

Current status of the TAx4 surface detectors

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Abstract. Telescope Array (TA) is the largest ultrahigh-energy cosmic-ray (UHECR) observatory in the northern hemisphere. It explores the origin of UHECRs using a surface detector (SD) array, covering approximately 700 km², and a fluorescence detector (FD) stations viewing the skies above the array. TA has found evidence for a cluster of cosmic rays with energies greater than 57 EeV known as a HotSpot. Recently, TA has obtained additional evidence for an excess of cosmic rays with energies above 10^{19.4} eV and also found implications of spectrum anisotropy. An expanded SD array and FD stations called TAx4 experiment was designed to increase the data collection rate at the highest energies to confirm the anisotropies with more data. We have constructed and deployed more than half of the SDs for the TAx4 experiment and began stable data taking operations. We present TAx4 SD's current status.

1 Introduction

The Telescope Array (TA) is the largest cosmic-ray observatory in the Northern Hemisphere [1]. The aim of TA is to explore the origin and nature of ultrahigh-energy cosmic rays (UHECRs) above 10¹⁸ eV. The TA experiment consists of 507 plastic scintillator surface detectors (SDs) arrayed in a square grid with 1.2 km spacing covering approximately 700 km². The TA area is overlooked by three fluorescence detector (FD) stations, two of which have 12 telescopes, while the third has 14 [2–4]. The full operation of TA began on May 11, 2008. The duty cycle of the SD array has been 95% throughout the 11-year observation period. The FD duty cycle has been approximately 10%, because the data is taken only on clear moonless nights. The layout of TA is shown in Fig. 1; its central laser facility (CLF) is located at 39.30°N, 112.91°W and 1370 m above sea level in Utah, USA.

In previous work using TA SD data collected over five years, we found that 19 out of 72 observed cosmic rays with energies above 57 EeV were concentrated within a single 20°-radius circle (the “HotSpot”) [5]. The result had a maximum local statistical significance of 5.1σ; for the HotSpot to arise by chance anywhere in the field of view would require a 3.4σ fluctuation, which is the global statistical significance of the result. As reviewed in [6], the global statistical significance does not reach 5σ even with TA SD data collected over fourteen years. More recently, an additional excess of events with energies greater than 10^{19.4} eV with a significance of more than 3σ in the direction of the Perseus-Pisces supercluster was also found [7].

Several additional indications of cosmic-ray energy-spectrum anisotropy have also recently been observed by the TA experiment [8, 9]. A difference in the spectral cut-

offs above and below the declination $\delta = 24.8^\circ$ has been reported in [8]; the high and low declination band cutoffs were found to be $10^{19.85^{+0.03}_{-0.03}}$ eV and $10^{19.59^{+0.05}_{-0.07}}$ eV, respectively. The difference was updated in [10]. The statistical significance of the difference of the breakpoints of the energy spectra was estimated to be 4.3σ. A relative energy distribution test compared events inside oversampled spherical caps of equal exposure to those outside. The center of maximum significance has been found at right ascension $\alpha = 9^h 16^m$ and declination $\delta = 45^\circ$, and has an excess of arrival directions for particles with energies above 10^{19.75} eV and a deficit for 10^{19.2} eV $\leq E < 10^{19.75}$ eV [9]. The post-trial significance was estimated to be 3.7σ. Correlation of arrival directions with energies was also reported in [11]; the post-trial significance of the correlation was estimated to be 4.2σ. These results were obtained using seven to eleven years of observations with the TA SD.

To accelerate the pace of data collection as we further investigate these apparent departures from isotropy, we have developed a quadrupled TA detector. We call this larger detector “TAx4.”

The new SD array of the TAx4 experiment is designed expressly to study cosmic rays with energies above 57 EeV [12]. The spacing of the new SD array is 2.08 km, in contrast to the original TA SD's 1.2 km. The area covered by new SDs over the area covered by the TA SDs can be estimated to be $(2.08/1.2)^2 \sim 3$ if there are a large number of SDs. The additional 500 new SDs cover approximately three times more area than the 507 TA SDs; the combined coverage of the TAx4 and TA SDs is approximately 2800 km². Fig. 1 shows the deployed and planned locations of new detectors for the TAx4 experiment. The first 257 of the new SDs were deployed in 2019. Deployed SDs have been running stably since November 2019. Two new FD stations for the TAx4 experiment were also com-

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2 Operation of new SDs

The design and expected performance of new SDs were shown in [12] in detail. The main updates are the wireless communication protocol for the data acquisition and the arrangement of instruments inside the scintillator box. The SDs of the TA experiment used a customized wireless communication protocol, and new SDs use Wi-Fi protocol for new wireless communication devices. Therefore, the required signal strength for stable data transfer required additional study for the TAx4 experiment.

Many collaborators visited the observation site to optimize the wireless communication status for the data acquisition in August, 2022. Amplifiers for the wireless communication were newly installed in many of new SDs, and the signal strength from communication towers was kept above -80 dBm after the maintenance for the stable data transfer.

The performance of deployed SDs was shown in [13]. The statistics of collected UHECRs is still small, but a reasonable agreement between simulations and data was found.

3 Hybrid observation of new FDs and SDs

New FDs are running stably except for a few months in 2020 due to COVID-19 pandemic. All geometrical parameters are in reasonable agreement with simulations in the monocular analysis of FDs, as shown in [14].

The trigger efficiency of new SDs is approximately 30% at around 10 EeV (see Fig. 4 in [12]). Therefore, hybrid triggers were implemented to increase the efficiency. FDs send the trigger timing to the communication towers of the SDs within $\pm 128 \mu\text{sec}$ time window. Three times larger equivalent number of the TA FD and SD hybrid events above 10 EeV is expected from the full TAx4 experiment. Hybrid triggers of new FDs and SDs have been stably operated from June 2020.

4 Summary

The TA experiment continues to observe UHECRs from 2008 with the largest detection area in the northern hemisphere. The global statistical significance of the HotSpot above 57 EeV was estimated to be more than 3σ with TA SD data collected over five years. A new excess of events with energies above $10^{19.4}$ eV was also found to have a significance greater than 3σ . The global statistical significance of spectrum anisotropy was also estimated to be more than 3σ . However, no global statistical significance of anisotropies exceeds 5σ even with TA SD data collected over fourteen years.

The TAx4 experiment plans to complete the TAx4 upgrade, i.e. totally 500 new SDs with 2.08 km spacing in order to realize approximately 2800 km² detection area by combining with TA SDs (1.2 km spacing). The first 257 new SDs were deployed in 2019. These SDs are running stably since November, 2019. Two new FD stations have

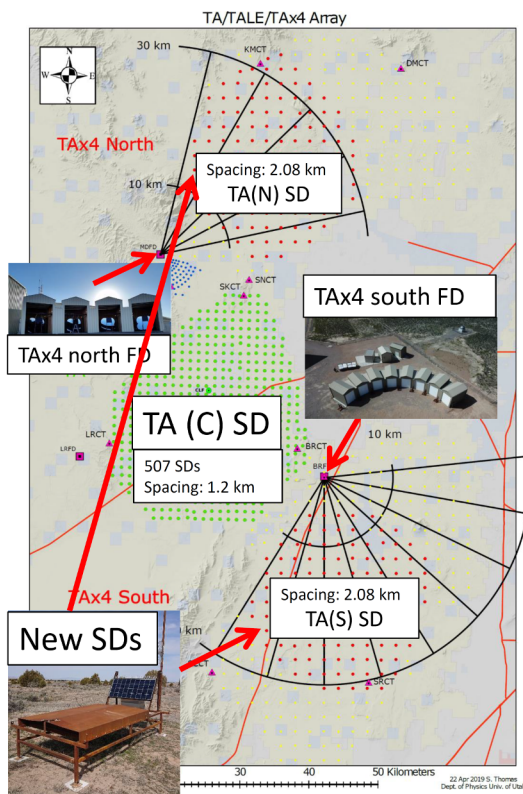


Figure 1. Map of the Telescope Array (TA) site. Each red circle in the north (N) and south (S) corresponds to the location of a newly deployed TA surface detector (SD); the spacing of the SDs is 2.08 km. Each yellow circle denotes the future location of a planned TAx4 SD. Each green circle in the west shows the location of a TA SD that is located at the center (C) between north and south array; the spacing of these is 1.2 km. The two fan shapes drawn with black lines are the fields of view of the TAx4 fluorescence detectors (FDs). Four telescopes have been built in the northern Middle Drum FD station, and eight telescopes in the southern Black Rock FD station. The overlap of the locations of the SDs and the fields of view of the FDs enables SD-FD hybrid observation. Pictures of new SDs and FDs are also shown.

pleted. The north FD station runs from June 2018, and the south FD station runs from September 2020. The field of view of each FD covers the sky above the area of the SDs so that FD and SD can observe cosmic-ray events simultaneously; we call such events “hybrids.”

The update of the operation of new SDs is shown in Section 2. The status of hybrid observation of new FDs and SDs checks are given in Section 3. Section 4 provides a summary.

been completed and are operational. New north FD is running stably since June, 2018. New south FD is running stably since September, 2020. Simulations and data of new SDs, FDs, and hybrid events are in reasonable agreement.

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