The Telescope Array Experiment: An Overview and Physics Aims

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Abstract

The Telescope Array (TA) experiment plans to deploy an array of 10 telescope stations in the west desert of Utah, USA and observes extremely high energy cosmic rays (EHECRs) by the atmospheric fluorescence. Its purpose is to study super-GZK ($E > 10^{20}$ eV) cosmic rays discovered by AGASA. In order to identify the origin of super-GZK events, TA has ∼30 times larger aperture than AGASA and provides a particle identification by the shower profile measurement. The first step of construction will start as a hybrid detector with an AGASA×10 ground array and a part of fluorescence telescopes, which will unambiguously establish

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the existence of super-GZK and cluster events with much improved statistics and systematics. This paper describes the physics of TA and its overall planning.

1. Physics of Telescope Array

The AGASA so far observed 11 super-GZK cosmic rays in 12 years of operation. The energy spectrum continues toward high energy without showing an indication of the GZK-cutoff[1]. The arrival directions are isotropic and does not show a correlation with the galactic plane or the super-galactic plane of nearby galaxies. A few point-like clusters were observed in the sky, from which 2 or more EHECRs were arriving[2]. High energy astronomical objects have been searched behind these events but no apparent candidates were found. A correlation with quasar remnants[3] and the BL Lac objects[4] had been suggested, but none seem definitive at this moment. The latest results of AGAGA are reported elsewhere in this conference. Several hypotheses have been proposed to explain super-GZK events and clusters[5];

- The production of EHECRs by the decay of long-lived, super-heavy relic particles concentrated in the halo of our galaxy and with some level of clumping to produce clustered events.
- The production of Z° by the collision of cosmological neutrino background with extremely high energy neutrinos ($E \geq 10^{21}$ eV) produced deep in the universe. The EHECR is produced as a decay product of Z°. The primordial neutrinos may be concentrated in the local super-cluster of galaxies by its gravitational interaction with the dark matter.
- The Lorentz invariance breaks down at a very high Lorentz factor such that the high interaction cross section of pion photoproduction via $\Delta(1232)$ resonance is avoided.
- The generation of EHECRs by the yet unknown dark stars which are over-populated by a factor of $\sim$10 in the vicinity of our galaxy.

Note that the Z-burst and the violation of Lorentz invariance explain the extension of the spectrum above GZK cutoff, but they leave the question of acceleration itself unanswered. It is certain that super-GZK events and clusters are difficult to explain in the standard framework of astrophysics and particle physics.

2. Prospects

The models with super-heavy relics and the Z-burst have a clear experimental signature to be tested, i.e. EHE gamma rays and neutrinos are an order of magnitude more abundant than protons in these models. The super-heavy relics

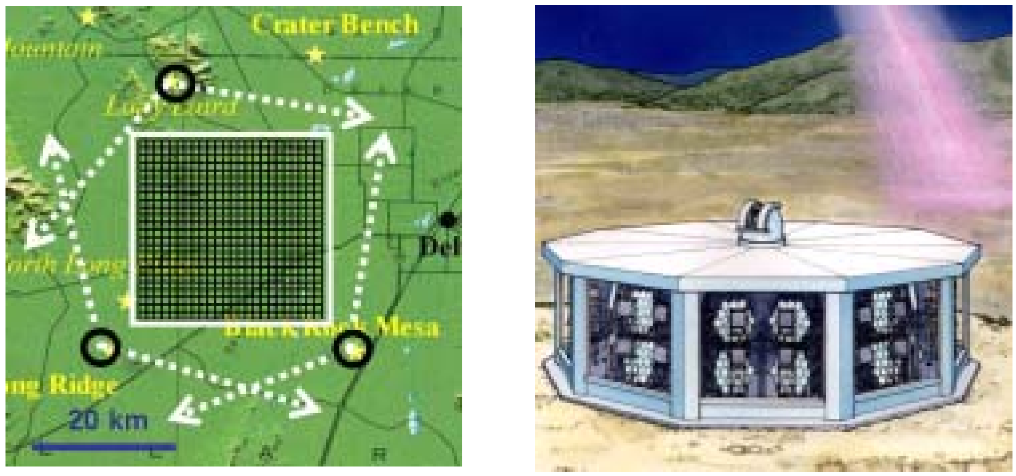

Fig. 1. The Hybrid TA (left panel) is composed of 576 plastic scintillation counters covering the ground area of 760 km^2 and 3 fluorescence telescope stations (right panel) surrounding the ground array and looking inward.

model also expects a concentration of the sources in the center of the galaxy. A realistic test of Lorentz invariance becomes possible when we identify the source objects of EHECR and measure the distance to the source. The detection of heavy nucleus as a major composition of the EHECR, on the other hand, excludes most of the particle physics origin and directly leads us to the shock wave acceleration. Thus, we expect the TA and the other next generation EHECR experiment will give a clear answer to many of these hypotheses.

The experimental situation around the GZK cutoff became unclear when the HiRes group submitted a paper[6] recently on the first measurement of the energy spectrum and concluded that it is consistent with the existence of the GZK cut-off. Discussions after the submission of the paper can be summarized as follows;

- Taking a systematic uncertainty of the energy determination by two groups, 25% for HiRes[6] and 18% for AGASA[7], the claim of neither group on the existence of the GZK cutoff has a statistical significance higher than 3 σ.
- Below 10^{20}eV where the comparison can be made with enough statistics, the energy spectra of both agree perfectly well, if we remake the HiRes spectrum by increasing the energy of all HiRes events by 25%, or by decreasing the AGASA energy by the same amount.

It is clear that the key of resolving the issue is the higher statistics and better understanding of the systematics. This can be best achieved by a large hybrid experiment making a simultaneous measurement with an AGASA type air shower

Table 1. Expected Acceptance, Resolution and Number of Events of Hybrid TA

Detector	Acceptance (km^2 sr)	Angular Resolution	# of Events per Year	
			$E > 10^{19}$ eV	$E > 10^{20}$ eV
AGASA	162	1.6°	100	1
TA:Ground Array	1371	1.0°	700	9
TA:Fluorescence	670	0.6°	300	4
TA:Hybrid	165	0.4°	80	1

array and a HiRes type air fluorescence telescope. The good statistics can be obtained by building a large ground array, which is relatively inexpensive and its stable operation and uniform coverage over the sky have been guaranteed by the experience of AGASA and other arrays. The better understanding of systematics can be made by the fluorescence measurement, which allows us a calorimetric measurement of the shower energy, a direct observation of the arrival direction and a determination of primary particle species by the shower longitudinal profile.

We therefore propose to urgently build a hybrid TA, an AGASA×10 ground array with a set of fluorescence stations making a simultaneous measurement with the ground array (see Figure 1). It will be built in the West desert of Utah, USA, and will become a first step of constructing the full TA[8]. The performance of the hybrid TA detector is summarized in Table 1 and further details are given elsewhere in this conference. The plan is to complete the hybrid TA by the end of 2006. We expect the full sky survey of EHECRs will be started by the southern hemisphere Pierre Auger observatory in Argentina in 2005, and the hybrid TA will start contributing to the northern hemisphere survey in 2007. We hope that astonishing discoveries of AGASA are confirmed, and the origin of super-GZK and cluster is identified by 2010.

3. References

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