Proceedings of ICRC 2001: 2747 © Copernicus Gesellschaft 2001

ICRC 2001

GRB spectra in optically thick expanding plasma shells model

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Abstract. We suppose that nonthermal spectra of radiation in the gamma-ray bursts (GRBs) are formed by optically thick spherical plasma shells that expand with relativistic velocities. The temperature of the shell decreases as power law. We discuss results of calculations which show that radiation spectrum of such shell is similar to observed spectra of GRBs. This model allows to define some characteristics of emitting regions.

1 Observed GRB spectra

In spite of resent progress in the observations of x-ray, optical and radio counterparts of GRB the nature of their internal engine and mechanism of γ-ray emission still remains unclear.

According BATSE observations GRB spectra are well described by Band model:

$$N_E(E), \frac{counts}{cm^2 \times s} = \begin{cases} A \times E^{\alpha} \times e^{-E/E_0}, E < E_0 \\ B \times E^{\beta}, E > E_0 \end{cases}, \qquad (1)$$

where α is low energy spectral index, β is high energy one. α, β, $\frac{A}{B}$ and E_0 can be different for each GRB.

The power law shape of this spectra can be possibly explained by a hypothesis of their nonthermal origin. Cohen and colegues (Cohen, 1997) found that the low energy spectral index α in the time-integrated spectra of GRBs is usially in the range $-\frac{3}{2} < \alpha < \frac{2}{3}$ as predicted by synchrotron shock model (Tavani, 1996). However, in work (Crider, 1997) the time-resolved spectra of 99 GRBs were analysed and it was found that for these spectra the α index is often outside the limits of syncrotron shock model.

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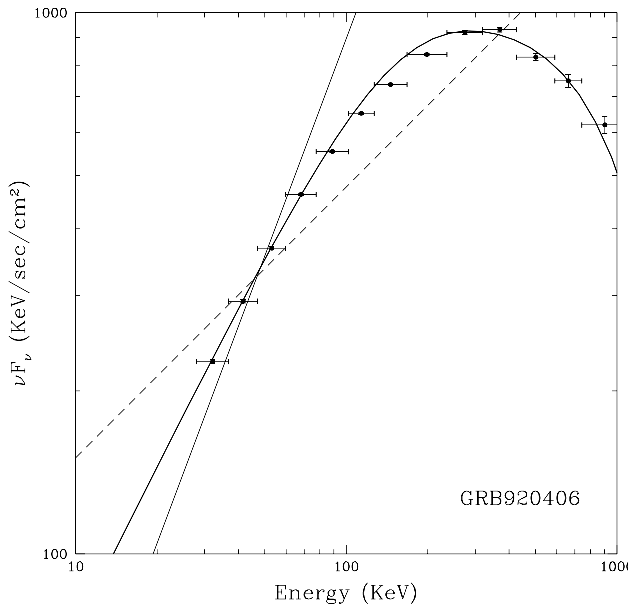

Fig. 1. The time-integrated spectrum of GRB920406. Synchrotron model limiting slopes are shown as dashed and solid lines.

2 Model of spectrum formation

We propose another solution of this problem. It is well known that a sum of different blackbody spectra can produce a power-like specrum looking as nonthermal one, for example in thin accretion disks (Shacura, 1973).

Moreover, some GRB spectra are well described by blackbody model. without any summation. It was found (Schaefer, 1998) that spectra of γ-bursts GRB930418 (BATSE trigger #2309), GRB931023 (BATSE trigger #2600) and GRB980213 (BATSE trigger #6599) were well fitted by blackbody model with temperature approximately 100 keV. Such shape of the spectrum contradicts with synchrotron limits of α: $\alpha = -2$ instead of $\alpha = -\frac{3}{2}$ which is required by synchrotron model.

In our work we analyse one of most general case of black-

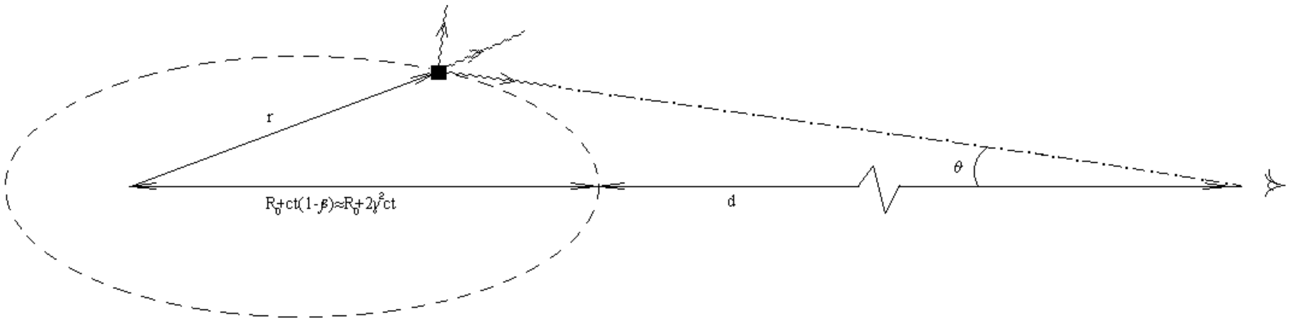

Fig. 2. Expanding plasma shell in the observer frame.

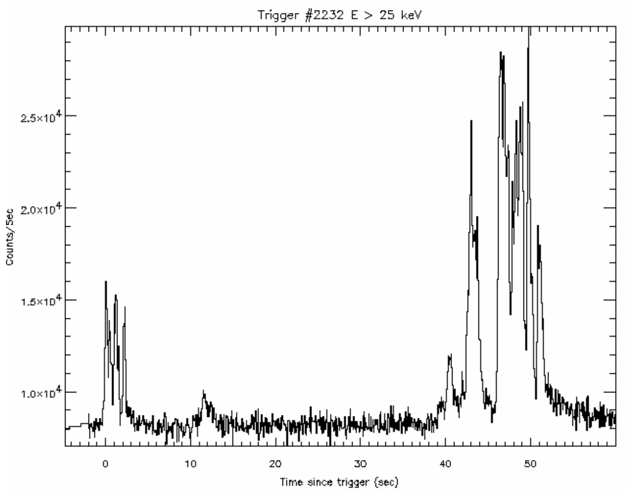

Fig. 3. The time profile of GRB930310.

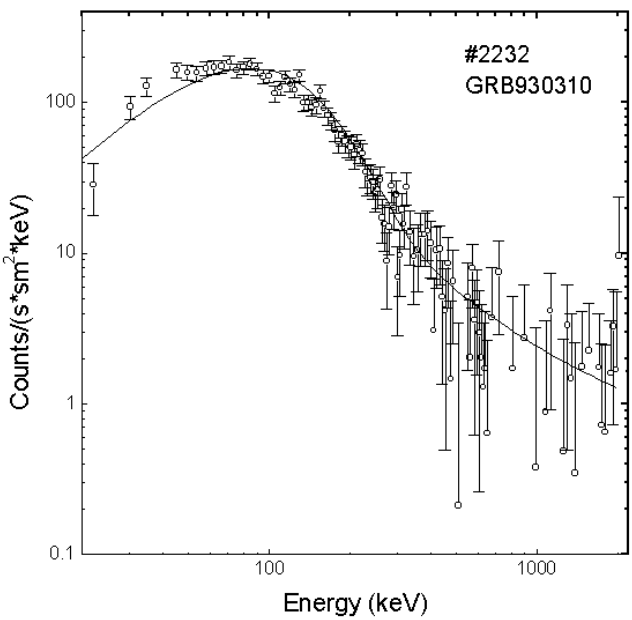

Fig. 4. The spectrum of GRB930310 with $t_0 = 49s$ from the BATSE trigger and $\Delta t = 1.34s$, solid line is the fit.

body models of GRBs spectra. We don't introduce a new physical model of GRBs, we only attract your attention to the fact that the observed non-thermal spectrum can be produced by a relativistically moving or expanding optically thick plasma shell. Such plasma shells could occur in numerous GRB models, for example, in fireball ones.

So, we consider a plasma shell (Arkhangelskaja, 2000) which expands with Lorents factor Γ - see fig. 2. Below, primed symbols are related to the comoving frame, symbols withoud prime are related to the observer frame.

The intensity of the blackbody emission of the expanding shell in the comoving frame is

$$E_\nu = \frac{2\pi h\nu^3}{c^2(\exp(h\nu/kT - 1)} \tag{2}$$

In this case we suppose spherical symmetry of the shell, i.e. the independence of the emission intensity on the direction.

It is known that frequency ν of a photon emitted with angle θ' is redshifted in the observer frame as

$$\nu' = \frac{\nu}{\Gamma(1 - \beta\cos\theta)}, \tag{3}$$

where θ depends from θ' as

$$\cos\theta = \frac{-\beta\Gamma^2\tan^2\theta' + 1/\cos^2\theta'}{(1 + \Gamma^2\tan^2\theta\prime)} \tag{4}$$

During its expansion the plasma shell is cooling. We suppose that its temperature decreases with time t as

$$T = T_0\left(\frac{t}{t_0}\right)^{-a}, \tag{5}$$

where a is called the cooling factor and T_0 is the initial temperature of the shell.

In the most simple case a plasma shell expands with a constant velosity and in the comoving frame

$$r' = R'_0 + \beta ct, \quad \beta = v/c \tag{6}$$

In the observer frame the locus of points from which the radiation arrives the observer at the same time (the dashed line in fig. 2) is described by the equation

$$r(\theta) = R_0 + \frac{\beta ct}{1 - \beta cos\theta} \tag{7}$$

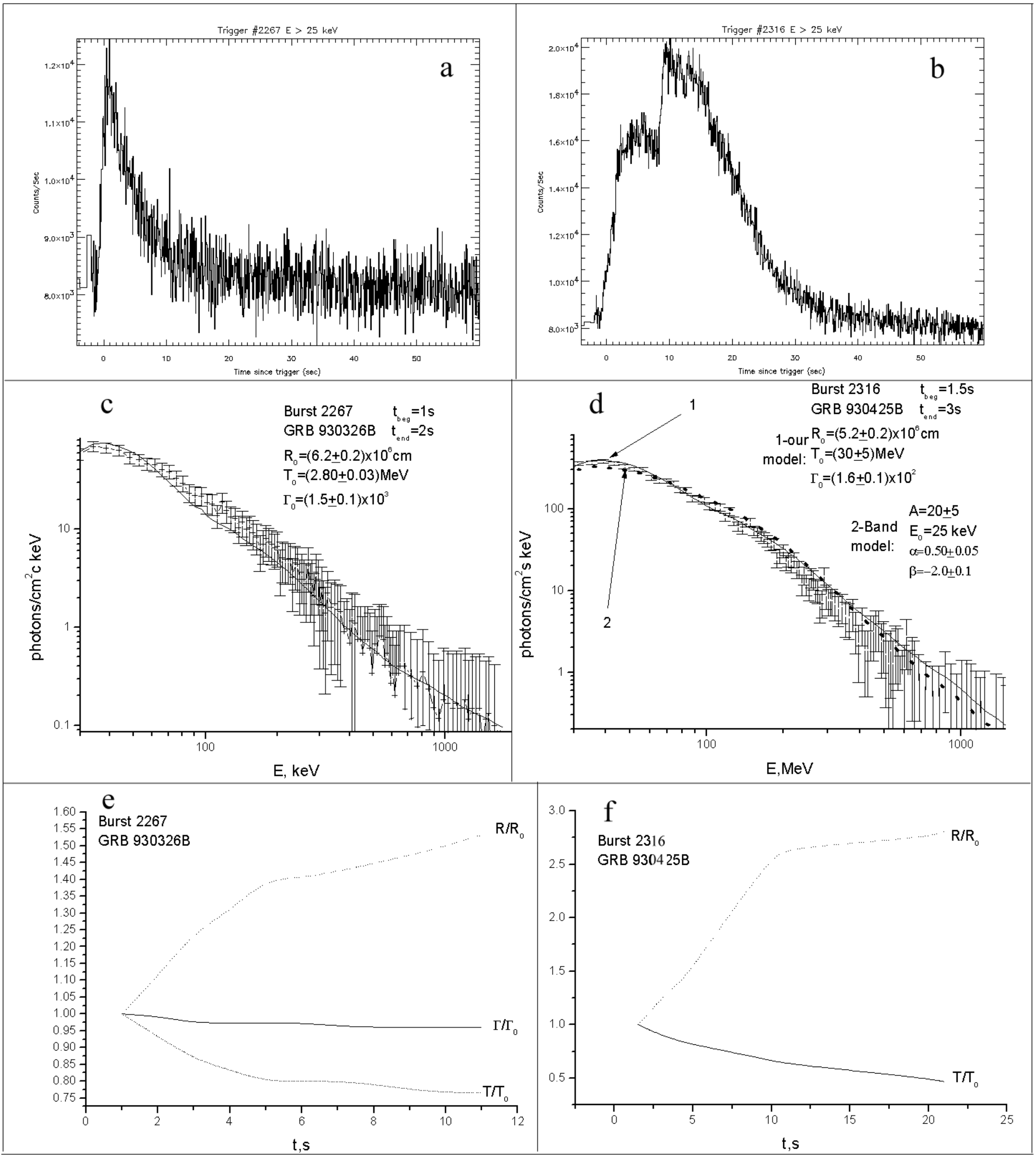

Fig. 5. The time profiles of GRB930326B (a) and GRB930425 (b), their spectra (c,d); time dependence of radius, lorentz-factor and temperature for these GRB(e, f) in our model.

Using the eq. (3-7) we obtain the transformation of the blackbody spectrum (2) into the observer frame:

$$F_\nu = \frac{1}{4\pi d^2} \int\limits_{t_0}^{t_0+\Delta t} dt \int\limits_{r(t_0,\pi/2)}^{R_0} \frac{RdRD(\theta')E_{\nu'}(R)}{\sqrt{(\gamma^2(\cos\theta+\beta)^2+\sin^2\theta)}} \quad (8)$$

Therefore, we have a model with 5 parameters, 4 of them are independent: d is the distance from the observer to the source of GRB, t_0 is the time of the beginning of the time integration, R_0 is the initial radius of the shell, θ is the angular coordinate, $D(\theta')$ is the directional diagram (constant for isotropic emission), Δt is the time integration interval (burst duration (t_{90}) for the time integrated spectra, the detector time resolution for the time resolved spectra). The popular

Band model 1 has 4 independent parameters too. BATSE observations provide 128-channel spectra, which allows to determine the model parameters reliably.

The recovery of the observed GRB spectra usually is an inverse incorrect problem. We fit the observed spectra of individual GRB from the current BATSE catalogue (Meegan, 2000) using BATSE detector responce matrix and BATSE team forward folding technique, developed by R. Preece, M. Briggs, R. Mallozzi and M. Brock in MSFC.

3 Results of the fit

As an example of time-integrated spectrum fit, we show the spectrum of GRB 920406 (see fig. 1). It contradicts the synchrotron model, but is fitted by our model with $\Gamma = 1000$, $a = 0.75$, and $T_0 = 0.5$ MeV (Blinnikov, 1999).

Result of the fit for GRB930310 (see fig. 3 is shown in fig. 4, The time of integration $\Delta t = 1.34s$ for this spectrum is the time resolution of the spectroscopic detectors of BATSE. For this burst we have the following parameters set:

$$\begin{aligned} T_0 &= (13.7 \pm 3.9)MeV, \\ a &= 0.75 \pm 0.03, \\ \gamma &= (1.1 \pm 0.5) \times 10^3, \\ R_0 &= 10^{6\pm1}cm. \end{aligned}$$

Results of the fit for GRB930326B and GRB930425B (time profiles see fig. 5.a and fig. 5.b) are shown in fig. 5.c and fig. 5.d. The distance to all fitted GRB is $d = 10^{24\pm3}cm$. For burst GRB930326B we have the following parameters set:

$$\begin{aligned} T_0 &= (2.80 \pm 0.03)MeV, \\ a &= 0.77 \pm 0.03, \\ \gamma &= (1.5 \pm 0.1) \times 10^3, \\ R_0 &= (6.2 \pm 0.2) \times 10^6 cm. \end{aligned}$$

For burst GRB930425B we have the following parameter set (curve 1 in fig. 5.d):

$$\begin{aligned} T_0 &= (30 \pm 5)MeV, \\ a &= 0.74 \pm 0.04, \\ \gamma &= (1.6 \pm 0.1) \times 10^3, \\ R_0 &= (5.2 \pm 0.2) \times 10^6 cm. \end{aligned}$$

Also we fit spectrum of burst GRB930425B by Band model (see curve 2 in fig. 5.d) with following parameters:

$$\begin{aligned} A &= 20 \pm 5, \\ E_0 &= 25keV \\ \alpha &= (0.50 \pm 0.05), \\ \beta &= (-2.0 \pm 0.1). \end{aligned}$$

It is seen that both fits (curve 1 and curve 2) gives same results and spectra of these GRB are well fitted by our model. Time evolution of some emitting regions characteristics shown in fig. 5.e and fig. 5.f.

4 Conclusions

So, we have found that both time integrated and time resolved spectra of some GRBs are well fitted by the model of optically thick expanding plasma shell. Other models, includeing the synchrotron shock model, explain only time integrated spectra.

We show that the effects of relativistic expansion of the emitting region cannot be neglected in computing the GRB emission models.

References

Cohen, E., Katz, J.I., et al, ApJ 488, 330, 1997.
Tavani, M., ApJ, 466, 768, 1996.
Crider, A., Liang, E. and Preece, R., Proceedings of the 4th Huntsville Symposium on Gamma-ray bursts, Eds. Meegan, C., Preece, R. and Koshut T., 1997
Meegan, C. et al, http://cossc.gsfc.nasa.gov/cossc/batse/4Bcatalog
Shacura, N.I. and Sunyaev, R.A., A & A, 24, 337, 1973.
Schaefer, B.E., Palmer, D.M., and Barthelmy, S.D. Proceedings of "Gamma-ray Bursts in the Afterglow Era". Roma, 1998.
Arkhangelskaja, I.V. Panchenko, I.E. and Blinnikov, S.I., Nuovo Chimento, 115B, 7-9, 921, 2000.
Blinnikov, S.I., Kozyreva, A.V., Panchenko, I.E. Astron. Rep., 43, 739-747, 1999.