A 3-Meter Atmospheric Cherenkov Telescope as a Test Bench for Very High Energy Gamma-Ray Astrophysics Projects

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Abstract

We have been setting up a 3-meter diameter atmospheric Cherenkov telescope in Akeno, Japan, for various R & D studies mainly on very high energy gamma-ray astrophysics. This Davies-Cotton type telescope (Akeno telescope, hereafter) was manufactured in 1998 and has been recommissioned at low cost. A low power consumption imaging camera system has been developed for a future gamma-ray astrophysics observatory with "mobile" imaging atmospheric Cherenkov telescopes, which can flexibly change the array configuration for a number of science targets, and has been installed to the Akeno telescope for test observations. We present performances of the optics and the drive system of the Akeno telescope, as well as the status of the imaging camera system. Some other R & D plans including test observations using a prototype imaging camera for CTA and simultaneous observations of the optical and radio Crab pulsar are also presented.

1. Akeno Atmospheric Cherenkov Telescope

The Akeno atmospheric Cherenkov telescope is located in the Akeno Observatory, Institute for Cosmic Ray Research (ICRR), The University of Tokyo (Figure 1). We obtained this old atmospheric Cherenkov telescope in 2009 and reinstalled it after recommissioning, as a test bench in the field. The telescope was originally prepared for R & D studies for the TenTen project [1], but can also be used in other R & D. Note that this is currently the only atmospheric Cherenkov telescope located in Japan and can provide unique opportunity of the field test to scientists developing instruments of imaging atmospheric Cherenkov telescopes (IACTs) especially in Japan. Basic characteristics of the Akeno telescope are summarized in Table 1.

***Figure 1:** 3 m atmospheric Cherenkov telescope located in Akeno, Japan.*

Optics	
Type	Davies-Cotton
Diameter	$\sim$ 3 m
Focal length	3 m
Number of segment mirrors	18
Shape of segment mirrors	Hexagonal
Material of mirrors	Glass (8.5 mm thickness)
Mirror reflectivity	$\sim$ 90 %
Optical PSF	$\lesssim 0.^\circ 15$ (FWHM)
Drive system	
Mount	Altazimuth
Type of motors	AC servo
Encoder resolution	$0.^\circ 001$
Pointing accuracy	$< 0.^\circ 01$

***Table 1:** Characteristics of the Akeno telescope.*

18 deteriorated segment mirrors of the Akeno telescope were recoated by ourselves at low cost, using a vacuum deposition system of the Okayama Astrophysical Observatory, National Astronomical Observatory of Japan (NAOJ) [2]. They were reinstalled to the telescope frame and manually aligned to form the Davies-Cotton optics. To check the optical performance of the readjusted optics, some bright star images focused on the focal plane were taken by a CCD camera. Figure 2 is an image of Vega taken at the elevation angle 44°. The size of the optical point spread function (PSF) is estimated from this result to be $\sigma = 3$–4 mm, which corresponds to FWHM $\sim 0.^\circ 15$.

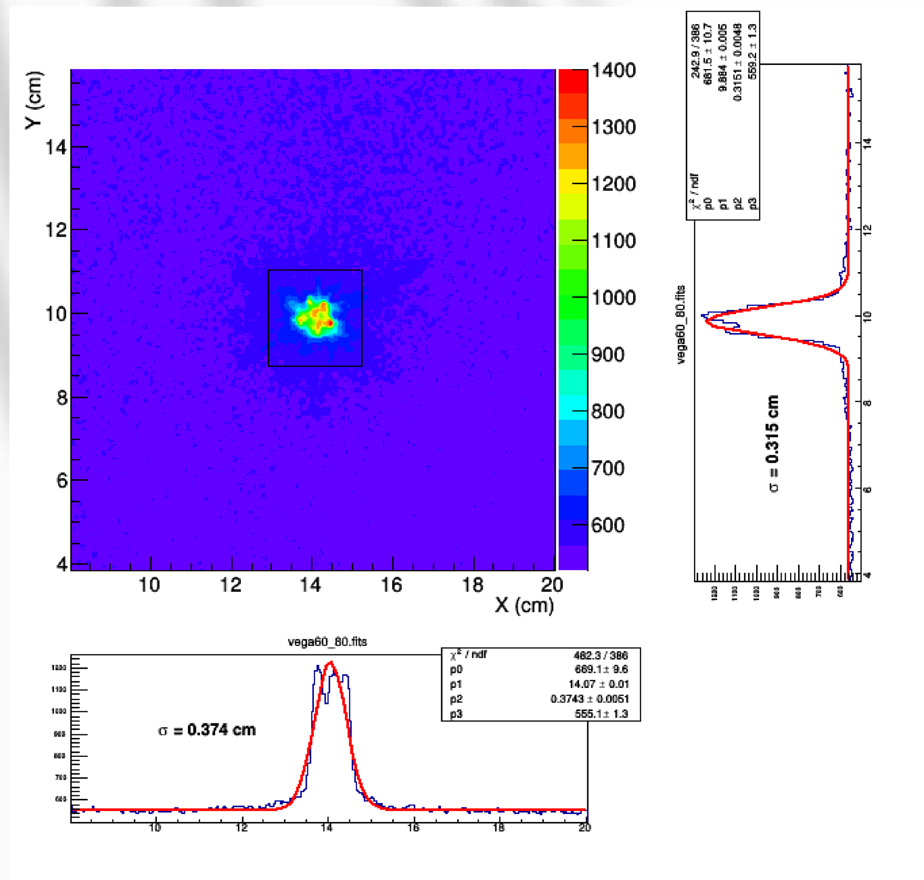

***Figure 2:** Bright star (Vega) image on the focal plane focused by the readjusted optics of the Akeno telescope. The size of the optical PSF is estimated to be σ = 3–4 mm, which is smaller than the pixel size (indicated by the black square in the center) of the R & D imaging camera described below.*

2. R & D Studies Using the Akeno Telescope

2.1 Low Power Consumption DAQ System for Mobile IACTs

We have proposed a concept of the "Mobile Telescope Array" project for ground-based gamma-ray astrophysics, in which the array has a number of movable IACTs and can flexibly change its configuration depending on the science target of interest [3]. To realize mobile IACTs, it is desirable to make telescopes run on their own local power supply, independent of cumbersome cables, and there is a need to reduce power consumption of the IACT system. We have developed a low power consumption electronics system with an ASIC implementing analog memory cell (AMC) circuits which sample voltages of a Cherenkov signal pulse with a speed of 1 GHz. One AMC chip is shared by 8 pixels in combination with optical delays (fibers) of different lengths (64 ns step). An imaging camera of 32 photomultiplier tubes (PMTs) was also prepared for estimating performance of the DAQ system. The block diagram of this system is shown in Figure 3.

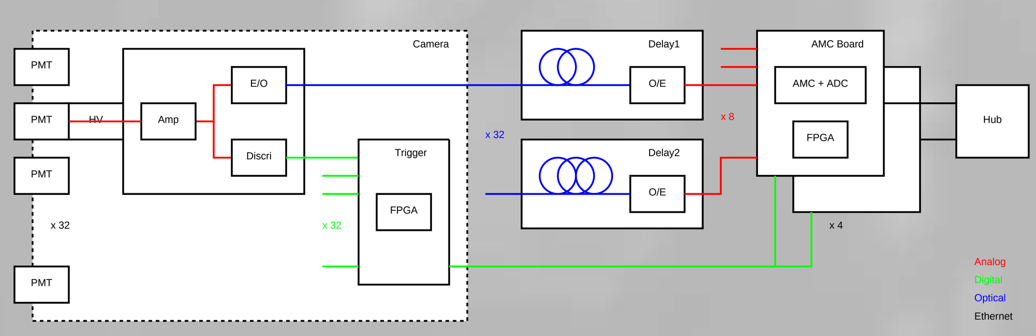

***Figure 3:** Block diagram of the low power consumption DAQ system.*

We installed the DAQ system to the Akeno telescope in March 2014 as shown in Figure 4. Figure 5 shows an example of 32 waveforms successfully recorded by the system simultaneously (except one dead pixel in the corner) with a blue LED flashed at the center of the reflector.

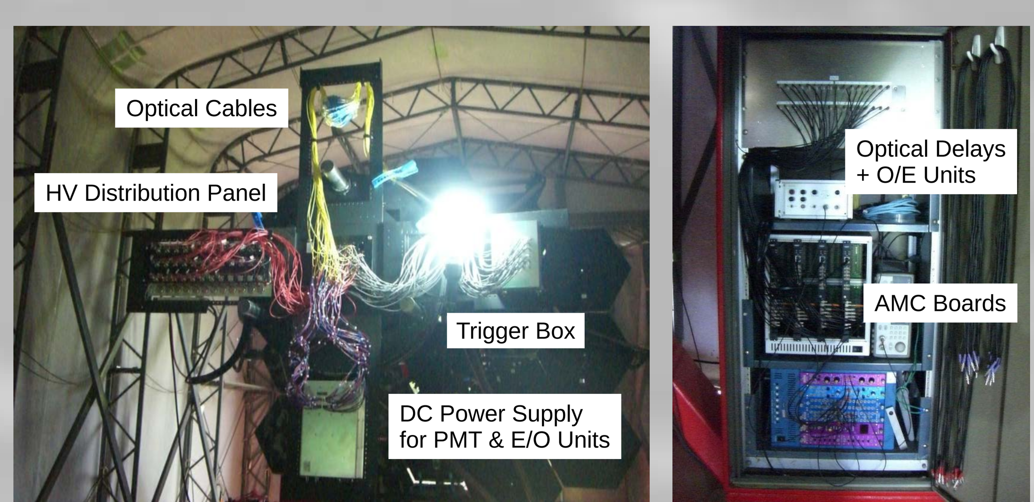

***Figure 4:** Instruments of the low power consumption DAQ system installed to the Akeno telescope. Left: instruments assembled behind the imaging camera at the focus. The four panels are closed when the telescope is operated. Right: instruments assembled in the 19 inch rack attached to the side of the azimuth chassis.*

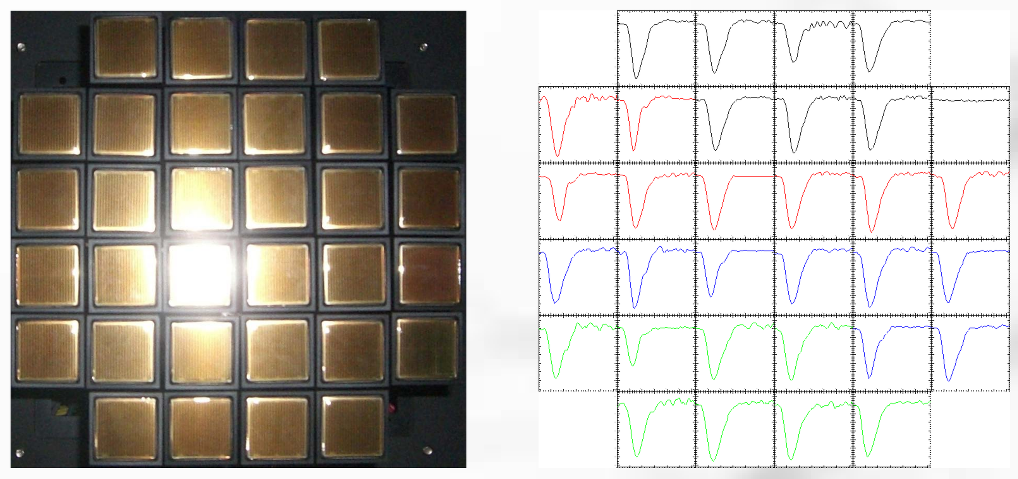

***Figure 5:** 32 pixel (PMT) imaging camera for the low power consumption DAQ system (left) and 64 ns waveforms of a blue LED light flash taken by corresponding PMTs (right).*

2.2 Observation of the Optical Crab Pulsar

As an application except VHE R & D, we plan to observe the optical Crab pulsar with the Akeno telescope using a PMT near the center of the imaging camera described above. The goal of this R & D is to carry out simultaneous observations with the 34 m radio antenna in Kashima, Japan. Radio pulses from the Crab pulsar inevitably pass through the Crab Nebula plasma and the effect there in the acceleration site is possibly seen as fluctuation of the dispersion measure (DM). The role of the optical observations with the Akeno telescope is to give a good timing reference to the DM measurement. We expect to get new insight on the acceleration site of the Crab Nebula with this new approach. This plan is schematically shown in Figure 6.

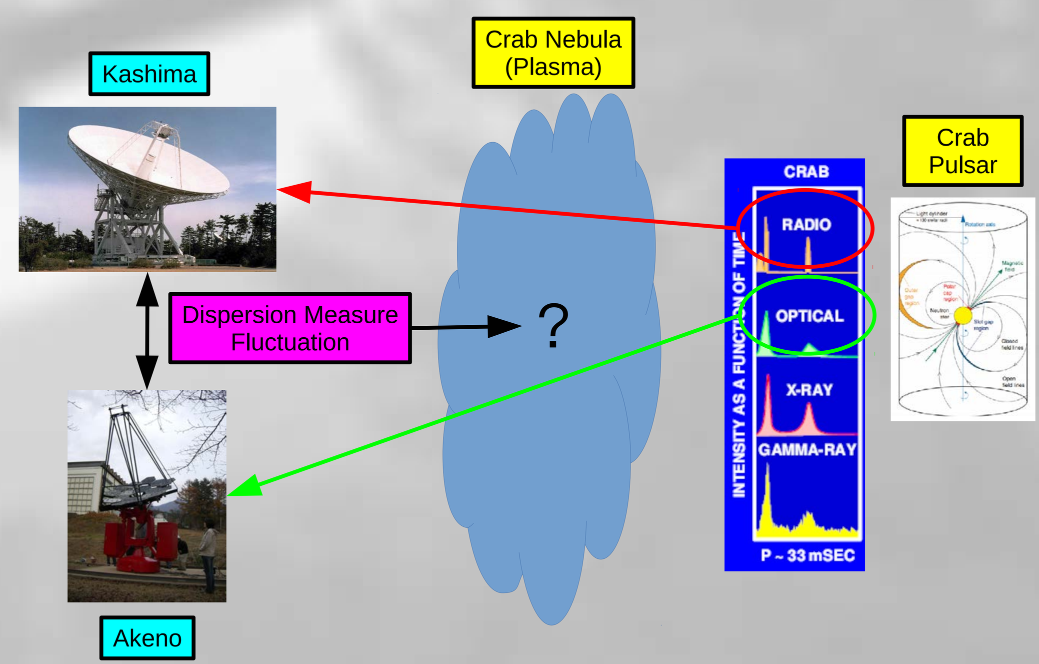

***Figure 6:** Schematic concept of the new approach observing the Crab Nebula plasma utilizing the radio and optical Crab pulsar.*

2.3 Other R & D Plans

Imaging cameras for CTA LSTs are going to consist of PMTs, which can however be replaced by SiPMs in the future. There is a plan to test a prototype SiPM camera for LSTs with the Akeno telescope. It is also considered that the CCD camera placed at the center of each LST camera for calibrations will be tested with the Akeno telescope. A compact imaging camera for CTA SSTs is developed by the Nagoya group and it will possibly be tested with the Akeno telescope, although this is a backup solution. An R & D study trying to detect radio emission from air shower particles coincide with the Cherenkov light signal is also planned.

3. Summary

We have reinstalled a 3 m atmospheric Cherenkov telescope in Akeno, Japan, which can be utilized as a test bench in various R & D studies for future ground-based gamma-ray astrophysics projects, etc. A low power consumption DAQ system was developed for the Mobile Telescope Array concept, and installed to the Akeno telescope for field tests. We confirmed that the system almost worked as we had designed and will perform test observations in the near future to estimate its performance. Some other R & D studies such as observations of the optical Crab pulsar and field tests of instruments developed for CTA are also ongoing or planned.

References

[1] G. P. Rowell, et al., Nucl. Instrum. Meth. A, **588**, 48–51 (2008).

[2] M. Ohishi, et al., Proc. 33rd ICRC (Rio de Janeiro), 587 (2013).

[3] T. Yoshikoshi, et al., Proc. 32nd ICRC (Beijing), **9**, 231–234 (2011).