

# The Synchrotron-self-Compton Radiation Accompanying Shallow Decaying X-Ray Afterglow: the Case of GRB 940217 \*

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**Abstract** High energy emission ( $>$  tens MeV) of Gamma-Ray Bursts (GRBs) provides an important clue on the physical processes occurring in GRBs that may be correlated with the GRB early afterglow. A shallow decline phase has been well identified in about half of *Swift* Gamma-ray Burst X-ray afterglows. The widely considered interpretation involves a significant energy injection and possibly time-evolving shock parameter(s). We calculate the synchrotron-self-Compton (SSC) radiation of such an external forward shock and show that it could explain the well-known long term high energy (i.e., tens MeV to GeV) afterglow of GRB 940217. We propose that cooperation of Swift and GLAST will help to reveal the nature of GRBs.

**Key words:** gamma-rays: bursts — ISM: jets and outflows — radiation mechanisms: non-thermal

## 1 INTRODUCTION

Among the high energy (above tens MeV) afterglow of Gamma-ray Burst (GRB) detected so far, that of GRB 940217 is the longest and also the most energetic. The sub-GeV emission lasted more than 5000 seconds and included also an 18 GeV photon (Hurley et al. 1994). The spectrum in the energy range 1 MeV to 18 GeV, cannot be fitted with a simple power law (see fig. 3 of Hurley et al. 1994). A new spectral component in the energy range above several tens MeV is needed. This finding motivates many interesting ideas: (i) interaction of ultra-relativistic protons with a dense cloud (Katz 1994), (ii) synchrotron-self-Compton (SSC) scattering in early forward/reverse shocks or during the prompt emission (Mészáros & Rees 1994) and (iii) an electromagnetic cascade of TeV  $\gamma$ -rays in the infrared/microwave background (Plaga 1995). However, two important observational facts, namely, (a) The count rate of high energy photons is almost a constant; (b) The typical energy of these photons is nearly unchanged, have not been satisfactorily reproduced.

To interpret the unusually high energy afterglow of GRB 940217, we very much need to know the physical processes involved in the early GRB afterglow phase. The successful launch of the *Swift* satellite has opened a new window to reveal what happens in the early GRB afterglow phase. As summarized in Zhang et al. (2006) and Nousek et al. (2006), in a canonical *Swift* GRB X-ray afterglow lightcurve there emerged some interesting features, including the very early sharp decline (phase-I), a shallow decline of the X-ray afterglow (phase-II), and the energetic X-ray flares (phase-V). The interpretation and the implication

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of these features have been discussed in great detail (see Mészáros 2006; Piran & Fan 2007; Zhang 2007, for recent reviews). For Phase-II, which interests us here, a widely considered explanation is a significant energy injection  $dE_{\text{inj}}/dt \propto t^{-q}$  (see Zhang et al. 2006; Nousek et al. 2006, and the references therein). However, an energy injection process, if there is one, does not seem to be the whole story. As shown in Fan & Piran (2006a), for some GRBs with good quality multi-wavelength afterglow data, the X-ray and optical light curves break chromatically and thus challenge the energy injection model (see also Panaitescu et al. 2006; Huang et al. 2007). Recently it is proposed that the early afterglow may arise from reverse shock emission (Genet et al. 2007; Uhm & Beloborodov 2007; Yu & Dai 2007, see also Dai 2004). An assumption additional to the energy injection to solve the puzzle is that the shock parameter(s) may be shock strength dependent (i.e., time-dependent).

In this work, we calculate the synchrotron-self-Compton (SSC) radiation of the external forward shock undergoing a significant energy injection. The shock parameters, the fraction of shock energy given to the shocked electrons ( $\epsilon_e$ ) and to the magnetic field ( $\epsilon_B$ ), are assumed to be time-dependent. We show that the high energy afterglow of GRB 940217 could be given rise to in such a scenario.

## 2 THE SSC EMISSION OF THE FORWARD SHOCK

In this section we calculate the SSC radiation of the external forward shock undergoing a significant energy injection and evolving shock parameters.

### 2.1 The SSC Emission in the Standard Fireball Model

**Synchrotron radiation.** We assume that the electrons accelerated by the shock follow, in the usual way, a power law distribution,  $dn_e/d\gamma_e \propto \gamma_e^{-p}$  for  $\gamma_e > \gamma_m$ , where  $\gamma_m$  is the minimum Lorentz factor of shocked electrons (Sari et al. 1998). Then following Yost et al. (2003) and Fan & Piran (2006), the observed typical frequency of synchrotron radiation is  $\nu_m = 4.2 \times 10^{14} (\frac{1+z}{2})^{1/2} \epsilon_{e,-1}^{1/2} \epsilon_{B,-2}^{1/2} E_{52}^{1/2} t_3^{-3/2}$  Hz, where  $z$  is the redshift of the GRB,  $\epsilon_e$ ,  $E$  the isotropic energy and  $t$  the observer time. Here we have adopted the convention  $Q_x = Q/10^x$  in cgs units throughout the text and taken the spectral index of the electron distribution,  $p = 2.5$ . The observed cooling frequency is  $\nu_c = 4.1 \times 10^{16} (\frac{1+z}{2})^{-1/2} \epsilon_{B,-2}^{-3/2} E_{52}^{-1/2} n^{-1} t_3^{-1/2} (1+Y)^{-2}$  Hz, where  $n$  is the surrounding medium density,  $Y = [-1 + \sqrt{1 + 4x\epsilon_e/\epsilon_B}]/2$  is the Compton parameter and  $x \simeq \min\{1, (\nu_m/\nu_c)^{(p-2)/2}\}$  (Sari & Esin 2001). The peak flux is  $F_{\nu, \text{max}} = 3.2 (\frac{1+z}{2}) \epsilon_{B,-2}^{1/2} E_{52} n^{1/2} D_{28}^{-2}$  mJy, where  $D_{28}$  is the luminosity distance in units of  $10^{28}$  cm. So in the fast cooling phase ( $\nu_c < \nu_m$ ), the light curve is (Sari et al. 1998):  $F_\nu \propto t^{1/6} (1+Y)^{2/3}$  for  $\nu_c > \nu$ ,  $F_\nu \propto t^{-1/4} (1+Y)^{-1}$  for  $\nu_m > \nu > \nu_c$ , and  $F_\nu \propto t^{-(3p-2)/4} (1+Y)^{-1}$  for  $\nu > \nu_m$ . While in the slow cooling phase ( $\nu_c > \nu_m$ ) the light curve is:  $F_\nu \propto t^{1/2}$  for  $\nu_m > \nu$ ,  $F_\nu \propto t^{-3(p-1)/4}$  for  $\nu_c > \nu > \nu_m$ , and  $F_\nu \propto t^{-(3p-2)/4} (1+Y)^{-1}$  for  $\nu > \nu_c$ .

Please note that the previous authors have consistently ignored the evolution of the Compton parameter  $Y$ . However, if  $Y \gg 1$ , then the effect of  $Y$  evolution should be considered. From the relation  $x = \min\{1, (\nu_m/\nu_c)^{(p-2)/2}\}$  we know in the fast cooling phase  $x = 1$  then  $Y$  is independent of the time, while in the slow cooling phase  $Y$  should evolve with time,  $x = (\nu_c/\nu_m)^{-(p-2)/2} \propto (1+Y)^{p-2} t^{-(p-2)/2}$ , then we obtain

$$Y \simeq 10^{\frac{3-p}{4-p}} \left(\frac{1+z}{2}\right)^{\frac{p-2}{2(4-p)}} \epsilon_{e,-1}^{\frac{p-1}{4-p}} \epsilon_{B,-2}^{\frac{p-3}{4-p}} E_{52}^{\frac{p-2}{2(4-p)}} n^{\frac{p-2}{2(4-p)}} t_3^{-\frac{p-2}{2(4-p)}}. \quad (1)$$

So we find  $Y \propto t^{-(p-2)/2(4-p)}$ , then  $\nu_c \propto t^{(3p-8)/2(4-p)}$ , and we have  $F_\nu \propto t^{\frac{3p^2-12p+4}{4(4-p)}}$  for  $\nu > \nu_c$ .

**The SSC emission.** The effect of SSC process on GRB afterglow emission has been discussed by several authors (e.g. Wei & Lu 1998, 2000; Sari & Esin 2001). The typical frequency of SSC emission is

$$\begin{aligned} \nu_m^{\text{IC}} &= 2\gamma_m^2 \nu_m = 3.36 \times 10^{21} \left(\frac{1+z}{2}\right)^{1/2} \\ &\epsilon_{e,-1}^4 \epsilon_{B,-2}^{1/2} E_{52}^{3/4} n^{-1/4} t_3^{-9/4} \text{ Hz}, \end{aligned} \quad (2)$$

where  $\gamma_m = \epsilon_e (\frac{p-2}{p-1}) \frac{m_p}{m_e} \Gamma \simeq 2 \times 10^3 \epsilon_{e,-1} E_{52}^{1/8} n^{-1/8} t_3^{-3/8}$  is the minimum Lorentz factor of the shocked electrons,  $\Gamma$  is the bulk Lorentz factor, the cooling Lorentz factor  $\gamma_c \simeq 2 \times 10^4 \epsilon_{B,-2}^{-1}$

$E_{52}^{-3/8} n^{-5/8} (\frac{1+z}{2})^{-1/2} t_3^{1/8} (1+Y)^{-1}$ . Then the cooling frequency of SSC emission is

$$\begin{aligned} \nu_c^{\text{IC}} &\approx 2\gamma_c^2 \nu_c = 3.28 \times 10^{25} \left(\frac{1+z}{2}\right)^{-3/2} \\ &\epsilon_{B,-2}^{-7/2} E_{52}^{-5/4} n^{-9/4} t_3^{-1/4} (1+Y)^{-4} \text{ Hz.} \end{aligned} \quad (3)$$

The peak flux of the SSC emission is (Sari & Esin 2001)

$$\begin{aligned} F_m^{\text{IC}} &\simeq \frac{1}{3} n \sigma_T r F_{\nu, \text{max}} = 1.2 \times 10^{-13} \left(\frac{1+z}{2}\right) \\ &\epsilon_{B,-2}^{1/2} E_{52}^{5/4} n^{5/4} t_3^{1/4} D_{28}^{-2} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ MeV}^{-1}. \end{aligned} \quad (4)$$

Therefore, in the fast cooling phase, the light curve is

$$F_\nu \propto \begin{cases} t^{1/3} (1+Y)^{4/3}, & \nu_c^{\text{IC}} > \nu, \\ t^{1/8} (1+Y)^{-2}, & \nu_m^{\text{IC}} > \nu > \nu_c^{\text{IC}}, \\ t^{-(9p-10)/8} (1+Y)^{-2}, & \nu > \nu_m^{\text{IC}}, \end{cases} \quad (5)$$

and in the slow cooling phase, the light curve is

$$F_\nu \propto \begin{cases} t, & \nu_m^{\text{IC}} > \nu, \\ t^{-(9p-11)/8}, & \nu_c^{\text{IC}} > \nu > \nu_m^{\text{IC}}, \\ t^{-(9p-10)/8} (1+Y)^{-2}, & \nu > \nu_c^{\text{IC}}. \end{cases} \quad (6)$$

Again, if the  $Y$  evolution is considered, then  $F_\nu \propto t^{(9p^2-38p+24)/8(4-p)}$  for  $\nu > \nu_c^{\text{IC}}$ .

## 2.2 The SSC Emission with Energy Injection and Evolving Shock Parameters

**A. SSC emission when there is energy injection.** In the standard fireball model, the shock energy  $E$  is assumed to be constant. However, there is increasing evidence that the shock energy may increase with time during some period. A good example is the discovery of the ‘‘shallow decay phase’’ in the early X-ray light curves of many GRBs, which is usually attributed to energy injection (Zhang et al. 2006; Nousek et al. 2006). Now we consider the case where there is a significant, continuous injection of energy into the fireball, so the fireball decelerates less rapidly and the afterglow emission shows a slower decline. The dynamical evolution and the synchrotron radiation signature of energy injection have been discussed by many authors (Rees & Mészáros 1998; Dai & Lu 1998; Cohen & Piran 1999; Zhang & Mészáros 2001a; Zhang et al. 2006; Nousek et al. 2006; Fan & Xu 2006). Here we assume the energy injection takes the form  $dE_{\text{inj}}/dt \propto t^{-q}$  (Cohen & Piran 1999; Zhang & Mészáros 2001), then the fireball energy evolves with time as  $E \propto t^{1-q}$ , the fireball radius  $r \propto t^{(2-q)/4}$ , the minimum electron Lorentz factor  $\gamma_m \propto \Gamma \propto t^{-(2+q)/8}$ , the observed typical frequency of synchrotron radiation  $\nu_m \propto \gamma_m^2 B \Gamma \propto t^{-(2+q)/2}$ , the cooling Lorentz factor  $\gamma_c \propto (1+Y)^{-1} t^{(3q-2)/8}$ , the observed cooling frequency of synchrotron radiation  $\nu_c \propto \gamma_c^2 B \Gamma \propto (1+Y)^{-2} t^{-(2-q)/2}$ , and the peak flux  $F_{\nu, \text{max}} \propto N_e B \Gamma \propto t^{1-q}$ . The typical frequency of SSC emission is  $\nu_m^{\text{IC}} \propto \gamma_m^2 \nu_m \propto t^{-3(2+q)/4}$ , the cooling frequency of the SSC emission is  $\nu_c^{\text{IC}} \propto \gamma_c^2 \nu_c \propto (1+Y)^{-4} t^{(5q-6)/4}$ , and the peak flux of the SSC radiation is  $F_m^{\text{IC}} \simeq \frac{1}{3} n \sigma_T r F_{\nu, \text{max}} \propto t^{(6-5q)/4}$ . Using these relations, we can obtain the light curves of synchrotron radiation and SSC emission when there is energy injection.

**B. SSC emission in the case of evolving shock parameters.** In the standard fireball model the shock parameters  $\epsilon_e$  and  $\epsilon_B$  are assumed to be constant, but it is possible that these quantities may vary with time. Yost et al. (2003), Fan & Piran (2006) and Ioka et al. (2006) have considered the afterglow emission in the case of time-dependent  $\epsilon_e$  and  $\epsilon_B$ . By modeling the afterglow of several GRBs, it was found that the values of  $\epsilon_e$  and  $\epsilon_B$  are quite different for the forward shock and the reverse shock (Fan et al. 2002; Zhang, Kobayashi & Mészáros 2003; Kumar & Panaitescu 2003; Wei et al. 2006). We note that the forward shock is ultra-relativistic, while the reverse shock is mildly-relativistic, so this result suggests that the shock parameters may be correlated with the strength of the shock.

**Table 1** Temporal index  $\alpha$  of afterglow emission. Here  $F_\nu \propto t^{-\alpha}$  is adopted. We define  $\alpha = \alpha_0 + \alpha_E + \alpha_v + \alpha_Y$ , where  $\alpha_0$  is the contribution of standard emission,  $\alpha_E$ , that of energy injection,  $\alpha_v$ , that of evolving shock parameters, and  $\alpha_Y$  comes from the evolution of the Compton parameter  $Y$ .

	$\alpha_0$	$\alpha_E$	$\alpha_v$	$\alpha_Y$
<b>Synchrotron radiation slow cooling</b>				
$\nu < \nu_m$	$-\frac{1}{2}$	$-\frac{5(1-q)}{6}$	$\frac{(2a-b)(2+q)}{24}$	0
$\nu_m < \nu < \nu_c$	$\frac{3(p-1)}{4}$	$-\frac{(1-q)(p+3)}{4}$	$\frac{4a(2+q)(p-1)+b(2+q)(p+1)}{32}$	0
$\nu > \nu_c$	$\frac{3p-2}{4}$	$-\frac{(1-q)(p+2)}{4}$	$\frac{4a(2+q)(p-1)+b(2+q)(p-2)}{32}$	$-\frac{4q(p-2)-a(2+q)(p-1)-b(2+q)(p-3)}{8(4-p)}$
<b>Synchrotron radiation fast cooling</b>				
$\nu < \nu_c$	$-\frac{1}{6}$	$-\frac{7(1-q)}{6}$	$-\frac{(2+q)b}{8}$	$-\frac{(2+q)(a-b)}{24}$
$\nu_c < \nu < \nu_m$	$\frac{1}{4}$	$-\frac{3(1-q)}{4}$	$\frac{(2+q)b}{8}$	$\frac{(2+q)(a-b)}{24}$
$\nu > \nu_m$	$\frac{3p-2}{4}$	$-\frac{(1-q)(p+2)}{4}$	$-\frac{4a(2+q)(p-1)+b(2+q)(p-2)}{32}$	$\frac{(2+q)(a-b)}{16}$
<b>SSC emission slow cooling</b>				
$\nu < \nu_m^{\text{IC}}$	-1	$-(1-q)$	$\frac{(2+q)(4a-b)}{24}$	0
$\nu_m^{\text{IC}} < \nu < \nu_c^{\text{IC}}$	$\frac{9p-11}{8}$	$-\frac{(1-q)(3p+7)}{8}$	$\frac{8a(2+q)(p-1)+b(2+q)(p+1)}{32}$	0
$\nu > \nu_c^{\text{IC}}$	$\frac{9p-10}{8}$	$-\frac{(1-q)(3p+2)}{8}$	$\frac{8a(2+q)(p-1)+b(2+q)(6-p)}{32}$	$-\frac{4q(p-2)-a(2+q)(p-1)-b(2+q)(p-3)}{4(4-p)}$
<b>SSC emission fast cooling</b>				
$\nu < \nu_c^{\text{IC}}$	$-\frac{1}{3}$	$-\frac{5(1-q)}{3}$	$-\frac{5b(2+q)}{24}$	$-\frac{(2+q)(a-b)}{12}$
$\nu_c^{\text{IC}} < \nu < \nu_m^{\text{IC}}$	$-\frac{1}{8}$	$-\frac{5(1-q)}{8}$	$\frac{5b(2+q)}{32}$	$\frac{(2+q)(a-b)}{8}$
$\nu > \nu_m^{\text{IC}}$	$\frac{9p-10}{8}$	$-\frac{(1-q)(3p+2)}{8}$	$-\frac{8a(2+q)(p-1)+b(2+q)(6-p)}{32}$	$\frac{(2+q)(a-b)}{8}$

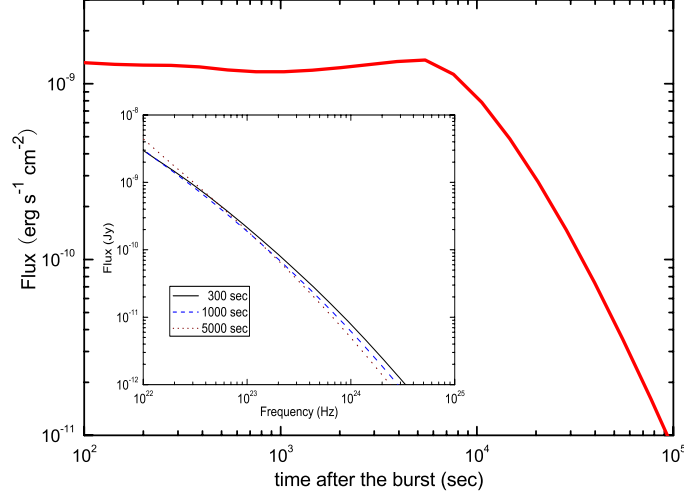
Following Fan & Piran (2006a), here we simply assume  $\epsilon_e \propto \Gamma^{-a}$ ,  $\epsilon_B \propto \Gamma^{-b}$ , and since  $\Gamma \propto t^{-(2+q)/8}$ , so  $\epsilon_e \propto t^{(2+q)a/8}$ ,  $\epsilon_B \propto t^{(2+q)b/8}$ . Then we can obtain the light curve of synchrotron radiation and SSC emission.

**C. SSC emission with both the above effects.** It is also possible that during the shock's evolution, both the shock energy and the shock parameters evolve with time. Based on the previous analysis, we can easily obtain the synchrotron radiation and SSC emission light curves in this case. Table 1 gives the temporal index  $\alpha$  of the afterglow emission, where  $F_\nu \propto t^{-\alpha}$  has been adopted. We define  $\alpha = \alpha_0 + \alpha_E + \alpha_v + \alpha_Y$ , where  $\alpha_0$  corresponds to the contribution of the standard emission,  $\alpha_E$  represents the contribution of the energy injection,  $\alpha_v$  stands for the contribution of the evolving shock parameters, and  $\alpha_Y$  comes from the evolution of the Compton parameter  $Y$ . For example, if we only consider energy injection, then  $\alpha = \alpha_0 + \alpha_E$ . If only evolving shock parameters are considered, then  $\alpha = \alpha_0 + \alpha_v$ , while if both effects are considered, then  $\alpha = \alpha_0 + \alpha_E + \alpha_v$ . Moreover, if  $Y \gg 1$  then the term  $\alpha_Y$  should be included.

### 3 THE CASE OF GRB940217

GRB 940217 is a very famous burst because of its long-lasting high energy afterglow emission (Hurley et al. 1994). The high energy photons ( $E > 30$  MeV) were recorded for about 5400 s, including an 18 GeV photon  $\sim 4500$  s after the low energy emission had ended. The 30 MeV to 30 GeV EGRET spectrum is  $(1.3 \pm 0.4) \times 10^{-8} (E/86 \text{ MeV})^{-2.83 \pm 0.64} \text{ photon cm}^{-2} \text{ s}^{-1} \text{ MeV}^{-1}$ , excluding the 18 GeV photon. By integrating this spectrum, the fluence at  $> 30$  MeV is  $7 \times 10^{-6} \text{ erg cm}^{-2}$ . In addition, for this GRB there are two important observational facts: (a) The count rate of high energy photons is almost a constant; (b) The typical energy of these photons is nearly unchanged. These two facts imply that the flux should be nearly a constant  $\sim 1.4 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$ .

Based on the above analysis, if we assume that the energy injection occurred at time  $t \sim 500$  s, and take the parameters as follows:  $\epsilon_{e,-1} \sim 0.7$ ,  $\epsilon_{B,-2} \sim 0.5$ ,  $n \sim 1$ ,  $E_{52} \sim 5$  and  $z \sim 0.1$ , then at this time, the typical frequency of SSC emission is  $\nu_m^{\text{IC}} \sim 20$  MeV, the cooling frequency of SSC emission is  $\nu_c^{\text{IC}} \sim 60$  GeV, and the peak flux of SSC emission is  $F_m^{\text{IC}} \sim 1.4 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ MeV}^{-1}$ , which agrees well with the observations. Moreover, we note that the observed photon energies lie between  $\nu_m^{\text{IC}}$  and  $\nu_c^{\text{IC}}$ , and since the spectrum is very soft,  $\beta = 1.83 \pm 0.64$ , the index of electron distribution is  $p \sim 4$ . From Table 1 we can find that, in the standard case, the flux would decrease with time as  $t^{-25/8}$ , which is obviously inconsistent with the observations. If we consider energy injection, then  $F_\nu \propto t^{-(6+19q)/8}$ , and since  $0 < q < 1$ , the flux would decay more steeply than  $t^{-3/4}$ , which is still inconsistent with the



**Fig. 1** SSC radiation of the forward shock undergoing energy injection with evolving shock parameters, the case of GRB 940217: the thick solid line is the light curve and the insert plot is the spectrum (the times have been marked in the plot) in the energy range of 30 MeV – 30 GeV. For  $10 \text{ s} < t < 5000 \text{ s}$ , the energy injection is taken to be of the form  $dE/dt = 4 \times 10^{50} (t/10\text{s})^{-0.55}$  and  $\epsilon_e = 0.06 (t/5000 \text{ s})^{0.4}$ . At late times, the energy injection disappears and  $\epsilon_e = 0.06$ . Other parameters involved in the calculation are: the initial kinetic energy  $4 \times 10^{52} \text{ erg}$ ,  $z = 0.1$ ,  $\epsilon_{B,-2} = 0.3$ ,  $p = 4$  and  $\theta_j = 0.2$ .

observations. Therefore, there is only one choice: the shock parameters should evolve with time. If we take  $q \sim 0.5$  (which is suggested by the recent *Swift* XRT data, see Zhang et al. 2006),  $a \sim 1.2$ ,  $b \sim 0$ , then the flux would be nearly a constant, which is agreement with the observations.

In order to investigate the SSC emission more carefully, Fan et al. (2007) have developed a numerical code to calculate the Compton process self-consistently for GRB high energy afterglow emission. Using this code, we calculate the SSC emission numerically, the result is shown in Figure 1, the parameters are: the initial kinetic energy is  $4 \times 10^{52} \text{ erg}$ ,  $n = 1$ ,  $z = 0.1$ ,  $\epsilon_{B,-2} = 0.3$ ,  $p = 4$ , and  $\theta_j = 0.2$ . For  $10 \text{ s} < t < 5000 \text{ s}$ , the energy injection is taken to be of the form  $dE/dt = 4 \times 10^{50} (t/10\text{s})^{-0.55}$  and  $\epsilon_e = 0.06 (t/5000 \text{ s})^{0.4}$ . At late times, the energy injection disappears and  $\epsilon_e = 0.06$ . From Figure 1 we find that the numerical results are consistent with the analytic estimates and can well account for the observations (both the light curve and the spectrum) of GRB940217.

#### 4 DISCUSSION AND CONCLUSIONS

Since its discovery, the long-lasting high energy afterglow emission of GRB 940217 has been extensively discussed (e.g. Katz 1994; Mészáros & Rees 1994; Plaga 1995; Cheng & Cheng 1996; Dermer et al. 2000; Wang et al. 2001; Zhang & Mészáros 2001b; Dai & Lu 2002; Guetta & Granot 2003; Pe’er & Waxman 2004; Wang et al. 2004, 2006; Fan & Piran 2006b). However, in most of these works, the count rate of the high energy emission and the spectrum have not been precisely modelled and their consistency with the data has not been examined. It is therefore not clear that whether or not these models work. For example, Dermer et al. (2000) calculated the synchrotron-self-Compton emission during the blast wave propagation and claimed that the observation have been well reproduced, but their spectrum is very hard, which is inconsistent with the observation of GRB 940217. As shown in Table 1, the flux of the SSC emission should decrease with time as  $t^{-25/8}$  for  $p \sim 4$  that is needed to reproduce the very steep MeV to GeV spectrum, and even when considering the energy injection, the flux would still decay more steeply than  $t^{-3/4}$ . Therefore, the nearly constant high energy flux strongly suggests that other physical processes should be involved,

such as evolution of the shock parameters and/or energy injection considered in this paper. A  $t^{-0.5}$ -like energy injection process lasting  $\sim 10^3 - 10^5$  s is a natural result of the collapsar model, as Zhang et al. (2007) showed. Possible physical scenario giving rise to time-evolving shock parameters is far from clear (Piran & Fan 2007). The peculiar chromatic break, detected in quite a few early X-ray and optical afterglow data (Fan & Piran 2006a), however, did indicate such a possibility. As shown in Ioka et al. (2006),  $a \sim 1.2$  is typical.

In previous analysis, the dependence of the Compton parameter  $Y$  on time has always been ignored. However, from Table 1 we can see that in some cases the influence of and evolving  $Y$  cannot be ignored. For example, in the standard case ( $q = 1$ ,  $a = b = 0$ , i.e., without energy injection and with constant shock parameters), the light curves of synchrotron radiation ( $\nu > \nu_c$ ) and SSC emission ( $\nu > \nu_c^{IC}$ ) will be flattened by  $t^{1/6}$  and  $t^{1/3}$  respectively for  $p = 2.5$ . If  $p = 3$ , then the effect will be more prominent, the light curves of synchrotron radiation ( $\nu > \nu_c$ ) and SSC emission ( $\nu > \nu_c^{IC}$ ) will be flattened by  $t^{1/2}$  and  $t^1$  respectively. So under some circumstances, the effect of an evolving  $Y$  should be considered.

GLAST will be launched soon and it is expected that GLAST will detect high energy emission (20 MeV to 300 GeV) of GRBs, which may open a new window to understand the physical processes occurring in GRBs. We hope that GLAST can detect more events like GRB940217, which will provide key clues on the nature of GRBs (see Fan et al. 2007 for an extensive discussion).

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