A Future Project at Tibet: The Large High Altitude Air Shower Observatory (LHAASO)

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***Abstract*. Gamma ray source detection above 30TeV is an encouraging approach for finding galactic cosmic ray sources. Wide field of view survey for gamma ray source population above 100GeV is essential. In order to target those goals, a large air shower particle detector array of 1km^2 (the LHAASO project) at 4300m a.s.l. is proposed. With two MagicII-type telescopes, the project will be enhanced for source morphologic investigation. The proposed array will be utilized also for energy spectrum measurement for individual cosmic ray species from 30TeV to 10PeV. Re-configuring the wide field of view telescopes into fluorescence light detector array allows cosmic ray spectrum and composition measurements above 100PeV where the second knee is located.**

***Keywords*: detector array, gamma ray astronomy, cosmic ray air shower**

I. Introduction

More than 80 sources with emission of gamma ray around 1 TeV have been discovered[1]in the last two decades. Mechanism of the emission has been investigated somewhat thoroughly among discovered sources. Evidences[2] are collected for the gamma rays are knocked by accelerated electrons in shock waves generated by various types of objects, such as pulsar wind nebulas (PWN), supernova remains (SNR), X-ray binaries (Micro-quasars) and active galactic nuclei (AGN) etc. Gamma ray energy spectra of the sources are measured up to nearly 100TeV for some sources[3]. Even if such a mechanism based on inverse Compton scattering model works for most sources, some of them seem to be difficult to fit, thus a more interesting mechanism based on neutral pion decay is introduced by many authors[4]. It implied that the sources with such a feature may be origins of cosmic rays. In order to confirm this and improve our understanding on even more complicated phenomena, such as transit behaviors of AGNs, collecting sufficient population for different type of sources is necessary. An all-sky survey for gamma ray sources will be an essential approach. A ground base large gamma ray shower detector array at high altitude is ideal to response to the strong demand. Such an array not only useful for the gamma ray source survey but also plays an essential role of bridging between direct measurements of spectra of individual cosmic ray species at balloon heights and ultra high energy cosmic ray experiments such as Auger and TA. Matching with direct measurements that use calorimeters and charge sensitive detectors sets an absolute energy scale for air shower experiments on the ground. From 30TeV to few EeV is expected to be covered by such a high altitude experiment.

II. A design of detector array for LHAASO

In order to fulfil all the goals, a large scale complex of many kinds of detectors is needed. For gamma ray source survey, a water Cherenkov detector array(WCDA) with a total active area of 90,000m^2 is proposed, as the blue circles in Fig. 1. It is sensitive to gamma ray showers above a few hundred GeV and will achieve a sensitivity of about 2% of emission intensity from Crab nebula (I_{crab}), as shown in Fig. 2. For discovered sources, we can do two type of further studies. One is to measure the energy spectra of gamma rays up to few hundreds of TeV for searching for galactic cosmic ray origins. The focus is the high energy ends of the spectra where one expects to see differences between electron or proton origins. For this purpose, a particle detector array with an effective area of 1km^2 is proposed (KM2A) including a muon detector array with 40,000m^2 active area. This allows a measurement of gamma ray spectra above 50TeV without any hadronic shower background by selecting muon-less showers. 5137 scintillator detectors, 1m^2 each as shown as black dots in Fig. 1, are used to measure arrival directions and total energies of showers. 1200 detectors made of scintillator, 36m^2 each and covered by 2.5m dirt as brown squares in Fig. 1, are used for muon content measurement. An expected sensitivity of this array is also plotted in Fig. 2 connecting with the WCDA sensitivity at 10TeV. It makes a perfect complementary to the narrow field of view CTA experiment which is the most sensitive detector at lower energies and details a morphologic probe within a FOV of 3°around the sources. The other is to carry out similar morphologic probe at much lower energies, e.g. 30GeV. Magic group is interested in making such an extension by introducing two MagicII-type telescopes to the LHAASO project, as shown in dark-green dishes.

To measure cosmic ray spectra for separated compositions, a multi-parameter investigation is necessary. In general, shower maximum, muon content and high energy component near the core are three independent parameters that have strong characteristics for different showers induced by different nuclei. Two more detector components with smaller scale are proposed. They are 24 wide FOV Cherenkov telescope array (WFCA) and high threshold core-detector array (SCDA) with an effective area of 5000m^2, shown

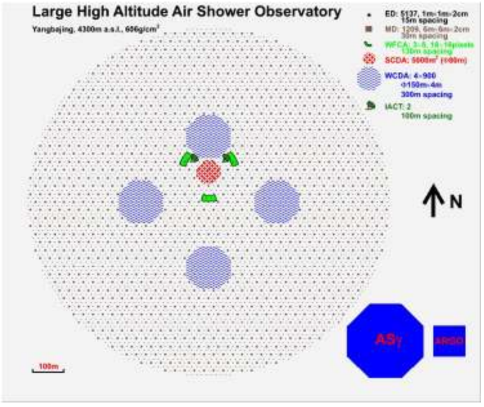

Fig. 1: Layout of the LHAASO array

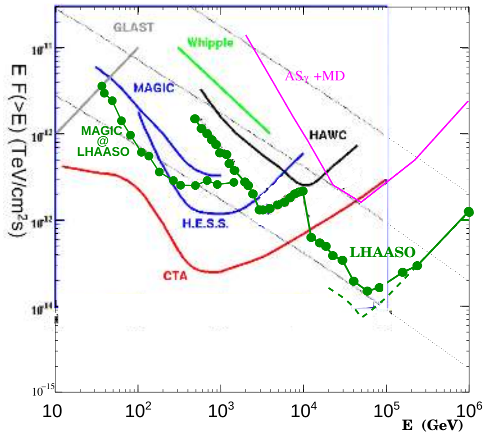

Fig. 2: The sensitivity of the major experiments and future projects for gamma ray astronomy

as light-green bends and red dots in Fig. 1, respectively.

III. Physics perspectives with LHAASO

A. Search for cosmic ray origins among galactic gamma ray sources

RXJ1713-3946, one of brightest gamma ray sources in the southern sky, has been thoroughly investigated[4] in terms of spectrum measurement and very detailed morphologic probing. As a shell type SNR, it has been naturally considered as an origin of cosmic rays, moreover its spectrum is difficult to be fitted with pure electron origin models. A concrete evidence for existence of accelerated protons relies on an accurate measurement of the spectrum extended in higher energies and even more importantly a collection of many similar sources in our galaxy that have the same feature. Using LHAASO KM2A, one will carry out a background-free measurement of spectra for such sources above 60TeV. All spectra of discovered sources by HESS are well above the LHAASO sensitivity up to few hundreds TeV if appear in the northern sky. More than 30 events above highest energies between 100TeV and 500TeV depending on the intensity of sources are expected in 3 years. According to recent theoretical investigation[5], old SNRs have great chances to accelerate protons to high energies thus produce higher energy photons than inverse-Compton scattering of electrons. All the physics goals set a standard for the LHAASO KM2A performance, such as the angular resolution of the array is 0.4°and energy resolution is better than 20% with a sensitivity of 1%I_{crab}[6].

B. Full-sky survey for collection of gamma ray source population

Number of sources with TeV gamma ray emission has been exponentially increasing since the discovery of the first source, Crab Nebula, using narrow FOV Cherenkov telescope in 1989. Without a guide by surveying results, an efficiency of successfully discovery TeV gamma sources remains at 10% level among very carefully selected candidates. After a strong progress in the last twenty years, the rate seems to start slowing down. According to experience in optical and X-ray astronomy, if there is no boost in sensitivity of the survey observation, the population of sources will not be expected increasing with the same pace. A demand in the community of having the survey observation with equal sensitivity as the narrow FOV observation becomes increasingly strong. Ground based shower detector arrays, such as the Milagro experiment, start to demonstrate their power of discovery of sources, especially to sources with spatial extension which is particularly difficult to be observed by the narrow FOV observation. Following Milagro recent results[7] of confirming some sources found by space borne FERMI/LAT detector, the ARGO-YBJ experiment confirmed as well that adding all sources in a category together, such as all brightest pulsar TeV sources, excesses are observed given a statistics of 2-year operation. The LHAASO project will have a sensitivity of seeing all sources in the whole northern sky that are stronger than 0.02Icrab simultaneously. With a similar sensitivity, HESS has surveyed a very small region near the center of our galaxy that resulted in discoveries of numerous sources. At least 99% of the sky is yet to be surveyed. With an operation of LHAASO for 1 or 2 years, one half of the sky will be surveyed just like the central region of our galaxy. A more detailed discussion on performance of the WCDA component can be found in [8].

C. Deep morphologic investigation for discovered sources

Two MaigicII-type Cherenkov telescopes are proposed in the LHAASO project. The sensitivity of the two telescopes alone is shown in Fig. 2. The performance is expected to be further improved with help from hybrid technique with other detectors in the array, especially with one of detectors in the WCDA. The sensitivity will be better than current HESS detectors. An angular resolution of 0.05° is estimated [9] above 3TeV using a simulation package developed by the Magic group.

The telescopes have thresholds of 40GeV in stereoscopic observation and still maintain an angular resolution of 0.3°. This allows a deep investigation of morphology of any source discovered in the survey mentioned in the previous sub-section. Detailed pictures of sources will be disclosed with a similar quality of those shown today, e.g. for RXJ-1713-3946. The energy resolution is also estimated to be better than 20% above 100GeV. This will allow an detailed measurement of bending of Inverse-Compton scattering spectrum. Strong constraints will be put on models for gamma ray production, especially by putting all observations at different energies. With such a low threshold, the telescopes fulfil a real connection with the space borne experiment FERMI/LAT in search for gamma ray bursts (GRB).

D. *"Knees" of individual species and absolute energy scale*

A detector array like LHAASO at a height of 4300m a.s.l. must be used for cosmic ray research because showers around the "knee" just reach their maximum 1 or 2km above the array thus effects due to shower fluctuations are minimized. Since the "knee" was found, its origin has yet to be clarified. A major difficulty is how to separate different primary species from each others in shower observations. Accurately measuring muon contents in showers with large enough active detector array is one of handles. LHAASO array, equipped with the largest muon detector array ever, should make its contribution to this topic. However, many historic experiments, such as CASA/MIA and Kascade, demonstrated that it is not sufficient to effectively separate species by using muon content only. With a small portion of extension by adding WFCA and SCDA, shower maximum depths, X_{max} and high energy fluxes carried by particles near shower cores can be measured. Simulation shows that the X_{max} can be determined with a resolution of 50g/cm^2 which can be useful for the separation, while a difference of 150g/cm^2 between protons and irons in average is expected in this energy range. Simulation also shows that SCDA will help to separate proton showers from others with high purity and efficiency. Working together, the three independent pieces of information will greatly enhance the selecting power for protons, helium and iron nuclei event by event bases above 30TeV. This is particularly important because the spectra of those particles had been measured directly in numerous balloon borne experiments that set absolute energy scale for the air shower observation. Using an array of 5000m^2, the spectra will be extended up to 10PeV or even higher within two or three years.[10]

E. *Extension to UHE for second knee*

To extend the spectrum to higher energies and make a connection with experiments, such as TA and Auger, at altitude around 1600m a.s.l., the wide FOV telescopes will be re-arranged to measure shower fluorescence light and monitoring the space above the ground array from a distance of 4 or 5km. The detector configuration is shown in Fig. 3, in which the main detector array is composed of 16 telescopes covering elevations from 3° to 59° and two other detector arrays, covering elevations from 3°to 31°,observe showers from perpendicular directions. Showers above 100PeV will be detected stereoscopically to maintain a high resolution of X_{max}. Muon content and X_{max} are used for composition measurement around the second knee of the spectrum. The performance of such an extension is detailed using simulation tools[11].

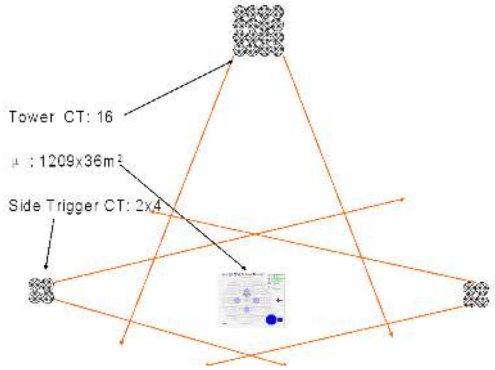

Fig. 3: Layout of the fluorescence detector array and the LHAASO array

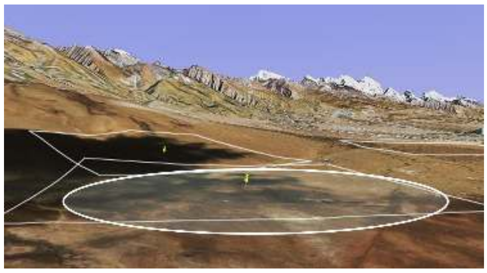

Fig. 4: A primary site of the LHAASO array in the Yangbajing valley , 90km north-west from, Lhasa, the capital city of Tibet Region, China. Latitude: 30°05'23.42"N, Longitude: 90°29'59.08"E, elevation: 4296m. Mountain in the North is the Mt. Nianqing-Kangula

IV. Site consideration for the LHAASO project

Yangbajing is a valley with a width of several kilometers in N-S direction and tens of kilometers long in E-W direction at 4300m a.s.l. where the AS and the ARGO-YBJ experiments are located. The operation of the two prototype telescopes demonstrates that it is suitable for WFCA in a dry climate at least in winter. A tentative site is selected near by a highway and 5km away from a major railway. A geo-thermal power plant, major microwave station and the two existing experiments are located within 3km. The infrastructure is rather convenient that makes the place a perfect site for the LHAASO project. The circle on the ground represents the primary selection for the LHAASO site, as shown in Fig 4.

V. CONCLUSION

The LHAASO project is designed for gamma ray source survey above few hundreds GeV. Complementary with CTA project, the focus of LHAASO experiment is mainly on full-sky survey and galactic cosmic ray origin search above 30TeV. With an extension using Cherenkov telescopes designed by Magic group, detailed source morphologic investigation is also in the scope of the experiment. To maximize the advantage of being at high altitude, cosmic ray spectrum and composition will be measured over a wide energy range spanning a bridge between the balloon borne measurements for each specie and UHECR observations above 1EeV at low altitudes.

VI. ACKNOWLEDGEMENTS

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