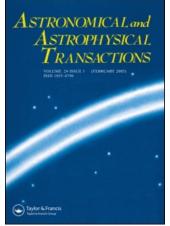
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Astronomical & Astrophysical Transactions The Journal of the Eurasian Astronomical

Society

Publication details, including instructions for authors and subscription information: http://www.informaworld.com/smpp/title~content=t713453505

Spectra of gamma-ray burst afterglows A. Tolstov ^a; S. Blinnikov ^a

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Online Publication Date: 01 December 2003 To cite this Article: Tolstov, A. and Blinnikov, S. (2003) 'Spectra of gamma-ray burst afterglows', Astronomical & Astrophysical Transactions, 22:6, 807 - 808 To link to this article: DOI: 10.1080/1055679031000148668

URL: http://dx.doi.org/10.1080/1055679031000148668

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SPECTRA OF GAMMA-RAY BURST AFTERGLOWS

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(Received 14 November 2002)

Gamma-ray burst afterglows are believed to be described reasonably by synchrotron emission from relativistic blast waves at cosmological distances. We perform a detailed calculation using a full angle-, time- and frequency-dependent transfer equation and taking into account the effect of synchrotron self-absorption. The method developed for solving the transfer equation can be applied to the motion of a fluid with a Lorentz factor of up to 1000. We consider emission from the whole region behind the shock front and use the Blandford–McKee self-similar solution to describe the fluid behind the shock. We calculate the spectra and the light curves from a power-law distribution of electrons in an expanding relativistic shock and compare them with theoretical estimations.

Keywords: Gamma-ray bursts; Hydrodynamics; Relativity; Shock waves

We use a simple self-similar solution describing the explosion with a fixed amount of energy E_0 and propagation of a relativistic shock through a uniform cold medium (Blandford and McKee, 1976) and we limit the discussion here to the fully adiabatic case. We assume that a constant fraction ε_e of the shock energy goes into the electrons and the initial electron distribution is given by $N(\gamma_e) = K_0 \gamma_e^{-p}$. We also assume that the magnetic energy density behind the shock is a constant fraction ε_B of the shock energy: $B^2 = 8\pi\varepsilon_B e$. The spectral emissivity and absorption coefficient is defined by synchrotron radiation (Rybicki and Lightman, 1979). The intensity *I* on the surface may be obtained by solving the radiative transfer equation in the comoving frame (Mihalas, 1980). We managed to solve the transfer equation numerically using a Runge–Kutta method with a global error control up to the Lorenz factor $\gamma \approx 1000$.

The flux density is given by

$$F_{0,v_0,t_{\text{obs}}} = \frac{2\pi}{D^2} \int_{\mu_{0,\min}}^{1} \mu_0 R^2 I\left(r(\mu_0), v_0\left(\frac{v}{v_0}\right), \cos\delta(\cos\delta_0)\right) \left(\frac{v_0}{v}\right)^3 \mathrm{d}\mu_0,$$

where we omit the time dependence for short brevity, the subscript 0 is related to the observer frame, δ is the angle between the normal to the radiating surface and the direction toward the observer, D is the distance to the observer and μ_{min} can be obtained from

$$p'_{\mu}(1-\mu^2) - p(\mu-p) = 0.$$

Here p = R/D.

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ISSN 1055-6796 print; ISSN 1476-3540 online © 2003 Taylor & Francis Ltd DOI: 10.1080/1055679031000148668

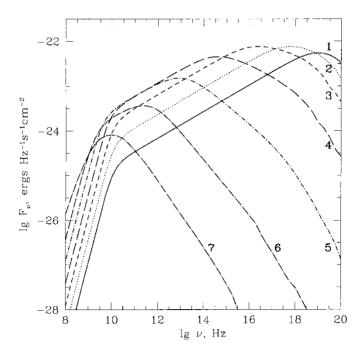


FIGURE 1 Synchrotron spectra of a relativistic shock with a power-law electron distribution at different times $t = 10^i$ s, $i \in \overline{1...7}$.

In the calculation we use the following parameters: $E_0 = 10^{53}$ erg, $\varepsilon_e = 0.5$, $\varepsilon_B = 0.1$, p = 2.5 and $D = 10^{27}$ cm. The high value of energy refers to a spherically symmetric explosion, while in reality a gamma-ray burst (GRB) may be produced by a jet within a solid angle Ω ; hence the total energy will be a factor of $\Omega/4\pi$ lower.

The main results of this calculation are summarized in Figure 1.

We have compared the calculated spectra with semianalytical estimates (Sari *et al.*, 1998; Granot *et al.*, 1999, 2001) for this simple problem and found that they are in good agreement with each other. This allows us to conclude that we have a workable method which is able to compute reliable spectra of GRBs and their afterglows in situations where simple analytical methods do not work (*e.g.* collisions of shocks).

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