JET LUMINOSITY OF GAMMA-RAY BURSTS: THE BLANDFORD–ZNAJEK MECHANISM VERSUS THE NEUTRINO ANNIHILATION PROCESS

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ABSTRACT

A neutrino-dominated accretion flow (NDAF) around a rotating stellar-mass black hole (BH) is one of the plausible candidates for the central engine of gamma-ray bursts (GRBs). Two mechanisms, i.e., the Blandford–Znajek (BZ) mechanism and the neutrino annihilation process, are generally considered to power GRBs. Using the analytic solutions from Xue et al. and ignoring the effects of the magnetic field configuration, we estimate the BZ and neutrino annihilation luminosities as functions of the disk masses and BH spin parameters to contrast the observational jet luminosities of GRBs. Our results show that although the neutrino annihilation processes could account for most GRBs, the BZ mechanism is more effective, especially for long-duration GRBs. Actually, if the energy of the afterglows and flares of GRBs is included, then the distinction between these two mechanisms is more significant. Furthermore, massive disk mass and high BH spin are beneficial for powering the high luminosities of GRBs. Finally, we discuss possible physical mechanisms that could enhance the disk mass or neutrino emission rate of NDAFs and the relevant difference between these two mechanisms.

Key words: accretion, accretion disks – black hole physics – gamma-ray burst: general – neutrinos

1. INTRODUCTION

The progenitors of short-duration gamma-ray bursts (SGRBs) and long-duration gamma-ray bursts (LGRBs) are, respectively, believed to result from the merger of two compact objects, i.e., two neutron stars (NSs) or a black hole (BH) and a NS, and the core collapse of a massive star (see, e.g., Eichler et al. 1989; Paczynski 1991; Narayan et al. 1992; Woosley 1993; Paczynski 1998). A BH hyperaccretion system is expected to form in the center of gamma-ray bursts (GRBs). This geometrically thick and extremely optically thick hyperaccretion disk with high density and temperature is referred to as the neutrino-dominated accretion flow (NDAF) and has been widely studied, including research on the time-independent radial structure and the relevant Blandford–Znajek (BZ, Blandford & Znajek 1977) or neutrino luminosity (e.g., Popham et al. 1999; Di Matteo et al. 2002; Kohri & Mineshige 2002; Kohri et al. 2005; Gu et al. 2006; Kawanaka & Mineshige 2007; Liu et al. 2007; Lei et al. 2009; Kawanaka et al. 2013; Li & Liu 2013; Luo et al. 2013; Xue et al. 2013), on the time-independent vertical structure and relevant neutrino luminosity (e.g., Liu et al. 2008, 2010a, 2012a, 2013, 2014, 2015a), on the applications to GRB observations (e.g., Reynoso et al. 2006; Lazzati et al. 2008; Liu et al. 2010b, 2012b, 2015b; Barkov & Pozanenko 2011; Sun et al. 2012; Hou et al. 2014a, 2014b), and on the various time-dependent simulations (e.g., Ruffert & Janka 1999; Lee et al. 2004, 2009; Janiuk et al. 2013).

The magnetic field plays an important role in astrophysics, especially in high-energy astrophysics. Without exception, it is also a key role in GRBs. Two scenarios are often discussed for the central engine of GRBs. First, as mentioned above, the hyperaccretion system should launch a relativistic jet to power a GRB, the origin mechanisms of which include neutrino–antineutrino annihilation (e.g., Popham et al. 1999; Liu et al. 2007, 2010a) and magnetohydrodynamical processes such as the BZ process (e.g., Lee et al. 2000a, 2000b; Di Matteo et al. 2002; Kawanaka et al. 2013). Second, apart from NDAF models, the events of the two NS mergers or core collapses may produce massive proto-magnetars to power GRBs and their X-ray flares (e.g., Dai et al. 2006; Metzger et al. 2011; Gao et al. 2013; Kumar & Zhang 2015; Lai 2015; Wang et al. 2015). Although the present GRB observations cannot clearly tell us which candidate certainly exists in the center of GRBs, it is still possible for the BH hyperaccretion process to contrast and identify the BZ mechanism and neutrino annihilation using actual measurements of GRBs. In this paper, we focus on a comparison of the jet luminosity driven by the BZ mechanism and neutrino annihilation by means of observational data of SGRBs and LGRBs. In Section 2, we present our NDAF model and provide the analytic formulae of the BZ jet power and neutrino pair annihilation. In Section 3, we apply these two mechanisms to explain the observational data of GRBs in order to discuss the feasibility of each mechanism. Conclusions and discussion are presented in Section 4.

2. MODELS

In Xue et al. (2013), we investigated one-dimensional global solutions of NDAFs, taking into account general relativity in the Kerr metric, neutrino physics, and nucleosynthesis more precisely than most previous works (e.g, Kohri & Mineshige 2002; Kohri et al. 2005; Kawanaka & Mineshige 2007; Liu et al. 2007). Specifically, we considered the total optical depth for neutrinos including scattering of electrons and nucleons and absorption through four terms, i.e., the Urca processes, electron–positron pair annihilation, nucleon–nucleon bremsstrahlung, and plasmon decay (e.g., Di Matteo et al. 2002; Liu et al. 2007). In order to allow for the transition
from optically thin to optically thick regions, a bridging formula of free protons and neutrons was established using the relations of the reaction rates in \( \beta \) processes. We applied proton-rich material in a state of nuclear statistical equilibrium (Seitenzahl et al. 2008) to the NDAR model, which is suitable for almost the entire range of the electron fraction. The complicated and detailed balance is included under equilibrium for the chemical potential.

We calculated 16 solutions with different characterized mass accretion rates and BH spins, and exhibited the radial distributions of various physical properties in NDARs. Our results showed that the gas pressure and neutrino cooling always become dominant in the inner region for large accretion rates, and the electron degeneracy should not be ignored. The electron fraction is always about 0.46 in the outer region, and the inner, middle, and outer regions are always dominated by the free nucleons, \(^4\)He, and \(^{56}\)Fe.

We also calculated the neutrino luminosity and annihilation luminosity by considering the influence of neutrino trapping and the proportion of heavy nuclei. Even in this case, most of the solutions show annihilation luminosities adequate to satisfy the requirement of the mean luminosity of GRBs. Therefore, we would like to estimate the jet luminosity through the candidate BZ process or neutrino annihilation based on Xue et al. (2013).

### 2.1. BZ Luminosity and Neutrino Annihilation Luminosity

Blandford & Znajek (1977) stated that the rotational energy of a BH can be tremendously extracted to power a Poynting jet via a large-scale poloidal magnetic field threading the horizon of the BH. The BZ luminosity can be estimated as (e.g., Krolik & Piran 2011; Kawanaka et al. 2013)

\[
L_{\text{BZ}} = f(a_\bullet) c R_g^2 \frac{B_{m}^2}{8\pi},
\]

where \(a_\bullet\) is the dimensionless BH spin, \(f(a_\bullet)\) is a factor depending on the specific configuration of the magnetic field (e.g., Blandford & Znajek 1977; Tchekhovskoy et al. 2008; Kawanaka et al. 2013), \(R_g = 2GM/c^2\) is the Schwarzschild radius, \(M\) is the mass of the BH, and \(B_{m}\) is the poloidal magnetic field strength near the horizon. Moreover, information on the magnetic field configuration is included in \(f(a_\bullet)\). For the specified magnetic field geometries, the analytical \(f(a_\bullet)\) were attempted (e.g., Blandford & Znajek 1977; Tchekhovskoy et al. 2008), but these configurations were not required to be consistent with the dynamics of the accretion disk. Many two- or three-dimensional MHD simulations have investigated how a large-scale vertical magnetic field evolves with an accretion disk and which configurations can power a jet (e.g., McKinney & Gammie 2004; Beckwith et al. 2008, 2009; McKinney & Blandford 2009), but the form of \(f(a_\bullet)\) is still unclear. We only know that it is an increasing function of \(a_\bullet\), and it ranges from small values to \(\sim 1\) (Hawley & Krolik 2006). We consider the structure of the magnetic field to be important for the BZ luminosity and the structure of the disk. For simplicity, we assume \(f(a_\bullet) = 1\) similar to the case in Kawanaka et al. (2013), which is suitable for the fast-spinning BH in the center of a GRB.

The magnetic field energy can be estimated by the disk pressure near the horizon \(P_{\text{in}}\) presented as

\[
\beta_h \frac{B_{m}^2}{8\pi} = P_{\text{in}},
\]

where \(\beta_h\) is the ratio of the midplane pressure near the horizon of the BH to the magnetic pressure in the stretched horizon. Following Kawanaka et al. (2013), we also adopt \(\beta_h\) to unity.

Following Xue et al. (2013), we set the BH mass \(M = 3M_\odot\) and the constant viscosity parameter \(\alpha = 0.1\), which are typical settings for GRBs. The analytic formula of the disk pressure near the horizon is a function of the BH spin \(a_\bullet\) \((0 \leq a_\bullet < 1)\) and the dimensionless mass accretion rate \(\dot{m}\) \((\dot{m} \equiv M/M_\odot \text{s}^{-1})\), and \(M\) is the accretion rate), which can be approximated from the data of Xue et al. (2013) as

\[
\log P_{\text{in}} \left(\text{erg cm}^{-3}\right) \approx 30.0 + 1.22a_\bullet + 1.00 \log \dot{m}.
\]

Under the same conditions stated above and considering the effect of neutrino trapping, the analytic formula of the neutrino annihilation luminosity above the accretion flow can be written as a function of the BH spin and accretion rate (Xue et al. 2013):

\[
\log L_{\nu\nu} \left(\text{erg s}^{-1}\right) \approx 49.5 + 2.45a_\bullet + 2.17 \log \dot{m}.
\]

We have verified that these analytic formulae are almost applicable for all mass accretion rates higher than the ignition accretion rate.

In addition, we noted that the BH mass and viscosity parameters significantly affect the structure and components of the disk (e.g., Popham et al. 1999; Chen & Beloborodov 2007). It is worth noting that variation of the viscosity parameter has little effect on the neutrino emission rate in the innermost region \((\lesssim 10 R_g)\) of the disk. In this region, the free protons and neutrons are dominant, and so the neutrino reactions related to the neutrino emission mainly occur here (e.g., Popham et al. 1999; Liu et al. 2007; Li & Liu 2013; Xue et al. 2013). In these cases with different viscosity parameters, the numbers of the launched neutrinos are roughly equal because of the similar temperatures in the innermost regions because the cooling rate of Urca and other processes are mainly related to the temperature of the disk (e.g., Di Matteo et al. 2002). Both the neutrino luminosity and the annihilation luminosity are almost independent of the viscosity value. Zalamea & Beloborodov (2011) also claimed that the uncertainty in the viscosity parameter has almost no effect on the annihilation luminosity. Furthermore, we calculated how the annihilation luminosity was determined by the fundamental parameters of the BH accretion system (Wang et al. 2009). It is shown that the annihilation luminosity is almost independent of \(\alpha\) and is not significantly related to the BH mass if it is set as several solar masses. Here, only the BH spin and accretion rate are taken into account.

### 2.2. Methods

For SGRBs and LGRBs, if we know the isotropic luminosity \(L_{\text{iso}}\) and jet opening angle \(\theta_{\text{jet}}\) or bulk Lorentz factor \(\Gamma\), then the jet luminosity \(L_{\text{jet}}\) can be expressed as

\[
L_{\text{jet}} = L_{\text{iso}} \left(1 - \cos \theta_{\text{jet}}\right) \approx L_{\text{iso}} \Gamma^{-2}.
\]
Moreover, the average accretion rate $\dot{M}$ can be estimated by

$$\dot{M} \approx M_{\text{disk}} (1 + z)/T_{90},$$

where $M_{\text{disk}}$, $T_{90}$, and $z$ are the mass of the disk, and the duration and redshift of the GRB, respectively. Hereafter, we use the dimensionless mass of the disk defined as $m_{\text{disk}} \equiv M_{\text{disk}}/M_\odot$. Once the disk mass and BH spin are given, we can estimate the BZ jet luminosity and neutrino annihilation luminosity using Equations (1) and (4). For convenience, we define a dimensionless parameter $\tau$, $r_1$ and $r_2$ correspond to the neutrino annihilation process and BZ mechanism.

$$r_1 = \log \left( \frac{L_{\text{jet}}}{L_{\nu\nu}} \right),$$

$$r_2 = \log \left( \frac{L_{\text{jet}}}{L_{\text{BZ}}} \right),$$

illustrating which mechanism is suitable for explaining SGRBs or LGRBs. It is difficult to estimate the jet opening angle independent of models, and so we have to replace the angles by the calculative Lorentz factors related to the fireball model. We consider that the jet luminosity calculated from Equation (5) can also generally evaluate the BZ power.

Eichler et al. (1989) proposed that the mergers of two NSs might be candidates to power SGRBs. Subsequently, Ruffert & Janka (1998) reported the results of three-dimensional Newtonian hydrodynamical simulations of the collision of two identical NSs with mass $\sim 1.6 M_\odot$. One of the products might be a BH $\sim 2.5 M_\odot$ surrounded by a disk $\sim 0.1-0.2 M_\odot$. The merger of a NS and a stellar-mass BH also can produce SGRBs (Paczynski 1991; Narayan et al. 1992). The simulations showed that the larger mass of the disk was formed, $\sim 0.5 M_\odot$ (e.g., Kluźniak & Lee 1998; Lee & Kluźniak 1999; Popham et al. 1999; Liu et al. 2012b). Woosley (1993) suggested that the core collapsar could power LGRBs, and the stellar-mass BH hyperaccretion systems might arise in the center (e.g., MacFadyen & Woosley 1999; Zhang et al. 2003), whose disk mass was approximately several solar masses (e.g., Popham et al. 1999). In summary, we assume the typical dimensionless mass of the disk as 0.2, 0.5 and 1, 3 for SGRBs and LGRBs, respectively.

The BH spin parameter is an important ingredient for the occurrence of GRBs (e.g., Janiuk & Proga 2008; Liu et al. 2010a; Xue et al. 2013), so we choose the large spin parameters to be 0.5 and 0.9 in the investigated cases, which are consistent with $f(a_\bullet) = 1$. The detailed definition of $\tau$ for two classes of GRBs, and different typical disk masses and BH spin parameters, are shown in Table 1.

### Table 1: Definition of $\tau$

| Class | $r_1$ | $r_2$ | $r_3$ | $r_4$ | $r_5$ | $r_6$ | $r_7$ | $r_8$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Mechanism | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| $a_\bullet$ | 0.5 | 0.5 | 0.5 | 0.5 | 0.9 | 0.9 | 0.9 | 0.9 |
| $m_{\text{disk}}$ | 0.2 | 0.5 | 0.2 | 0.5 | 0.2 | 0.5 | 0.2 | 0.5 |

#### Notes.

* Class: S—SGRBs; L—LGRBs.

* Mechanism: 1—neutrino annihilation process; 2—BZ mechanism.

3. RESULTS

The parameters of 21 SGRBs and 55 LGRBs in our sample are presented in Tables 2 and 3, respectively, which include the redshift $z$, GRB duration $T_{90}$, isotropic mean gamma-ray luminosity $L_{\text{iso}}$, initial Lorentz factor $\Gamma$, and dimensionless parameters $\tau$ with different disk masses and BH spin parameters as shown in Table 1. The data are taken from Fan & Wei (2011), Lü et al. (2012), Berger (2014) and Tang et al. (2014), and the Lorentz factor of SGRBs cited from Berger (2014) are estimated by the peak time of the afterglow $t_{\text{peak}}$ as well as methods in Fan & Wei (2011) or Lü et al. (2012).

Although the calculative Lorentz factors are related to the fireball model, we consider that the jet luminosity can also roughly evaluate the BZ power.

In these tables, the local durations of SGRBs are shorter than 2 s; conversely, the durations of LGRBs are much longer than 2 s. The Lorentz factors and isotropic luminosities of LGRBs are generally larger than those of SGRBs. The parameters $\tau$ are calculated using Equations (1)–(8) to measure which mechanism is more effective and which set of parameters is more suitable for a certain GRB than the others as well as Figures 1 and 2.

Figures 1 and 2 display the distributions of $\tau$ for SGRBs and LGRBs under the BZ mechanism or neutrino annihilation with different BH spins and disk masses, respectively. No matter what class or what mechanism the GRB is, the larger BH spin or larger disk mass can more effectively produce the jet luminosity of GRBs. For example, for the data of LGRBs and the BZ mechanism, there are only 5 and 3 GRBs with $\tau > -3$ for the case of $m_{\text{disk}} = 1$ and $a_\bullet = 0.5$ and the case of $m_{\text{disk}} = 3$ and $a_\bullet = 0.5$, as the black solid lines shown in Figures 2 (a) and (b). This means that larger disk masses are more conducive for satisfying the energy requirements of GRBs. Also, for the data of LGRBs and BZ mechanism, there are only 3 and 1 GRBs with $\tau > -3$ for the case of $m_{\text{disk}} = 3$ and $a_\bullet = 0.5$ and the case of $m_{\text{disk}} = 3$ and $a_\bullet = 0.9$, as the black solid line and dashed line shown in Figure 2 (b). This means that larger BH spins are more conducive to powering GRBs. From the number distributions in the histograms, the effect of BH spin is more significant than that of disk mass for SGRBs and LGRBs.

More importantly, we should focus on the comparison between the black solid (or dashed) lines and red solid (or dashed) lines in these figures, i.e., the comparison between BZ mechanisms and neutrino annihilation. Obviously, despite the high BH spin and disk mass benefiting the high annihilation luminosity, overall the BZ power is more effective than the annihilation process for both SGRBs and LGRBs. For the SGRB cases of $m_{\text{disk}} = 0.2$ and $a_\bullet = 0.5$, there are 3 and 0 GRBs with $\tau > 0$, respectively, corresponding to the annihilation processes and BZ mechanism, which means that the annihilation process absolutely cannot be the candidate of the central engine in the these three SGRBs. For the SGRB cases with $m_{\text{disk}} = 0.5$ and $a_\bullet = 0.9$, the mean $\tau$ of the BZ mechanism is also much lower than that of the annihilation process. More seriously, for LGRBs, there are more instances which cannot be explained by the annihilation process.
### Table 2: Data of SGRBs

| SGRB     | $z$  | $T_{90}$ (s) | $L_{90}$ (10^{52} erg s^{-1}) | $\Gamma$ | Reference | $\tau_{11}^c$ | $\tau_{12}^c$ | $\tau_{21}^c$ | $\tau_{22}^c$ | $\tau_{11}^b$ | $\tau_{12}^b$ | $\tau_{21}^b$ | $\tau_{22}^b$ |
|----------|------|--------------|-------------------------------|---------|-----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 021211   | 1.006| 2.3          | 0.98                          | 195     | a         | -1.67       | -2.53       | -4.24       | -4.64       | -2.65       | -3.51       | -4.73       | -5.13       |
| 040924   | 0.858| 2.39         | 1.17                          | 490     | a         | -2.28       | -3.15       | -4.92       | -5.31       | -3.26       | -4.13       | -5.40       | -5.80       |
| 050709   | 0.16  | 0.07         | 0.11                          | 4.76    | b         | -2.15       | -3.02       | -3.23       | -3.63       | -3.13       | -4.00       | -3.71       | -4.11       |
| 050724   | 0.257| 3             | 0.02                          | 5       | b         | 0.44        | -0.43       | -2.51       | -2.91       | -0.54       | -1.41       | -3.00       | -3.39       |
| 051210   | 1.3   | 1.3          | 0.63                          | 39.34   | c         | -1.14       | -2.00       | -3.35       | -3.75       | -2.12       | -2.98       | -3.84       | -4.24       |
| 051221A  | 0.55  | 1.4          | 0.27                          | 10      | b         | 0.12        | -0.74       | -2.33       | -2.73       | -0.86       | -1.72       | -2.82       | -3.22       |
| 060313   | 1.7   | 0.7          | 31.09                         | 7.05    | c         | 1.32        | 0.45        | -0.50       | -0.90       | 0.34        | -0.53       | -0.99       | -1.39       |
| 061201   | 0.4377| 0.4          | 0.75                          | 9.09    | b         | -0.45       | -1.32       | -2.31       | -2.70       | -1.43       | -2.30       | -2.79       | -3.19       |
| 061201    | 0.11  | 0.8          | 0.01                          | 3.52    | c         | -0.50       | -1.37       | -2.84       | -3.24       | -1.48       | -2.35       | -3.33       | -3.73       |
| 070714B  | 0.92  | 3            | 0.08                          | 12.5    | b         | -0.10       | -0.96       | -2.83       | -3.23       | -1.08       | -1.94       | -3.31       | -3.71       |
| 070724A  | 0.46  | 0.4          | 0.06                          | 3.5     | c         | 0.76        | -1.62       | -2.60       | -3.00       | -1.74       | -2.60       | -3.09       | -3.49       |
| 070809   | 0.47  | 1.3          | 0.04                          | 8.04    | c         | -0.33       | -1.20       | -2.78       | -3.17       | -1.31       | -2.18       | -3.26       | -3.66       |
| 071112c  | 0.82  | 0.3          | 0.51                          | 6       | c         | -0.75       | -1.62       | -2.34       | -2.74       | -1.73       | -2.60       | -2.83       | -3.22       |
| 071227   | 0.381 | 1.8          | 0.04                          | 11.11   | b         | -0.40       | -1.27       | -3.04       | -3.44       | -1.38       | -2.25       | -3.53       | -3.92       |
| 080905A  | 0.12  | 1            | 0.01                          | 11.18   | c         | -1.69       | -2.55       | -4.13       | -4.53       | -2.67       | -3.53       | -4.62       | -5.02       |
| 090426   | 2.609 | 1.25         | 0.87                          | 16.67   | b         | -0.71       | -1.58       | -2.68       | -3.08       | -1.69       | -2.56       | -3.17       | -3.56       |
| 090510   | 0.903 | 0.3          | 40.3                          | 123     | b         | -1.52       | -2.39       | -3.09       | -3.49       | -2.50       | -3.37       | -3.57       | -3.97       |
| 090515   | 0.4   | 0.04         | 0.30                          | 30.99   | c         | -4.07       | -4.94       | -4.77       | -5.16       | -5.05       | -5.92       | -5.25       | -5.65       |
| 100117A  | 0.92  | 0.3          | 1.30                          | 37.23   | c         | -1.98       | -2.85       | -3.54       | -3.94       | -2.96       | -3.83       | -4.03       | -4.43       |
| 100625A  | 0.45  | 0.3          | 0.57                          | 19.07   | c         | -1.50       | -2.36       | -3.20       | -3.60       | -2.48       | -3.34       | -3.69       | -4.08       |
| 100816A  | 0.8035| 2.8          | 0.37                          | 100     | b         | -1.22       | -2.08       | -3.95       | -4.35       | -2.20       | -3.06       | -4.44       | -4.83       |

**References.** (a) Lü et al. (2012), (b) Fan & Wei (2011), (c) Berger (2014).
outflow for the angular momentum transfer, which also caused mass loss from the disk (Liu et al. 2012b). Furthermore, for NDAFs, the high accretion rate leads to the violent evolution of the mass and spin of the central BH, which should also affect the neutrino radiation rate from the disk. In the future, we will calculate the co-evolution of a BH and its surrounding NDAF to present a more complete picture of what truly happens in the centers of GRBs.

4.2. Neutrino Emission Rate

Recently, Jiang et al. (2014) studied BH super-Eddington accretion flows using a global three-dimensional radiation
magnetohydrodynamical simulation. They found that the vertical advection of radiation caused by magnetic buoyancy can effectively transport energy to increase photon emission. A similar mechanism may exist in NDAF models, which can increase the neutrino emission rate. Similarly, Liu et al. (2015a) investigated the effects of the vertical convection on the structure and luminosity of NDAF. Since the gas and neutrinos are carried to the nearby disk surface, and the convective energy transferred in the vertical direction can be effective at suppressing the advection, the neutrino luminosity and annihilation luminosity are increased by more than an order of magnitude for $M \gtrsim 1 M_\odot \, \text{s}^{-1}$, which is conducive to achieving the energy requirement of GRBs.

Furthermore, Lei et al. (2009) and Luo et al. (2013) studied the NDAF model with magnetic coupling between the inner disk and BH. In this framework, the angular momentum and energy can be transferred from the horizon of the BH to the disk. Thus, the neutrino luminosity and relevant annihilation luminosity can be significantly enhanced to power the high luminosities of GRBs.

### 4.3. Polarization

If the jet powering the prompt emission and late X-ray flares of GRBs is launched by magnetic fields, then GRBs are expected to be the astronomical candidate sources of linear polarization (e.g., Fan et al. 2005; Mao & Wang 2013). Mundell et al. (2013) reported the detection of degrees of linear polarization of about 28% in the afterglow of LGRB GRB 120308, which might indicate that large-scale magnetic fields were present in the GRB jets (Lai 2015). Whether or not high polarizations do exist in all GRB jets, future GRB observations by the POLAR detector may further test this possibility and identify the BZ mechanism and neutrino annihilation process.

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