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Telescope Array; Status and Prospects

The Telescope Array (TA) Collaboration
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The Telescope Array (TA) is the air shower experiment designed for observing extremely high energy cosmic rays. It consists of an array of scintillation counters covering the ground area of 760 km^2 and 3 sets of air fluorescence telescopes placed in the perimeter of the array. The TA aims at making a decisive measurement of the cosmic ray spectrum in the GZK cutoff region, and pinning down the nature of cosmic rays exceeding 10^{20} eV, which have been the subject of extensive studies by AGASA, HiRes and other air shower experiments. The TA is being constructed in Utah, USA, and the commissioning is expected in the spring of 2007. An extension of hybrid measurement is planned down to $10^{17.5}$ eV in order to elucidate the galactic to extra-galactic transition of cosmic ray sources (TALE proposal).

1. Nature of Extremely High Energy Cosmic Rays (EHECRs)

The EHE proton propagating a long distance through the extragalactic space is expected to lose its energy by interacting with the cosmic microwave background (CMB). Following the Lorentz invariance, the CMB is equivalent to a gamma ray of energy ~100 MeV in the rest frame of 10^{20} eV proton. Thus the proton of this energy is expected to result in a pion photo-production, and a significant part of its initial proton energy is carried away by the produced pions. This was first predicted by Greisen, Zatsepin and Kuzmin (GZK) [1]. Two outcomes of the theory are;

1. The energy spectrum of EHECRs arriving from uniformly distributed sources in the universe should exhibit a clear cutoff structure at ~10^{20} eV (= GZK cutoff).

2. If the cosmic rays above 10^{20} eV (= super-GZK events) are detected, most of them should have an origin within 50 Mpc of the Earth.

Despite the prediction of GZK, the energy spectrum measured by AGASA [2] shows no indication of the GZK cutoff [3]. The AGASA 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 clusters of 2 or 3 events (5 doublets and 1 triplet) indicating they originate from a common "point source" in the sky [4]. A correlation with high energy astronomical objects such as active galactic nuclei, radio galaxy lobes and gamma ray bursts have been searched but no obvious candidates were identified within 100 Mpc [5]. In order to circumvent the difficulties met with the astrophysical models, several particle physics oriented models have been proposed for the origin of EHECRs. 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, the violation of Lorentz invariance at the extremely high γ factor and others [6].

2. Decisive Measurement of GZK Spectrum

The HiRes air fluorescence telescope, on the other hand, recently reported an energy spectrum which is consistent with the existence of the GZK cut-off [7]. After floating the energy scale error of each experiment, ~18% for AGASA and ~25% for HiRes, the spectra of both experiments agree well below 10^{20} eV, yet leave a 3 σ level of disagreement on the existence of GZK cutoff. It should be noted that two experiments differ not only in the experimental method but also in the measured shower parameters; the AGASA measures the lateral shower profile in the shower periphery and the HiRes measures the longitudinal shower profile at the shower center. The discrepancy above 10^{20}eV therefore may very well originate from the physics of the shower development at EHE or the nature of the incoming particles. 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.

The hybrid TA is proposed as the first step of building the full TA [8] with the urgent questions in mind; 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 hybrid TA is shown in Figure 1. The ground detector consists of an array of 576 plastic scintillators with an area of 3 m^2 deployed in a grid of 1.2 km spacing covering the ground area of ~760 km^2. The detector acceptance is approximately 9 times that of AGASA. The detection efficiency is 100% for cosmic rays with energies more than $10^{19.5}$ eV with zenith angles less than 45^0. 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 telescopes are installed at each station and covers the sky of 3^0-34^0 in elevation and 108^0 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 1^0 x 1^0. 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. Details of the TA detector design and performance as well as the proposal for low energy extension (TALE) are reported elsewhere in this conference.

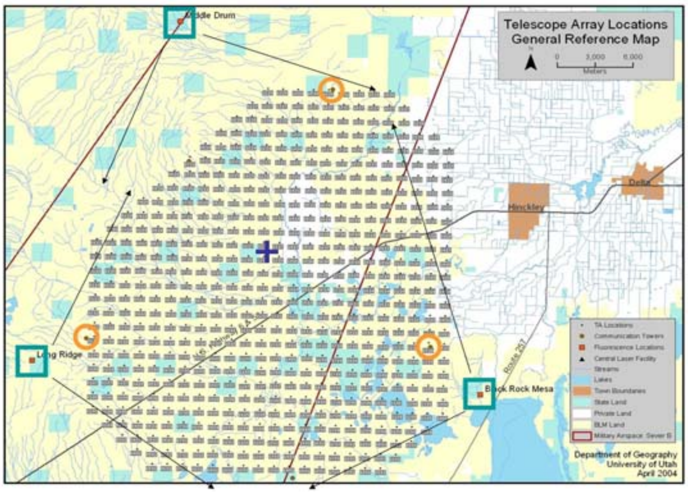

Figure 1. Detector Arrangement of Telescope Array. Three square boxes indicate the location of fluorescence telescope stations overlooking a scintillation counter array at the center. The circles indicate the locations of communication tower, by which all the controls and data acquisition are relayed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

3. Status and Prospects

The ground array of hybrid TA uses the plastic scintillator, which is sensitive to the charged particles in the air shower. For energies greater than 10^{20}eV, more than 90 % of the primary energy is transferred to the electromagnetic component (e$^+$, e$^-$and γ) at the end of the shower development. Since electrons and positrons outnumber muons by an order of magnitude, the thin (~12mm) plastic scintillator array of TA is sensitive in effect only to the electromagnetic component of the air shower. By this reason, the energy measurement of TA is less affected by the difference of the primary composition and the detail of unknown hadronic interactions at EHE. 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 cut down to below 10% 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.

The angular resolution of the TA ground array will be about 1^0 and is better than 1.6^0 of AGASA by virtue of the full wave form sampling of the PMT signal. The angular resolution expected for the fluorescence and hybrid events are significantly better and they contribute for identifying the cluster events particularly at the lower energy below $10^{19.6}$ eV. 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. Photons with energies greater than 5 x 10^{18} eV may be identified by the Landau - Pomeranchuk - Migdal (LPM) effect leading to a deeply penetrating shower in the atmosphere. Above 2 x 10^{19} eV, a geomagnetic cascade starts and the LPM effect is largely cancelled. The geomagnetic effect is strongly related with the CR arrival direction with respect to the Earth magnetic field and will clearly be identified by the north-south asymmetry when enough samples are collected.

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 0.04 - 2 event in 10 years for the decay of super-heavy relic particles or the Z-burst model depending on the assumption of models. In general, the detection of EHE gamma rays and neutrinos is hard with a limited acceptance of the first phase hybrid TA. We will have to wait for a future deployment of the full TA or the AGASA x 100 large ground arrays.

As of June 2005, 18 scintillation counters and 2 telescopes are deployed in the field of Utah and are being tested. The mass deployment will start later in 2005 and will be completed by March 2007. We expect that astonishing discoveries of AGASA on EHECRs are confirmed or refuted by 2010.

4. Acknowledgements

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