Towards 100 TeV gamma-ray astronomy with the Tibet air shower array

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The Tibet air shower array with effective area 37,000 m² located at 4300m in altitude, in Tibet, China, is sensitive to celestial gamma rays with energies above a few TeV. Stimulated by the recent HESS galactic survey which discovered 14 new TeV gamma-ray sources, it is now important to measure 100 TeV gamma rays from celestial sources to locate possible cosmic-ray accelerators up to PeV energies in our galaxy. For this purpose, we have a plan to add a large (∼10,000 m²) underground water Cherenkov muon detector array to the existing Tibet air shower array.
1. Introduction

Based on observation by 4 large imaging air Cherenkov telescopes in Namibia, the HESS group recently reported on discovery of new 14 gamma-ray sources [1]. Most of them are UNIDentified (UNID) sources and faint in X-rays or other wavelengths. It was surprising that the conventional method to search for a new TeV gamma-ray source by an air Cherenkov telescope has assumed strong X-rays emission accompanied with it. Upon the HESS discovery, the importance of a wide field-of-view unbiased survey is recognized. Furthermore, many of the 14 sources have a harder energy spectrum (indices:-1.8 to -2.8) at TeV energies than the standard candle Crab (index:-2.6). The energy spectra turned out to extend up to 10 TeV approximately. Cosmic rays are supposed to be accelerated up to the knee energy region at supernova remnants (SNRs) in our galaxy. Therefore, we naturally expect gamma rays in the 100 TeV region (10-1000 TeV) which originate in \( \pi^0 \) decays produced by the accelerated cosmic rays interacting with matter surrounding the SNRs.

We have a plan to construct a large (\( \sim 10,000 \text{ m}^2 \times 1.5 \text{m deep} \)) underground (\( \sim 2.5 \text{ m soil+concrete overburden} \)) water Cherenkov muon detector array (Tibet MD) under the existing Tibet air shower array (Tibet III). By Tibet III + MD, we aim at background-free detection of celestial gamma rays in the 100 TeV region (10 TeV – 1000 TeV) with world-best sensitivity and at locating the origins of cosmic rays accelerated up to the knee energy region in the northern sky. The measurement of cut off energies in the energy spectra of such gamma rays in the 100 TeV region may contribute significantly to understanding of the cosmic-ray acceleration limit at SNRs. Search for extremely diffuse gamma-ray sources by Tibet III + MD, for example, from the galactic plane or from the Cygnus region may be very intriguing as well.

2. The Tibet Air Shower Experiment

The Tibet air shower experiment has been successfully operated at Yangbajing (90°31’ E, 30°06’ N; 4,300 m a. s. l.) in Tibet, China since 1990. The Tibet I array was constructed in 1990 [2] and it was gradually expanded to the Tibet II by 1994 which consisted of 185 fast-timing (FT) scintillation counters covering 36,900 m², and 36 density (D) scintillation counters around the FT-counter array. From 1996 we upgraded the array again and the Tibet III was set up in 1999 which consists of 497 FT counters covering 36,900 m² and 36 D counters around them. In the inner 22,000 m², 429 FT counters are deployed with 7.5 m lattice interval, the rest of 68 FT counters with 15m lattice interval, and 36 D counters with 30 m lattice interval around FT counter array. We kept upgrading the array up to 2003 as shown in Fig. 1, and at present, it consists of 761 FT counters covering 50,400m² and 28 D counters around them. The effective area is now 37,000m² for gamma rays above a few TeV. Above 100 TeV, the angular resolution of Tibet III with 2-steradian wide field of view is 0.2 degrees, while the energy resolution is estimated to be \( \sim 40 \% \).

With the Tibet air shower array, we have successfully observed a new cosmic-ray anisotropy in the Cygnus region at multi-TeV energies [3] as well as TeV gamma-rays from Crab [4], Mrk501 [5] and Mrk421 [6]. As the cosmic-ray anisotropy discovered in the Cygnus region is relatively nar-
row, it may favor existence of some gamma-ray component as claimed by the Milagro group [7]. Meanwhile, we can not draw any clear conclusion on the Milagro result, as the Tibet air shower array is unable to distinguish between cosmic gamma rays and hadrons in the multi-TeV energy region at present.

3. The Tibet Muon Detector Array

Let us imagine, for example, a large (∼10,000 m²×1.5m deep) underground (∼2.5 m soil+concrete overburden) Tibet MD [8] under the existing Tibet III. The hadron rejection power of Tibet MD is 1/100. In the case of Crab, assuming a constant power-law index of -2.6, we expect approximately 100 gamma-ray events against 1 cosmic-ray background event above 100 TeV during 3-calendar-year operation, i.e., 5σ gamma-ray flux sensitivity of 20 % in unit of Crab above 100 TeV or 5 % in unit of RX J1713.7-3946.

4. Discussions

Then, how many unknown/known sources do we expect to detect by Tibet III + MD, assuming the energy spectra of the gamma-ray sources extend up to the 100 TeV region? Eleven of the HESS new 14 sources discovered by the galactic plane survey in the southern sky would be detected by Tibet III + MD, as is shown in Fig. 2, if it were located at the HESS site. As no extensive search has been done by an apparatus with sensitivity comparable to HESS (1 % in unit of RX J1713.7-3946/50-hour observation) in the northern sky, we expect to discover some 10 new gamma-ray sources in the northern sky. In addition to unknown point-like sources, we expect to detect established sources in the 100 TeV region: TeV J2032+4130 (∼1 Crab intensity), HESS J1837-069 (∼0.4 Crab intensity), Crab, Mrk421, Mrk501 are sufficiently detectable and Cas A, HESS J1834-087, and M87 are marginal.

Furthermore, our integral flux sensitivity to diffuse gamma rays will be the world-best as well, i.e., $3 \times 10^{-11}$ /cm²/s/sr above 3 TeV and $3 \times 10^{-13}$ /cm²/s/sr above 100 TeV. As our sensitivity around 3 TeV will be better than the Milagro experiment by a factor of 3, the diffuse gamma rays from the Cygnus region reported by the Milagro group [7] will be clearly detected.

![Figure 2](image_url)

Figure 2. From Ref [9]. Tibet III+MD (red curve) integral flux sensitivity (5σ/3yr) to the observed HESS galactic (3 established + 14 new) gamma-ray sources extrapolated to the 100 TeV region (blue lines), if Tibet III+MD were located at the HESS site. The flat region above 200 TeV in the Tibet sensitivity corresponds to 15 events. The filled circles with error bars are HESS data points for HESS sources, while the crosses with error bars are HEGRA data points for Crab. The yellow line is the extrapolated Crab gamma-ray energy spectrum, while the dashed green curves represent the MAGIC, VERITAS and HESS sensitivities (5σ/50h).

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