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THE CURRENT STATUS AND PROSPECT OF THE TA EXPERIMENT

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The Telescope Array (TA) experiment is designed to observe cosmic-ray-induced air showers at extremely high energies. It is being deployed in a desert of Utah, USA; an array of 3 m^2 scintillation counters will be distributed over 760 km^2 and 3 sets of air fluorescence telescopes will be placed in the perimeter of the array. It's primary purpose is to make a decisive measurement of the cosmic ray spectrum in the GZK cutoff region. We expect the first data from the TA in the spring of 2007. As its unique features are included 1) hybrid measurement planned down to $10^{17.5}$ eV, 2) calibration of fluorescence detection by using artificial air showers generated by an electron linac, 3) interaction model calibration by the LHC.

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1 Introduction

1.1 Why Extremely High Energy Cosmic Rays (EHECRs)?

EHE protons are expected to reach the Earth after traveling distant extragalactic space and therefore lose energy by interacting with the cosmic microwave background (CMB). Lorentz invariance tells us that the interaction takes place over $\sim 10^{20}$ eV for protons; this will result in significant energy loss of protons and show up in the energy spectrum of EHE protons as a rather sharp cutoff over 10^{20}eV. This was first predicted by Greisen, Zatsepin and Kuzmin[1] and called the GZK cutoff. Should there be cosmic rays well above 10^{20} eV (= super-GZK events), it implies their origin be most probably within 50 Mpc from the Earth.

What interesting is that the energy spectrum measured by AGASA shows no indication of the GZK cutoff.[2] They recorded 11 super-GZK cosmic rays in 13 years of operation. Moreover, in the sample of 59 events above $10^{19.6}$ eV, 13 events were found to form a cluster of 2 or 3 events (5 doublets and 1 triplet) indicating each cluster corresponds to a common "point source" in the sky.[4]

However, within 100 Mpc, we don't find any corresponding astronomical objects such as active galactic nuclei, radio galaxy lobes and gamma ray bursts which could be a plausible source of the super-GZK or cluster events.[5] In order to circumvent the difficulties in the astrophysical models, several particle physics oriented models have been proposed for the origin of EHECRs.[6] They are the decay of super-heavy relic particles in the galactic halo, the interaction of EHE neutrinos with the cosmic neutrino background in the local cluster. Violation of Lorentz invariance at the extremely high γ factor is also proposed.

1.2 Things are not quite that easy

The HiRes group, on the other hand, recently reported an energy spectrum which is consistent with the existence of the GZK cut-off.[3] After adjusting the energy scale by an amount of error of each experiment($\sim$18% for AGASA and $\sim$25% for HiRes), the spectra of both experiments agree well below 10^{20} eV, yet leave more than a $\sim 2\sigma$ level disagreement on the existence of GZK cutoff. We should note that the AGASA uses surface detectors and the HiRes uses fluorescence detectors; both have drawback and advantage. The best way to resolve this contradiction is to measure the air shower simultaneously with an AGASA type air shower array and a HiRes type air fluorescence telescope.

2 The TA experiment

In view of these circumstances, the hybrid TA was proposed as the first step of building the full TA. The first step was financially approved in late 2002 in Japan and the construction was started in the Utah desert in collaboration with the US side. The present TA focuses whether the EHECR spectrum continues or ends at the GZK energy and whether the discrepancy between AGASA and HiRes is from the statistics, the systematics or the physics.

The configuration of the hybrid TA is shown in Fig. 1. The site is located at latitude $\sim$39.3°N, longitude $\sim$112.8°W, and the elevation is $\sim$1400m above sea level ($\sim$875 g/cm^2 atmospheric depth).

The ground detector consists of an array of 576 counters each of which contains 2 layers of a 1.2 cm thick plastic scintillator plate of 3 m^2 . They are deployed in a grid of 1.2 km spacing covering the ground area of $\sim$ 760 km^2. The detector acceptance is approximately 9 times that of AGASA. The detection efficiency is 100 % for cosmic rays with energy more than $10^{19.5}$ eV within zenith angles 45°. The fluorescence measurement is made at 3 stations surrounding the ground array. The stations form a triangle with a separation of 30 - 40 km. Twelve reflecting

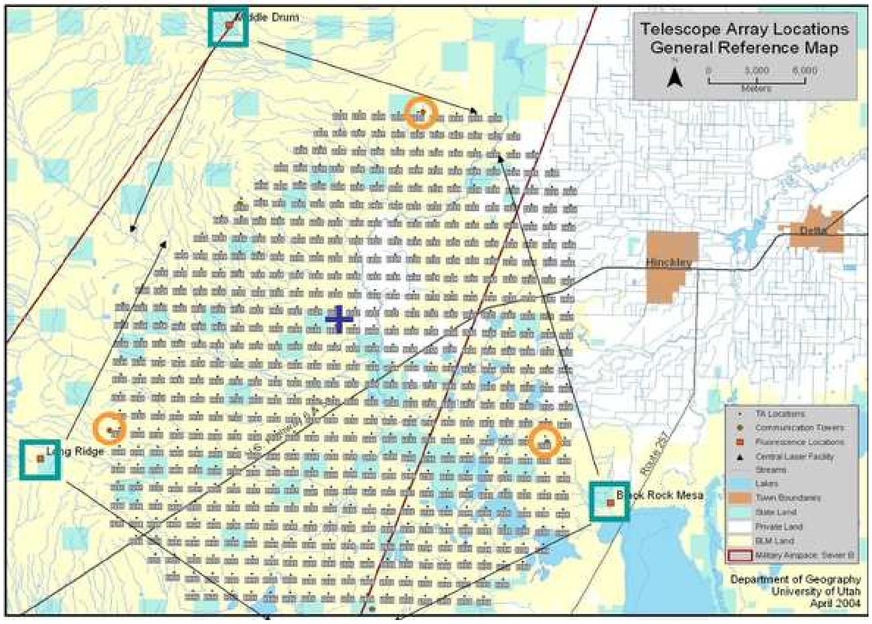

Figure 1: Detector Arrangement of Telescope Array. Three square boxes indicate the location of fluorescence telescope stations overlooking a scintillation counter array indicated by a number of small boxes. The circles indicate the locations of communication tower, by which all the controls and data acquisition are relayed to the operation center in the nearby town of Delta, which is at the rightmost shadow area on the map.

telescopes are installed at each station and covers the sky of 3°-34° in elevation and 108° in azimuth looking toward the center of the ground array. The diameter of the telescope mirror is ∼3.3 m and the pixel resolution is approximately $1^\circ \times 1^\circ$. The stereo acceptance is ∼670 km^2 sr for $E > 10^{20}$ eV by requiring at least one station is within 45km from the shower center. The fluorescence acceptance is 4 times that of AGASA assuming 10% duty factor for observation.

2.1 A bit more detail, current status and prospect

The surface detectors of hybrid TA uses thin plastic scintillator. Since the electro-magnetic component of the air shower dominates second dominant component, i.e, muons more than order of magnitude at least at distances not very far from the air shower core, thin detector response is governed by the e-m component. This means the energy measurement of TA is less affected by the difference of the primary composition and the detail of unknown hadronic interactions at EHE.

That is, the e-m component is governed by the energetic forward particles which are less affected by the nucleus effect, while muons at EHE come only from the backward hemisphere of the CMS where nucleus effect is very large, and forward pions and kaons must wait for the 2nd, 3rd ... collisions until their product can copiously decay into muons.

This is the advantage with respect to the use of water Cherenkov counter, which is equally sensitive to the high energy muons and soft gamma rays. We expect the uncertainty of the absolute energy scale can be tuned better than10 % accuracy by carefully analyzing the simultaneously measured events for $E > 10^{19}$ eV. All together, an energy spectrum with twice smaller statistical error than the present AGASA will be obtained by the 3-year measurement of the array and the telescope.

We use flush ADC and able to record the full wave form of PMT signal. Therefore, the angular resolution of the TA ground array is expected to be $\sim 1^\circ$ which is better than AGASA's 1.6°. Moreover, the angular resolution expected for the fluorescence and hybrid events are significantly better and they contribute for identifying the cluster events particularly at energies below $10^{19.6}$ eV. It may be noted that the energy spectrum from the clusters shows a difference from the general spectrum and can be given a plausible reasoning.[7]

In addition, the magnetic deflection by the galactic field is smaller and more regular in the northern sky, which will be advantageous to confirm the cluster event of AGASA and to search for corresponding astronomical sources. If the primary EHECRs are charged particles, systematic magnetic deflections with respect to the direction of the galactic field would be observed, which may be used for determining the chemical composition of the primary cosmic rays. Some of the EHECR source models also predict a large scale anisotropy of arrival directions.

For identifying the origin of EHECRs, it is essential to identify the particle species of the primary cosmic ray. For example, many of the particle physics oriented models predict an abundant generation of EHE gamma rays and neutrinos rather than protons. On the other hand, the conventional shock wave acceleration will be strongly supported if heavy nuclei are identified as the major composition of EHECRs. For the TA, the particle identification is provided by the shower profile measurement by the fluorescence telescopes. The Landau-Pmenranchuk-Migdal and geomagnetic effects on the photon primary showers over $\sim 10^{19}$ eV give us an interesting clue to identify EHE photons.[8]

The EHE neutrinos produce nearly horizontal showers and are easy to identify. The target volume of the first phase TA for EHE neutrino is $\sim 10^{10}$ ton sr and the effective neutrino aperture is ~ 0.03 km^{2}sr for energies above 10^{20} eV. The expected neutrino event rate is, however, $0.04 \sim 2$ events in 10 years, so that we will have to wait for a future deployment of the full TA or the AGASA$\times$100 large ground arrays.

The mass deployment of detectors will start in early 2006 and will be completed by March 2007. The LHC calibration of the interaction models and liniac calibration of fluorescence detection will help to draw the decisive conclusion on the GZK region spectrum by 2010.

Details of the TA detector design and performance as well as the proposal for low energy extension (TALE) are in the proceedings of the International Cosmic Ray Conference, 2005 (India).

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