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

(The Tibet ASy Collaboration)

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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 ~ 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 (90.52°E, 30.10°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 2010. The Tibet III air shower array is located at 4300 m above sea level, Tibet, China.
We compare significance maps of MGRO J2019+37 and MGRO J2031+41 with the Tibet Air Shower Array.

We analyze the air shower data set collected by the Tibet III experiment (b) [5] in Figure 2. It is remarkable that the MGRO J2031+41 between the Tibet III (a) and the Milagro is not inconsistent with the ARGO-YBJ upper limits [7]. And our energy spectrum of MGRO J2019+37 is consistent with the Milagro [6] and is not inconsistent with the ARGO-YBJ [7].

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References

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 $\rho = \frac{E^{\alpha}}{\Sigma \rho_{FT}}$, which is shown to maximize the significance by Monte Carlo study assuming a point-like gamma-ray source, where the size $\Sigma \rho_{FT}$ 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 Milagro [6].

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 $\chi^2$ method assuming $f(E) = \alpha (E/10 \text{ TeV})^\beta$.

\[ \frac{dJ}{dE} = (3.41 \pm 0.88) \times 10^{-14} \left( \frac{E}{10 \text{ TeV}} \right)^{-3.13 \pm 0.33} \text{ cm}^{-2} \text{s}^{-1} \text{TeV}^{-1} \]

and

\[ \frac{dJ}{dE} = (3.29 \pm 1.11) \times 10^{-14} \left( \frac{E}{10 \text{ TeV}} \right)^{-3.15 \pm 0.50} \text{ cm}^{-2} \text{s}^{-1} \text{TeV}^{-1} \]

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].
The ARGO-YBJ reports upper limits \[7\].

J2019+37 observed with the Milagro \[6\] and the Tibet III.

**Figure 3**

Differential flux \((\text{E}^{-1} \text{s}^{-1} \text{TeV}^{-1})\) of TeV gamma rays from MGRO J2019+37.

### Table 1:

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

**Figure 4**

Differential flux \((\text{E}^{-1} \text{s}^{-1} \text{TeV}^{-1})\) of TeV gamma rays from MGRO J2031+41.

### Table 2:

<table>
<thead>
<tr>
<th>(\sum \rho_{\text{FT}})</th>
<th>Energy (TeV)</th>
<th>(N_{\text{on}})</th>
<th>(&lt; N_{\text{off}} &gt;)</th>
<th>Significance</th>
<th>Differential Flux ((\text{cm}^{-2} \text{s}^{-1} \text{TeV}^{-1}))</th>
</tr>
</thead>
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<td>(10^{1.50} - 10^{1.75})</td>
<td>3.4</td>
<td>2499053</td>
<td>2493090</td>
<td>3.60(\sigma)</td>
<td>((1.21 \pm 0.34) \times 10^{-12})</td>
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<td>(10^{1.75} - 10^{2.00})</td>
<td>5.7</td>
<td>797381</td>
<td>796088</td>
<td>1.38(\sigma)</td>
<td>((1.08 \pm 0.78) \times 10^{-13})</td>
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<td>(10^{2.00} - 10^{2.33})</td>
<td>9.5</td>
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<td>237589</td>
<td>1.95(\sigma)</td>
<td>((3.22 \pm 1.65) \times 10^{-14})</td>
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<tr>
<td>(10^{2.33} - 10^{2.67})</td>
<td>18.3</td>
<td>37921</td>
<td>37448</td>
<td>2.33(\sigma)</td>
<td>((8.11 \pm 3.50) \times 10^{-15})</td>
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<tr>
<td>(10^{2.67} - 10^{3.00})</td>
<td>40.2</td>
<td>6720</td>
<td>6736</td>
<td>-0.19(\sigma)</td>
<td></td>
</tr>
</tbody>
</table>

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.