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The Plan of the Telescope Array Experiment for the Next Five Years

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Abstract: The Telescope Array (TA) is the largest experiment in the northern hemisphere currently studying the origin and nature of ultra-high-energy cosmic rays above $\sim 10^{18}$ eV by measuring their energy spectrum, mass composition, and arrival directions. The TA consists of a surface array of 507 scintillation counters deployed on a square grid of 1.2-km spacing, and 38 fluorescence telescopes located at three sites looking over the surface array. Here we present the plan for continued operations and further extension of the TA detector over the next five years. The TA will have the potential to provide answers to important scientific questions that are required for progress toward the next generation of detectors.

Keywords: Ultra-high energy cosmic rays, Telescope Array experiment, Next five-year plan.

1 Introduction

The Telescope Array (TA) is the largest Ultra-High Energy Cosmic Ray (UHECR) observatory in the northern hemisphere, located in the West Desert in Millard County, Utah, USA (latitude 39.3° N, longitude 112.9° W, altitude ∼1400 m) [1, 2]. It is designed to observe extensive air showers (EAS) induced by the UHECRs with energies greater than $\sim 10^{18}$ eV for the measurement of the energy spectrum, arrival direction and mass composition in order to explore their origin, propagation and interaction. The TA detector consists of an air shower surface detector (SD) array of plastic scintillation counters to measure the lateral distribution of secondary particles on the ground, and fluorescence detectors (FD) to measure the longitudinal development of the EAS in the atmosphere. The layout of the TA detector is shown in Figure 1. The TA is operated by an international collaboration of researchers from Japan, USA, Russia, Belgium and Korea. Hybrid observation with both surface detectors and fluorescence detectors started in March 2008.

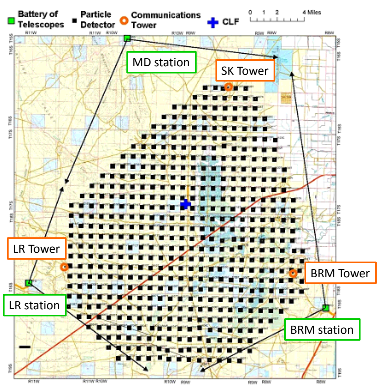

Fig. 1: The layout of the TA: an array of 507 surface detectors (black squares), three fluorescence telescope stations (green squares), and three communication towers (orange circles).

The TA surface detector consists of 507 scintillation counters deployed on a square grid of 1.2-km spacing, and covers ~ 700 km^2. Each SD has two 1.2-cm thick layers of plastic scintillator. Signal light from energy deposited by particles is collected by wavelength shifting optical fibers in extruded grooves on the scintillator layers and brought out to a photomultiplier tube (PMT) for each layer. The resulting electronic waveforms are digitized by 12-bit FADCs at 50 MHz sampling rate. A solar photovoltaic panel provides power for the PMTs and readout electronics. The SD is divided into three sub-arrays. Within each sub-array, the SDs communicate via wireless LAN with a host computer located at a communication tower. The performance of the SD system is described in [3].

Three FD stations are located at the periphery and look inward over the SD array. The Middle Drum (MD) FD site is located to the north of the TA-SD array, and is instrumented with 14 refurbished telescopes from the HiRes-I station from the High-Resolution Fly's Eye (HiRes) experiment. These telescopes view from 3°-31° above the horizon and 114° in azimuth. The Black Rock Mesa (BRM) and Long Ridge (LR) FD sites are located to the southeast and southwest of the TA-SD array, respectively. They are each instrumented with 12 new telescopes [4].

We summarize the recent TA results in Section 2. Based on the TA results, the plan for continued TA operations, research at the TA observatory and the extension of the TA detector over the next five years is presented in Section 3. Section 4 summarizes this paper.

2 Recent TA results

Here we summarize the recent TA results of energy spectrum, mass composition, and arrival directions of UHECRs.

2.1 Energy spectrum

Recently we published the result of the energy spectrum using the first four years of SD data [5]. The TA SD spectrum is consistent with the HiRes spectra. Using a power-law fit, we found two breaks at $(4.6 \pm 0.3) \times 10^{18}$ eV and $(5.4 \pm 0.6) \times 10^{19}$ eV, corresponding to the ankle and the GZK suppression expected for protons, respectively. We observed 21 events above the break at 5.4×10^{19} eV while a linear extrapolation of the power law below the break predicted 58.6 events above the break. Thus an extended spectrum beyond the GZK cutoff energy is ruled out with a statistical significance of 5.5σ. We have published MD monocular energy spectrum [6], which is consistent with the SD spectrum. In this conference, we will update on these results together with energy spectra by other methods.

2.2 Mass composition

The dependence of shower maximum depth (X_{max}) on the primary energy is used to determine the mass composition. The preliminary result from the events simultaneously observed at two new FD stations (stereo events) for about three years was presented in [7]. The distribution of reconstructed X_{max} for the TA data was in agreement with theoretical predictions for proton distribution. The energy evolution of the average X_{max} was compared with the MC data above $10^{18.2}$ eV. The observed TA data was in agreement with the QGSJET-01 pure proton prediction. Recently a similar result was obtained by using the events simultaneously observed with the Middle Drum FD station and SD (hybrid events). We will update the X_{max} results at this conference [8, 9].

2.3 Arrival directions

We published the studies of arrival directions of UHECRs for correlations with AGNs, autocorrelations and correlations with the Large-Scale Structure (LSS) using 40-month SD data, which contained 988 events above 10^{19} eV, 57 events above 4×10^{19} eV, and 25 events above 5.7×10^{19} eV [10].

The TA reported correlations between the arrival directions of UHECRs with E $> 5.7\times10^{19}$ eV and positions of nearby AGNs from the Veron 2006 catalog with $0 < z < 0.018$. There were 11 correlating events (44%) out of a total of 25 events, with 5.9 random coincidences expected. This result is compatible both with isotropic distribution and the AGN hypothesis. From a binomial distribution with a probability of correlation of $p_{iso} = 0.24$, the chance probability for observing 11 correlated events out of 25 is about 2% assuming an isotropic model distribution.

For cosmic rays above 4×10^{19} eV, TA found 0 pairs separated by less than 2.5°, while 1.5 pairs are expected by chance for the isotropic model. There was no excess of small-scale clusters in the TA data, and no significant excess was found for angles from 0° to 40° and the three energy thresholds of 10^{19} eV, 4×10^{19} eV and 5.7×10^{19} eV. There was a hint of grouping of events at angular scales between 20° and 30° for E $> 5.7\times10^{19}$ eV.

The TA event sets at above both 4×10^{19} eV and 5.7×10^{19} eV were compatible with the LSS model even without the inclusion of the regular Galactic Magnetic Field (GMF). For E $> 10^{19}$ eV, the TA data set was compatible with the LSS hypothesis that included the regular GMF with a strong (4 μG) and thick (1.5 kpc) halo component, but this data set was also compatible with an isotropy model. We will update our search for arrival direction anisotropy at this conference [11, 12].

In summary, the TA results are consistent with a picture of cosmic rays from extragalactic objects dominated by protons, and interacting with cosmic microwave background photons. Subjected to relatively small deflections, their arrival directions can be correlated with nearby matter distribution. The interpretation of TA SD energy spectrum by this picture will be presented in this conference [13].

3 TA next five years

We propose to continue TA operation to further elucidate physics discussed above with more data. We are considering a moderate aperture extension that will be described later.

There are some discrepancies between the results from the TA and Auger collaborations. The two collaborations have begun a program of joint studies, in order to understand better the nature of these differences, which are related to energy spectrum, X_{max}, and arrival directions. A progress report from these joint studies will be presented at this conference [14, 15, 16]. This cooperative effort between the TA and Auger collaborations will continue beyond the 2013 ICRC.

A low energy extension designed to extend the energy range of TA physics from 10^{19} eV down to $10^{16.5}$ eV is near completion at and around the Middle Drum site (TALE: TA Low-energy Extension). Using the new high-elevation FD telescopes in conjunction with an infill SD array, we will study the transition from galactic to extragalactic cosmic rays expected in this energy range. The 10 additional TALE FD views 31-59° in elevation angle, and is constructed from refurbished HiRes-II telescopes. The TALE infill SD array consists of scintillation counters identical to those of the TA SD array, with graded spacings ranging from 400 m near the FD to 600 m further away, and merging with the main TA SD array of 1.2-km spacing at its northwestern corner. The TALE FD started its operation in the spring of 2013. At about the same time, about one third of the surface detectors were deployed and have begun operation. An update on the progress of TALE will be reported at this conference [17]. Further low energy extension down to $10^{15.8}$ eV by Non-Imaging CHErenkov array (NICHE) has also been proposed and its design features and physics potential will be presented at this conference [18].

Our current grant supports TA operation until the spring of 2014. In the fall of 2013, the TA members plan to submit proposals for continued operations for the next five years. Our proposal will include a plan to quadruple the acceptance of the current TA detector as a whole for the observation of cosmic rays in highest energy region. In this plan, we would start construction in the spring of 2014. The outline of the plan is described below.

The current TA surface detector array consists of 507 detectors with a square grid of 1.2-km spacing and it covers approximately 700 km^2. For an aperture extension, we plan to fabricate additional 500 surface detectors and deploy them in a square grid of 2.08-km spacing around the existing TA site. The new array will cover three times the area of the current TA SD array, thereby quadrupling the detection area of the TA SD array overall (see Figure 2). A default plan for the expanded surface is to use the current TA surface detector design.

We also plan to install one additional FD station consisting of 14 refurbished HiRes-II telescopes at the Black Rock Mesa site. These telescopes will view from 3°-31° above the horizon and 114° in azimuth. The center of the telescope station views the southeast direction to cover the new surface array. It adds the hybrid observation and checks on the energy scale of the new surface detector array with wider spacing.

We assume an additional five-year period of data taking for the current TA from 2014, two years of construction from 2014, and three years of data-taking starting in 2016 with the new SD and FD. By 2019, we expect to have accumulated the equivalent of 20 years of data from the current

TA SD and 14 years of current TA hybrid observation. Since the duty cycle of FD is ∼10%, the number of hybrid events is ∼10% of that SD events. We expect the following result after 5-year operation with the extension listed above:

From the extrapolation of the result of TA SD spectrum for four years [5], statistical significance to rule out an extended energy spectrum beyond GZK suppression is expected to be 10σ with TA extended TA SD.

Assuming the fraction of the number of UHECRs above 5.7×10^{19} eV correlated with nearby AGNs reported in [10], statistical significance to rule out isotropic distribution would be at the 5σ level.

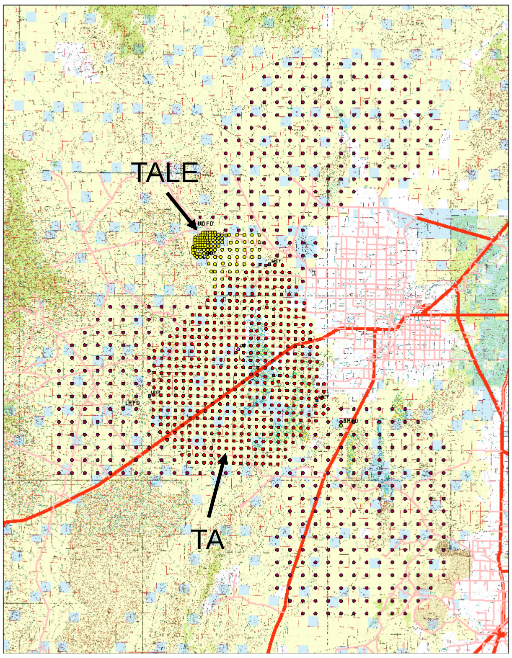

Fig. 2: The layout of the TA×4

The TA site has been, and continues to be used for R&D tests of much larger aperture extensions envisioned for the future. For example, the TA RAdio echo detection (TARA), which would detect radio echo expected from the air showers is an ongoing project funded by both the U.S. National Science Foundation (NSF) as well as the Keck Foundation. A dedicated oral presentation and posters from the TARA Collaboration will be given separately at this conference [19, 20, 21].

4 Conclusions

The Telescope Array (TA) is the largest experiment studying the origin and nature of ultra-high energy cosmic-rays in the northern hemisphere. From its first four years of SD data, TA has confirmed flux suppression above 5.4×10^{19} eV, which is consistent with GZK suppression, with a statistical significance of 5.5σ and the ankle at 4.6×10^{18} eV. TA's X_{max} measurement above $10^{18.2}$ eV is consistent with proton composition. The analyses of arrival directions of UHECRs for the correlations with AGNs, correlations with the LSS proton model, and autocorrelations have shown some hints of anisotropy. The TA data, however, are also consistent with the isotropic model with the current statistics. In summary, the TA results are consistent with a picture that UHECRs proton are extra-galactic in origin, are dominated by protons, and their arrival directions can be correlated with nearby matter distribution. With the added statistics afforded with moderate aperture extension, we will have the potential to observe anisotropy for UHECRs from the northern sky. Here we present the plan for continued operations and expansion of the TA experiment over the next five years. We propose to expand the aperture of the TA SD by a factor of four by building 500 additional counters, tentatively based on the existing TA SD design, but deployed in a square grid with 2.08-km spacing. Coupled with an additional FD site, the expanded TA will achieve the equivalent of 20 and 14 years of SD and hybrid exposures of the existing TA, respectively, by 2019. The TA low energy extension (TALE) will expand the physics search of TA down to $10^{16.5}$ eV. We have begun, and will continue a joint program with the Auger collaboration to understand the differences in the current results from the two experiments. All of these efforts combined will give TA the potential to answer a number of scientific questions critical to the development of a next-generation cosmic ray detector.

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