Search for Gamma-Ray Emission from SNRs with the Tibet Air Shower Array

The Tibet ASγ Collaboration

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Abstract

Supernova remnants (SNRs) are believed to be responsible for accelerating particles up to energies of at least 100 TeV, and a fraction of the accelerated particles would interact within SNR and produce high energy gamma-rays. Using the data obtained from the Tibet air-shower array at Yangbajing, we have searched for multi-TeV gamma-ray emission from 27 SNRs located within 10 kpc distance in the declination band of $-10°$ to $+70°$. No significant DC excess was found from any of these SNRs except from the Crab Nebula.

1. Introduction

It is widely believed that expanding supernova remnants (SNRs) are sites for acceleration of cosmic rays with the energy up to at least 100 TeV. One should expect to detect high-energy gamma-rays initiated by interactions of cosmic rays with matter in SNRs[1,2]. Searches for such gamma-rays in the TeV energy region have been so far performed with atmospheric Čerenkov telescope techniques. There are some ambiguities in such intensities determined because that those observations much depend on atmospheric conditions.

A high-density air-shower array (HD array) has been successfully operating in Tibet since 1996. Highly unambiguous observations of multi-TeV gamma-rays has been realized by using this array. In this paper we present the results given by this array on the search for gamma-ray emission from 27 SNRs.

2. Experiment

The Tibet air shower array shown in Fig. 1 is located at Yangbajing (4300 m a.s.l., 606 g/cm^2, 90.52°E, 30.11°N) in Tibet, China. The HD array consists of 109 scintillation counters of 0.5 m^2 each placed in a lattice with a spacing of 7.5 m, covering an area of 5,175 m^2.

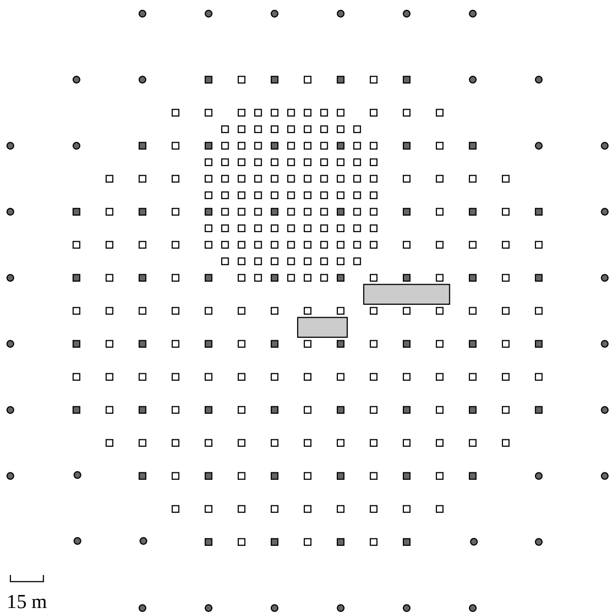

Fig. 1. Schematical view of the Tibet air shower array. Closed and open squares are equipped with fast response photomultipliers (FT-detectors). Closed circles are equipped with wide range photomultipliers (D-detectors). The dense part in arrangement indicates the HD array.

This array allows us to detect small air showers initiated by cosmic-ray particles and cosmic gamma-rays with the energy around 3 TeV with an angular resolution better than 1°. The shower energy determined has been confirmed by observing the shift of the moon shadow due to the Earth's magnetic field[3]. This is the first success in the energy calibration of air showers in the multi-TeV region.

The original air shower data in the HD array were taken at a triggering rate of about 110 Hz in average under any 4-fold coincidence of FT-detectors. The dead time of the system is estimated to be about 10 % of the total running time.

3. Analysis

The analysis was made by using the data set taken during the period from November 1996 through June 1998. The effective running time is about 359 days.

We first selected the data from the original data set by imposing the following conditions: 1) Each of any four detectors out of every FT-detectors should detect signal more than 1.25 particles. 2) The sum of signals should be greater than 7.5 particles. 3) At least two detectors of highest four signals should be in the inside of the border FT-detectors of the HD array. 4) The zenith angle of incident direction should be less than 50°.

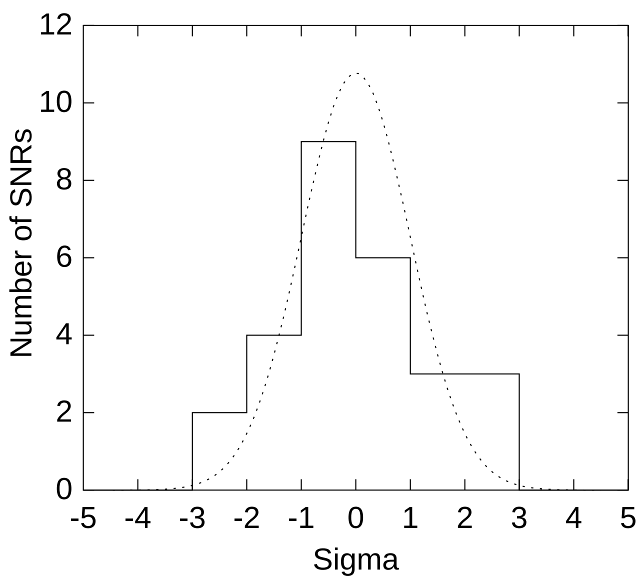

Fig. 2. Distribution of significance of 27 SNRs.

The number of air shower events selected is about 1.29×10^9.

An equi-zenithal scan method was used to search for a gamma-ray emission from each object. That is, we counted the number of showers contained in a circle of a certain apparent radius from the source direction. The background number of events was evaluated from events falling into the five windows adjacent to the source window on both the east and west sides at the same zenith angle. A comparison of the number of events between into the source and into the background windows was made to examine an excess of signals from the source direction.

According to the angular resolution of the HD array, one should set the window size for a circle of an apparent radius of 0.8° in the search for gamma-ray signals from a point source with the highest statistical significance[3]. In order to observe spread SNRs, we used the window size of a 1° radius in the present analysis.

4. Results and Discussion

Search for continuous emission was made for 28 SNRs located within 10 kpc distance in the declination band of -10° to $+70^\circ$ in referring to the Green's Catalog[4]. These are classified into three types and 23 SNRs belong to the S type.

A statistical significance was evaluated for each SNR except for the Crab Nebula, as shown in Fig. 2. No excellent excess was found for steady emission of 3 TeV gamma-rays from any object of these SNRs except from the Crab Nebula. The detailed results on the Crab Nebula appear in another paper[3]. The mean value of significance is estimated to be -0.10 ± 0.26.

Some of these SNRs have the source regions spread widely. There is a possibility of misdirecting in the analysis for such widely spread sources. Also, it is hard to detect gamma-rays from distant sources. Only nearby small-sized SNRs are listed in Table 1. The distances of the SNRs in the table are less than 5 kpc and their apertures are smaller than 1°. In the table are given the number of counts in each background window, the statistical significance and the flux upper limit at the 90% confidence level in the energy larger than 3 TeV. The flux values are estimated by a simulation calculation assuming a differential power-law spectrum of the form of $E^{-2.5}$[3]. It seems in the table that there is no correlation between significance and distance.

Table 1.

R.A.	Decl.		Type	kpc	N_b	σ	Flux*
6.33	64.14	Tycho	S	2.3	109891	−1.04	< 6.07
22.09	63.18	R5	S	1.2	116002	−0.57	< 6.75
31.42	64.82	3C58	F	3.2	104711	0.48	< 1.09
81.65	42.91		S	4.5	229543	−1.49	< 2.40
94.26	22.58	IC443	S	0.7	224200	2.12	< 5.16
284.01	1.37	W44	S	3	108454	0.09	< 8.03
290.95	14.10	W51	S	4.1	187179	−0.69	< 3.71
296.99	27.73		F	3.8	213561	1.07	< 4.35
350.86	58.81	Cas A	S	2.8	146755	−0.56	< 5.41
359.80	62.44	CTB 1	S	2.7	121732	−0.08	< 7.72

*Flux limits at 90 % confidence level in the unit of 10^{-12} cm^{-2} s^{-1}.

According to a simple model of shock acceleration in typical SNRs[1,2], the intensity of gamma-rays is expected to be a flux level of 10^{-11} cm^{-2} s^{-1} in the energy region greater than 3 TeV from a SNR of 3 kpc distant. The observation with the Tibet HD array seems to reach such level. The Whipple group reported the upper limits on the flux of gamma-rays of about 300 GeV given from the observations with an atmospheric Čerenkov telescope[5] and discussed their results in comparison with the EGRET data. Under the assumption that the EGRET data give evidence for acceleration of cosmic rays, the present results on the flux upper limits lie slightly below the corresponding expected values, same as the Whipple's ones.

Next November, we will start to operate the HD array enlarged by a factor of about five. Using this array, the statistics would be much improved in the near future.

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