# Survey of Supernova Remnants to Search for Emission of 10 TeV Gamma Rays

The Tibet AS$\gamma$ Collaboration

M.Amenomori[1], Z.Cao[2], B.Z.Dai[3], L.K.Ding[2], Y.X.Feng[3], Z.Y.Feng[4], K.Hibino[5], N.Hotta[6], Q.Huang[4], A.X.Huo[2], H.Y.Jia[4], G.Z.Jiang[4], S.Q.Jiao[4], F.Kajino[7], K.Kasahara[5], Labaciren[8], S.M.Liu[2], Y.Matsui[7], D.M.Mei[8], L.Meng[2], X.R.Meng[8], Mimaciren[8], K.Mizutani[9], J.Mu[3], H.Nanjo[1], M.Nishizawa[10], A.Oguro[9], M.Ohnishi[10], I.Ohta[6], T.Ouchi[10], J.R.Ren[2], To.Saito[11], M.Sakata[7], Z.Z.Shi[2], M.Shibata[12], T.Shirai[5], H.Sugimoto[13], X.X.Sun[2], K.Taira[13], Y.H.Tan[2], N.Tateyama[5], S.Torii[5], M.Tsukamoto[7], H.Wang[2], C.Z.Wen[4], Y.Yamamoto[7], G.C.Yu[4], P.Yuan[2], T.Yuda[10], C.S.Zhang[2], H.M.Zhang[2], L.Zhang[3], Zhasang[8], Zhaxiciren[8] and W.D.Zhou[3]

[1] Department of Physics, Hirosaki University, Japan ; [2] Institute of High Energy Physics, Academia Sinica, China ; [3] Department of Physics, Yunnan University, China ; [4] Department of Physics, South West Jiaotong University, China ; [5] Faculty of Engineering, Kanagawa University, Japan ; [6] Faculty of Education, Utsunomiya University, Japan ; [7] Department of Physics, Konan University, Japan ; [8] Department of Mathematics and Physics, Tibet University, China ; [9] Department of Physics, Saitama University, Japan ; [10] Institute for Cosmic Ray Research, University of Tokyo, Japan ; [11] Tokyo Metropolitan College of Aeronautical Engineering, Japan ; [12] Faculty of Education, Yokohama National University, Japan ; [13] Shonan Institute of Technology, Japan

## Abstract

We have searched for emission of 10 TeV gamma rays from the direction of 20 SNRs in the nothern sky (declination: +1.3~+64.6), using the data taken in the period from 1990 June through 1991 April with the Tibet Air Shower array. DC significance of excess events to the background was examined on each source to search for evidence of gamma-ray emissions. No obvious DC excess is found from these sources.

## 1. Introduction

It is widely believed that the Galactic cosmic rays in the energy region of $< 10^{14}$ eV have their origin in supernova remnants (SNRs). These cosmic rays are considered to be accelerated by the first order Fermi process at the shocks of SNRs. Recently, Naito and Takahara (1994) have suggested that high energy gamma rays are expected to be efficiently generated through the decay of neutral pions produced by interactions of cosmic rays with dense gas and cosmic rays in SNRs. The Tibet air shower array sensitive to gamma rays of 10 TeV region would give one of the most promissive information on this theoritical prediction. We have analyzed air showers, using the data of about 560 days in the period from 1990 June through 1992 July obtained by Tibet AS$\gamma$ array (4300m a.s.l, 90.52°E, 30.11°N).

## 2. Analysis and results

The event selection was made imposing the following three conditions. First, each of the four FT detectors should give a signal more than 1.25 particles per 0.5 m$^2$. Second, among the four detectors which record the highest particle densities two or more should be inside the central $5 \times 5$ detector matrix, and the third is that the laser calibration system for the sintillation counter array should be working. These conditions are the same ones as used by Amenomori et al.(b) except for the last condition. By this selection rule we have obtained $2.8 \times 10^8$ events through observation days of about 560 days. Angular resolution is 1.1° which has been well confirmed by observing the moon's shadow with value 8.7° as descrived in Amenomori et al.(a) and (b). In the case of gamma-ray incident, the mode energy of the selected events are estimated to be 10 TeV ( median energy is about 20 TeV ) by Monte Carlo simulation.

In order to search for intensity excess of showers from the direction of a candidate source which may emit VHE gamma rays, the background event density must be carefully estimated. We estimated the background event density by the method of the equi-zenith angule cut.

As shown in Figure 1, the background area is taken within zenith angle band of $\pm 1.5^\circ$ centered at the on-source zenith angle $\theta_{on}$ and within $\pm\varphi_{max}$, where $\varphi_{max} = 20^\circ/sin\theta_{on}$, in azimuthal angle from the on-source direction except for the central area of $\pm\varphi_{min}$, where $\varphi_{min} = 3^\circ/sin\theta_{on}$. Hence the solid angle of the background area $\Omega_{OFF}$ is given by

$$\Omega_{OFF} = 2\int_{\varphi_{min}}^{\varphi_{max}} d\varphi \int_{\theta_{ON}-1.5^\circ}^{\theta_{ON}+1.5^\circ} \sin\theta d\theta = 0.0310674[\mathrm{sr}],$$

where $\varphi$ is azimuthal angle, and the on-source cell, of solid angle $\Omega_{ON} = 9.56959 \times 10^{-4}$[sr], is chosen as a circle of radius $1^\circ$ centered at the on-soorce direction. Then the ratio of the on-source versus off-source solid angle is

$$\Omega_{ON}/\Omega_{OFF} = 1/32.4647$$

This method of background estimation is not available when the on-source direction becomes nealy the zenith, because the background areas will overlap each other and with the on-source cell. So in the case of on-source declination is within $30^\circ \pm 5^\circ$, we have not used the data of this zenith angle range.

The stastical significance of excess of on-source cell is calculated by using the Li and Ma method in which statistical fluctuations , both of numbers of background events and of on-source events, are taken into account.

20 SNRs, which we analyzed for search for gamma-ray emission are quoted from Lang (1991), and remnant name, known distances of some SNRs and other propaties are shown in table 1. Locations of 20 SNRs in the celestial cordinate are illustrated in Figure 2.

Table 2 shows result of analysis 20 SNRs, where $N_{ON}$ and $N_{OFF}$ is event number of on-source region and off-source region, respectively. Upper limits on the excess number of events at the 95 % confidence level are obtained for these SNRs using the same mathod described in Amenomori et at. (a) and are shown in the table.

## 3. Discussion and summary

We have searched for DC emission from 20 SNRs. As shown in Table 2, we obtained Li-Ma significance $s \leq 3.14\ \sigma$ as the DC excess. However, they have no obvious evidence for gamma-ray emission from SNRs.

According to Naito and Takahara (1994), gamma ray flux of 10 TeV region emitted from near SNRs

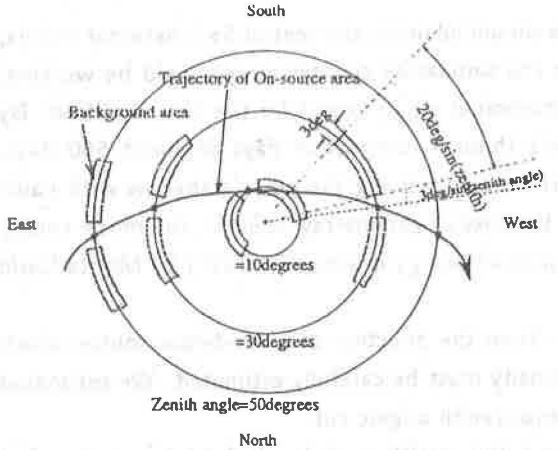


**Figure 1** Shematic illustration for the equi-Zenith angle method

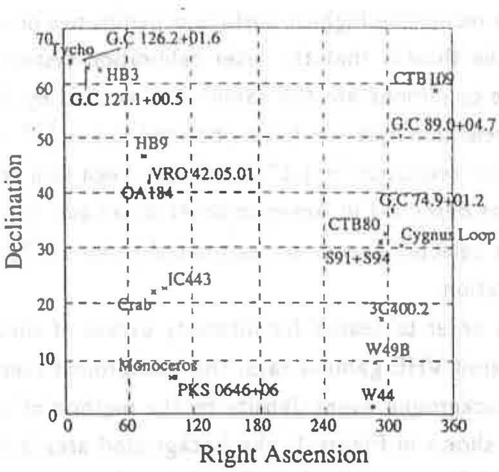


**Figure 2** The celestial positions of examined 20 SNRs

located in 2~3kpc from the sun will be about $0.7{\sim}1.5\times10^{-13}\text{cm}^{-2}\text{s}^{-1}$ when protons are accelerated up to $10^{16}$eV in SNRs. For the nearby SNRs (W44, Tycho, HB3, and Crab) our results have shown one order greater than the theoretical model.

It, although, may be noted that HB3 is giving the highest Li-Ma significance of $3.14\sigma$ which corresponds to the rather small upper probability of $8.4\times10^{-4}$. If we consider the total number of trial 20, the expected number of SNRs showing significances greater than 3.14 is $1.7\times10^{-2}$, which is not large enough to reject HB3 to be potential gamma-ray emitter of 10 TeV region.

Since Monoceros, S91+S94 and Cygnus-Loop are widely spreading beyond 2° of the diameter of our ON-source area, it may be better to introduce wider ON-source area for analysis of them.

## Acknowledgments

This work is supported in part by Grants-in-Aid for Scientific Research and also for International Scientific Research from the Ministry of Education, Science and Culture, in Japan and the Committee of National Nature Science Foundation in China.

## References

Amenomori, M. et al. (a), 1992, Phys. Rev. Lett., 69, 2468
Amenomori, M. et al. (b), 1993, Phys. Rev. D, 47, 2675
Lang, K. R.: *Astrophysical Data: Planets and Stars*, p723, Springer-Verlag, 1991
Li, T. P. and Ma, Y. Q., 1993, Astrophys. J. 272, 317
Naito, T. and Takahara, F., 1994, J. Phys. G : Nucl. Part. Phys. 20, 477

| Remunant Name | Right Assention | Decrination | Size(') | Type | Distance(kpc) |
|---|---|---|---|---|---|
| W44 | 285.3 | +1.3 | 35×27 | F | 3.0±1.0 |
| Tycho | 5.7 | +63.9 | 8 | S | 2.3±0.3 |
| W49B | 287.2 | +9.0 | 4×3 | F | 10. |
| HB3 | 33.5 | +62.5 | 80 | IR | 3. |
| Crab | 82.9 | +22.0 | 7×5 | F,CO | 2.0±0.5 |
| HB9 | 74.3 | +46.6 | 140×120 | IR,CO | |
| OA184 | 78.9 | +41.8 | 90×70 | S | |
| VRO 42.05.01 | 80.8 | +42.9 | 55×35 | S | |
| IC443 | 93.5 | +22.6 | 45 | IR | |
| Monoceros | 99.0 | +6.5 | 220 | S | |
| PKS 0646+06 | 101.5 | +6.5 | 60×40 | S? | |
| S91+S94 | 292.8 | +31.1 | 310×240 | S? | |
| 3C400.2 | 294.1 | +17.1 | 28 | S | |
| CTB80 | 297.9 | +32.8 | 80 | F,CO | |
| Cygnus Loop | 312.3 | +30.5 | 230×160 | S | |
| CTB109 | 344.9 | +58.6 | 28 | S,CO | |
| G.C. 126.2+01.6 | 19.6 | +64.0 | 70 | S? | |
| G.C. 127.1+00.5 | 21.3 | +62.9 | 45 | S | |
| G.C. 74.9+01.2 | 303.5 | +37.0 | 8×6 | F | |
| G.C. 89.0+04.7 | 310.9 | +50.4 | 120×90 | S | |

Table 1: SNRs data : Type S is shell, F is filled center, plerionic, IR is irregular, and CO is central object. Quated from Lang (1991).

| Remnant name | Days | $N_{ON}$ | $N_{OFF}$ | $s$ : Li-Ma Significance | Upper Probability | Flux upper limit $\times 10^{-13} cm^{-2} s^{-1}$ |
|---|---|---|---|---|---|---|
| W44 | 551 | 26701 | 879458 | -2.33 | 0.99 | 5.83 |
| Tycho | 565 | 30108 | 966181 | 1.98 | 0.024 | 20.1 |
| W49B | 550 | 39090 | 1258838 | 1.57 | 0.058 | 15.8 |
| HB3 | 566 | 32846 | 1047711 | 3.14 | 0.00084 | 27.9 |
| Crab | 586 | 55497 | 1800051 | 0.21 | 0.42 | 8.89 |
| HB9 | 568 | 54876 | 1777348 | 0.54 | 0.29 | 9.58 |
| OA184 | 567 | 58807 | 1895810 | 1.67 | 0.047 | 13.5 |
| VRO 42.05.01 | 569 | 58225 | 1874295 | 2.01 | 0.022 | 14.8 |
| IC443 | 567 | 56155 | 1821512 | 0.20 | 0.42 | 8.89 |
| Monoceros | 561 | 36313 | 1174922 | 0.63 | 0.26 | 12.9 |
| PKS 0646+06 | 563 | 36123 | 1176778 | -0.64 | 0.74 | 8.81 |
| S91+S94 | 557 | 46327 | 1506855 | -0.40 | 0.66 | 7.20 |
| 3C400.2 | 553 | 49188 | 1599928 | -0.42 | 0.66 | 7.79 |
| CTB80 | 558 | 47724 | 1549005 | 0.047 | 0.48 | 8.18 |
| Cygnus Loop | 558 | 45812 | 1500806 | -1.91 | 0.97 | 4.64 |
| CTB109 | 562 | 38422 | 1243469 | 0.60 | 0.27 | 11.5 |
| G.C 126.2+01.6 | 567 | 30020 | 964710 | 1.74 | 0.041 | 18.6 |
| G.C 127.1+00.5 | 568 | 32088 | 1023844 | 3.05 | 0.0011 | 27.2 |
| G.C 74.9+01.2 | 559 | 59416 | 1919974 | 1.12 | 0.13 | 11.3 |
| G.C 89.0+04.7 | 561 | 49946 | 1609392 | 1.65 | 0.049 | 14.0 |

Table 2: result of analysis : Upper probabilities are give by the upper probability integrals of the normal distribution in the region of significance greater than $s$. Flux upper limits are obtained by the same method presented in Amenomori et al(a)(1992).