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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 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 methods will be applied for the accurate determination of event energy scale. A total acceptance of the ground array and the telescope will be more than 20 times larger than that of AGASA. An operation of partial detector has started in spring 2007. The status of the experiment is reported and prospects for the physics are given.

Search for the GZK Cutoff

A cutoff structure is expected in the energy spectrum of extremely high energy cosmic rays (EHE-CRs) 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 EHE-CRs. 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 the discrepancy in the Flux(E) $\times E^3$ plots is largely due to the systematic difference of energy measurement between the 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 significance. This disagreement is originating from the physics of UHECRs if it is not 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 by the hybrid experiment.

New Generation Detectors

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. Both 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 675 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].

Telescope Array (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 with zenith angle smaller than $60°$ and the FD will have a monocular aperture of $\sim$1800 km^2 sr at 10^{20} eV with a duty factor of approximately 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.

Status of TA

The status of construction and the observation of first events by TA are reported in this conference by H.Sagawa for SD and by S.Ogio for FD.

Prospects

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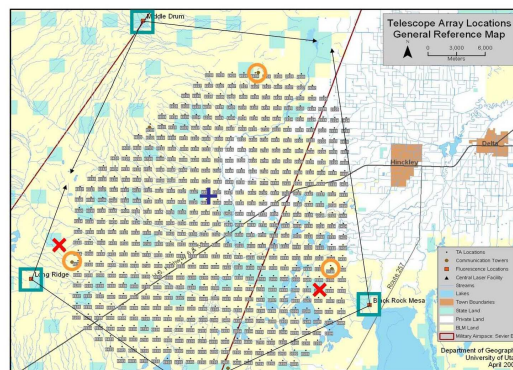

Figure 1: Detector Arrangement of TA. The locations of SDs are indicated by small numbers. The locations of 3 FD stations are marked by square boxes.

We will obtain the AGASA equivalent exposure (1.62×10^3 km^2 sr yr with zenith angles smaller than $45°$) by SD before the summer of 2009 after $\sim$17 months of measurement. If we assume the AGASA flux (2.0×10^{20} $E^{-2.78}$ m^{-2} s^{-1} sr^{-1} eV^{-1}), we should have $\sim$14 events with $E > 10^{20}$ eV and $\sim$870 events with $E > 10^{19}$ eV detected by the SD below zenith angles $45°$.

The energies of these events are calibrated at the level of 10% using $\sim$87 hybrid events with $E > 10^{19}$ eV. One hybrid event is 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.

Meanwhile the construction of Auger in Argentina is expected to be completed in 2007. The acceptance of Auger ground array is $\sim$4 times larger than that of TA using the same zenithal acceptance. The value of TA data therefore resides on 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

Table 1: Projected Performance of TA. The values are estimated at 10^{20} eV. The total acceptance is the summation of the SD and the monocular FD acceptances. The SD acceptance is taken for zenith angles below $60°$. The energy resolution of SD and the energy scale uncertainty of FD are listed.

Total Acceptance	3,510	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)	1878	31.0
SD only	1018	16.8
FD stereo	459	7.7
Hybrid (SD $\times$ FD)	102	1.7

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 of TA 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, the determination of the primary composition using the muon content is not possible for TA. It is a significant disadvantage for the identification of EHE gamma rays and neutrinos.

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. The northern sky has more numbers of Active Galactic Nuclei identified thanks to

much smaller zone of unfavorable galactic influences. The coverage of northern sky by TA will thus complement the measurement of the southern sky by Auger.

Acknowledgements

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