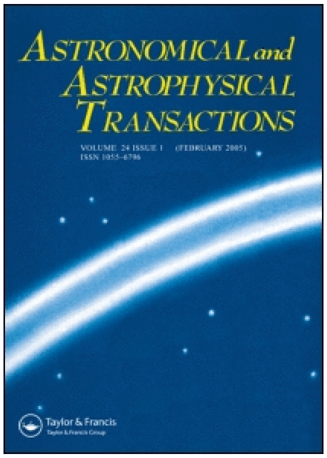

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

# Cosmic gamma ray bursts and catastrophies on the earth

A. Bershansky [a]; A. Misaki [b]; T. Roganova [a]; I. Rozental [c]
[a] Institute of Nuclear Physics, Moscow State University, Moscow, Russia
[b] Department of Physics, Saitama University, Urawa, Japan
[c] Institute for Cosmic Research, Academy of Science of the Russia, Moscow, Russia

Online Publication Date: 01 February 2000
To cite this Article: Bershansky, A., Misaki, A., Roganova, T. and Rozental, I. (2000) 'Cosmic gamma ray bursts and catastrophies on the earth', Astronomical & Astrophysical Transactions, 18:4, 567 - 572
To link to this article: DOI: 10.1080/10556790008208162
URL: http://dx.doi.org/10.1080/10556790008208162

*Astronomical and Astrophysical Transactions*, 2000,
Vol. 18, pp. 567–572
Reprints available directly from the publisher
Photocopying permitted by license only

# COSMIC GAMMA RAY BURSTS AND CATASTROPHIES ON THE EARTH

A. BERSHANSKY[†], A. MISAKI[*], T. ROGANOVA[†], and I. ROZENTAL[††]

[†]*Institute of Nuclear Physics, Moscow State University,*
*Vorobievy gory, 119899, Moscow, Russia*
[*]*Department of Physics, Saitama University, Urawa 338, Japan*
[††]*Institute for Cosmic Research, Academy of Science of the Russia,*
*Profsoyuznaya str. 84/32, Moscow, Russia*

*(Received May 15, 1997)*

In the past few years the hypothesis that cosmic gamma ray bursts (GRB) are mainly produced due to collisions of compact stars at cosmological (metagalactic) distances has become rather popular. However observational data show that such collisions should occur, with a relatively small probability, in our Galaxy, too. In this case the radiation in the gamma range will be so strong that it may lead to catastrophic consequences in the Earth's biosphere and atmosphere.

KEY WORDS Gamma ray bursts

In the 1960s the American system of *Vela* satellites was launched in the Earth's environment. On July 2, 1967 short (~ 1 c) increases of the gamma ray intensity in the range (0.1–1) MeV (Klebsadel *et al.*, 1973) were recorded onboard the *Vela* 4a satellite. Detailed investigations made later onboard the *Vela* satellites demonstrated the astronomical (non-terrestrial) origin of GRB.

Though GRB were discovered some thirty years ago unambiguous arguments indicating the nature of their sources are still lacking. Moreover, it is now impossible to say anything clearly about the distances to the GRB sources. In the papers available three possible scales of distances to the GRB sources are analysed: (i) the solar system periphery ($\sim 100$ a.e. $\sim 10^{15}$ cm); (ii) the Galactic halo ($\sim 10^{22}$ cm); (iii) metagalactic distances ($\sim 10^{28}$ cm). Similar arguments pro and contra various hypotheses of the origin of GRB have been analysed in the latest review (Luchkov *et al.*, 1997).

Let us recall the main mean observational GRB characteristics:

(1) the duration is $\sim 1$ s;

(2) the observed intensity is $\sim 10^{-5}$ erg cm$^{-2}$ s$^{-1}$;

(3) the mean photon energy is $E_\gamma \sim 0.5$ MeV;

(4) similar and simultaneous gamma ray bursts in the soft ranges (soft X-rays, ultraviole radiation, optical and radio ranges) are not observed;

(5) the GRB frequency is $\sim 1$ burst/day;

(6) GRB sources on the celestial sphere a distributed isotropically.

The latter characteristic is the most significant for the determination of GRB sources. It really eliminates the possibility that the main part of GRB appears on the Earth, on the Sun or within the Galactic disk.

Though none of the three characteristic distances to the GRB sources noted above may be entirely excluded out of consideration, recently the most popular is the hypothesis of the origin of GRB at cosmological distances produced as a result of collision (merging) of two compact stars (two neutron stars, a neutron star and a black hole, or two black holes) (Band, 1994; Kollat and Piran, 1996; Mao and Paczynski, 1992; Meszaros and Rees, 1993; Norris *et al.*, 1994). In a forthcoming paper by Rozental and Belousova, observational data on GRB have consistently been compared with a theory based on the following hypothesis: some fraction of the GRB appears at cosmological distances due to the collision of two compact objects. Theory (Rozental and Belousova) incorporates three natural parameters: the mean solar mass $M_\odot \sim 10^{33}$ g, the dimensions of compact sources $R_\odot \sim 10^6$ cm, and the electron mass $m_e \sim 0.5$ MeV. The latter parameter defines the GRB energy spectrum and the characteristic (4). Using the numerical values of the parameters, it is possible to obtain all the main GRB characteristics.

The conclusion that the main fraction of GRB takes its origin at cosmological distances is strongly confirmed by observation of three double pulsars in our Galaxy. The analysis made by Narayan *et al.* (1991) showed that in the Galaxy two compact objects merge with a frequency of $\sim 10^{-5.5}$ year$^{-1}$ which corresponds to the observed GRB frequency. Consequently, though the majority of GRBs occur at cosmological distances, bursts seldom occur in the nearest galaxies and even in our own. The purpose of the present paper is to briefly analyse the influence of such bursts on the vital activity on the Earth's surface.

It should be stressed that the analysis of the frequency of the merging of compact objects is fairly complex, therefore the obtained theoretical values of this magnitude differ by approximately an order in different papers. So, in the papers by Tutukov and Jorgensen (1993) and Jorgensen *et al.* (1995), this frequency is closer to $10^{-4}$ year$^{-1}$. That is why in the considerations below we shall use three values of the frequency of the merging of compact stars in the Galaxy: $10^{-4}$ year$^{-1}$, $10^{-5}$ year$^{-1}$, and $10^{-6}$ year$^{-1}$.

The main idea of the present paper is to estimate the processes occurring on the Earth as a result of the merging of double compact stars in the Galaxy with subsequent release by gamma quanta with an energy of $\sim 10^{51}$–$10^{52}$ erg during $\sim 1$ s. Similar processes have been estimated many times when analysing the scenarioes of nuclear wars and supernovae bursts. However it should be noted that the radiation of the Earth by GRB products has its own peculiarity. So, compared with supernovae bursts, GRB occurs practically momentarily, whereas supernovae bursts may last for months or years. Moreover, the energy of supernovae bursts is radiated mainly in the soft range (optical and radio) and in the form of neutrinos. Meanwhile the collision of two compact objects should be accompanied by strong gravitational radiation and radiation of photons in the hard range.

The total energy of nuclear charges is by several orders less than the GRB energy. So, in accordance with data obtained till 1985, the total energy of nuclear charges corresponds to $\sim$ 11 000 Mt of trotyl which gives after transformation to the usual physical units an energy release of $5 \times 10^{24}$ erg. An estimate of the total energy $E_{t\gamma}$ of the gamma radiation falling on the Earth during GRB shows that $E_{t\gamma} \sim 10^{30}$ erg if the GRB occurs at a distance $R \sim 10^{20}$ cm from the Earth and $E_{t\gamma} \sim 10^{26}$ erg if $R \sim 10^{22}$ cm.

It should be noted, however, that the hypothetical nuclear explosions are directed at some object and occur in the lower layers of the atmosphere. Therefore their effectiveness could be significantly higher than that of GRB uniformly affecting the Earth's atmosphere which shields them.

Note in conclusion that the intensity of GRB photons falling on the Earth significantly exceeds the intensity of solar flares. So, in the flares the cosmic ray energy flux is $\sim 10^2$ erg cm$^{-2}$ s$^{-1}$, the intensity of GRB originating in the Galaxy being $\geq 10^7$ erg cm$^{-2}$ s$^{-1}$.

The character of GRB action on the Earth's biosphere is defined by the interaction of GRB gamma quanta with the atmosphere.

The GRB energy spectrum has been measured fairly accurately at the GRO cosmic observatory with the BATSE device (Band *et al.*, 1993; Ford *et al.*, 1995). In our estimates below we will use the spectrum (Band *et al.*, 1993; Ford *et al.*, 1995)

$$N_E(E), \left(\frac{\text{photons}}{\text{keV s cm}^2}\right) = \begin{cases} A\left(\dfrac{E}{100\ \text{keV}}\right)^{-\alpha} \exp(-E/E_0), & E \leq (\beta - \alpha)E_0 \\ A'\left(\dfrac{E}{100\ \text{keV}}\right)^{-\beta}, & E \geq (\beta - \alpha)E_0 \end{cases}$$

where $E$ is the gamma quantum energy in keV, $A$ is the dimensional normalized coefficient, $A'$ is the coefficient determined from the condition of the spectrum continuity; various estimates of the mean values of $\alpha$, $\beta$, and $E_0$ are obtained. To perform estimation calculations in the present paper, the following values were assumed: $\alpha = 1$, $\beta = 2$, $E_0 = 150$ keV. The energy of gamma quanta will be assumed to change in the range from 2 KeV to 20 MeV.

The characteristic feature of this spectrum is the fact that the main fraction of GRB energy is released in the form of gamma quanta with energies $E_\gamma \sim 0.1$–1 MeV. This circumstance is associated with the fact that the last stage of the GRB formation, i.e. free scatter of gamma quanta, occurs when the temperature in the GRB source drops to $T \sim m_e c^2$ and the $2\gamma \to e^+e^-$ reaction becomes inefficient. For gamma quanta in this energy range the main mechanism of interaction with atomic nuclei is the Compton effect.

**Table 1.** GRB energy fractions transferred to various processes

| *Heating of the atmosphere* | *Backward scatter* | *Energy of photons incident at the Earth's surface* |
|---|---|---|
| $8 \times 10^{-1}$ | $2 \times 10^{-1}$ | $10^{-8}$–$10^{-9}$ |

**Table 2.** Frequency of appearance of GRB, mean intensity and heating

| *Distance R cm* | *Frequency of appearance (year$^{-1}$)* | *GRB intensity (erg cm$^{-2}$)* | *Heating of the atmosphere (degree)* |
|---|---|---|---|
| $10^{20}$ | $10^{-8}$–$10^{-12}$ | $10^{11}$–$10^{12}$ | 1–10 |
| $10^{21}$ | $10^{-6}$–$10^{-8}$ | $10^{9}$–$10^{10}$ | $10^{-1}$–$10^{-2}$ |
| $10^{22}$ | $10^{-4}$–$10^{-6}$ | $10^{7}$–$10^{8}$ | $10^{-3}$–$10^{-4}$ |

Generally speaking, the kinetics of penetration of gamma quanta with energy $E \leq 1$ MeV through the atmosphere is fairly complex. In other words, the pattern of GRB interaction with the atmosphere can be represented as follows: gamma quanta undergoing multiple Compton scattering on air atoms (electrons) lose some fraction of their energy. As a result of this multiple scattering, the main energy fraction of GRB photons is transferred to air while heating it. A definite fraction of gamma quanta leaves the atmosphere due to scattering at large angles. Some small fraction of the gamma quanta arrives at the Earth's surface. The rest of the gamma quanta are absorbed within the atmosphere.

Table 1 lists the GRB energy fraction heating the atmosphere and arriving at the Earth's surface. There is also presented the energy fraction arriving from the atmosphere due to Compton scattering at large angles (backward scatter).

As mentioned above, in accordance with Narayan *et al.*, (1991) and Jorgensen *et al.* (1995), we assume that the frequency of bursts in the Galaxy is equal to $1O^{-4}$–$10^{-6}$ year$^{-1}$. This frequency corresponds to the Galactic disk dimension $R \sim 10^{22}$ cm. It is possible, however, that the distance to the GRB source (and, consequently, the probability for GRB to appear at this distance) is significantly less.

Table 2 lists estimates of the frequency of GRB formation at various distances $R$ from the Earth (obtained under the assumption that the Galaxy is disk-shaped), the GRB intensity above the Earth's atmosphere corresponding to these distances and the mean increase of the atmospheric temperature (presented in K) caused by GRB energy absorption.

One circumstance should be emphasized. Table 2 lists the data averaged over the atmospheric height. In fact, the heating is realized non-uniformly. In the upper layers of the atmosphere, when the GRB photons do not lose much energy, the heating is significantly stronger. At high altitudes ($\geq 100$ km) the air is heated to several tens of thousands of degrees. This circumstance can lead to the serious ecological consequences: the production of large concentrations of nitrogen oxides $NO_n$

with subsequent destruction of the ozone layer, the production of radionuclides of fairly large concentration, significant changes in the electromagnetic characteristics of the atmosphere, ionosphere and troposphere, and a change of the climate and other factors dangerous for vital activity.

The estimates obtained for the value of a radioactive absorbed dose at sea level ($\leq 1$ rad for GRB formed at a distance of $\sim 10^{20}$ cm) show that such action should not entail the death of the animal world. Nevertheless, it should cause noticeable genetic transformations. In particular, it cannot be discarded that the extinction of the dinasaurs about one million years ago could be caused by this phenomenon.

Note also that the Marsian atmosphere is several times rarer than the Earth's, therefore the action of GRB on the atmosphere (biosphere) of this planet could lead to essentially more catastrophic consequences.

If the temperature in the lower atmospheric layers increases by more than 10 K, the momentary heating could lead to inflamation of organic substances, to numerous fires and to the intensive evaporation of aerosols that, as is known (see, e.g., Pittoik *et al.*, 1986), can lead later to a significant global cooling and to serious changes in the biosphere (Harwell, *et al.*, 1985).

Since the total energy of GRB photons incident on the Earth's surface is comparable with the total kinetic energy of atmospheric atoms, a global shock wave with unpredictable consequences will appear during the GRB transition through the atmosphere.

Thus, the GRB bursts in our Galaxy can lead to essential ecological consequences on the Earth.

When this paper was completed, our attention was attracted to the paper by Thorsett (1995) dealing with some questions of the possible influence of the nearest GRBs on the terrestrial processes such as an increase of the stratospheric nitric oxide concentration, greatly reducing the ozone concentration and the growth of radionuclide abundances. However, this paper did not examine two of the most important phenomena, namely, the heating of the atmosphere due to the absorption of GRB radiation and the direct radiation of the animal world by the gamma rays of a burst at Sea level, which significantly affects our conclusions concerning the role of GRB in the catastrophies on the Earth.

In the paper by Kurt and Zaydel'(1996) possible consequences of GRR occuiring in our Galaxy were analysed. However, in their calculations the authors used an outdated form of the splash energy spectrum that led to an underestimated (compared with the latest data) value of gamma ray energy. So, the mean energy of gamma rays is $\vec{E}_\gamma = 3.15$ keV (relation 1) whereas $\vec{E}_\gamma \sim 50$–$100$ keV according to the BATSE data. This discrepancy entails a drastic difference in the physical processes occurring in the atmosphere. So, the data of Kurt and Zaydel' (1996) indicate that the main process in the atmosphere is the photoeffect, meanwhile our estimate shows that this is Compton effect.

## *References*

Band, D., Matteson, J., Ford, L. *et al.* (1993) *Astrophys. J.* **413**, 281.
Band, D. (1994) *Astrophys. J. Lett.* **432**, 17.

Ford, L., Band, D., Matteson, J. *et al.* (1995) *Astrophys. J.* **439**, 307.
Harwell, M., Hutchinson, T. *et al.* (eds.) (1985) *Environmental Consequences of Nuclear War. Vol 2. Ecological and Agricultural Effects*, Wiley, New York.
Klebsadel, R., Strong, I., and Olson, R. (1973) *Astrophys. J.* **182**, L85.
Kollat, T. and Piran, T. (1996) *Astrophys. J.* **467**, L41.
Kurt, V. G. and Zaidel', R. M. (1996) *Kosmicheskie Issledovaniya* **34**, No. 4, 400.
Luchkov, B., Mitrofanov, I., and Rozental, I. (1997) *Physics Uspekhi* (*Uspekhi Fizicheskikh Nauk Russian Academy of Sciences*) **39**, No. 7, 695.
Mao, S. and Paczynski, B. (1992) *Astrophys. J.* **380**, L45.
Meszaros, P. and Rees, P. (1993) *Astrophys. J.* **405**, 278.
Narayan, R., Piran, T., and Shemi, J. A. (1991) *Astrophys. J.* **379**, L17.
Norris, J., Nemirof, R., Scargle *et al.* (1994) *Astrophys. J.* **424**, 540.
Pittoik, A., Ackerman, T., Crutzen, P. *et al.* (eds.) (1986) *Environmental Consequences of Nuclear War. Vol 1. Physical and Atmospheric Effects* Wiley, New York.
Rozental, I. and Belousova I. *Astron. Space Sci.* (in Press).
Thorsett, S. E. (1995) *Astrophys. J.* **444**, L53.
Tutukov, F. and Jorgensen, H. (1993) *Mon. Not. Roy. Astron. Soc.* **260**, 675.
Jorgensen, H. *et al.* (1995) *Astron. Space Sci.* **231**, 389.