Development of the Cosmic Ray Air Fluorescence Fresnel lens Telescope (CRAFFT) for a next generation UHECR observatory

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Abstract : In near future, it is expected that sources of ultra-high-energy cosmic rays (UHECRs) can be identified, because the Telescope Array experiment reported that there is a Hotspot in the UHECR arrival direction. However, it is required to observe UHECRs with higher statistics. Moreover, the mass composition should be determined, which is important information for anisotropy study. Then, we should extend the scale of observatory with fluorescence telescopes which can observe X_{max}, but they cost more than particle detectors at the ground. In order to reduce the cost, we are developing the Cosmic Ray Air Fluorescence Fresnel lens Telescope (CRAFFT) which is a simple structure fluorescence telescope consisting of a plastic Fresnel lens of 1 m^2 and a 8 inch PMT. In this presentation, we will report the current status of development and test observation.

Introduction

Future direction of the ultra-high-energy cosmic ray observation is to enlarge the detection area to earn more statistics to identify cosmic ray sources. However it will take too much cost to construct the huge detector with current detection technique. Fig. 1 is one of the typical fluorescence detector (FD) for Telescope Array (TA) which consist of the spherical mirror of 3 m diameter and 256 PMTs on the focal plane. On the other hand, Fig. 2 is a simple fluorescence detector consisting of a Fresnel lens of 1 m^2 and a PMT of 8 inch which can cover the 4 times larger F.O.V. of TA FD. This is very simple structure and make the cost much lower than current FDs.
If achieve the effective cost reduction, we will be able to construct the huge array of simple FDs to observe highest energy cosmic rays to clarify their origin.

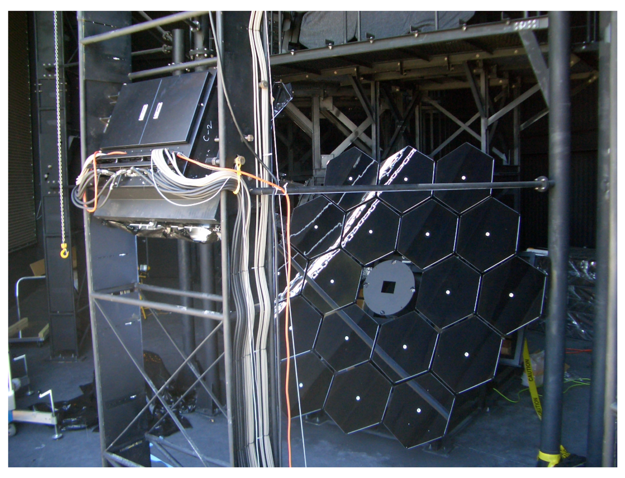

Fig.1 : One of the typical fluorescence detector used in Telescope Array.

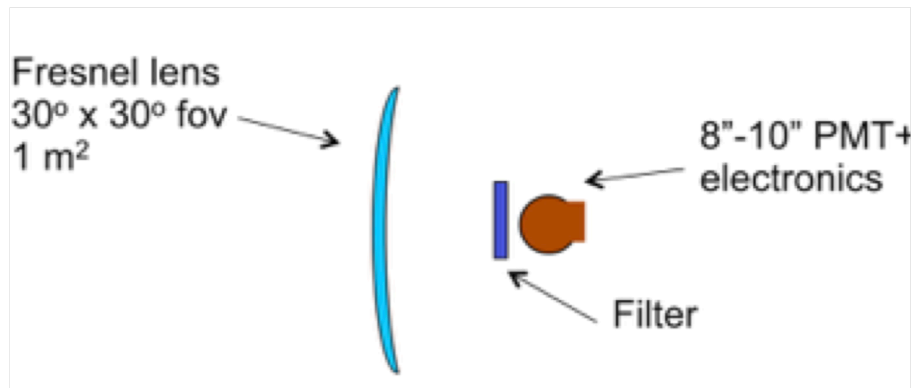

Fig.2 : Concept of a simple fluorescence detector. [P.Privitera,et.al.UHECR(2012)]

Detector

CRAFFT is a FD of which structure is very simple. Assembled CRAFFT is shown in Fig.3, which consists of Fresnel lens, UV transmitting filter, PMT, electronics and aluminum frame. When we operate CTAFFT, PMT and lens mount are covered to prevent incident light. The aperture and focus of Fresnel lens are 1 m^2 and 1.2 m and the diameter of the PMT is 8 inch. Then F.O.V. of CRAFFT is about 12 deg. This is almost same as the F.O.V. of TA FD. A spot of the moon focusing on the focal plane is shown in Fig.3 (c). We recorded the spot in order to check the F.O.V. at the Akeno observatory. Fig. 4 and Fig. 5 are the transparency of the Fresnel lens and UV transmitting filter. Both of the transparency are almost 90 % between 300 to 400 nm of wavelength.
The costs for each component are listed in table 1. Total cost is quite low and 1/10 or less than current typical FDs at least. These costs of each components are estimated as commercial products. The total cost can be less for mass production in the future.

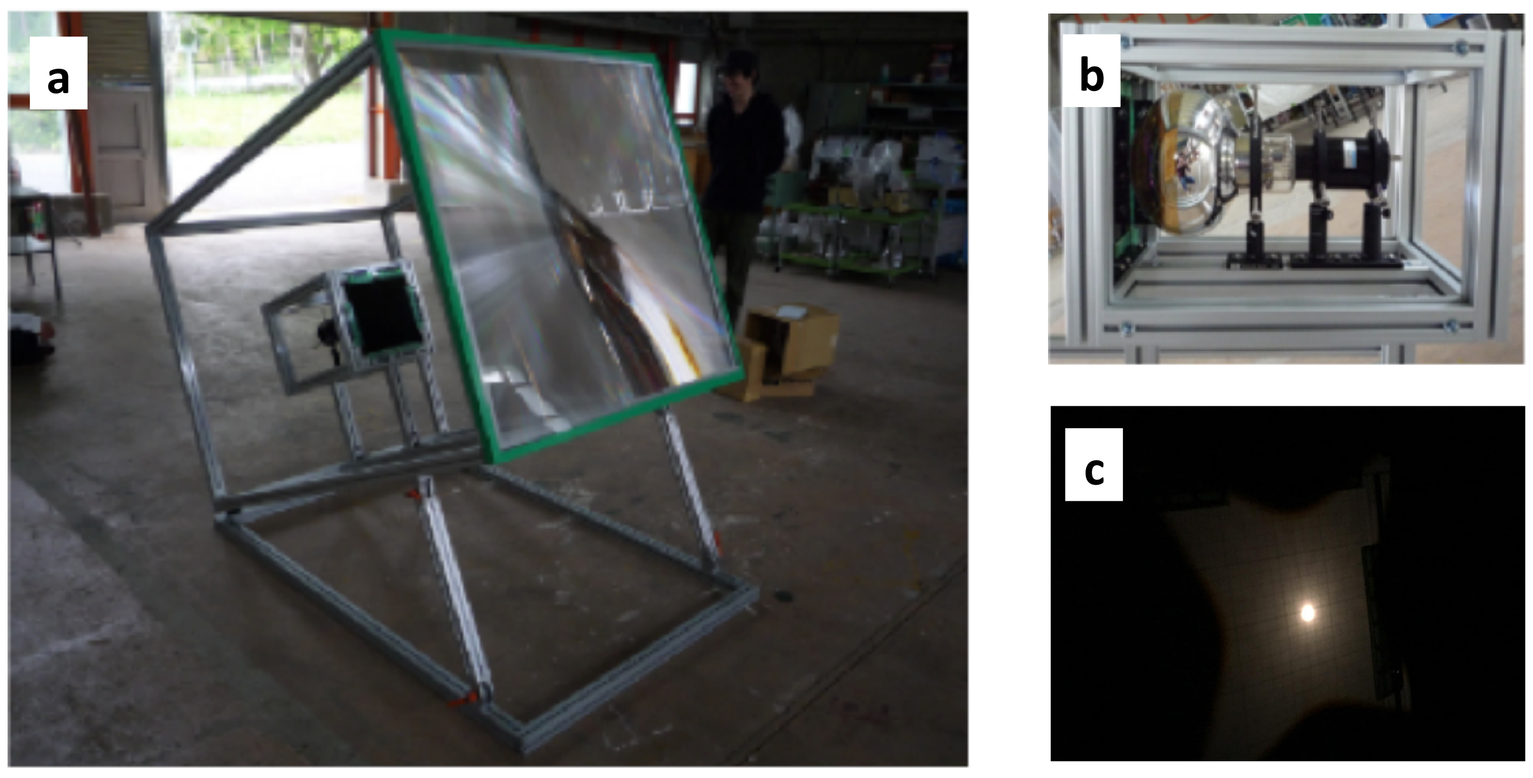

Fig.3 : (a) Assembled CRAFFT prototype at the Akeno observatory.
(b) Eight inch PMT and UV transmitting filter which is mounted on the focus.
(c) Spot of the moon at the focus.

Table 1 : The list of cost for each component of CRAFFT.

Component	Product	Specification	Cost [$]
Fresnel lens	NTKJ, CF1200-B	1m^2, f=1.2m	208
UV transmitting filter	O.M.G., UL330	90%, 300-360nm	2667
PMT	Hamamatsu, R5921	8 inch	1708
HV power supply	CAEN, N1470AR	8kV, 3mA	1375
FADC	TokushuDenshiKairo, Cosmo-Z	80MHz, 12bit	258
Structure	MIWA	Aluminum frame	833
		Total :	7049

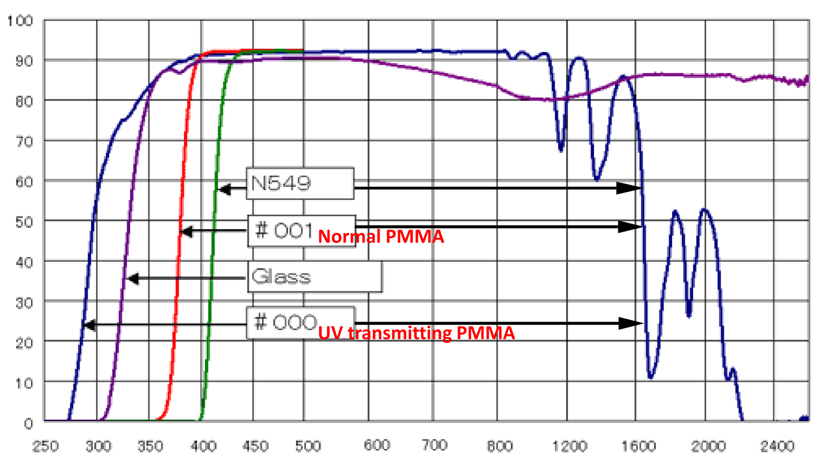

Fig.4 : Transparency of Fresnel lens. We use UV transmitting PMMA (#0000)

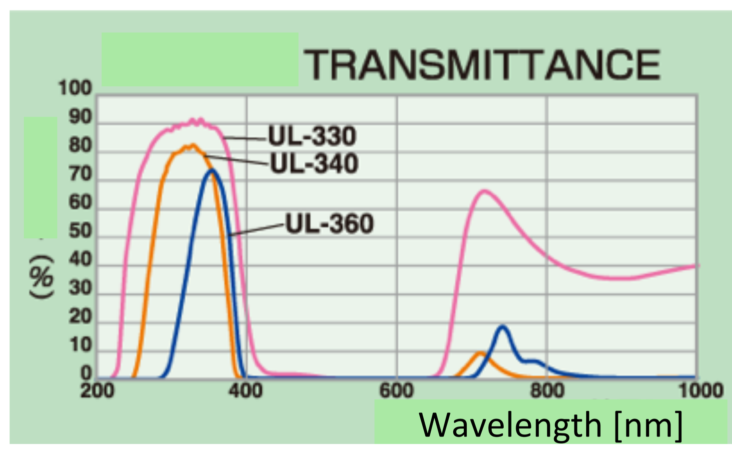

Fig.5 : Transparency of UV transmitting filter. We use UL-330.

Fluorescence spectrometer. F-7000 (HITACH) Transparency of the lens and filter will be measured with F-7000.

Detection Efficiency

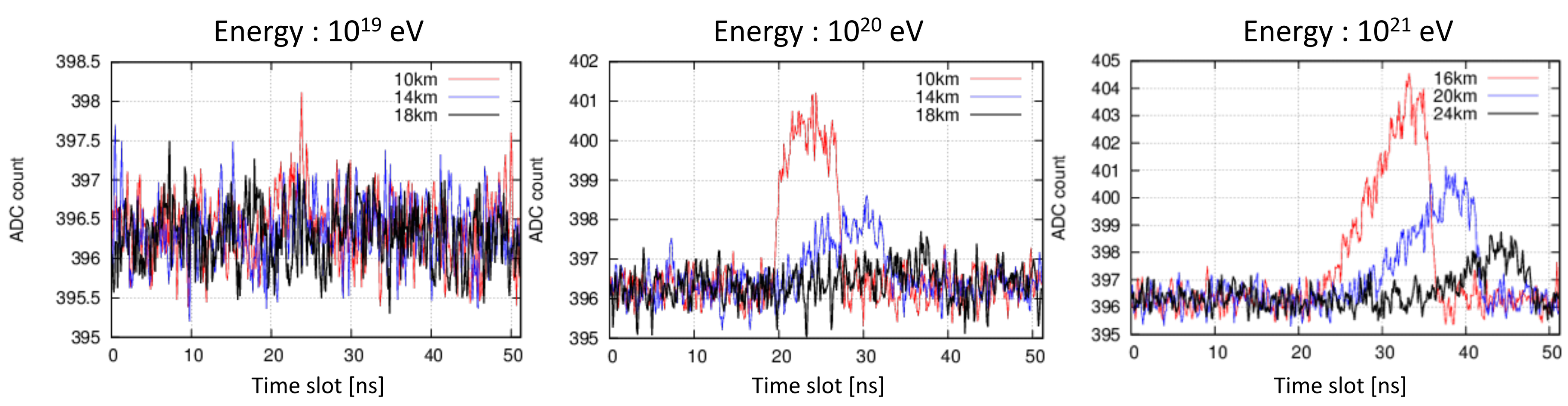

Fig.6 : Simulated waveform of CRAFFT for three energy regions of $10^{19,20,21}$ eV.

We estimated the detector efficiency of CRAFFT by detector simulation. We take into account the detector configuration. The simulated waveform are shown in Fig.6. where vertical air showers with energies of $10^{19,20,21}$ eV were generated and core positions are from 1 to 40 km apart from the detector. The S/N ratio estimated by the simulation is shown in Fig.7. If we suppose that air showers with S/N greater than 4 can be triggered, CRAFFT can observe air showers with 10^{20}eV within 25 km apart from the detector.

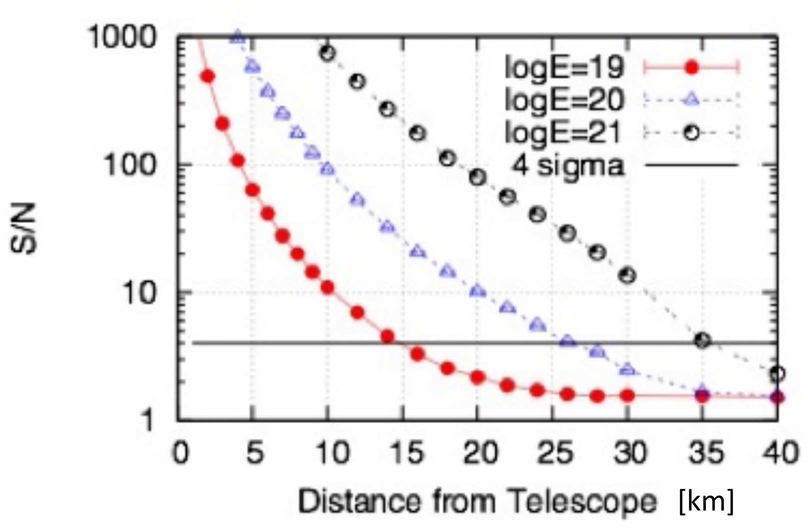

Fig.7 : Estimated S/N ratio by simulation.

Detector performance test @ TA FD site (2016 Sep.)

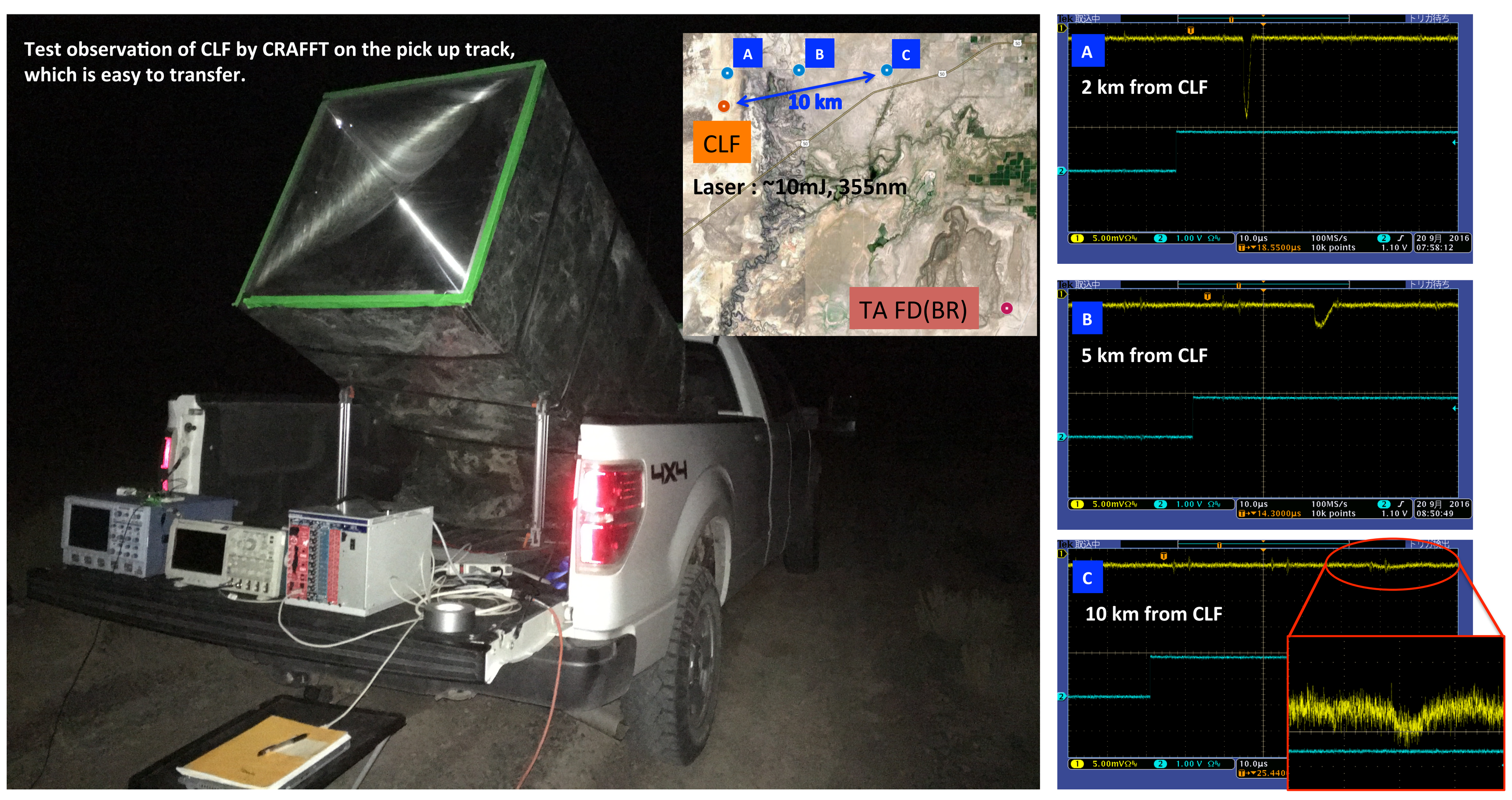

Fig.8 : Summary of the test observation on Sep. of 2016 at TA FD site.

We tested the detector performance at TA FD site in Sep. of 2016. We succeeded to observed the laser shot at 2, 5, 10 km apart from the TA Central Laser Facility (CLF), of which energy and wavelength are ~10 mJ and 355 nm. Right side figures of Fig. 8 are waveform of laser shot observed at each point by CRAFFT. The laser shot is as a pseudo air shower event with energy of $10^{19\sim20}$ eV.

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