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The GRB events and spectra of the afterglow

S. Simić[1] and L. Č. Popović[2]

[1] Faculty of Science, Department of Physics, University of Kragujevac, Radoja Domanovića 12, 34000 Kragujevac, Serbia; e-mail: ssimic@kg.ac.rs
[2] Astronomical Observatory, Volgina 7, 11000 Belgrade, Serbia

Abstract. Here we will discus a possibility to use Gamma Ray Burst (GRB) phenomena in order to study the properties of host galaxy environment as well as the intergalactic medium. First we will present an external shock wave model and its capabilities to explain GRBs afterglow. Separately we will present phenomenological equations for evolution of shock variables and empirical equations for description of radiated energy spectra of the event. Further on, a current observation of absorption spectral lines will be presented as well as their properties, like redshift and equivalent widths. Also, we have presented few recent observations of high resolution instruments in order to demonstrate capabilities of current instruments.

Key words. Gamma rays: bursts; Gamma rays: theory; Shock waves

1. Introduction

Observational calculational evidence has demonstrated that long-duration gamma-ray bursts (GRBs) arise in active star-forming regions e.g. Bloom et al. (2002); Stanek et al. (2003), supporting a physical connection between the bursts and the catastrophic death of massive stars (Woosley 1993; Paczynski 1998). Studies of the circumburst environment together with the progenitor stars therefore bear directly on our understanding of star formation and metal production in the early universe. The extreme brightness of GRB optical afterglows, albeit brief, offers a unique means to unveil the physical conditions of the ambient medium around the burst progenitors. For example, low-resolution afterglow spectra have yielded a few diagnostic measurements such as the HI column density, the gas metallicity, and the dust-to-gas ratio of the GRB hosts e.g. Savaglio et al. (2003); Vreeswijk (2004). High-resolution spectroscopy of the optical afterglows has further uncovered detailed kinematic signatures, population ratios of excited ions, and chemical compositions of the interstellar medium (ISM) and the circumstellar medium (CSM) of the progenitor star of the GRB e.g. Fiore et al. (2005); Chen et al. (2005).

Whatever the density of the GRB environment, photoionization of the circumburst material by the prompt X-ray emission and by the X-ray and UV afterglow emission will be inevitable. If the circumburst density is high, it will lead to time dependent (on hour timescale) absorption (Prochaska et al. 2006) and emission line features (Perna & Loeb 1998; Bottcher et al. 1999), such as those claimed to be seen in X-rays. On longer timescales, the GRB photoionization may

Send offprint requests to: S. Simić

lead to indicative recombination line features, which allow the identification of remnants of GRBs in nearby galaxies (Ghisellini et al. 1999; Band & Hartmann 1992).

2. Brief description of employed model

The central engine continuously creates new small mass shocks which cause the flow of shock waves with different initial parameters. With time, they are able to accelerate particles of the Inter-Stellar Medium (ISM) surrounding the GRB and to accumulate in another, massive shock wave that is spreading with a lower velocity than initial shocks. Then, the second phase of the GRB event starts, with the creation of the afterglow.

In the fireball model of GRBs (Rees & Meszaros 1992), the energy released from the collapse of a massive star is converted into kinetic energy of thin baryonic shells which expand at ultra-relativistic speeds. After producing the prompt *gamma*-ray emission by internal shocks between different shells, the residual impacts on the surrounding gas and drives an ultrarelativistic shock into the ambient medium. The shock accelerates relativistic electrons leading to the observed X-ray to radio afterglow radiation through synchrotron emission. The emission of the X-ray afterglow, integrated over the first 710 days, typically contains the same energy as the primary *gamma*-ray burst itself (Rees & Meszaros 1998).

For proper description of evolution of the relativistically moving matter we have developed a phenomenological model based on the Huang et al. (1998) which present the system of first order differential equation which evolve three important variables: mass, Lorentz factor and distance of shock wave (Simić et al. 2007) as:

$$\frac{dR}{dt} = c\sqrt{\Gamma^2-1}\left[\Gamma + \sqrt{\Gamma^2-1}\right], \quad (1)$$

$$\frac{d\Gamma}{dm_s} = -\frac{\Gamma^2-1}{M_{ej} + 2(1-\varepsilon)\Gamma m_s + \varepsilon m_s}, \quad (2)$$

$$\frac{dm_s}{dt} = 2\pi n m_p (1-\cos\theta)\frac{R^2}{\Gamma^3}\left(3\Gamma\frac{dR}{dt} - 2R\frac{d\Gamma}{dt}\right), \quad (3)$$

where the parameter ε takes values from 0 for the adiabatic expansion, to 1 which describes a fully radiative case, and M_{ej} is the mass of a primary ejected material. Eqs. (1) - (3) are derived for an observer reference frame, and they have to be solved simultaneously, together with the density equation. Initial values of parameters and variables are highly dependent on the properties of the shocks. For a specific density of surrounding media one can use equation developed by Blandford & McKee (1976):

$$n = n_0\left(\frac{R_0}{R}\right)^s (4\Gamma + 3) \quad (4)$$

Solution of this system for variables Γ_0 and m_s is presented in the Figures 1 and 2, together with the used set of standard parameters. When the hydrodynamical system of equations is established, one can proceed to calculate the radiation generated by the expanding shock wave. For this purpose we use analyze of Sari & Piran (1998), where they present GRB afterglow spectra in the fast and slow cooling regime of heated electrons.

When $\gamma_m > \gamma_c$, all the electrons cool down to roughly γ_c, and the spectral power at ν_c is approximately $N_e P_{\nu,max}$. We call this the case of *fast cooling*. The flux at the observer F_ν, is given by

$$F_\nu = \left\{\begin{array}{lr} (\nu/\nu_c)^{1/3}F_{\nu,max}, & \nu_c > \nu \\ (\nu/\nu_c)^{-1/2}F_{\nu,max}, & \nu_m > \nu > \nu_c \\ (\nu_m/\nu_c)^{-1/2}(\nu/\nu_m)^{-p/2}F_{\nu,max}, & \nu > \nu_m \end{array}\right\} (5)$$

where $\nu_m \equiv \nu(\gamma_m)$ and $F_{\nu,max} \equiv N_e P_{\nu,max}/4\pi D^2$ is the observed peak flux at distance D from the source.

When $\gamma_c > \gamma_m$, only those electrons with $\gamma_e > \gamma_c$ can cool. We call this *slow cooling*, because the electrons with $\gamma_e \sim \gamma_m$, which form the bulk of the population, do not cool within a time t, and we have

$$F_\nu = \left\{\begin{array}{lr} (\nu/\nu_m)^{1/3}F_{\nu,max}, & \nu_m > \nu \\ (\nu/\nu_m)^{-(p-1)/2}F_{\nu,max}, & \nu_c > \nu > \nu_m \\ (\nu_c/\nu_m)^{-(p-1)/2}(\nu/\nu_c)^{-p/2}F_{\nu,max}, & \nu > \nu_c \end{array}\right\} (6)$$

The typical spectra corresponding to fast and slow cooling are shown in Figures 2a,b. The low-energy part of these spectra has empirical support even within the GRB itself (Cohen et al. 1997). In addition to the various power-law regimes described above, self-

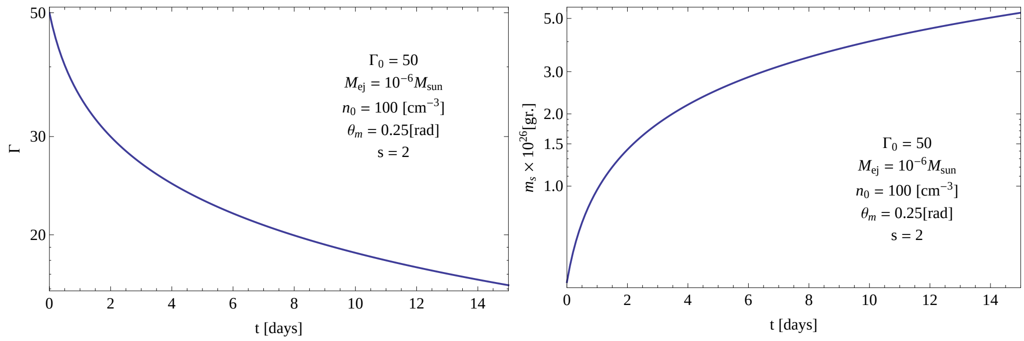

Fig. 1. Evolution of Lorentz factor Γ and shock mass m_s of expanding shock wave.

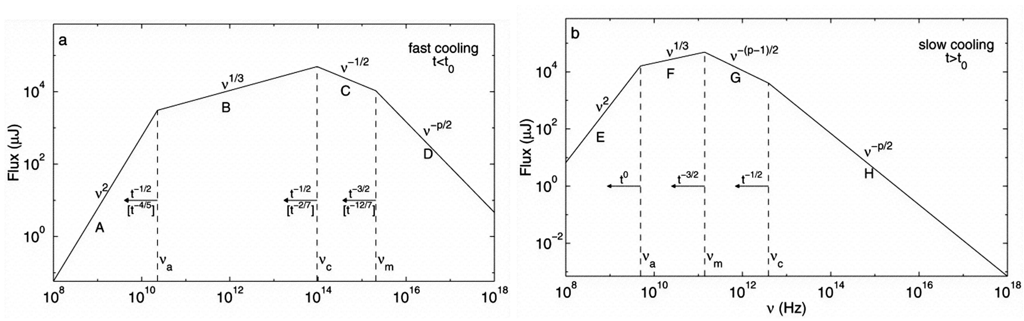

Fig. 2. Synchrotron spectrum of a relativistic shock with a power-law electron distribution. (a) Fast cooling, which is expected at early times $t < t_0$. (b) Slow cooling, which is expected at late times $t > t_0$.

absorption causes a steep cutoff of the spectrum at low frequencies (Katz 1994; Waxman 1997; Katz & Piran 1997).

3. Circumburst environment of GRB progenitors

An emerging feature of GRB progenitor environments is the presence of strong fine structure transitions from excited states of Mg^+,C^+, Si^+, and Fe^+. In contrast to resonance transitions of the dominant ions in neutral gas, these absorption lines can reveal the temperature and density of the gas, as well as the ambient radiation field. In particular, detections of Fe II fine structure transitions have only been reported in rare places such as broad absorption-line (BAL) quasars, η Carinae and the circumstellar disk of β Pictoris. Identifications of strong Fe II fine-structure transitions therefore suggest extreme gas density and temperature in the GRB progenitor environment.

One can examine the excitation mechanism and gas density of the absorbing medium through comparisons of the observed relative abundances between different excited states of the Fe^+ ion. The population ratios between different states are determined based on the balance between excitation and de-excitation rates. When the density is sufficiently large that the collisional de-excitation rates exceed the spontaneous decay rate, the excited states are populated according to a Boltzmann distribution:

$$\frac{n_i}{n_j} = \frac{g_i}{g_j} exp[\frac{E_{ij}}{kT_{ex}}] \tag{7}$$

where g_i is the degeneracy of state i, $E_{ij} \equiv E_i - E_j$ is the difference in energy between the two states, and T_{ex} is the excitation temperature.

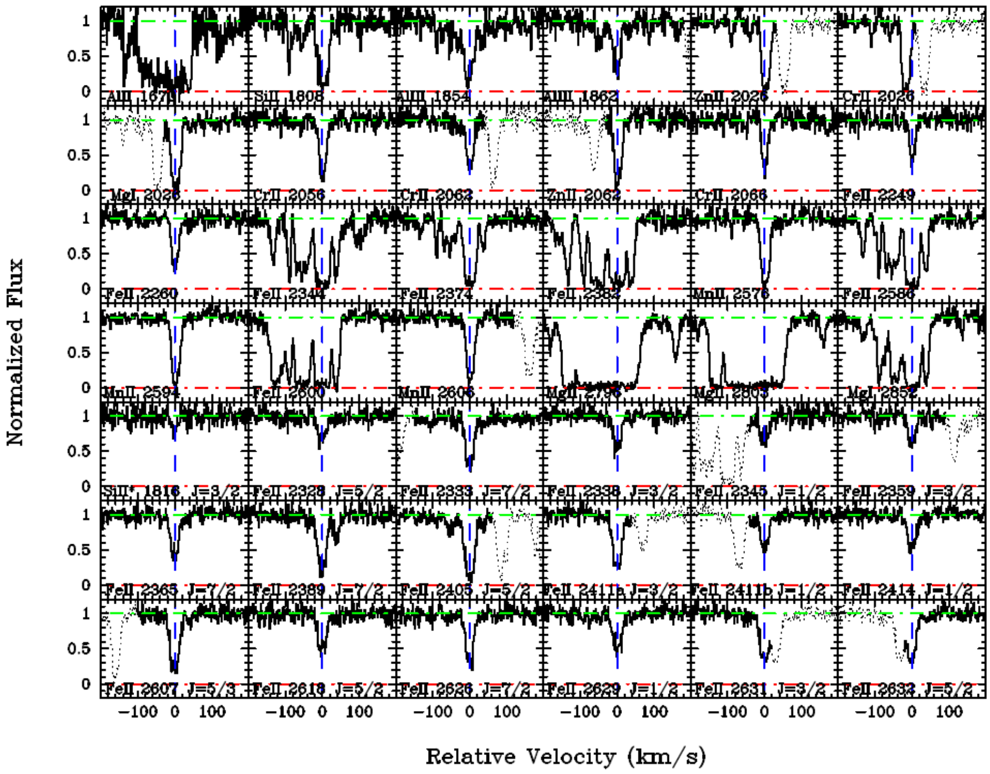

Fig. 3. Absorption profiles of various ionic transitions found at the host redshift of GRB 051111. Resonance transitions are presented in the top four rows, while absorption features from excited Si+, and Fe+ are presented in the bottom three rows. The zero relative velocity corresponds to redshift z=1.54948.

4. Conclusions

The advent of Gamma-ray burst (GRB) exploration in the last 10 years has changed our view of the universe. These highly energetic events have been found over a very large interval of redshift, from the local to z = 6.3 (Kawai et al. 2006). They are so bright that when one of these events occurs, the most remote structures can be temporarily "illuminated" and studied in unprecedented detail (Chen et al. 2005). At z > 1.5, the optical (UV rest frame) afterglows of long duration GRBs are revealing properties of the forming universe never detected before, such as the existence of a population of metal enriched, star-forming and relatively small galaxies (Berger et al. 2006; Fynbo et al. 2006; Savaglio 2006). As bright lighthouses for high-resolution optical spectroscopy, GRBs are now fulfilling their promise as detailed complementary probes of the distant universe. It is only a matter of time when high-resolution spectroscopy at infrared wavelengths will afford a picture of star formation and chemical enrichment in the epoch of reionization.

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