Illuminating Extremely Energetic Phenomena in Nearby Universe with Ultrahigh-Energy Cosmic Ray Astronomy: Fluorescence Detector Array of Single-Pixel Telescopes

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The origin and acceleration mechanism of ultrahigh-energy cosmic rays (UHECRs) are of the upmost importance in particle astrophysics and astronomy. The less deflection in galactic and extra-galactic magnetic fields due to their enormous kinetic energies expects a directional correlation between UHECRs and extremely energetic phenomena in the nearby universe, achieving a next-generation astronomy. The Fluorescence detector Array of Single-pixel Telescopes (FAST) is a future project for UHECR observatories, addressing the requirements for a large-area, low-cost detector suitable for measuring properties of the highest energy cosmic rays with an unprecedented effective area. I will develop a prototype array of the FAST telescopes consisting of four 200 mm photomultiplier-tubes at the focus of a segmented mirror of 1.6 m in diameter and establish new observation method for the UHECR astronomy.

1 Aims for Observing Ultrahigh-Energy Cosmic Rays

In 1912, V.F. Hess discovered a flux of energetic elementary particles arriving from outer space, now known as “Cosmic Rays”. The cosmic-ray energy spectrum has been measured at energies from 10^8 electron-volt (eV) to beyond 10^{20} eV in the last century, and follows a power-law relationship of the form E^{-3}, where E is the cosmic ray energy. Cosmic rays above 10^{18} eV (= 1 EeV) are known as ultrahigh-energy cosmic rays (UHECRs).

Since UHECRs are the most energetic particles in the universe, their origins are ostensibly related to extremely energetic astrophysical phenomena, such as gamma-ray bursts, active galactic nuclei, or other exotic processes such as the decay or annihilation of super-heavy relic particles created in an early phase of the development of the universe. However, their origin and acceleration mechanism above 100 EeV are still unknown. Therefore, they are one of the most intriguing mysteries in particle astrophysics and astronomy.

2 Methods to Detect UHECRs

Given their minute flux, less than one particle per century per square kilometer at the highest energies, a very large area must be instrumented to collect significant statistics. The energy, arrival direction, and mass composition of UHECRs can be inferred from studies of the cascades of secondary particles (Extensive Air Shower, EAS) produced by their interaction with the Earth’s atmosphere. Two well-established techniques are used for UHECR detection: (i) arrays of detectors (e.g. plastic scintillators, water-Cherenkov stations) sample EAS particles reaching the ground; (ii) large-field-of-view telescopes allow for reconstruction of the shower development in the atmosphere by imaging Ultra-violet fluorescence light from atmospheric nitrogen excited by EAS particles.

Two giant observatories with an effective ground coverage of ~1000 km², one in each hemisphere, the Telescope Array Experiment (TA) in Utah, USA and the Pierre Auger Observatory (Auger) in Mendoza, Argentina, combine the two techniques with arrays of particle detectors overlooked by fluorescence detectors.

3 A Next-Generation Astronomy with UHECRs

Following the detection of a cosmic-ray with an energy of 100 EeV by J. Linsley in 1963, K. Greisen, G. T. Zatsepin and V. A. Kuzmin (GZK) predicted the UHECR energy spectrum to be suppressed above 50 EeV due to the interaction of high-energy particles with the 3 K cosmic microwave background radiation via pion production, the so-called GZK cutoff.

If the GZK cutoff exists, origins of UHECRs are significantly restricted to the nearby sources distributed non-uniformly within ~50 Mpc (~160 million light years). Additionally, UHECRs propagate with less deflection in magnetic fields of the universe due to their enormous kinetic energies. As a result, the arrival directions of UHECRs should be correlated with directions of extremely energetic sources or objects, leading to a next-generation astronomy with UHECRs for illuminating extremely energetic phenomena in the nearby universe.

4 Developments for Fluorescence Detector Array of Single-Pixel Telescopes (FAST)

We propose a ground-based fluorescence detector array which is low-cost, easily-deployable, and has an unprecedented effective area with an order of magnitude larger than that of TA and Auger [1]. The fluorescence detector Array of Single-pixel Telescopes (FAST)[https://www.fast-project.org] consists of compact fluorescence telescopes featuring a smaller light collecting area and many fewer pixels than current designs, leading to a significant reduction in cost.

In the current design of fluorescence telescopes, a large mirror system of ~3.5 m diameter reflects a 30° × 30° patch of the sky onto a focal plane composed of several hundred photo-multiplier tubes (PMTs). In the FAST design, the same field-of-view is covered by just four 200 mm PMTs at the focal plane of a compact segmented mirror of 1.6 m in diameter [2], as shown in Figure 1. Each FAST station would consist of 12 telescopes, covering 360° in azimuth and 30° in elevation.

Figure 2 shows a schematic view of FAST, and the expected signal from a UHECR shower with coincidence detections at three adjacent stations. An example of the ground coverage using 60 stations is also indicated with a comparison to Auger and TA coverages. The operation of a full-size FAST array will provide conclusive results on the origin and acceleration mechanism toward 100 EeV, and accomplish the next-generation astronomy with UHECRs.

For the sake of developments for FAST, we will install a prototype array consisting of the FAST telescopes at Auger site. These telescopes are deployed at different locations with 20 km spacing, having a common target atmosphere in their field-of-views. The prototype array of FAST will reconstruct EAS profiles using geometries, also reconstructed by timings from a coincidence of UHECR at different telescopes. Powered by solar panels, and with the ability to communicate remotely via wireless LAN, we will make comprehensive tests to deduce the viability of a future observatory proposed in FAST.

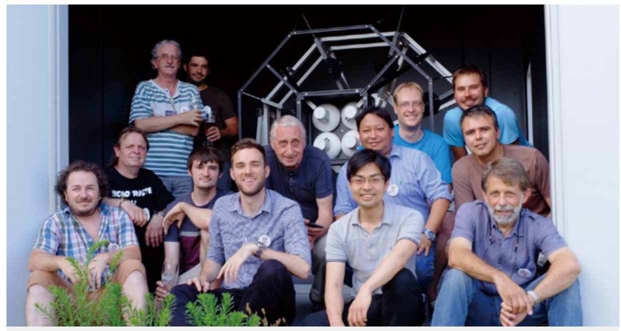

Figure 1

A constructed prototype together with the FAST collaborators.

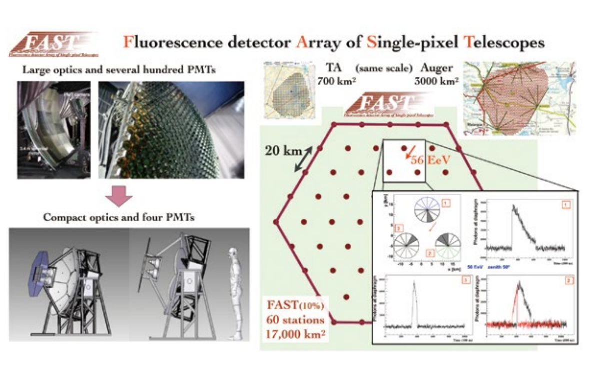

Figure 2

Schematic view of the Fluorescence detector Array of Single-pixel Telescopes: one of the possible solutions for a future observatory [1].

References

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