Current status and future prospects of the CRAFFT project for the next generation UHECR observatory

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Abstract. A key to understand the origin of the Ultra High Energy Cosmic Ray (UHECR) is higher statistics with the composition information. One of the concepts to realize the future huge observation is an array of simple and low cost fluorescence telescopes. The fluorescence telescope can measure not only the arrival direction and energy spectrum but also the mass composition which is the important information to understand the origin of UHECR. A concept of a simple FD is to reduce the cost by changing from the imaging with multiple PMTs to the time information of a few PMTs, and minimization of the optical system by focusing the high energy events. In order to demonstrate this concept, we are developing Cosmic Ray Air Fluorescence Fresnel lens Telescope (CRAFFT), which further reduces the cost by using Fresnel lens and stand alone system without telescope hut unlike existing fluorescence detector in present UHECR observatory. We have constructed four prototype CRAFFT\textsuperscript{s} and observed air showers by simultaneous observation with Telescope Array. By those study, the cost of a simple FD reaches 1/10 of that of a present FD.

1. Introduction

The Ultra High Energy Cosmic Rays (UHECRs) which have energies around $10^{20}$eV have been observed at several giant observatories, but the origin and acceleration mechanism of the UHECR is still a mystery. Currently Telescope Array (TA) [1] and Auger [2] continue to observe UHECR at northern and southern hemisphere, respectively. In addition, both of the observatories are upgrading their experiments in order to increase the effective aperture (TAx4 [3]) or to improve the sensitivity for the mass composition (AugerPrime [4]).

The underlying idea to search for the origin of UHECR bases on the small deflection at the Galactic and extragalactic magnetic field because of the high rigidity and the limitation of the distances from sources up to a few hundreds of Mpc because of the interaction with the cosmic microwave background (CMB) and the extragalactic background light (EBL). But several issues are found by current researches. A possibility of the transition from light to heavy composition [5], separation of the effects both from propagation and acceleration limit at UHECR source for the interpretation of the spectrum suppression [6], effect for the deflection in the magnetic
field at the cosmic filaments [7] and so on. In such a interesting and complex situation, a key to understand the origin of UHECR is higher statistics with the information of mass composition. Anisotropies of the lighter and heavier components of cosmic rays, or the energy spectrum and arrival directions together with the mass composition will be powerful tools to solve current issues. Therefore, as a future plan for UHECR observation, a observatory which has 10 times or more effective aperture than TAx4 and Auger, and has a sensitivity for the mass composition is expected.

A simple Fluorescence Detector (FD) is one of the candidates to realize the future huge observatory. Using the technique to observe fluorescence photons, the FD measures the longitudinal development of an air shower, and in particular the depth at its maximum, so called $X_{\text{max}}$ which is known as a sensitive parameter for the nuclear type of the primary cosmic ray. The cost of a FD can be significantly reduced by (1) changing the technique from an imaging with multiple PMTs to a time information with a few PMTs (2) minimizing and optimizing the optical system targeting only the highest energy cosmic rays. Such a next generation FD is being developed by FAST [8] and CRAFFT [9].

2. CRAFFT
Cosmic Ray Air Fluorescence Fresnel lens Telescope (CRAFFT) is being developed to confirm a concept of a simple FD described in section 1. In order to reduce the detector cost more, CRAFFT is designed to use a 1.4 m$^2$ Fresnel lens instead of the mirror and intended to be installed directly on the ground without telescope hut. At the TA site, we developed four prototype CRAFFTs which consist of a 8 inch PMT, a UV transmitting filter, and a spacial filter to expose only the central area of the PMT where its properties are well calibrated (Figure 1). By the simultaneous observation with TA FD, 10 obvious air shower events have been observed during 10 nights [9]. By those study, the cost of a simple FD reaches 1/10 of that of a present FD.

![Figure 1. The block diagram of the CRAFFT prototype detectors and its data acquisition system (left), and the picture of CRAFFTs at TA site (right).](image)

3. Progress for future huge deployment
The CRAFFT prototype is designed to use a Fresnel lens and a single PMT to confirm the concept of a simple fluorescence detector for future generation cosmic ray experiments. For future huge deployment, detector configuration such as the number of PMTs in a detector and the field of view of a PMT should be optimized for efficient and precise observation. In order to study those, a Monte-Carlo simulator of the CRAFFT prototype based on CORSIKA [10] and ROBAST [11] has been developed. Figure 2 shows the shape of a spot at focal plane for a
parallel light obtained by simulation. The sensitivity to air showers can also be obtained (Figure 3). Those optimization works are currently in progress.

Figure 2. The shape of spot at focal plane obtained by simulation. The green (27 mm dia.) and blue (44 mm dia.) circles show the area which includes 68% and 95% of total photons, respectively.

Figure 3. The scatter plot of core positions and its S/N ratio (color) for 10^{20} eV air showers obtained by simulation.

Another necessary work is to construct an automation system. For a future project with a number of remote FDs separated by distances of 20-30 km spacing, those should be worked with minimum maintenance. We have tested a low powered electric shutter which can be controlled by remote operation (Figure 4), and automatic data acquisition system using the Raspberry Pi and an FPGA based FADC board. Those are powered by a solar panel and battery system like surface detectors in present UHECR experiments. A stable and low cost wireless network communication is also necessary for data transfer and remote control. A field test of the wireless network will be started from the next year. The details of the currently progresses are described in another paper [12].

Figure 4. A tested electric shutter attached at the front of the CRAFFT detector (left), and solar panel and battery system to prepare a electric power for CRAFFTs.
4. Future prospects
A plan to cover huge area by using CRAFFT is to construct an array of CRAFFT stations with 25 km spacing. A CRAFFT station consists of a cluster of CRAFFT telescopes which totally has 360 degrees field of view. When the effective area of future observatory set as 25 times as large as that of TAx4 or Auger (100 times of TA) and the duty cycle is assumed as 10%, we should cover the area of 700,000 km$^2$. In this case, we need 900 CRAFFT stations, and the total cost is estimated to be less than $200M. Because the CRAFFT array is ground-based observatory, that can be placed separately to several places like northern and southern hemisphere, and can be scaled up from smaller area.

The separation of the stations depends on a sensitivity of the optimized CRAFFT, an efficiency of the triggering system and a performance of the reconstruction method. In order to confirm those observation technique, we will construct two or more stations in the TA site and operate in the stereo mode.

5. Conclusions
In order to realize future huge UHECR observatory, we propose the plan of an array of simple FDs. The concept is to reduce the cost by changing from the imaging with multiple PMTs to the time information of a few PMTs, and minimization of the optical system by focusing the high energy events. The CRAFFT further reduces the cost by using a Fresnel lens and stand alone system without a telescope hut unlike the existing fluorescence detectors in present UHECR observatories. We have developed four prototype CRAFFTs and observed air showers by simultaneous observation with TA. By those study, the cost of a simple FD reaches 1/10 of that of a present FD.

Currently we are optimizing the detector configuration by simulation study, and developing an automation system such as an electric shutter and solar panel system. We will construct two or more stations in TA site to confirm techniques of the triggering system for stereoscopic detection and the reconstruction method to be clear the performance of our proposing plan for the future huge UHECR observatory.

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