PROCEEDINGS OF SCIENCE

The extension of the Telescope Array experiment

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TA×4, Telescope Array Low Energy extension (TALE) and the Non-Imaging CHErenkov Array (NICHE) are extension plans of the Telescope Array (TA) experiment. The TA experiment was originally designed to study ultra-high energy cosmic rays with energies above about 1 EeV (1 EeV = 10^{18} eV) using surface detectors (SDs) and fluorescence detectors (FDs). These extension plans will enable us to observe cosmic rays with energies over 5 orders-of-magnitude (1 PeV - 100 EeV) in the same observation site in Utah. The construction of the detectors of TA×4, TALE and the prototype of NICHE (j-NICHE) has been already started. New SDs and FDs will be constructed for TA×4 to cover 4 times larger area than TA to observe cosmic rays with energies above 10 EeV with high statistics. This project is expected to clarify the source of the hotspot in the arrival directions of cosmic rays with energies above 57 EeV. The TALE experiment has already measured cosmic rays to well below 0.1 EeV using newly developed FDs. New SDs are being constructed to be added around TALE FDs for better efficiency and resolution. The NICHE detectors are designed to observe cosmic rays with energies above 1 PeV using non-imaging Cherenkov technique. The measurement by TALE and NICHE over wide range of energies will provide accurate understandings of the transition from galactic cosmic rays to extragalactic cosmic rays using cross-calibration between different techniques. The current status and the future prospects of the extension plans are shown here.

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1. The TA×4 experiment

Telescope Array (TA) is the largest cosmic-ray observatory in the Northern Hemisphere. The TA experiment has 507 surface detectors (SDs) on a square grid with 1.2 km spacing covering approximately 700 km^2. The SDs are surrounded by three fluorescence detector (FD) stations (12, 12 and 14 telescopes). The duty cycle of the SD array is greater than 95% throughout 5-year observation period, whereas the FD duty cycle is about 10% because the data is taken only on moonless clear nights. The left figure of Fig.1 is the map with locations of the detectors of TA. The latitudes and the longitudes of the locations of the detectors are around 39.30°N and 112.91°W in Utah in the USA.

The hotspot was observed in the arrival directions of 72 cosmic rays with energies above 57 EeV [1]. The data used in the analysis was obtained by observing with TA SD for 5 years. The chance probability to exceed the obtained maximum significance (5.1 σ) in an isotropy sky is estimated to be 3.4 σ in the published paper.

TA×4 SD array was designed to study cosmic rays with energies especially above 57 EeV. The spacing of the array is 2.08 km. 500 TA×4 SDs are planned to cover about 3 times larger area than 507 TA SDs and the combined coverage of TA×4 SDs with TA SDs is about 3000 km^2. This coverage is comparable to that of the Pierre Auger Observatory which has the largest coverage in the Southern Hemisphere.

25% energy resolution, 2.2 degree angular resolution and 95% reconstruction efficiency with TA×4 SD array for cosmic rays with energies above 57 EeV are expected using simulation studies.

The basic design of TA×4 SD is same as TA SD [2]. There are 2 layers of 1.2 cm thick, 3m^2 plastic scintillators. The scintillation light is read out by wave length shift (WLS) fibers and PMTs. The arrangement of WLS fibers was changed from TA SD. About 67% of WLS fibers is reduced from TA SD, because the quantum efficiency of PMTs (R8619 Hamamatsu) in TA×4 SD is about twice as large as that in TA SD. 173 TA×4 SDs were assembled in Japan and will be finally assembled in the observation site in the near future. 100 TA×4 SDs were already transported to the observation site.

2. TALE

The TALE SD will cover 70 km^2 with 103 SDs in the FOV area of the TALE FDs. There are three different detector spacing. The closer look at around the TALE site is the top right figure in Fig.1. We plan to install 40 SDs with 400 m spacing, and 36 SDs with 600 m spacing. In the connecting area between the TALE and the TASD array, 27 detectors will be installed with 1.2 km spacing. The green points in Fig.1 are the locations of TALE SDs and the red points are the locations of TA SDs. Based on simulation studies, this air shower array has 100% detection efficiency for energies above 1.4×10^{17} eV, and hybrid observations with FDs provides a remarkable improvement in the Xmax determination achieving the error of 20 g/cm^2 comparing with the monocular FD resolution of 40 g/cm^2.

The TALE experiment has already measured cosmic rays to well below 0.1 EeV using newly developed 10 additional telescopes. 35 SDs were already deployed in the site with 400 m spacing. The same design of SD as TA×4 SD will be deployed in the rest of sites in 2017.

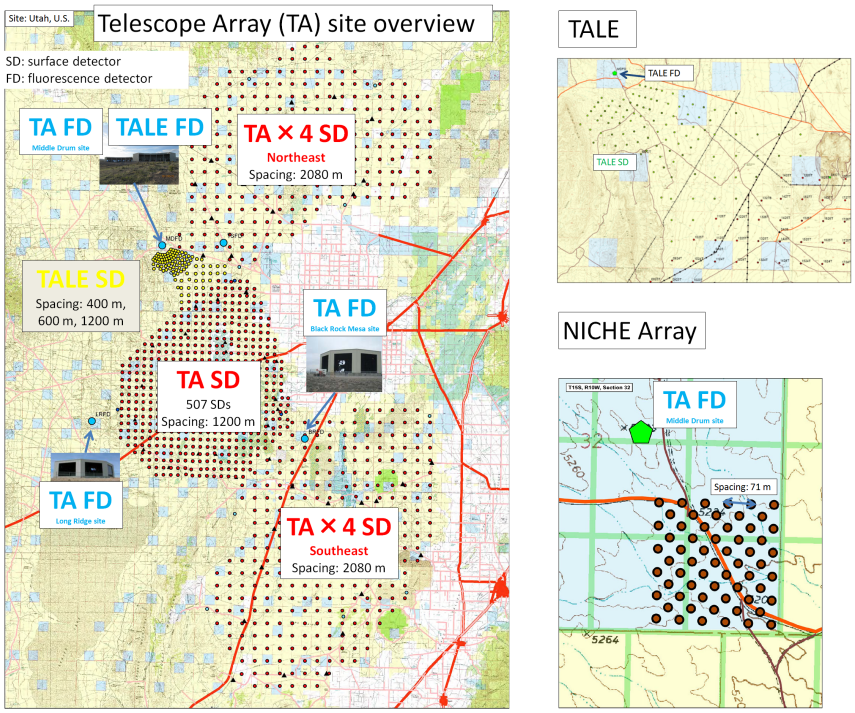

Figure 1: The overview of the TA site is in the left figure. The closer look at around the TALE site is the top right figure. The even closer map around the TA and TALE FD site is the bottom right figure. The locations of NICHE are brown points in this figure.

3. NICHE

NICHE was designed to observe cosmic rays with energies down to 10^{15} eV [3]. NICHE detectors observe Cherenkov light and the cosmic rays with energies 1-100 PeV will be reconstructed using both the Cherenkov light Lateral Distribution and the Cherenkov Time Width Lateral Distribution. These two methods will allow energies of cosmic rays and Xmax to be determined. Constructing 15 NICHE detectors are already funded and started as j-NICHE. The location of NICHE is shown in the bottom right figure in Fig.1. The brown points in Fig.1 are the locations of the NICHE detectors. The j-NICHE detectors will be deployed at the 15 locations of them.

4. Future prospect

The construction of the first 173 TA×4 SDs is in progress. We try to clarify the source of the hotspot in the arrival directions of cosmic rays with energies especially above 57 EeV with these new SDs. If the full operation of 500 TA×4 SDs starts, we will obtain about 4 times larger statistics in this energy range than using only TA SDs.

The TALE experiment has already measured cosmic rays to well below 0.1 EeV using FDs. 35 SDs were already deployed in the site in the FOV of the FDs with 400m spacing. The construction of 70 SDs was funded and will be deployed in the TALE site in 2017. Especially the improvement in the composition studies for above 10^{17} eV will be provided by SD and FD hybrid detectors of TALE.

15 j-NICHE detectors were funded and the construction was started. Cosmic rays with energies down to about 10^{15} eV will be observed in the near future.

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