Expected Event Rate of Subhundred-GeV Gamma Ray Bursts using the Tibet-III Air Shower Array with Single Particle Counting Technique

The Tibet ASγ Collaboration

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Abstract

We calculate the expected event rate of subhundred-GeV gamma-ray bursts using the Tibet-III air shower array with single particle counting technique. The calculation is done under reasonable assumptions that the attenuation effect of gamma rays in the intergalactic space as well as the distributions of redshift, luminosity and emission time of GRBs.

1. Introduction

One of mysteries with respect to gamma ray bursts (GRBs) is their maximum energy released in GRB. Among EGRET observations of GRBs, photons >1 GeV were detected in 3 observations. So far, 18 GeV photon detected in association with GRB940217[1] is the highest energy one observed in GRB. However, sensitivity of EGRET to gamma rays was in the energy region 30 MeV - 30 GeV. Hence, it can not be ruled out that higher energy gamma rays did not arrive at the earth. Since EGRET re-entered the atmosphere on 2000 June 4, there has been no way to detect gamma rays in the GeV energy region in space. However,

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according to Vernetto[2], it is possible to detect 1 GeV - 1 TeV gamma rays using ground-based extensive air shower array with single particle counting technique. In addition, Totani[3] has proposed that TeV gamma-ray emission from GRB is detectable on the ground, originating from synchrotron radiation process of protons accelerated up to $\sim 10^{21}$eV via external shock in afterglow phase. Therefore, it is very important to continuously observe 1 GeV - 1 TeV gamma rays from GRB on the ground for the purpose of studying absorption of high-energy gamma rays in the intergalactic space via interactions with intergalactic infrared radiations[4] as well as emission mechanism of very high-energy(VHE) gamma rays at source.

2. Experiment using single particle counting technique

The Tibet-III air shower array located at 4300 m above sea level in Tibet, China has been in operation since fall 2002 with 733 plastic scintillation counters. Each counter is 0.5 m^2 in area $\times$ 3 cm in thickness and deployed with 7.5 m spacing. The total photosensitive area thus amounts to 370 m^2. Details of the Tibet-III air shower array is found elsewhere[5].

Taking advantage of high altitude as well as large photosensitive area, it is possible to observe subhundred-GeV gamma rays with single particle counting technique instead of normal trigger mode (4-fold coincidence). Here, it is worthwhile to mention that gamma rays >1 TeV from GRB can be detected efficiently by our normal 4-fold coincidence trigger mode since it has the capability of rejecting cosmic ray background using information on arrival direction, while the single particle counting technique loses directional information.

The observation with single particle counting technique has started with a CAMAC scaler module, which records number of events/1ms for two trigger modes, '*any1*'(= single particle counting technique) and '*any2*', where *any1* represents *any 1* hit detector with discriminator level equivalent to 0.6 particle among all and *any2* represents the 2-fold coincidence of any hit detectors among all. The counting rate is 180 kHz for *any1* and 26 kHz for *any2*, respectively. In the future, it is planned to install FlashADCs instead of simple scaler for the purpose of discriminating possible noises.

3. Calculation of expected event rate of GRBs using the Tibet-III air shower array

In order to evaluate expected event rate of 1 GeV - 1 TeV GRBs, the following assumptions are made in the calculation.

At first, the redshift(z) distribution of GRBs is assumed to be uniform between 0 - 5. As there have been only $\sim$ 20 GRBs observed with known redshift so far, it is difficult to derive real redshift distribution due to such low statistics. Next, the luminosity(L) distribution of GRBs is assumed to be a power-law function($\propto$ L$^{-\beta}$) between 10^{50}erg/s and 10^{56}erg/s. Finally, T90(Δt_{90}), which is defined by the BATSE group[6], is employed as emission time of gamma rays isotropic at source.

For estimating the expected *any1* and *any2* counting rates using the Tibet-III air shower array, the effective area for gamma rays is calculated by a Monte Carlo(MC) simulation. Primary gamma rays with power-law index of -2.0 is assumed in the energy range between 1 GeV - 100 TeV at the top of the atmosphere. The primary gamma rays are generated by CORSIKA 6004[7]. As a result of the MC simulation, the effective area is obtained. At 100 GeV, the effective area turned out to be 1,000 m^2 for the *any1* mode and 400 m^2 for the *any2* mode, respectively.

Under these assumptions and with the effective area, the expected event rate of GRB can be estimated. Hereafter, $>10\ \sigma$ level significance during 1-sec observation in the *any 1* mode is required to 'claim positive detection of a GRB'. The actual procedures of the simulation is the following. In the first place, redshift, luminosity and emission time are randomly determined under the assumed distributions. Then, the optical depth of 1GeV - 1TeV gamma rays emitted from a source with the determined redshift is calculated in order to include the intergalactic attenuation effect. The calculation of optical depth needs the Hubble constant and Ω parameters(Ω_l and Ω_m), which are 71 km/s/Mpc, 0.7 and 0.3, respectively. Subsequently, the counting rate and corresponding significance are calculated. In calculating the significance, the actual background counting rate of the *any1* mode(180kHz) is used. Therefore, 1 σ equals to $\sqrt{1.8 \times 10^5}$. Significance is defined as $N_o/\sqrt{1.8 \times 10^5}$, where N_o is the expected counting rate by a GRB in the *any1* mode.

Figure 1 shows the result of the simulation. The left panel in Figure 1 demonstrates the total energy of detected GRBs as a function of redshift. The total energy is evaluated by a formula of $L \times \Delta t_{90}/(z+1)$. As shown in the figure, in fact, the Tibet-III air shower array with single particle counting technique is sensitive to nearby GRBs up to $z \sim 0.2$ with total energy $\sim 10^{56}$erg. It is uncertain whether a GRB with such high total energy exists or not. However, if one takes into account strong beaming effect, it may be not unreasonable to expect it. The right panel in Figure 1 shows the expected detection rate of GRBs. The horizontal and vertical axes indicate the power-law index of the luminosity function and the event rate per year. Here, in calculating the event rate, the total number of GRBs per year is assumed to be 1000. From the figure, in the standard case($\beta \sim 2$), the expected event rate turns out to be ~ 0.1 /year.

4. Summary and future work

The expected event rate of GRBs by the Tibet-III air shower array with the single particle counting technique is evaluated under reasonable assumptions and

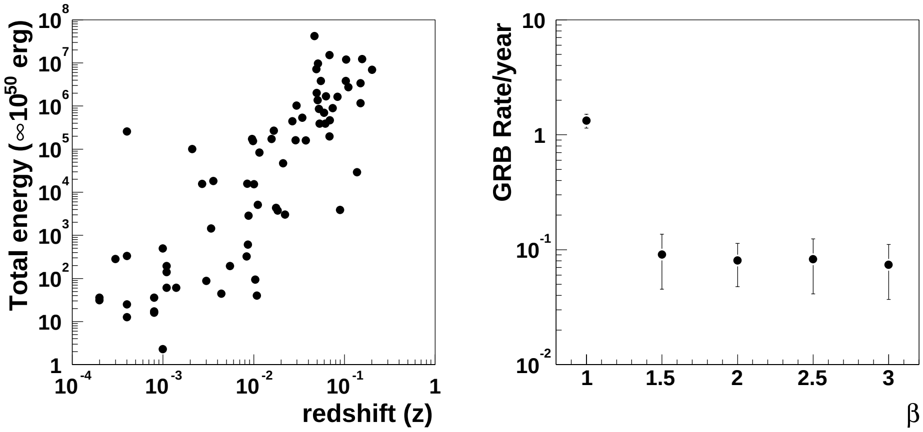

Fig. 1. Results of the GRB simulation. See text for detail.

found to be ~ 0.1 /year. So far, there are few observations of gamma rays at GeV - TeV energies on the ground in association with GRBs. However, the continuous observation using ground-based extensive air shower array is indispensable to elucidate the mechanism of VHE gamma-ray emission from GRBs. The Tibet-III has been in operation with single particle counting technique since fall 2002, aiming at detection of subhundred GeV gamma rays from GRBs.

We are now carefully analyzing interesting data taken on/after March 29, 2003, when a huge GRB(GRB030329) occurred[8]. The zenith angle of the GRB was very large($\sim 60°$) at onset time of the GRB, while in subsequent afterglow phase the observation condition became better since the GRB was coming up to the zenith.

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References

1. Hurley K. et al. 1994, Nature 372, 652
2. Vernetto S. 2000, Astropart. Phys. 13, 75
3. Totani T. 1998, ApJ 502, L13; Totani T. 1998, ApJ 509, L81
4. Salamon M.H. & Stecker F.W. 1998, ApJ 493, 547
5. Amenomori M. et al. 2001, Proc. 27th ICRC, 2, 573
6. Preece R.D. et al. 2000, ApJS 126, 19
7. Heck D. et al. 1998, Forschungszentrum Karlsruhe Report FZKA 6019
8. Caldwell N. et al. 2003, GCN 2053