Status and Prospect of Telescope Array (TA) Experiment

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Abstract: Telescope Array (TA) is an air shower experiment composed of an array of ground particle detectors and 3 sets of fluorescence telescopes installed in Utah, USA. It aims at drawing a conclusion on the (non-)existence of the GZK cutoff reported controversially by AGASA and HiRes experiments. An anisotropy of the UHECR arrival directions will be studied as well in the northern hemisphere where the galactic disturbances are small. The plastic scintillator is useful for the determination of the air shower energy independent of the hadronic interaction model and the primary composition. Various calibration and monitoring methods have been applied for the accurate determination of event energy scale. It has a total acceptance more than 20 times larger than that of AGASA. An operation of partial detector has started. The status of the experiment is reported and prospects for the physics are given.

Search for the GZK Cutoff by AGASA and HiRes

A cutoff structure is expected in the energy spectrum of extremely high energy cosmic rays (EHECRs) at $\sim 10^{20}$ eV. It originates from the interaction of cosmic ray protons with the cosmic microwave background and was predicted by Greisen, Zatsepin and Kuzmin (GZK) in 1966 [1]. Since that prediction, the search for the GZK cutoff has been a central theme in the study of EHECRs. Major efforts were made by the Akeno Giant Air Shower Array (AGASA) in Japan and the High Resolution Fly's Eye (HiRes) in the USA.

The AGASA experiment published an energy spectrum which does not exhibit the GZK cutoff in 1998 [2]. The spectrum above 10^{19} eV is well described by $E^{-2.78}$ distribution, and a total of 6 events was observed above 10^{20} eV with an exposure of 0.83×10^3 km^2 sr yr. It is updated to 11 events in 2003 with an exposure of 1.62×10^3 km^2 sr yr [3]. The HiRes published a result of monocular measurement in 2004 [4] and asserted that the energy spectrum is consistent with the existence of the GZK cutoff. In the monocular HiRes data set, the number of events above 10^{20} eV is 2 with an exposure of 2.4×10^3 km^2 sr yr.

It is apparent that a part of the discrepancy in the Flux(E) $\times E^3$ plot is due to the systematic shift of energy measurement between two experiments. It is known that the spectra of AGASA and HiRes agree well below $\sim 10^{20}$ eV if either the overall energy scale of AGASA is lowered by $\sim$20% or the energy scale of HiRes is increased by the same amount. The AGASA claims its uncertainty in energy determination is 18% [3] and the corresponding number of HiRes is 17% [4].

Even after the energy rescaling, however, the number of events above 10^{20} eV seems to show a disagreement between AGASA and HiRes. For AGASA, the number of events with $E > 10^{20}$ eV becomes 5 with -20% energy rescaling. Normalizing the exposure to that of AGASA but keeping its energy scale, the corresponding number is 1.4 events for HiRes. Each experiment stays unchanged on the conclusion of the GZK cutoff but with less statistical confidence. This disagreement may be originating from the physics of UHECRs, or otherwise, it must be explained by the systematics inherent to two experimental methods; AGASA is the ground particle array and HiRes is the fluorescence telescope. In order to establish the energy spectrum for cosmic rays in the GZK cutoff region, it is urgent to understand the reason of this difference.

New Generation Detectors: TA and Auger

AGASA completed 13 years of data collection in January, 2004. The HiRes stopped taking data in April, 2006. Two new experiments, the Pierre Auger Observatory (hereafter called "Auger") and the Telescope Array (TA), are now proceeding to examine this issue.

Both of the new experiments are hybrid. They employ an array of Surface Detectors (SDs) and several sets of Fluorescence Detectors (FDs) in the same location and make a simultaneous observation of an air shower by two different detector technologies.

Auger uses the water Cherenkov counter as a SD and covers a ground area of 3,000 km^2. TA uses plastic scintillators and covers an area of 680 km^2. The construction of Auger in Malargue, Argentina and TA in Utah, USA will be completed in 2007. Preliminary data from Auger was already presented in 2005 with an exposure of 1.75×10^3 km^2 sr yr but the conclusion on the GZK cutoff was not given as the energy calibration was incomplete [5].

Status of TA

The detector configuration of TA is shown in Fig.1. It consists of a large array of Surface Detectors (SDs) and 3 stations of Fluorescence Detectors (FDs) overlooking the array from the surrounding hilltops of approximately 100 m elevation. The SD will give an aperture of $\sim$1900 km^2 sr and the FD will have a stereoscopic aperture of $\sim$860 km^2 sr at 10^{20} eV with a duty factor of 10%.

It is located 140 miles south of Salt Lake City (lat. 39.3°N, long. 112.9°W) in the West Desert of Utah with an average altitude of 1400 m.

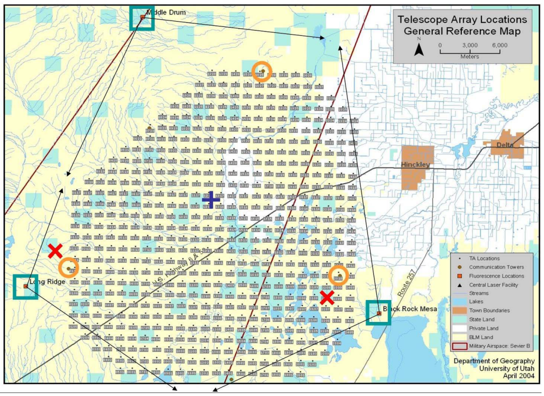

Figure 1: Detector Arrangement of TA. The locations of SDs are indicated by small numbers. The locations of 3 FD stations are marked by square boxes.

As of May 2007, 90% of the total SDs and two FD stations are installed and a test data acquisition from these detectors has started. The 3rd FD station is being built by the transfer of HiRes-1 mirror and electronics. The status of construction and the performance of each detector is reported in this conference[6].

We are making our best effort to establish the energy scales of TA-SD and TA-FD measurements independently, which will help us understanding the systematic problems of each measurement. To this end, we have developed ingenious ways of FD camera calibration and atmospheric transparency monitoring using UV pulsed lasers[7]. An absolute calibration of FD will be performed in situ by using an electron linac beam[8]. The Monte Carlo air shower generation program, which is critical for determining the SD energy scale, will be examined using very forward π° and neutron production data soon to be obtained by the LHCf experiment[9] at CERN.

Prospects

An overall performance of TA is summarized in Table-1. The expected number of events collected in one year of TA operation is listed in Table-2.

Table 1: Projected Performance of TA. The values are estimated at 10^{20} eV. The trigger acceptances are calculated for SDs with zenith angles below 60° and for 3 full FD stations. The total acceptance is the summation of the SD and the monocular FD acceptances. The energy resolution is derived from the SD and the energy scale uncertainty is from the FD.

Total Acceptance	3,500	km^2 sr
SD Acceptance	1,900	km^2 sr
FD Acceptance (stereo)	860	km^2 sr
FD Acceptance (mono)	1,800	km^2 sr
Hybrid Acceptance	190	km^2 sr
Energy Resolution	25	%
Energy Scale Uncertainty	10	%
SD Angular Resolution	2.0	degree
FD Angular Resolution (stereo)	0.6	degree
Hybrid Angular Resolution	0.5	degree
FD Xmax Resolution (stereo)	17	g cm^{-2}

Table 2: The number of events expected in one year of TA operation. The AGASA flux is used for the estimation.

	E $>10^{19}$eV	E $>10^{20}$eV
Total (SD + FD)	750	31.0
SD only	1020	16.8
FD stereo	230	7.6
Hybrid (SD × FD)	100	1.7

We will obtain more than the AGASA equivalent exposure[1] both for the SD and FD monocular measurement in one year of running. If we assume the AGASA flux[2], we should have ∼16.8 events with $E > 10^{20}$ eV and ∼1000 events with $E > 10^{19}$ eV detected by the SD only in one year of running.

The energies of these events are cross-calibrated at the level of 10% using ∼100 hybrid events with E $> 10^{19}$ eV. One or two hybrid events are expected above 10^{20} eV for which the energy measurement is 4-fold; one by the ground array and three by the fluorescence telescopes. The first re-examination of the GZK cutoff by TA will be made using these sets of event.

1. 1.62×10^3 km^2 sr yr.
2. 2.0×10^{20} E$^{-2.78}$ m^{-2} s^{-1} sr^{-1} eV^{-1}

The acceptance of Auger ground array is ∼4 times larger than that of TA using the same zenithal acceptance. The value of TA data therefore depends upon the accurate energy determination and the measurement in the northern hemisphere.

The plastic scintillator of TA measures the number of penetrating charged particles which is dominated by the electrons. It is known that the number of electrons in a fully developed air shower outnumbers the muon by an order of magnitude. Air shower Monte Carlo also tells us that the number of muons in a shower depends on the primary composition. Compared to the muon based measurement, the electron based measurement is less affected by the composition of the primary cosmic rays, which is unknown and may be changing over the measurement range of GZK cutoff.

On the other hand, TA is not good at determining the primary composition. It is a significant disadvantage for the identification of EHE gamma rays and neutrinos even though the energy measurement for these exotic shower events are well performed by TA.

The association of EHECRs with an astronomical object, if possible, will be essential for identifying the origin of such EHECRs. The southern hemisphere sky contains the galactic center. The northern hemisphere sky contains abundant galaxies in a local cluster and has more numbers of AGNs identified due to the lack of the zone of avoidance. In addition, directional disturbances of EHECRs by the galactic magnetic field is significantly smaller. The coverage of northern sky by TA will thus complement the measurement of the southern sky by Auger.

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