Observation of Multi-TeV Gamma Rays from MGRO J2019+37 and MGRO J2031+41 with the Tibet Air Shower Array

M. AMENOMORI[1], X. J. BI[2], D. CHEN[3], T. L. CHEN[4], W. Y. CHEN[2], S. W. CUI[5], DANZENGLUOBU[4], L. K. DING[2], C. F. FENG[6], ZHAOYANG FENG[2], Z. Y. FENG[7], Q. B. GOU[2], Y. Q. GUO[2], H. H. HE[2], Z. T. HE[5], K. HIBINO[8], N. HOTTA[9], HAIBING HU[4], H. B. HU[2], J. HUANG[2], H. Y. JIA[7], L. JIANG[2], F. KAJINO[10], K. KASAHARA[11], Y. KATAYOSE[12], C. KATO[13], K. KAWATA[14], M. KOZAI[13], LABACIREN[4], G. M. LE[2], A. F. LI[15,6,2], H. J. LI[4], W. J. LI[2,7], C. LIU[2], J. S. LIU[2], M. Y. LIU[4], H. LU[2], X. R. MENG[4], K. MIZUTANI[11,16], K. MUNAKATA[13], H. NANJO[1], M. NISHIZAWA[17], M. OHNISHI[14], I. OHTA[18], S. OZAWA[11], X. L. QIAN[6,2], X. B. QU[19,2], T. SAITO[20], T. Y. SAITO[21], M. SAKATA[10], T. K. SAKO[14], J. SHAO[2,6], M. SHIBATA[12], A. SHIOMI[22], T. SHIRAI[8], H. SUGIMOTO[23], M. TAKITA[14], Y. H. TAN[2], N. TATEYAMA[8], S. TORII[11], H. TSUCHIYA[24], S. UDO[8], H. WANG[2], H. R. WU[2], L. XUE[6], Y. YAMAMOTO[10], Z. YANG[2], S. YASUE[25], A. F. YUAN[4], T. YUDA[14], L. M. ZHAI[2], H. M. ZHANG[2], J. L. ZHANG[2], X. Y. ZHANG[6], Y. ZHANG[2], YI ZHANG[2], YING ZHANG[2], ZHAXISANGZHU[4], X. X. ZHOU[7]
(THE TIBET ASγ COLLABORATION)

[1] *Department of Physics, Hirosaki University, Hirosaki 036-8561, Japan*
[2] *Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China*
[3] *National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China*
[4] *Department of Mathematics and Physics, Tibet University, Lhasa 850000, China*
[5] *Department of Physics, Hebei Normal University, Shijiazhuang 050016, China*
[6] *Department of Physics, Shandong University, Jinan 250100, China*
[7] *Institute of Modern Physics, SouthWest Jiaotong University, Chengdu 610031, China*
[8] *Faculty of Engineering, Kanagawa University, Yokohama 221-8686, Japan*
[9] *Faculty of Education, Utsunomiya University, Utsunomiya 321-8505, Japan*
[10] *Department of Physics, Konan University, Kobe 658-8501, Japan*
[11] *Research Institute for Science and Engineering, Waseda University, Tokyo 169-8555, Japan*
[12] *Faculty of Engineering, Yokohama National University, Yokohama 240-8501, Japan*
[13] *Department of Physics, Shinshu University, Matsumoto 390-8621, Japan*
[14] *Institute for Cosmic Ray Research, University of Tokyo, Kashiwa 277-8582, Japan*
[15] *School of Information Science and Engineering, Shandong Agriculture University, Taian 271018, China*
[16] *Saitama University, Saitama 338-8570, Japan*
[17] *National Institute of Informatics, Tokyo 101-8430, Japan*
[18] *Sakushin Gakuin University, Utsunomiya 321-3295, Japan*
[19] *College of Science, China University of Petroleum, Qingdao, 266555, China*
[20] *Tokyo Metropolitan College of Industrial Technology, Tokyo 116-8523, Japan*
[21] *Max-Planck-Institut für Physik, München D-80805, Deutschland*
[22] *College of Industrial Technology, Nihon University, Narashino 275-8576, Japan*
[23] *Shonan Institute of Technology, Fujisawa 251-8511, Japan*
[24] *Japan Atomic Energy Agency, Tokai-mura 319-1195, Japan*
[25] *School of General Education, Shinshu University, Matsumoto 390-8621, Japan*

ohnishi@icrr.u-tokyo.ac.jp

Abstract: The Tibet III air shower array is located at 4300 m above sea level, Tibet, China. Multi-TeV gamma rays were observed from MGRO J2019+37 and MGRO J2031+41 in the Cygnus region using data taken by the Tibet III air shower array in the period between 1999 and 2010.

Keywords: Gamma rays, Cygnus region, Tibet air shower array

1 Introduction

The Cygnus region contains many known supernova remnants, and has been taken notice as source of high energy gamma rays for many years. We reported $\sim 0.1\%$ increase of the CR intensity in the Cygnus region in 2006 [1].

In this paper we will report results on observation of multi-TeV gamma rays from MGRO J2019+37 and MGRO J2031+41 in the Cygnus region using data taken by the Tibet III air shower array in the period between 1999 and 2010.

2 Experiment

The Tibet air shower experiment has been successfully operating at Yangbajing (90.522°E, 30.102°N, 4300 m above sea level) in Tibet, China since 1990. The array, originally constructed in 1990, was gradually upgraded by increasing the number of counters [2][3]. The Tibet III array, used in this work, was completed in the late fall of 1999. This array consists of 533 scintillation counters of 0.5 m^2 each placed on a 7.5 m square grid with an enclosed area of 22050 m^2 and each viewed by a fast-timing (FT) photomultiplier tube (Fig. 1). A 5 mm thick lead plate is

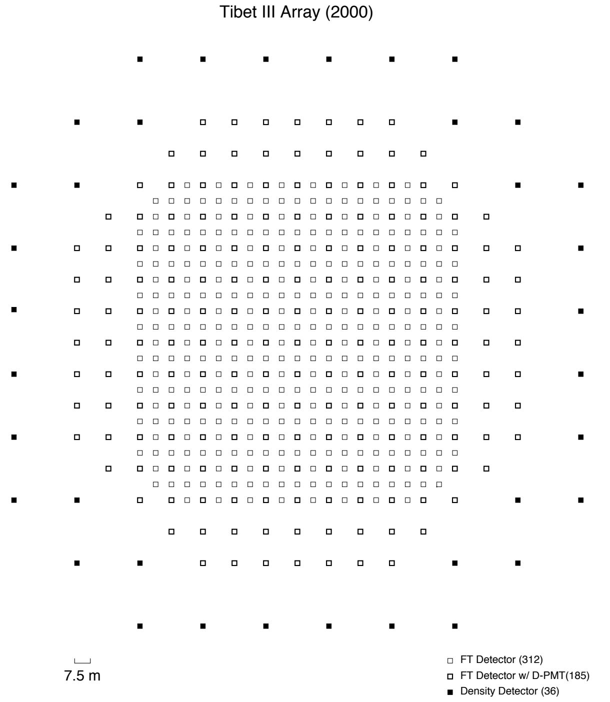

Figure 1: The Tibet III air shower array used in this work.

placed on the top of each counter in order to increase the array sensitivity by converting gamma rays into electron-positron pairs.

3 Analysis

We analyze the air shower data set collected by the Tibet III array during 2131.6 live days from November 1999 through January 2010. To extract an excess of multi-TeV gamma-ray air shower events coming from the direction of a target source in this analysis, we adopt almost the same event selections and the background estimation method published in our previous work [4]. The modal gamma-ray energy is estimated to be approximately 3 TeV by the Monte Carlo simulation. The search window radius centered at the target source is expressed by $R(\sum\rho_{\rm FT}) = 6.9/(\sum\rho_{\rm FT})$ degrees, which is shown to maximize the significance by Monte Carlo study assuming a point-like gamma-ray source, where the size $\sum\rho_{\rm FT}$ is defined as the sum of the number of particles per m^2 for each FT detector. Therefore, an excess might be underestimated if the target source actually extends beyond our angular resolution size.

4 Results

We compare significance maps of MGRO J2019+37 and MGRO J2031+41 between the Tibet III (a) and the Milagro experiment (b) [5] in Figure 2. It is remarkable that the Tibet III obtains images consistent with those observed in the Milagro.

Figures 3 and 4 show the differential energy spectra of MGRO J2019+37 and MGRO J2031+41 observed by the Tibet III with the results obtained by the Milagro and the ARGO-YBJ respectively. The differential flux for each is presented in Tables 1 and 2. The energy spectra are fitted by the least χ^2 method assuming $f(E) = \alpha(E/10\ \mathrm{TeV})^{\beta}$,

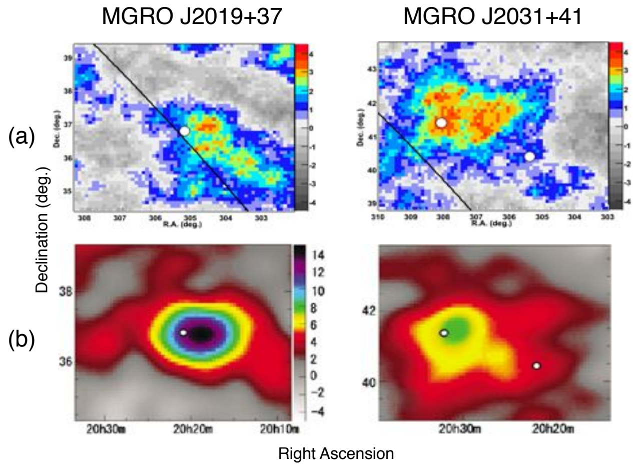

Figure 2: Significance maps of MGRO J2019+37 and MGRO J2031+41. Upper panels (a) show results in this work above 3 TeV. Lower panels (b) show results from Milagro with energy around 35 TeV [5].

and we obtain the differential power-law spectra of MGRO J2019+37 and MGRO J2031+41 as

$$\frac{dJ}{dE} = (3.41\pm0.88)\times10^{-14}\left(\frac{E}{10\ \mathrm{TeV}}\right)^{-3.13\pm0.33}\ \mathrm{cm^{-2}s^{-1}TeV^{-1}}$$

and

$$\frac{dJ}{dE} = (3.29\pm1.11)\times10^{-14}\left(\frac{E}{10\ \mathrm{TeV}}\right)^{-3.15\pm0.50}\ \mathrm{cm^{-2}s^{-1}TeV^{-1}}$$

in the ranges of 3–40 TeV and 3–20 TeV respectively.

Our energy spectrum of MGRO J2019+37 is consistent with the Milagro [6] and is not inconsistent with the ARGO-YBJ upper limits [7]. And our energy spectrum of MGRO J2031+41 is consistent with the Milagro [6] and the ARGO-YBJ [7].

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$\sum \rho_{\rm FT}$	Energy (TeV)	$N_{\rm on}$	$< N_{\rm off} >$	Significance	Differential Flux ($\rm cm^{-2}\ s^{-1}\ TeV^{-1}$)
$10^{1.50} - 10^{1.75}$	3.4	2592205	2587022	3.07σ	$(1.11 \pm 0.36) \times 10^{-12}$
$10^{1.75} - 10^{2.00}$	5.7	825726	824189	1.61σ	$(1.34 \pm 0.83) \times 10^{-13}$
$10^{2.00} - 10^{2.33}$	9.5	247490	246958	2.91σ	$(5.08 \pm 1.75) \times 10^{-14}$
$10^{2.33} - 10^{2.67}$	18.3	39126	38899	1.10σ	$(4.05 \pm 3.70) \times 10^{-15}$
$10^{2.67} - 10^{3.00}$	40.2	7098	6999	1.12σ	$(4.87 \pm 4.36) \times 10^{-16}$

Table 1: Logarithmic mean of energy and differential flux for each $\sum \rho_{\rm FT}$ bin for MGRO J2019+37.

$\sum \rho_{\rm FT}$	Energy (TeV)	$N_{\rm on}$	$< N_{\rm off} >$	Significance	Differential Flux ($\rm cm^{-2}\ s^{-1}\ TeV^{-1}$)
$10^{1.50} - 10^{1.75}$	3.4	2499053	2493090	3.60σ	$(1.21 \pm 0.34) \times 10^{-12}$
$10^{1.75} - 10^{2.00}$	5.7	797381	796088	1.38σ	$(1.08 \pm 0.78) \times 10^{-13}$
$10^{2.00} - 10^{2.33}$	9.5	238588	237589	1.95σ	$(3.22 \pm 1.65) \times 10^{-14}$
$10^{2.33} - 10^{2.67}$	18.3	37921	37448	2.33σ	$(8.11 \pm 3.50) \times 10^{-15}$
$10^{2.67} - 10^{3.00}$	40.2	6720	6736	-0.19σ	

Table 2: Logarithmic mean of energy and differential flux for each $\sum \rho_{\rm FT}$ bin for MGRO J2031+41.

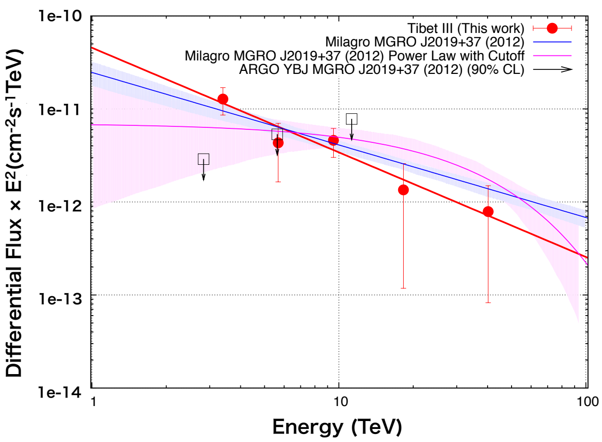

Figure 3: Differential flux of TeV gamma rays from MGRO J2019+37 observed with the Milagro [6] and the Tibet III. The ARGO-YBJ reports upper limits [7].

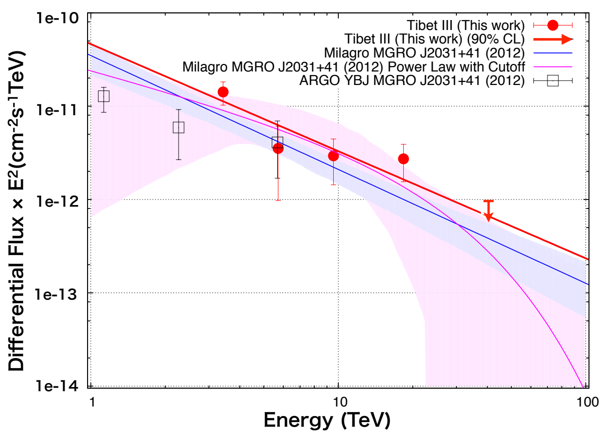

Figure 4: Differential flux of TeV gamma rays from MGRO J2031+41. observed with the Milagro [6], the ARGO-YBJ [7] and the Tibet III.