CAN THE BUMP BE OBSERVED IN THE EARLY AFTERGLOW OF GRBS WITH X-RAY LINE EMISSION FEATURES?

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ABSTRACT

Extremely powerful emission lines are observed in the X-ray afterglow of several GRBs. The energy contained in the illuminating continuum which is responsible for the line production exceeds $10^{51}$ erg, much higher than that of the collimated GRBs. It constrains the models which explain the production of X-ray emission lines. In this paper, We argue that this energy can come from a continuous postburst outflow. Focusing on a central engine of highly magnetized millisecond pulsar or magnetar we find that afterglow can be affected by the illuminating continuum, and therefore a distinct achromatic bump may be observed in the early afterglow lightcurves. With the luminosity of the continuous outflow which produces the line emission, we define the upper limit of the time when the bump feature appears.

We argue that the reason why the achromatic bumps have not been detected so far is that the bumps should appear at the time too early to be observed.

*Subject headings:* gamma rays: bursts-line: general-radiation mechanisms

1. Introduction

X-ray emission lines observed in the X-ray afterglow of GRBs are important clues for identifying the nature of the progenitors of the long ($t \geq 2s$) GRBs. So far there are at least eight GRBs to show evidence for X-ray emission features in the early afterglow. GRB970508 (Piro et al.1999) and GRB000214 (Antonelli et al.2000) were detected
by Bepposax, GRB970828 (Yoshida et al.2001) by ASCA, GRB991216 (Piro et al.2000) and GRB020813 (Butler et al.2003) by Chandra, GRB011211 (Reeves et al.2002), GRB001025A (Watson et al.2002) and GRB030227 (Watson et al.2003) by XMM-Newton.

Mainly there are two classes of models to explain the X-ray lines in the X-ray afterglow, Geometry Dominated Models (GD models) (eg. Lazzati et al.1999) and Engine Dominated Models (ED models) (eg. Rees & Mészáros 2000, Mészáros & Rees 2001). The main difference between these two classes of models lies on how to explain the observed duration of the line emission and the energy where the X-ray lines come from. The detailed properties of X-ray emission lines can be seen in the paper of Lazzati (2002). We note here that there is a strict constraint on the energy powering the luminous lines in the Geometry Dominated Models. In GD models, since the input energy is taken from GRB or early afterglow continuum, this energy should not be larger than that of the GRB explosion. However in the ED models the energy powering the emission lines is assumed to be provided by a continuous injecting inner engine at the end of the GRB emission instead of turning off abruptly (Rees & Mészáros 2000). So less constraint can be put on the energy in ED models.

It has been pointed out that the emission lines can be used to put a firm lower limit on the energy of the illuminating continuum (Lazzati 2002, Ghisellini et al.2002). These lines last at least several hours. It implies that the energy is of the order of $10^{49}$ erg, therefore the energy contained in the illuminating continuum must exceed $10^{51}$ erg, beyond the energy of the GRBs corrected by the estimate of their degree of collimation (Frail et al.2001, Bloom et al.2003). Therefore, it is difficult to explain the production of the emission lines with the energy of GRBs or the early afterglow continuum.

Rees & Mészáros (2000) considered that an extended, possibly magnetically dominated wind from a GRB impacting the expanding envelope of a massive progenitor can account for the observed emission features. In this case, luminosity as high as $10^{47}$ erg s$^{-1}$ can be produced 1 day after the original explosion and last (but decaying) for enough time to support so high energy of illuminating continuum. It is natural that the Engine Dominated Models can solve the contradiction between the energy obtained from X-ray emission lines and that of the collimated GRBs. But in ED models the afterglow can be affected by the continuous injection.

In this paper we investigate the Engine Dominated Models, focusing on the central engine is a highly magnetized millisecond pulsar or magnetar, following the work of Dai & Lu (1998a, 1998b), who first considered continuous injection from a millisecond pulsar to interpret the afterglow light curves of some GRBs. We also reanalyze the energy limited by the emission features and compare it with that of the collimated GRBs (Frail et al.2001, Bloom et al.2003). The cosmological parameters will be set through this paper to $H_0=65$ km
s^{-1}\text{Mpc}^{-1}, \Omega_m=0.3, \Omega_\Lambda=0.7.

2. Reanalyze the energies of observed emission features

The main information obtained for the seven bursts detected so far is presented in Table 1. The quantities listed in the Table are described as following:

Redshift: GRB000214 did not have a standard optical or radio afterglow and therefore there is no identification of the host galaxy. The value of the redshift of this GRB was inferred from the X-ray line, identified as an iron 6.97 keV emission line.

Line luminosity: The line luminosity listed in the Table 1 is derived under the assumption of isotropic emission. The collimation of the line photon will enhance the observed flux by a factor $4\pi/\Omega_{\text{line}}$ with respect to isotropic emission, which has been discussed by Ghisellini et al. (2002). They found that if electron scattering was important, the amplification of the line could be at most a factor of two.

Time of the line emission: the start time $t_s$ corresponds to the beginning of the emergence in the X-ray observation in the afterglow, while the end time $t_e$ is defined by the time when the line is not detected any longer or the time of the end of the observation though the line can still be detected.

ISM Density: There are only two GRBs (GRB970508 and GRB991216) whose interstellar medium density has been derived. For GRB970508, the ambient medium density was found to be $\sim 1 \text{ cm}^{-3}$ from long time of the radio observation (Frail et al. 2000). The interstellar medium density was calculated to be $4.7 \text{ cm}^{-3}$ by modelling the broadband emission of the afterglow of GRB991216 (Panaitescu & Kumer 2001).

Energy of the observed X-ray line: A line of constant flux comes from GRB000214 (Antonelli et al. 2000). For GRB970508 and GRB011211 the emission lines became undetectable before the end of the X-ray observation, while for GRB020813 the lines could also be detected until the observation ended. For GRB030227, the emission lines were detected only in the final segment of the observation, implying that the lines not only faded but also appeared at a significant time after the GRB. Since we can not know if it is true for other GRBs and can not find out the exact time at which the emission lines appear, we adopt two values of duration of the lines as Ghisellini et al. (2002). The first is assumed that the lines exist only for the time interval $t_e-t_s$ (” short lived” line ), while the second is assumed that the lines remain constant in flux for the interval $t_e-0$ (” long lived ” line ). So two values of the total line energy can be obtained.
Lower limit constraint on the total energy of the burst: Emission lines can be used to constrain the total energy of the burst. In fact, the line energy is only a fraction $\eta_{\text{line}}$ of the illuminating continuum which is in turn a fraction $\eta_x$ of the energy emitted in $\gamma$-ray during the prompt emission. Considering the collimating of the line photons, we take the amplification factor $4\pi/\Omega_{\text{line}}$ with respect to the isotropic case.

In the reflection mechanism the efficiency of the production of line photon $\eta_{\text{line}}$ was computed numerically by Lazzati et al. (2002). The reprocessing efficiency for iron can not be larger than 2%, while the combined light elements, for very small ionization parameters, can reprocess up to 5% of the continuum into soft X-ray narrow lines. $\eta_x \sim 0.05-0.1$ is the value commonly observed during the prompt emission of most bursts, which corresponds to a spectrum $F(\nu) \propto \nu^0$ up to 300 keV (Lazzati 2002). It implicitly assumes that $\eta_x$ is same in the collimated cone. The amplification of the line luminosity after line photons reprocessed by scattering off the funnel wall has been discussed by Ghisellini et al. (2002). No or weak collimation of the line photons is found.

The total energy derived from the emission line can be written as:

$$E_\gamma \geq \frac{2E_{\text{iso}}^{\text{line}} \Omega_{\text{line}}}{\eta_x \eta_{\text{line}} 4\pi} = 500E_{\text{iso}}^{\text{line}}(0.1)(0.02)(\frac{\Omega_{\text{line}}/4\pi}{0.5})$$

(1)

Applying the fiducial values discussed above for the efficiencies involved, we obtain the total energy listed in the Table 1.

For GRB011211 only emission lines of elements lighter than iron can be seen (Reeves et al. 2002). We used $\eta_{\text{line}}=0.05$ to derive the lower limit for the energy radiated in $\gamma$-rays, we then obtain $E_\gamma \gtrsim 5 \times 10^{50}$ erg and $E_\gamma \gtrsim 4.4 \times 10^{51}$ erg for short and long lived line respectively. We find that the lower limit of the energy is about a factor of 4 to 33 larger than the energy estimated by Frail et al. (2001) ($E_\gamma = 1.32 \times 10^{50}$ erg corrected by $\theta_j=3.6$ degree).

For GRB020813, only the exact value of flux of S line can be measured. We derive $E_\gamma \gtrsim 3 \times 10^{51}$ erg and $E_\gamma \gtrsim 6 \times 10^{51}$ erg for short and long lived cases, a factor $\sim$8 to 16 above the estimate of Frail et al. (2001) for this burst.

The lower limit value of energy for GRB030227 is $E_\gamma \gtrsim 2.4 \times 10^{51}$ erg and $E_\gamma \gtrsim 2.1 \times 10^{52}$ erg for short and long lived cases. We do not know the time when the break appeared in the afterglow lightcurves after the trigger. If we take the value of energy for GRB030227 to be $5 \times 10^{50}$ erg (Frail et al. 2001), we find this value is a factor of 5 to 40 smaller than the lower limit of energy derived from the line emission.

The detailed discussion on GRB970508, GRB000214 and GRB991216 has also been made
by Ghisellini et al. (2002).

Compared with the corrected $\gamma$-ray energy of the GRBs (Frail et al. 2001, Bloom et al. 2003), a quite significant discrepancy of the energy can be seen.

Since the GRB explosion energy depends on $n_1^{4+}$, to explain the discrepancy of the energy, Ghisellini et al. (2002) assume that circum-burst density should be $0.1 \times (E_{\gamma}/E_{01})^4 \text{cm}^{-3}$, larger than the values derived from modelling broad-band afterglow light curves (Panaitescu & Kumer 2001).

We consider this energy is attributable to the source of the illuminating continuum which produces the line features and does not come from GRB prompt explosion. A continuous postburst outflow is taken into account for the extremely powerful emission lines.

3. Continuous injection from a highly magnetized millisecond pulsar

A decaying magnetar model was suggested to explain the line emission in the X-ray afterglow (Rees & Mészáros 2000). In this model the outflow after the GRB explosion continues at a diminishing rate for a longer time of hours to days, not as the typical GRB model in which its energy and mass outflow are either a delta or a top-hat function. The prolonged activity could arise either due to a spinning-down millisecond pulsar or to a highly magnetized torus around a black hole, which could produce a luminosity as high as $L_m \sim 10^{47} t_{\text{day}}^{-1.3} \text{ erg s}^{-1}$ even one day after the original explosion to produce the observed lines.

Although the ED models can explain the production of the extremely powerful X-ray lines, it is important to stress that the continuous injection which is reprocessed in the expanding envelope of a massive progenitor to produce the line features can affect the early afterglow lightcurves. In this case, anachromatic bump may be found in the lightcurves of the afterglow.

Considering the central engine that emits an initial impulsive input energy $E_{\text{imp}}$ as well as a continuous luminosity which varies as a power law in the emission time, in which a self-similar blast wave forms at the late times (Blandford & McKee 1976), the differential energy conservation relation (Zhang & Mészáros 2001) is

$$\frac{dE}{dT} = L - k(E/T)$$

Here $L = L_0 (T/T_0)^\eta$ is the intrinsic luminosity of the central engine. The integrated relation is
\[ E = \frac{L_0}{k + q + 1} \left( \frac{T}{T_0} \right)^q T + E_{imp} \left( \frac{T}{T_0} \right)^{-k}, T > T_0 \]  \hfill (3)

when \(1+q+k \neq 0\) (Cohen & Piran 1999, Zhang & Mészáros 2001). Here \(E\) and \(T\) denote the energy and time measured in the observer frame, and \(q\) and \(k\) are dimensionless constants. \(T_0\) is a characteristic timescale for the formation of a self-similar blast wave, which is roughly equal to the time for the external shock to start to decelerate, and \(E_{imp}\) is constant that describes the impulsive energy input. The first term denotes the continuous luminosity injection, and second term takes into account radiative energy losses in the blast wave. A self-similar blast wave is assumed to exist only at \(T > T_0\). Setting \(T = T_0\), total energy at the beginning of the self-similar expansion is \(E_0 = L_0 T_0 / (1+k+q)+E_{imp}\). The first term is the energy from the continuous injection before the self-similar solution starts. The second term is the energy injected impulsively by the initial event. Note that \(1+k+q > 0\), otherwise, \(E_0\) no longer has a clear physical meaning for the first term will be negative.

The total energy \(E\) discussed above may be dominated either by the continuous injection term \((\propto T^{(1+q)})\) or by the impulsive term \((\propto T^{(-k)})\). A distinctive influence will appear on the GRB afterglow lightcurves if the continuous injection term dominates over the impulsive term after a critical time \(T_c\). By equating the injection and impulsive term we can define the critical time \(T_c\),

\[ T_c = \text{Max}\{1, \left[ (1 + k + q) \frac{E_{imp}}{L_0 T_0} \right]\} T_0 \]  \hfill (4)

noticing that \(T_c > T_0\) must be satisfied to ensure that a self-similar solution has already formed when the continuous injection dominates. It is only \(T > T_c\) that the continuous injection would have a distinctive effect on the lightcurves of the afterglow.

We focus the central engine on a highly magnetized millisecond pulsar or magnetar to satisfy that the continuous injection varies as a approximate power law (Dai & Lu 1998a,1998b). The continuous injection into the fireball may be mainly due to electromagnetic dipolar emission. For an electromagnetic-loss-dominated case, the luminosity of dipole radiation is

\[ L_{dil} = L_{em,0} \left( \frac{1}{1 + \frac{T}{T_{em}}} \right)^2 \approx \begin{cases} L_{em,0}, & T \ll T_{em} \\ L_{em,0} \left( \frac{T}{T_{em}} \right)^{-2}, & T \gg T_{em} \end{cases} \]  \hfill (5)

where \(L_{em,0}\) is the initial luminosity of the dipolar spin-down emission. In this case, \(L_0 = L_{em,0}\). \(T_{em}\) is the characteristic timescale for dipolar spin-down and \(T\) can also be defined as the time when the emission lines begin to appear, accordingly \(L_{dil}\) is the luminosity of the
X-ray illuminating continuum which produces the line features just at the time \( T \). \( L_{\text{ill}} \) can also be defined as following:

\[
L_{\text{ill}} = \frac{L_{\text{line}}}{\eta_{\text{line}}} \gtrsim \begin{cases} 50L_{\text{line}}, & \text{Fe line} \\ 20L_{\text{line}}, & \text{soft narrow lines} \end{cases}
\]  

(6)

where \( L_{\text{line}} \) can be derived from observation of the flux of the X-ray emission lines and in this case a solar metallicity is assumed. \( \eta_{\text{line}} \) is estimated in reflect mechanism (Lazzati et al. 2002).

In Eq(5), \( T_{\text{em}} \) can be given by the equation:

\[
T_{\text{em}} = \frac{3c^3 I}{B_5^2 P_0^4 \Omega_0^2} = 2.05 \times 10^5 s (I_{45} B_{p,15}^{-2} P_{0,-3}^{-2} R_6^{-6})
\]

(7)

Here \( B_{p,15} = B_p/(10^{15} \text{G}) \), and \( P_{0,-3} \) is the initial rotation period in units of millisecond, and \( I_{45} \) is the moment of inertia in units of \( 10^{45} \text{ g cm}^2 \), and \( \Omega_0 \) is the initial angular frequency.

And

\[
L_0 = L_{\text{em},0} = \frac{I \Omega_0^2}{2T_{\text{em}}} \simeq 1.0 \times 10^{49} \text{ergs}^{-1} (B_{p,15}^2 P_{0,-3}^{-4} R_6^6)
\]

(8)

During the time interval \( T_c < T < T_{\text{em}} \), one can expect a distinctive achromatic bump to appear in the lightcurves (Zhang & Mészáros 2001).

Considering the pulsar case, in Eq.(5), to derive \( T_c \), we take \( T < T_{\text{em}} \), \( L = L_0 = L_{\text{em},0} \), therefore \( q=0 \) in Eq.(3). Further we assume the blast wave is adiabatic, \( k=0 \). Eq.(4) can be simplified as

\[
T_c = \text{Max}(1, \frac{E_{\text{imp}}}{L_0 T_0}) T_0
\]

(9)

Under the estimation of Eq.(5), considering \( T \) as the time of the lines appearing, we can get \( T \gg T_{\text{em}} \). \( L_{\text{ill}} \) can be taken from Eq.(6). We derive the values of \( B_{p,15} \), \( P_{0,-3} \) and the critical time at which the bump begins to appear. All of them can be found in Table 2.

Since there is no exact value of the GRB explosion energy for GRB030227, we have assumed that the \( \gamma \)-ray energy is \( E_{\gamma} \sim 5 \times 10^{50} \text{ erg} \) (Frail et al. 2001).
4. Discussion

If extremely high energy which accounts for the production of the X-ray line features comes from a continuous postburst outflow from a highly magnetized millisecond pulsar or magnetar, early afterglow light curves may be affected by this continuous postburst outflow and show a distinct, achromatic bump feature. In this case, the afterglow light curves flatten after a critical time $T_c$ (Eq.(9)) and steepen again after a time $T_{em}$ (Eq.(7)). With the flux of X-ray lines and the time when the lines begin to appear, we can obtain the upper limit of the critical time $T_c$ when the bump appears. It should be noted that a solar metallicity is assumed.

We assume the time when Fe line began to appear was $t_s$ in Table 1. Given the value of $\eta_{\text{line}}$ (the efficiency of conversion of the X-ray ionizing continuum into X-ray line photons), $L_{\text{ill}}$ can be estimated by Eq.(6). So the upper limit of critical time $T_c$ can be obtained from Eq.(9).

$\eta_{\text{line}}$ is adopted to be not more than 2%, and from the observed flux of the iron line $F_{\text{line}} = 3.0 \times 10^{-13}$ erg cm$^{-2}$s$^{-1}$, we can obtain $L_{\text{ill}} \gtrsim 6.0 \times 10^{46}$ erg s$^{-1}$ and $T_c \ll 1.1$ hrs for GRB970508. It is much earlier than the time when optical and X-ray afterglow began to be detected (e.g. Fruchter & Pian 1998, Piro et al.1999). So it is too early for the distinctive achromatic bump in the afterglow of GRB970508 to be detected.

The most latest time of the bump to appear is GRB020813 with the critical time $T_c \ll 6.4$ hrs. It should be noticed that there is only one line (S line) with the exact value of flux defined, although Si line was also detected. For this GRB, $\eta_{\text{line}} < 2\%$ is adopted, we obtain the luminosity of S line from the observed flux as $L_{\text{ill}} \gtrsim 1.6 \times 10^{46}$ erg s$^{-1}$.

Recently, Urata et al.(2003) claimed that for GRB020813 they detected an early break around 0.2 days after the burst using the data of V-band optical afterglow observation. They argued that the early break was unlikely to be a jet break but was likely to represent the end of an early bump in the lightcurves. In addition, Li et al.(2003) reported an early break about 0.14 days after the burst based on the R-band data of the KAIT telescope. Although the exact time of the early break does not agree with each other, they claimed the early break is more likely to be ascribed to an early bump emerged in the lightcurve. If these results are true, then it is obvious that the existence of the early break is consistent with what we have predicted above that an achromatic bump would appear at the time $T_c \ll 6.4$ hrs. For the result of $T_{em} \approx 0.2$ days in Urata et al.(2003) paper, we obtained that the continuous injection from GRB020813 would be due to a pulsar with $B_{p,15} \approx 0.68$ and $P_0 \approx 1.98$ ms. $T_c \approx 0.3$ hrs could also be obtained. However, more complete analysis of the V-band data by Gorosabel et al.(2003)(including the data of Urata et al.(2003)) indicated that there is no evidence for the
existence of an early bump break. They obtained a jet break at the time \(0.33 < t_{\text{break},V} < 0.88\) days, in agreement with the results by Covino et al. (2003; \(t_{\text{break},V} = 0.50\) days). If the early bump break reported by Li et al. (2003) and Urata et al. (2003) does not exist, we can conclude that the early bump should appear at the time \(T_{e,m} < 2\) hrs (The optical observation began at the time of 2hrs after the burst (Fox et al.2002)).

For GRB011211, we adopt \(\eta_{\text{line}} < 5\%\) (Lazzati et al.2002). In this case, a very early bump will appear at the critical time \(T_c < 0.5\) hours. The early optical afterglow observation was obtained 6 hours after the bursts (Bloom & Berger 2001). And X-ray afterglow was observed about 11 hours after the burst (Reeves et al.2002). So the bump is too early to be detected.

Same as GRB011211, for GRB030227 we obtain the critical time \(T_c < 0.2\) hrs, but it should be noticed that we assume the fireball energy is \(5 \times 10^{50}\) erg (Frail et al.2001) since we do not know the exact energy of this burst. For GRB030227, early optical afterglow observation was obtained about 2 hours after the burst (Izumiura et al.2003). XMM-Newton began the X-ray afterglow observation 8 hours after the burst (Mereghetti et al.2003, Watson et al.2003). So the bump also can not be detected.

As for GRB970828 and GRB991216, the early bump should appear at the time \(T_c < 4.1\) hrs and 3.5 hrs respectively. For GRB991216, the optical afterglow observation began at about 10.8 hrs after the GRB (Halpern et al.2000), and X-ray afterglow observation is even later (Piro et al.1999). For GRB970828, X-ray afterglow observation began about 1.17 day after the GRB (Yoshida et al.2001) and optical afterglow observation began at 4 hours after the burst (Groot et al.1998). For these two GRBs the observation time is also too late to observe the bump.

However, a slightly weaker luminosity could also explain the Fe line or soft narrow lines if assuming a larger metal abundance. In this case the upper limit of the critical time will be slightly late accordingly, but it is also early enough to evade the detection of the achromatic bump in the GRBs.

5. Conclusions

The line emission features observed in the X-ray afterglow of GRBs are very luminous, and pose strong limit on the energy which produces the line feature. These limits are almost unaffected by the abundance of metals and collimation of the illuminating continuous. If the energy of GRB explosion contributes to the production of the line emission, it leads to much larger densities of the material surrounding the bursts (Ghisellini et al.2002), which is not consistent with the results from broadband spectral fitting (Panaitescu & Kumar 2001).
We consider that the high energy in the illuminating continuum comes from the continuous injection outflow after the GRB explosion. We argue that the constraint on the energy can be avoided.

At the early time of the GRB afterglow, this continuous injection may contribute to the flux of the afterglow, and it will produce a distinct achromatic bump in the light curves. Focusing on a highly magnetized millisecond pulsar or magnetar, we have obtained the critical time when this bump began to appear. For the GRBs discussed above, we find that the bump will appear in the very early afterglow. We hope this bump may be observed by Swift.

In conclusion, we have presented a scenario in which the bump can appear in the early afterglow light curves if we consider a continuous postburst outflow comes from a highly magnetized millisecond pulsar. This scenario can be tested by the observations of Swift satellite in near future.

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Table 1. Properties of the X-ray emission lines detected so far.

| GRB     | Z_{opt} | $E_{\text{line}}^{14}$ | $\epsilon_{\text{line}}$ | $t_s-t_e$ | $L_{44}^{iso}$ | $E_{49}^{iso}$ | $\theta_j$ | n   | $E_{\gamma,50}^{B1c}$ | $E_{\gamma,50}^{B1d}$ | $E_{\gamma,50}^e$ | Ref. |
|---------|---------|------------------------|--------------------------|----------|----------------|----------------|-----------|-----|---------------------|---------------------|-----------------|------|
| 970508  | 0.835   | 30±10                  | 3.4±0.3                  | 6-16     | 12±4           | 2.25-3.6       | 16.7      | 1.00| 2.34                | 3.84                | 110-180         | 1,8,9,10 |
| 970828  | 0.958   | 15±8                   | 5±0.25                   | 32-38    | 8.1±4.3        | 0.9-5          | 4.1       | 5.75| 17.00               | 45-250              | 2,8,9           |       |
| 991216  | 1.02    | 17±5                   | 3.5±0.06                 | 37-40    | 11±3           | 0.6-7.7        | 2.9       | 4.70| 6.95                | 17.07               | 30-380          |       |
| 002124  | 0.46$^a$| 6.7±2.2                | 4.7±0.2                  | 12-41    | 0.6±0.2        | 0.4-0.6        |           |     | 20-30               |                     |                 | 4     |
| 011211  | 2.14    | 4.0±1.6                | Tot$^b$                  | 11-12.4  | 15.6±6.3       | 0.25-2.2       | 3.6       | 1.32| 4.17                | 5-44                | 5,8,9           |       |
| 020813  | 1.254   | 1.6±0.8                | S                        | 21-42.7  | 1.7±0.85       | 0.6-1.2        | 1.8       | 3.66| 11.58               | 30-60               | 6,8,9           |       |
| 030227  | 1.6     | 17.8                   | Tot                      | 19.4-22  | 34.4           | 1.2-10.5       |           |     | 24-210              |                     |                 | 7     |

$^a$This burst does not have an optical determination of the redshift, which is inferred from the X-ray line, identified as a iron Kα line.

$^b$Tot means $\epsilon_{\text{line}}$ is the total energy of soft lines including S, Si, Ar, Mg and Ca.

$^d$total energy of the GRB prompt explosion in units of $10^{50}$ erg corrected by the degree of the collimation by Frail et al. (2001)

$^e$total energy of the GRB prompt explosion in units of $10^{50}$ erg corrected by the degree of the collimation by Bloom et al. (2003)

$^f$total energy in $\gamma$-rays in units of $10^{50}$ erg as measured from the emission lines fluence.

$^f$Two values in this column are corresponding to the short lived line and long lived line respectively.

Note. — The units of $E_{\text{line}}^{14}$, $t_s-t_e$, $L_{44}^{iso}$, $E_{49}^{iso}$, $\theta_j$, and n are erg cm$^{-2}$ s$^{-1}$, keV, hr, s$^{-1}$, erg, degree and cm$^{-3}$. We use the notation $Q=10^x Q_x$. References: 1: Piro et al. 1999; 2: Yoshida et al. 3: Piro et al. 2000; 4: Antonelli et al. 2000; 5: Reeves et al. 2002; 6: Butle 7: Watson et al. 2003; 8: Frail et al. 2001; 9: Bloom et al. 2003; 10: Frail e 11: Panaitescu et al. 2001.
Table 2: Properties of the highly magnetized millisecond pulsar and the critical time of the achromatic bump appearing.

| GRB      | \(L_{ill,46}\) | \(B_{p,15}\) | \(P_{0,-3}\) | \(T_c(h)\) |
|----------|----------------|--------------|--------------|-------------|
| GRB970508 | 6.0            | 1.2          | < 3.97       | < 1.1       |
| GRB970828 | 4.0            | 0.23         | < 2.12       | < 4.1       |
| GRB991216 | 5.5            | 0.21         | < 1.67       | < 3.5       |
| GRB011211 | 7.8            | 0.58         | < 2.56       | < 0.5       |
| GRB020813\(^a\) | 1.6          | 0.68         | < 4.12       | < 6.4       |
| GRB030227\(^b\) | 68.8        | 0.11         | < 0.65       | < 0.2       |

\(^a\)The estimation of the luminosity of the ionizing continuum which produce the emission line feature in this burst is from S line although Si line is also detected. \(\eta_{line}\) is taken to be 2%.

\(^b\)To estimate \(T_c\) we assume the fireball energy of GRB is \(5\times10^{50}\) erg (Frail et al. 2001).