the paper by Carrigan and Katz [2], in 1992 it was generally accepted that typical energies of most photons in observed GRB spectra are still rather small. Further in the peper, Carrigan and Katz adduce the estimates of distances to burst sources of such photons with the *semirelativistic* energies. The matter is that the problem of a compact source (in relation to the 1979 March 5 event in LMC) and a surprisingly big distance arises indeed, but not because of a problem with the release of “heavy” (100 MeV, 1 GeV, or more) ultrarelativistic photons which interfere with “light” (</~1 MeV) target photons. The powerful 1979 March 5 event in LMC was observed without any super heavy photons in its spectrum. To make sure of it one should just look at the spectra of this burst published by Mazets and Golenetskii in their review [9].

To explain why the effect of the photon “e^-e^+ confinement” does not function in this GRB source (1979 March 5 event in LMC), different possibilities were discussed [1, 2].. In particular, the authors immediately point out to the angle dependence (1) of the threshold of the e^-e^+ production. A possible “loophole” exists if the source produces a *strongly collimated* beam of photons. Thus, the question is about an asymmetry of the radiation field in the source. In this case, even high-energy photons are below the threshold for the pair production if $и_{12}$ is small enough. The presence of such a “window” in the opacity for *collimated* photons suggests that in a region opaque to pair production much of the radiation may emerge through this window, in analogy to the great contribution of windows in the material opacity to radiation flow in the usual (Rosseland mean) approximation.

The use of the words “strongly collimated” in the (“old”) paper [2] could be somewhat confusing. What means *strongly* indeed? At that time there were no observations of GRB spectra in the region of high energy E. Heavier photons with E ~ 10 MeV (beyond the peak of ~ 1 MeV) have been reliably observed only with EGRET/BATSE. In particular, from formula (1) for such photons an estimation of the collimation angle can be obtained (without any “target-photons”): $1 - \cos и_{12} = 0.522245\ \mathrm{MeV}^2/(10\mathrm{MeV} \cdot 10\mathrm{MeV}) \approx 0.005$. It corresponds to $и_{12}$ less than 6° only. It means that the quanta with energy ~ 10 MeV leaving the source within a cone of ~ 6° opening angle do not give rise to pairs, and all *softer* radiation can be uncollimated at all. So the collision of 10 MeV quanta with quanta of lower energy occurs at angles greater than 60° ($0.522245\ \mathrm{MeV}^2/(10\ \mathrm{MeV} \cdot 100\ \mathrm{KeV}) \approx 0.5$), and softer quanta leaving the source within the cone of such opening angle do not prevent neither heavy nor (especially) light quanta to go freely to infinity.

Thus, formula (1) demands more or less strong collimation only for *a small part* of the heaviest quanta radiated by the source. If one looks at energetic spectra of typical GRBs (the same reference to Mazets and Golenetskii [9]) presented in F($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{KeV}^{-1}$) vs. E(KeV) – *the number* of photons per a time unit in an energy range unit per an area unit versus the photons energy, – then everything becomes clear. Only a small part or a small *amount* of quanta/photons observed beyond a threshold of ≈ 700 KeV can be collimated, but within a cone of < 90° opening angle.

At present, 6 degrees for 10 MeV quanta would not be considered as a strongly collimated beam. Now such opening angles (of jets) are considered to be quite suitable in the “standard” or the most popular theory of fireballs. If one proceeds right away from an idea that it is necessary to release quanta with the energy up to 10 MeV, then we would obtain at once a version of a collimated theory with the Γ of ~ 10. But such a way in the standard fireball theory is a dead end also. The allowing for an initial collimation of GRB radiation can drastically change this model (see below) for the collimation arising *directly in the source* but not because of a huge Γ of ~ 1000 what would be needed to solve the compactness problem if a ultra-relativistic jet is a GRB source indeed.

One way or another, the light flux is to lead to corresponding effects of radiation pressure upon the matter surrounding the source. And if in addition the radiation is collimated, then the arising of jets (at so enormous light flux) becomes an inevitable consequence of even a small asymmetry of the radiation field *in the source*.

But the question is if:

4. Is the jet a GRB source or not?

Indeed, perhaps one should take into account right away this angular dependence of the threshold of the pair e^-e^+ production (1) before the ultra relativistic limit, allowing for a possibility of a preferential (most probably by a magnetic field) direction in the burst source on the surface of a compact object – the GRB source. Can we do without the radiating and accelerated jet (in the model of fireball) up to a huge value of the Lorentz factor, but supposing that the source of GRB radiation is *already* collimated by the burst source itself (in a compact GRB model)?

The rather strong collimation of GRB г-rays, reaching near-earth detectors, can be observably justified if, due to further accumulation of observational data about coincidence of GRBs and supernovae (SNe), it will turn out indeed that the GRBs could be the beginning of explosions of *usual* massive or core-collapse SNe [24]. At least, all results of photometrical and spectral observations of GRB host galaxies confirm the relation between GRB and evolution of a *massive star*, i.e., the close connection between GRB and relativistic collapse with SN explosion in the end of the star evolution [25, 26, 27]. The main conclusion resulting from the investigation of these galaxies is that the GRB hosts do not differ in anything from other galaxies with close value of redshifts z: neither in colors, nor in spectra, the massive star-forming rates [27], and the metallicities [28]. It means that these are generally starforming galaxies ("ordinary" for their redshifts) constituting the base of all deep surveys. In point of fact, this is the first result of *the GRB optical identification* with already known objects: GRBs are identified with ordinary (or the most numerous in the universe at any z) galaxies up to ≈ 26 stellar magnitudes. So, with allowing for the results of direct optical identifications this makes it possible to estimate directly from observations an average yearly rate of GRB events in every such galaxy by accounts of these galaxies for the number of galaxies brighter than 26th st. magn. It turns out to be equal to $N_{GRB} \sim 10^{-8}$ yr^{-1} galaxy^{-1}. (But most probably this is only an upper estimate [24].)

Allowing for the yearly rate of (massive) SN explosions $N_{SN} \sim 10^{-3}$ - 10^{-2} yr^{-1} galaxy^{-1}, the ratio of the number of GRBs, related with the collapse of massive stars (core-collapse SNe), to the number of such SNe is close to $N_{GRB}/N_{SN} \sim 10^{-5}$ - 10^{-6}. (This is also can be only the upper estimate for Ib/c type SNe [24].) Certainly, only the further increasing of the number of coincidences of GRBs and SNe (*identifications of GRBs with Type Ib/c SNe*) should finally tell us whether we have a core-collapse SN (spanning a large range of luminosities) *in each* GRB or whether the collapse of a massive star evolves following different paths according to the value of parameters as mass, angular momentum, and metallicity [29]. But here we proceed from the simplest assumption, which has been confirmed from 1998 by increasing number of observational facts, that *all* long-duration GRBs are related to explosions of massive SNe. Then the ratio N_{GRB}/N_{SN} should be interpreted as a very strict ``г-ray beaming" for a part of quanta *reaching an observer*, when gamma-ray radiation (a part of it) of the GRB source propagates to very long distances within a very small solid angle

$$\Omega_{beam} = N_{GRB} / N_{SN} \sim (10^{-5} - 10^{-6}) \cdot 4\pi \qquad (2)$$

Another possible interpretation of the so small value of N_{GRB}/N_{SN} – a relation to a rare class of some peculiar SNe – seems to be less possible (or hardly probable), since then GRBs would be related only to the 10^{-5}-10^{-6}th part of all observed SNe in distant galaxies (up to 28th mag). These are already not simple peculiar SNe, with which the Paczycnski's hypernova is sometimes identified [30]. The peculiar supernovae (hypernovae), such as 1997ef, 1998bw, 2002ap, turn out to be too numerous [31]. On the other hand, the more numerous are GRB/SN coincidences [29] of type of GRB\,030329/SN 2003dh, GRB 060218/SN 2006aj, or GRB/"red shoulder" in light curves, the more confident will be the idea that GRB radiation is collimated, but not related to a special class of SNe. The more so, that explosion geometry features (SN explosion can be axially symmetrical) make the attempts to select a class of "hypernovae" more complex [33] (see the end of their text). Now there are already other papers [31], pointing out to a possibility of collimated radiation from the GRB source (2).

Let us suppose that only the most collimated part of gamma radiation get to an observer, say, along a rotation axis of the collapsing core of a star with magnetic field. And if GRBs are so highly collimated, radiating only into a small fraction of the sky, then the energy of each event E_{beam} must be much reduced, by several orders of magnitude in comparison at least with a (so called) “isotropic equivalent” E_{iso}, of a total GRB energy release ($E_{iso} \sim 10^{51}$ - 10^{52} ergs and up to 10^{53} ergs):

$$E_{beam} = E_{iso}\Omega_{beam} / 4\pi \sim 10^{45} - 10^{47} ergs \qquad (3)$$

If it is just this case which is realized, and if the energy (3) of r-rays propagating in the form of a narrow beam reaching an observer on Earth is only *a part* of the total radiated energy of the GRB source, then the other part (from ~ 10^{47} ergs to ~ 10^{49} ergs, see below) of its energy can be radiated in *isotropic* or almost isotropic way indeed. But at the spherical luminosity corresponding to a total GRB energy of, e.g., ~ 10^{45} - 10^{47} ergs, no BATSE gamma-ray monitor detector, even the most sensitive one, would detect flux, corresponding to so low luminosity for objects at cosmological distances of z >/~1, and if the observer is outside the cone of the collimated component of radiation (2). I.e. (3) can be close to the lower estimate of the total radiated energy of GRB sources, corresponding to the flux measured within the solid angle (2), in which the most collimated component of the source radiation is propagating. (We always suppose that *all* long-duration GRBs are related to SNe.) So, there is a possibility at least to considerably *reduce* at once the total (bolometric) energy of GRB explosions.

Apparently, this question (what radiates: a central compact source or an extent jet?) is crucial for any GRB mechanism. If the GRB source radiation (mainly a hard component of the GRB spectrum) is collimated indeed, then we will have to return to the old idea: the radiation (GRB) arises *on a surface* of a compact object of the order of tens of kilometers(?). Further we will try to do without an (a priori) assumption that it is only the jet’s “end” which radiates. The jet arises for sure, but because of the strong pressure of the collimated radiation on the matter surrounding a compact (down to 10^7 cm and less) GRB source. Certainly, this jet accelerated by photons up to relativistic velocities will radiate also, but it would be already an afterglow, but not GRB itself.

5. The radiation pressure and origin of the jet

If the scenario: *massive star → WR star → pre-SN = pre-GRB → the collapse of a massive star core* with formation of a shell around WR is true, then it could be supposed that the reason for arising of a relativistic jet is the powerful light pressure of the collimated or non-isotropic prompt radiation of the GRB source onto the matter of the WR star envelope located immediately around the source itself – a collapsing core of this star.

For example, the radiation field arising around the compact source can be non-isotropic – axially symmetric due to magnetic field and effects of angular dependence (1) of the threshold of the e^-e^+ pair production. And only a part (~ 10% or even 1%) of the total GRB energy (~ 10^{47} - 10^{49} erg) may be the collimated radiation within the solid angle (2), which breaks through the dense envelope surrounding the collapsing core of the WR star and reaches the Earth. The main things now are: 1) *the collimated flux* of radiation from the source and 2) existence of *dense* gas (windy) environment pressed up by radiation from the GRB compact source embedded in it. This environment can be the most dense just near the source, if the density is close to $n = Ar^{-2}$ (the WR law for stellar wind). Here the distance r is measured from the WR star itself, and A ~ 10^{34} cm^{-1} [33].

For the force of light pressure that can act on gas environment (plasma) around the GRB source (the WR star) we have $L_{GRB} \cdot (4pr^2)^{-1} \cdot (y_T/c)$, where L_{GRB} is a so called isotropic *luminosity* equivalent of the source (~ 10^{50-51} erg · s^{-1} and more), r is a distance from the center (or from the source), $\sigma_T = 0.66 \cdot 10^{-24} cm^2$ is the Thomson cross-section, c is the velocity of light. It is clear even without detailed calculation that near the WR core (r ~ 10^9cm) such a force can over and over exceed (by 12-13 orders) the light pressure force corresponding to *the Eddington limit* of luminosity (~ 10^{38} erg · s^{-1} for 1 $M_\odot$). The isotropic radiation with so huge luminosity $L_{GRB} \sim 10^{50-51}$ erg · s^{-1} (or the light pressure) can also lead to fast acceleration (similar to an explosion) of environment adjacent to the source. But if we assume that the radiation of the GRB source is non-isotropic and a part of it is collimated or we have very strong beaming with the solid angle $\Omega_{beam} \sim (10^{-5} - 10^{-6}) \cdot 4\pi$, then the forming of directed motion of relativistic/ultrarelativistic jets becomes inevitable, only because of so huge/enormous light pressure affecting the *dense* gas environment in the immediate vicinity of the source - collapsing stellar nucleus.

We can estimate the size of the region *within* which such a jet can be accelerated by the radiation pressure up to relativistic velocities:

1. If the photon flux producing the radiation pressure accelerating the matter at a distance r from the center (near the GRB site) is equal to $L_{GRB} \cdot (4p\ r^2)^{-1}$, then in the immediate vicinity from the GRB source (the collapsing nucleus of WR star) such a flux can be enormous. It is *inside* this region where the jet originates and undergoes acceleration up to ultra relativistic velocities.
2. To accelerate the matter up to velocity of at least ~ 0.3c, at the *outer* boundary of this region the photon flux must be at least not less than the Eddington flux $L_{Edd} \cdot (4\pi R_*^2)^{-1}$. Here L_{Edd} is the Eddington limit ~ 10^{38} erg·s^{-1} for 1 $M_\odot$ and R_* is the size of a compact object of ~ 10^6 cm. (By definition: $L_{Edd} \cdot (4\pi R_*^2)^{-1}$ is a flux *stopping* the accretion onto a compact source – the falling of matter on the source at a parabolic velocity. For a neutron star it is equal to ~ 0.3c.)

From the condition that the photon flux $L_{GRB} \cdot (4\pi r^2)^{-1}$ at distance r is equal to $L_{Edd} \cdot (4\pi R_*^2)^{-1}$ (or at least not less than this flux), and taking into account that the luminosity or rather its *isotropic equivalent* of the GRB radiation is L_{GRB} ~ $10^{50\text{-}51}$erg · s^{-1}, it is possible to obtain an estimate of the size of ~ 10^{12} cm ≈ 14$R_\odot$. At least, at this outer boundary the light pressure is still able to accelerate the initially stable matter up to sub-light velocities ~ 0.3c. And *deeper*, at less distances than ~ 10^{12} cm from the source, say, at r ~ 10^9 cm (somewhere *inside* the region of the size less than the characteristic size of collapsing core of the massive star) the light accelerates the matter up to ultra relativistic velocities with the Lorentz factor of ~ 10 at L_{GRB} ~ 10^{50}erg · s^{-1}. It can occur in a rather small volume of the typical size of </~$R_\odot$. Thus, inside the region of a size of less (in any case) than 10-15 $R_\odot$, a relativistic jet arises as a result of the strong light pressure onto the ambient medium.

6. Concluding remarks: the observational consequences

The superluminal radio components: From the above-said it follows that the suggested compact GRB scenario allows also predicting the behavior of superluminal radio components which, e.g., have been observed for GRB 030329 [37]. If it is no considerable deceleration of the jet (bullet) with the Lorentz factor of order 10, hence we expect that the superluminal radio components related to the jet have the following properties:

1) the radio component will move with the constant observed superluminal velocity;
2) the characteristic observed velocity of the superluminal component is of the order of the Lorentz factor, i.e. of order 10 c.

Thus, it is undoubtedly that the GRB radiation is to be collimated in the compact model with GRB source ~ 10^8-10^6 cm, but the collimation (2) concerns mainly only a small part of hard quanta. The pairs production threshold (1) for such quanta naturally and smoothly, according to the law $(1-\cos\theta)^{1/2}$, rises with the decreasing of the angle θ between the direction at which the photon is radiated from the surface of the compact object and a *selected* direction (e.g. the magnetic field) on the surface. As a result, beside a soft component, the more and more hard part of the burst spectrum is passing through, and it is possible to suggest non-isotropic (axially symmetrical) field of radiation around the source.

The non-collimated XRFs and SNe: E.g. the XRFs can be not collimated at all or slightly collimated (XRR GRB), but with the low total bolometric energy of ~ 10^{47} ergs. Since most probably these are actually the explosions of massive SNe at distances of 100 Mpc [35, 36], they can be observed much more frequently than it is predicted by the standard fireball GRB model. One should try to find early spectral and photometrical SN features. Then, in general, the observational problem of XRF/XRR/GRB identification becomes a special section in the study of cosmological SNe. (It will be recalled that the GRB~030329/SN 2003dh was a XRR GRB but not a classical GRB and XRF/GRB 060218/SN2006aj was the X-ray flash [29, 32].)

As to normal classical GRBs and especially those ones with many heavy quanta in spectra, it is possible to obtain directly from formula (1) a kinematical estimate of the limit collimation of this г-radiation, which, in turn, independently agrees with the observational ratio (2) of the yearly rates $N_{GRB}/N_{SN} \sim 10^{-5} - 10^{-6}$. If the matter concerns quanta with E ~ 100MeV [7] of distant and the most distant

GRBs, then from $1-\cos\theta_{12} \approx 0.5MeV^2/(100MeV\cdot 100MeV) = 0.5\cdot 10^{-4}$ it follows that the radiation of such GRBs turns out to be the most collimated. Such photons must be radiated in the cone of an opening of ≈ 0.5° and be detected in the spectra of the rather distant GRBs with z ~ 1 and farther because of geometrical factor only.

The Amati law: Thus, a natural consequence of our compact model of the GRB source is the fact that distant bursts (z >/~1) turn out to be harder ones, while close “GRBs” (z ~ 0.1) look like XRF and XRR GRBs with predominance of soft X-ray quanta in their spectra (though the factor 1+z also works). Naturally, the effects of observational selection due to finite sensitivity of GRB detectors should be also taken into account. For example, the soft spectral component of the distant (classical) GRBs is “cut” out by the detector sensitivity threshold. And the isotropic X-ray burst, simultaneous with the GRB, can be simply not seen in distant (classical) GRBs because of the low total/bolometric luminosity of the source in the compact GRB model (< 10^{49} ergs). Actually, XRF and XRR GRBs have lower values of E_{iso} (so called isotropic equivalent), than GRBs [16, 32]. It is an important *observational* result of BeppoSAX and HETE-2 missions. We mean the detection of obvious XRFs and XRR GRBs first by BeppoSAX [16] and then by HETE-2. In our compact model of GRB source it (the Amati law) can be a “simple” consequence of formula (1) + collimation (most probably) by magnetic field on the surface of the compact object.

The yearly rate of core-collapse SNe and Fast X-ray Trasients: In the scenario of jet formation, which was discussed in this paper an isotropic X-ray, optical and radio emission of GRB *afterglow* is possible. At that an initial assumption was just a possibility of the GRB collimation (2), which follows from the comparison of the rates of GRBs and SN explosions in distant galaxies. It means that the close relation between GRBs and SNe was taken as the basic assumption: *all* long GRBs are always accompanied by SN explosions, which are sometimes observed, and sometimes not [24]. In other words, the long GRB is the beginning of a massive star collapse or the beginning of SN explosion, and GRBs must always be accompanied by SN explosions (of Ib/c type or of *other* types of massive SNe). Then in any case the total energy release at the burst in г-rays can be *not more* than the total energy released by any SN (</~10^{49} ergs) in all *electromagnetic* waves. But with so “low” total energy of the GRB explosion (</~10^{49} ergs) the only possibility to see GRB at cosmological distances (z >/~1) is the detection of at least the most collimated part of this energy (1-10%) leaving the source within the solid angle of $\Omega_{beam} \sim (10^{-5}-10^{-6})\cdot 4\pi$. The rest can be inaccessible for GRB *detectors* with a limit sensitivity of $\sim 10^{-7} erg\cdot s^{-1}\cdot cm^{-2}$. Certainly, it does not concern the 10000 times more sensitive X-ray *telescopes* which were used to make sky surveys with the Ariel V, HEAO-1, Einstein satellites [15]. For the limit sensitivity of $\sim 10^{-11} erg\cdot s^{-1}\cdot cm^{-2}$ in the band of 0.2-3.5 keV the X-ray observatory (Einstein) recorded *Fast X-ray Transients* (unidentified with anything) at a rate of ~ 10^6 yr^{-1} all over the sky. It agrees well with an average rate of the massive SNe explosions in distant galaxies, but for the present, GRB-detectors see only ~ 10^{-4} part of this huge number of the distant SN explosions as GRBs.

It is natural that at the total/bolometric energy of “GRB” ~ 10^{47} - 10^{49} ergs and at the GRB energy (3) released in the narrow cone (2), “the fireball” also looks in quite a different way. As to the compactness problem solved by the fireball model for GRB energies of 10^{52} - 10^{53} ergs, there is no such a problem for “г-burst” energies ~ 10^{47} - 10^{49} ergs. In any case, allowing for the low г-ray collimation from the surface of the compact object – GRB/XRR/XRF source, which is necessary for the angular dependence of e^-e^+ pair production (1), this problem is solved under quite different physical conditions in the GRB-source than that supposed by Piran [18]. In the scenario: *massive star → WR → pre-SN = pre-GRB*, in which only a small part of the most collimated radiation with the collimation (2) goes to infinity and, correspondingly, with the total energy of 10^4 - 10^6 times less than in the standard theory, the source can actually be of a size </~10^8 cm. It means that at the energies of up to ~ 10^{49} ergs the old (“naive”) estimate of the source size resulting directly from the time variability of GRB can be quite true. Thus, the point can be that the burst energy is much less than in the standard fireball model.

The strong polarization of the GRB radiation: But in such a model [38] the compact source must always have some radiating *surface* (but not the event horizon) and, respectively, always occupy some finite volume. Such an object can have both a strong regular magnetic field and a nonuniformly-raidating surface connected with it . The radiation field arising around the source could be anisotropic, e.g., axially symmetric due to the local magnetic field. In particular, non-uniform radiation at the source surface (e.g. polar caps) could lead to efficient collimation or anisotropy of the radiation field [2], due to the influence of the angular dependence (1) for the e- e+ pair-creation threshold. Such anisotropy could be associated with the transport of radiation in a medium with a strong (~ 10^{14} -10^{16} G) magnetic field , when the absorption coefficient for photons polarized orthogonal to the magnetic field is very small [39, 40]. In this case, the observation of strong linear polarization of the GRB radiation should be another consequence of our compact GRB model.

We always suppose that *all* long-duration GRBs are related to core-collapse SNe, or the rate of GRB-SNe is the rate of all massive star deaths. Thus, in the compact model of GRBs, the formation of massive (>/~$3M_{\odot}$) and compact remnants of the core-collapse SNe (with the massive progenitor stars > 30-40 $M_{\odot}$) can be always accompanied by the GRB (or XRF) phenomenon. But the observations should finally tell us whether we have an SN in each GRB or whether the collapse of a massive star evolves following different paths. Whatever the answer may be the fundamental point of the connection is that GRBs may serve as a guideline to better understand the mechanism, and possibly solve the long-standing problem of the core-collapse SN explosion, since in the GRBs we have additional information related to the core-collapse [41].

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