PROCEEDINGS OF SCIENCE

Prospect of γ-ray source spectrum measurements with the LHAASO Project

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The Large High Altitude Air Shower Observatory (LHAASO) project is a new generation EAS array, which will be built in Daocheng, Sichuan province, China at 4400m above sea level. With a wide field-of-view and high duty cycle, LHAASO will survey a large sky region in the declination band from -20° to 80° with a sensitivity of 10 mili-Crab per year at a much wider energy range from 100 GeV to 1 PeV. Besides increasing the number of VHE gamma-ray sources, it will also provide accurate spectrum measurement for the known γ-ray sources, especially for extended sources and transient phenomena. These are very important for us to look sight into γ-ray emission mechanism and particle acceleration within the sources. In this paper, we will investigate, basing on detector simulation, the ability of LHAASO on the measurement of spectra of SNRs, Cygnus region, diffuse galactic γ-rays and AGN flares.

The 34th International Cosmic Ray Conference,
30 July- 6 August, 2015
The Hague, The Netherlands

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PoS(ICRC2015)974

1. Introduction

The Large High Altitude Air Shower Observatory (LHAASO, 100.01°, east, 29.35°, north) project is a new generation EAS array, which will be built at 4400m above sea level in Sichuan province, China (Figure 1). The main physical goals of LHAASO are to explore the origin of high energy cosmic rays, search γ-ray sources through all-sky γ-ray sources survey and provide precise measurement of γ-ray spectrum. To achieve these physical goals the setup of LHAASO is:

• The one kilometer square array (KM2A) is the main part of LHAASO covered an area of 1 km^2 which has the ability to observe the γ-rays from 10 TeV up to 1 PeV. It is composed of 5235 electronmagnetic particle detectors(ED) and 1146 muon detectors(MD). The size of each ED detector is 1 m $\times$ 1 m $\times$ 2 cm, placed on a triangle with distance of 15 m, and covered by 0.5 cm thick lead plate as γ-ray converter. MD is designed as a water tank with diameter of 6.8 m and height of 1.2 m, placed on a triangle with distance of 30 m. Each MD is covered by an overburden of 2.5 m soil used to absorb the electromagnetic component in the showers. The main physical target for KM2A is to accurately measure the γ-rays spectrum above 30 TeV and cosmic ray physics in the "knee" region[1].

• Water Cherenkov detector (WCDA) with an area of 90,000 m^2 will be built at the center of the array. The cell size of WCDA is about 5 m $\times$ 5 m and the effective water depth is about 4m. Besides, each detector cell has 8-in. diameter hemispherical PMT at the center of the bottom that faces upward to receive Cherenkov light produced in water by those secondary particles that are induced by showers. It focuses on detecting γ-ray showers above 300 GeV and discovering new γ-ray sources[2].

• 24 wide field of view imaging Cherenkov telescopes (WFCTA) and 5000 m^2 high threshold core-detector array (SCDA) will be built inside KM2A. Both arrays are well worked on identifying the composition of cosmic rays. Moreover WFCTA can be further modified as fluorescence telescopes to detect the "second knee" of the cosmic ray spectrum[3].

Operated with large field of view and full duty cycle, LHAASO could monitor any sources with -20° < Dec < 80° day by day at a wider energy range from 100 GeV to 1 PeV. In the following sections, we will investigate the ability of LHAASO on different gamma-ray sources basing on detector simulation.

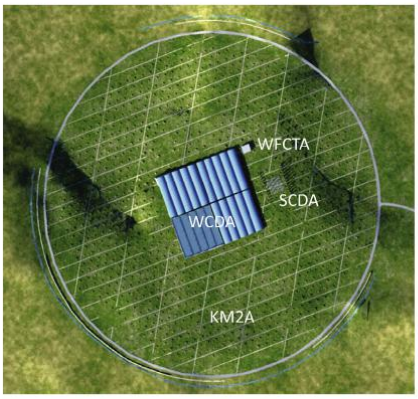


Figure 1: Configuration of LHAASO.

2. VHE γ-ray sources

Over the past decade, great advances have been made in very high energy (VHE,>100 GeV) γ-ray astronomy. Up to now, more than 150 VHE γ-ray sources have been observed[4], of which 32 galactic sources (including 6 SNRs, 11 pulsar wind nebulae, 2 binary system, 1 massive star cluster and 12 unidentified sources) and 40 extragalactic sources will be in the view of LHAASO. Besides, with a sensitivity of 10 mili-Crab, LHAASO can not only provide accurate spectrum for the known γ-ray sources, but also search new TeV γ-ray sources.

2.1 SNRs

In galactic point sources, SNRs are considered to be one of the most plausible candidates for acceleration of cosmic-rays up to PeV energies [5][6][7]. Generally, there are two types of scenarios for the production of high-energy γ-rays from SNRs: the leptonic acceleration via inverse Compton(IC) scattering of background photos by relativistic electrons and hadronic acceleration via decay of neutral pions produced by elastic collisions of relativistic ions with ions in the background plasma [8].

Up to now, the evidence for efficient leptonic acceleration in SNRs is now clearly established [9][10]; however, the question of whether SNR are efficient hadron accelerators is more difficult to answer. The recently observation of γ-ray spectrum for W44 and IC443 by Fermi shows that accelerated protons and nuclei via hadronic interactions with ambient gas and subsequent π^0 decays into γ-rays [11], but no observations above 10 TeV region have succeeded in identifying hadronic acceleration mechanism. According to the current experiment results [12][13][14], the measurement of spectrum is up to several TeV and the error value is not enough to explain the acceleration mechanism in high energy region. With the wide FOV, LHAASO is suitable not only to measure their SEDs but also carry out morphologic investigations on those sources at high energies. Based on the current observation data of SNRs, there has been identified 20 TeV γ-ray sources corresponding to galactic SNRs in TeV region.

For example, IC443 is a shell-type SNR with mixed morphology and penetration of shock fronts into dense molecular clouds. The gamma-ray spectrum of IC443 has been measured by Fermi-LAT[15] , VERITAS[16] and MAGIC[17] in the energy region from 0.1GeV to 1 TeV, but for high energy range, which is very important for determination on g -ray emission mechanism, there is still no observation. In order to obtain expectation of LHAASO on IC443, we take the unified model[18] and the accumulative diffusion model[19][20] to extend the spectrum of Tycho up to 300 TeV (Figure 2). According to the expectation results, we can see from 100 GeV to 100 TeV, the statistic error of data obtained by LHAASO will be less than 10%. Distinguish of the expectations from the two models will reach more than 5 sigma above 20 TeV. The γ-ray spectrum of IC443 from LHAASO will strengthen the high accurate measurement in energy range from 100 GeV to 400 TeV which is important for judgement between these two models, inside the SNR or in the region of molecular cloud cross the SNR.

2.2 Cygnus region

The Cygnus region of the Galactic plane is the famous region in the northern sky for the complex features observed in radio, infrared, X-rays, and γ-rays. It contains a high density interstellar

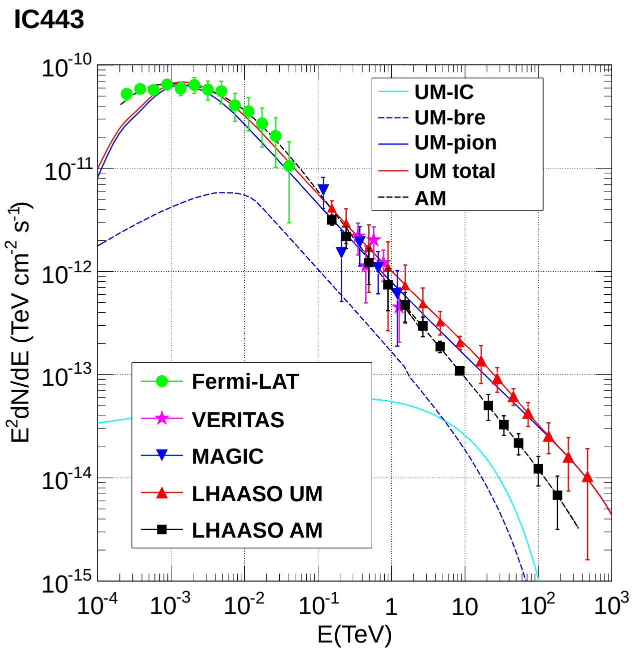


Figure 2: Expectation of the LHAASO project on the spectrum of IC443 calculated with the UM(unified model) and the AM(accumulative diffusion model) by using 5 years MC data, compared with the measurement of Fermi[15], VERITAS[16], and MAGIC[17].

medium and is rich in potential cosmic ray acceleration sites such as Wolf-Rayet stars, OB associations, and supernova remnants(SNRs). This region is home of a number of GeV gamma-ray sources detected by Fermi-LAT[21] and several noteworthy TeV γ-ray sources detected by Milagro, ARGO-YBJ in the past decade. The Cygnus Cocoon, located in the star-forming region of Cygnus X, is interpreted as a cocoon of freshly accelerated cosmic rays related to the Cygnus super-bubble. The extended TeV gamma-ray source ARGO J2031+4157 (or MGRO J2031+41) is positionally consistent with the Cygnus Cocoon discovered by Fermi-LAT at GeV energies in the Cygnus superbubble, and another TeV source MGRO J2019+37 is a mysterious source only being detected by MILAGRO[22] above 20 TeV and VERITAS[23] above 1 TeV. The reason for the hard SED from such a spatially extended region is totally unknown. The discovery of this kind of sources and the more detailed multi-wavelength spectroscopic investigations can be an efficient way to explain the radiation mechanism of them.

Figure 3 shows all the spectral measurements by Fermi-LAT [24], ARGO-YBJ [25], Milagro [26][27][28], and the expectation results with LHAASO. One year observation of LHAASO will be sufficient to give a judgement on the different energy cutoff models from 300GeV to several hundreds TeV. It will provide important information for investigating the particle acceleration within the super-bubble.

2.3 Diffuse galactic γ-rays

Diffuse γ-rays produced by interactions of cosmic rays with the interstellar medium and radiation fields. It represents the natural background to many different signals[29], and the observa-

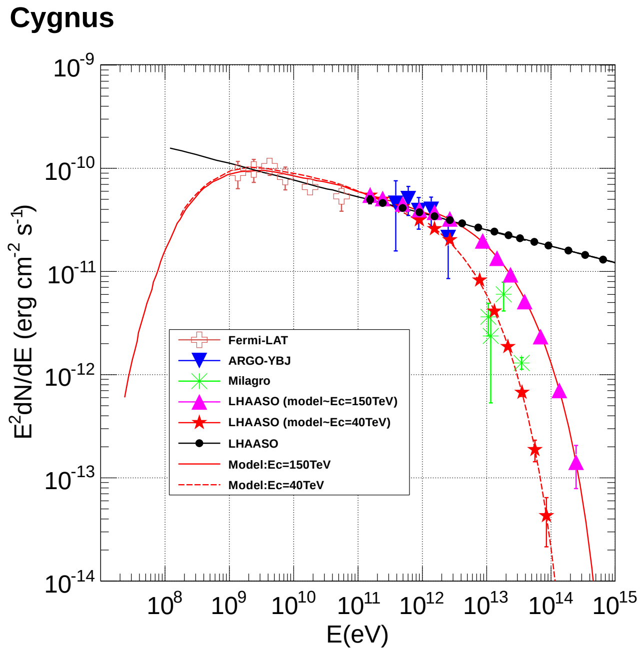


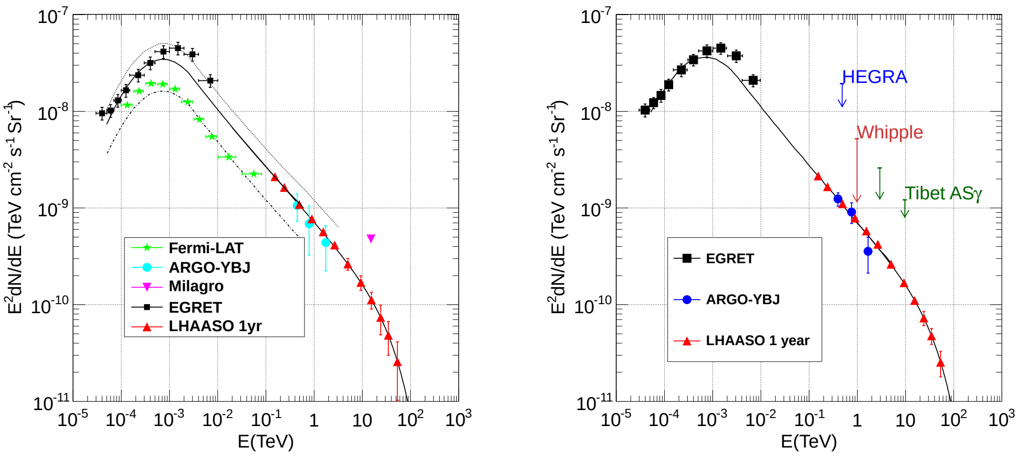
Figure 3: Expectation of the LHAASO project on Cygnus Cocoon by using one year MC data, compared with the measurement of Fermi-LAT[24], ARGO-YBJ[25], Milagro[26][27][28].

tion for diffuse emission is necessary for detecting accurate spectrum of γ-ray sources, either as point-like or extended. Diffuse γ-rays can be used to probe the cosmic ray spectrum and density throughout the whole Galaxy. This phenomenon was detected by Fermi at GeV region and ARGO-YBJ/Milagro at TeV region. The newest results by ARGO-YBJ experiment are consistent with the predictions of the Fermi model for the diffuse Galactic emission[30].

We provide the expectation of LHAASO on diffuse γ-rays in the Galactic region $25^\circ < l < 100^\circ$, $|b| < 5^\circ$ (Figure 4(a)) and in Cygnus region (Figure 4 (b)). We assume that the energy cutoff is 50TeV and LHAASO will extend the measurement to several hundreds TeV and the statistic error is less than 10%. It is going to be very interesting to observe a cutoff at slightly higher energy and it will very useful for us to clarify the radiation mechanism of Galactic plane diffuse γ-rays.

2.4 AGN flares

In extragalactic sources, Blazars, including BL Lac objects and flat-spectrum radio quasars, are the most extreme subclass of active galactic nuclei (AGNs). Most of the identified extragalactic γ-ray sources belong to this category. LHAASO has a high duty cycle and a large field of view, thus LHAASO can monitor flare of AGN continuously. In Figure 5, the flare on Mrk501 for 35 days is measured by Swift, Fermi-LAT and ARGO-YBJ [31]. It clearly differs from the stable emission which fits well with the Synchrotron Self-Compton (SSC) model. Assuming the similar flare occurs again, the prediction for LHAASO's observation is plotted in Figure 5 and LHAASO will give an accurate spectrum at TeV region which can be the key to explain the radiation mechanism of flare. LHAASO not only serves as a global alarm system for the high energy flares, but also opens a great opportunity to identify the emitting mechanism during the flares. The potential of LHAASO in



(a) (b)

Figure 4: Expectation of the LHAASO project on diffuse γ-ray emission in the Galactic region (a): 65° < l < 85°, |b| <5°, (b) 25° < l < 100°, |b| <5°, compared with the measurement of Fermi-LAT, ARGO-YBJ, Milagro and Egret[30]. The solid line shows the flux in the same region according to the Fermi-DGE model[33].

these researches, including exploring on new physics such as intergalactic magnetic field detection and Lorentz invariance tests, has been discussed in depth elsewhere [32].

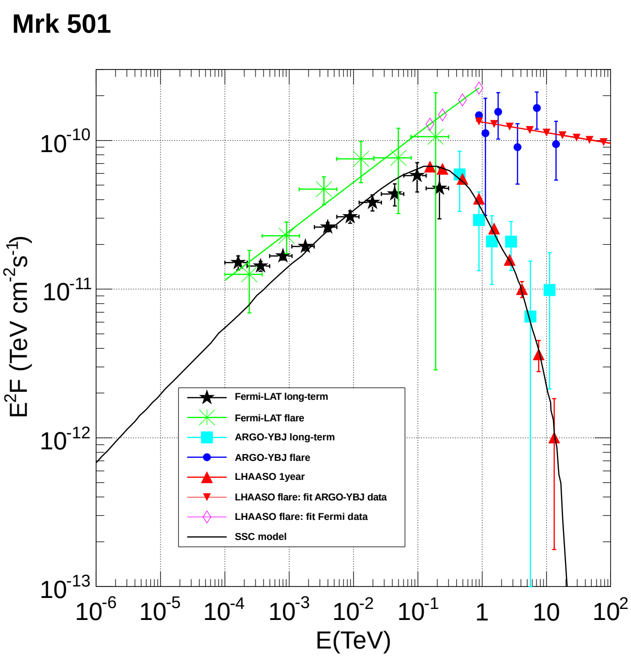


Figure 5: Expectation of the LHAASO project on Mrk501, compared with the measurement of Fermi-LAT, ARGO-YBJ[31].

3. Conclusion

With a sensitivity of 10 mili-Crab and wide field-of-view, LHAASO will survey the northern sky in the declination band from -10° to 70° with a 100% duty cycle and observe not only the γ-ray point sources, but also extended sources, diffuse sources and transient phenomena. The discussion on observation of SNRs, Cygnus region, diffuse galactic γ-rays and transient sources shows that LHAASO has a strong ability to provide the accurate spectrum from 100GeV to 1 PeV which will play an key role in explaining the cosmic ray acceleration mechanism at high energy region and giving a final judgement on different acceleration mechanism models.

Acknowledgment: This work is supported in China by NSFC (NO.11205165, NO. 11375210, No.11375224, No.11405181, No.11475190), the Chinese Academy of Science, Institute of High Energy Physics, the Key Laboratory of Particle Astrophysics, CAS and in Italy by the istituto nazionale di fisica nucleare (INFN).

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