

Light Source Test at the Telescope Array Site

K. MACHIDA¹, K. HONDA¹, M. TAKEDA², T. FUJII^{2,5}, D. IKEDA², Y. TAMEDA², H. SAGAWA², J.N. MATTHEWS³, S.B. THOMAS³, G.B. THOMSON³, R. ENGEL⁴, K. DAUMILLER⁴, R. SMIDA⁴, L. TOMANKOVA⁴, F. WERNER⁴, FOR THE ICRC COLLABORATION.

¹ *University of Yamanashi, Kofu, Japan*

² *Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Japan*

³ *University of Utah, Department of Physics and Astronomy and High Energy Astrophysics Institute, Salt Lake City, UT USA*

⁴ *Karlsruhe Institute of Technology, Institute for Nuclear Physics, Karlsruhe, Germany*

⁵ *now at: University of Chicago, Chicago, USA*

khonda@yamanashi.ac.jp

Abstract: The Telescope Array (TA) Experiment and the Pierre Auger Observatory (PAO) are carrying out a joint calibration campaign for their fluorescence telescopes. The technique employs a calibrated light source carried by a remote-controlled flying device called an octocopter. We have placed the light source in known positions in the field of view of both TA and PAO fluorescence telescopes. The first trial octocopter calibration had been done in TA site on Oct. 14, 15, and 16 in last year. The second trial had been done in TA site on March 16 and 19 in this year. In this paper, we report on analysis results of a part of the first trial octocopter calibration at the TA site.

Keywords: Telescope Array, Calibration, Octocopter, UHECR

1 Introduction

Telescope array (TA) experiment studied cosmic rays at highest energies combine air fluorescence telescopes with a large array of surface detectors. In order to measure the energy of incident cosmic rays with high accuracy, stable operation and absolute calibration of light intensity of the telescope equipment is important. Some reference PMTs for each camera are calibrated the absolute energy of the light by CRAYs in the TA. The variation of reference PMT's gain during the observation is measured the signal from YAP attached in the reference PMT. The relative variation of the entire PMTs in the camera is measured hourly observing by xenon flasher installed in the center of each telescope. YAPs and xenon flashers for each telescope are same equipment. However they have the particular character. In order to avoid these problems, the only portable UV light source is required to calibrate the PMTs in different cameras. Further, the Pierre Auger Observatory (PAO) experiment doing same study used different configured telescopes from the TA. It is necessary to use the only UV light source for the calibration between the telescopes of the TA and PAO experiments. Such a source, flying isotropic UV light source has been developed at Karlsruhe Institute of Technology (KIT)[1, 2]. This portable light source is presently undergoing careful evaluation of isotropy, pulse rate and temperature dependence, and temporal stability. The source is carried by a remote controlled flying platform called an octocopter (Mikrokopter)[3, 4]. These UV light source, the octocopter and source calibration in the Laboratory are described in detail[5].

2 The flight at the Telescope Array Site

In October 2012, a team from Auger including KIT octocopter experts visited the Telescope Array site in Utah to conduct a campaign of octocopter light source flights. The team from Auger worked along with a team of researchers

from the Telescope Array. The first test flights were conducted on 2012-10-14 at distances of 350m and 1000m from telescope 7 at the Black Rock Mesa (BRM) site.



Figure 1: Octocopter at the base position

The photo of KIT octocopter in front of the Black Rock Mesa site is shown in Fig. 1. The external temperature was about 0 C. degree. Data was recorded using five of the six standard source settings in the telescope 7. The flight list on 14-16 Oct. is shown in Fig. 2.

In this list, the target PMT in the telescope 7, Start Time (UTC), Amplitude of the light source and the distance (m) from the octocopter to the center of the mirror in the telescope are described. The Octocopter was positioned near the center of pixels 33, 73, 77, and B3 in the camera 07. Pixel 77 is located near the center of the camera and pixel 33 is half way to the corner as shown in Fig. 3. Pixel 33 would be expected to be more affected by spherical aberration. Pixels 73, 77, and B3 are equipped with a YAP to monitor the PMT response. We note that pixel 77 in each

FlightNO	TargetPMT(c amera07)	startTIME (UTC)	Amplitude (ADCcount)	distance
1	77	02:45:20	997	350
2	77	02:55:34	851	350
3	77	03:05:20	552	350
4	77	03:19:00	354	350
5	77	03:32:36	223	350
6	73	04:01:27	851	999
7	33	04:16:30	997	1000
8	77	04:31:10	997	999
9	B3	04:55:42	997	999

FlightNO	target	Starttime(UTC)	Amplitude (ADCcount)	distance	
1	07	77,73	02:40:30	997	1000
2	05,07	77,33	03:07:24	997	999,1000
3	07	77,73	03:36:03	997	1000
4	01	77,b3	04:21:37	997	1000
5	01	77,33	04:55:03	997	1000

FlightNO	Target	Starttime (UTC)	Amplitude (ADCcount)	distance	
1	07	77,33	02:33:33	851	1000
2	07	77,33	03:08:22	552	1000
3	07	77	04:05:26	155	110
4	06	75	04:31:43	150	110
5	06	75,73	04:53:04	140	110
6	06	7d,7b	05:05:02	140	111

Figure 2: The flight list on 14(top), 15(middle), 16(bot-
tom) Oct. of 2012.

camera is the telescope standard CRAYs calibrated PMT [6]. Additional flights were flown in the FOV of nine pixels the following two nights along with flights in pixel 77 at telescope 5 and telescope 1. During these flights the highest light setting (ADC count =997) was used.

2.1 The flight Position of KIT Octocopter

The position data from GPS attached in the octocopter are calculated X(km), Y(km) and Z(km) in TA coordinate whose origin is Central Laser Facility (CLF). The example of the flight position data of flight No. 8 on 14 Oct. are shown in Fig. 4.

This figure shows X(km) position (east) vs. shot No. and shows Y(km) (north) and shows Z(km) height from the origin whose 250 position data are chosen from 550 shot ID to 800 shot ID in all shot data.

The figure 5 are shown the histogram of the selected 250 position data which are fitted by the Gaussian curve. The standard deviation of the octocopter position in the flight No. 8 are ±26 cm for X axis, ±30 cm for Y axis and ±16 cm for Z axis. We check the standard deviation of the Octocopter position for other five flights, almost deviation are less than about ±30 cm for X, Y and Z except one flight. The deviation in flight No. 9 on 14 Oct. are worst one, twice value for other normal deviation.

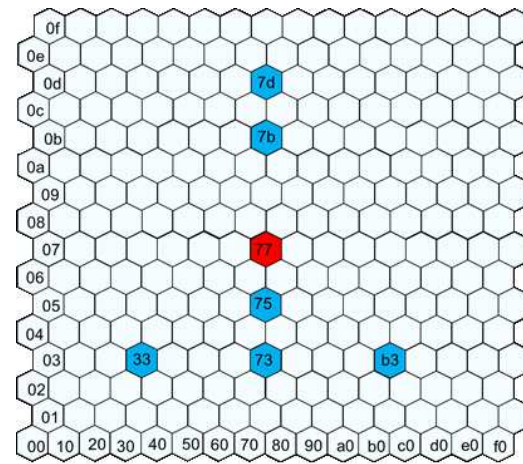


Figure 3: PMT position in the camera of the telescope.

2.2 Number of the photo-electrons for each PMT in the telescope 7

The observed number of the photo-electrons for PMTs in the telescope 7 are calculated using normal routine of fluorescence telescope. The Map of average number of the photo-electrons for PMTs is shown in Fig. 6 which observation is for the center PMT (PMT 77) in camera 07, flight No.1 on 15 Oct. (187 events).

The average number of the photo-electrons for the center PMT 77 is 2.592×10^5 as shown in this figure, one for 6 PMTs around the center PMT 77 is 7.166×10^4 , one for 12 PMTs of more outer circle is 1.442×10^3 . The ratio of the center PMT 77 for total the photo-electronss is 78.0%, 21.6% for 6 PMTs around the center PMT, 0.4% for 12 PMTs. It's no problem that consider only the center PMT and 6 PMTs around the center PMT for PMT 77 in camera 07. The additional data for the center PMT 77 in camera 07 are analyzed for other three different flights, 14 Oct. flight No.8 (243 events), 16 Oct. flight No.1 (237 events) & 2 (191 events). From four flights, the ratio of the center PMT 77 for total the photo-electronss is 75%, 25% for 6 PMTs around the center PMT. The average number of the photo-electrons for the center PMT 77 and one for 6 PMTs around the center PMT 77 are shown in the left side of Fig. 7. Right side in this figure are shown the ratio of the photo-electronss normalized to one of 14 Oct. flight No.8. The observations of lower two flights are changed the amplitude ADC count of light source to 851 and 552 respectively. The amplitude of upper two flights are same ADC count=997.

2.3 Amplitude of The Light Source

In order to obtaine the dependence of the amplitude, total number of the photo-electrons in 7 PMTs is useful recognized from Fig. 5. Because the photo-electrons in the center PMT is only 75% to total photo-electrons. The observed four average photo-electrons in 7 PMTs are shown in Fig. 8 as a function of the amplitude ADC count.

The straight line in this figure is the fitting line used with the least square method by the logarithmic function. The equation of this fitting line is following;

$$I_{the\ photo-electrons} = 1.8 \times 10^6 + 7.2 \times 10^5 \log(Amplitude)$$

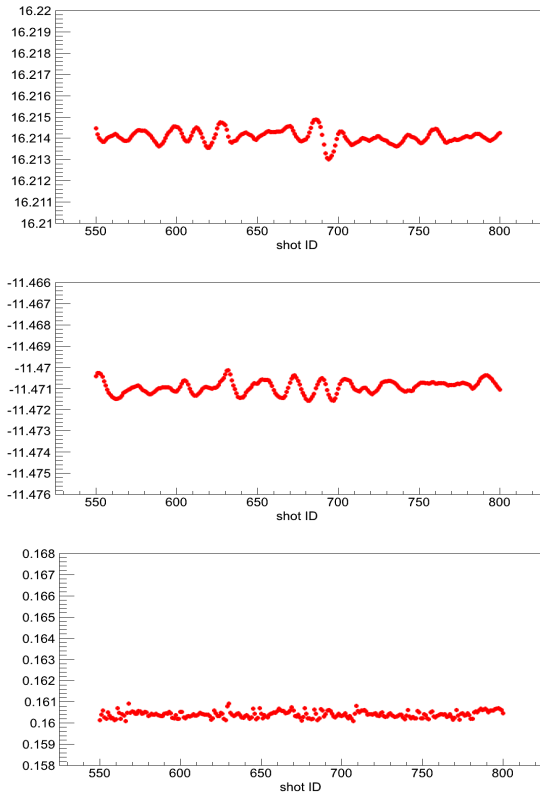


Figure 4: The example of the flight position per each shot in CLF coordinate. X(km)(top), Y(km)(middle) and Z(km)(bottom)

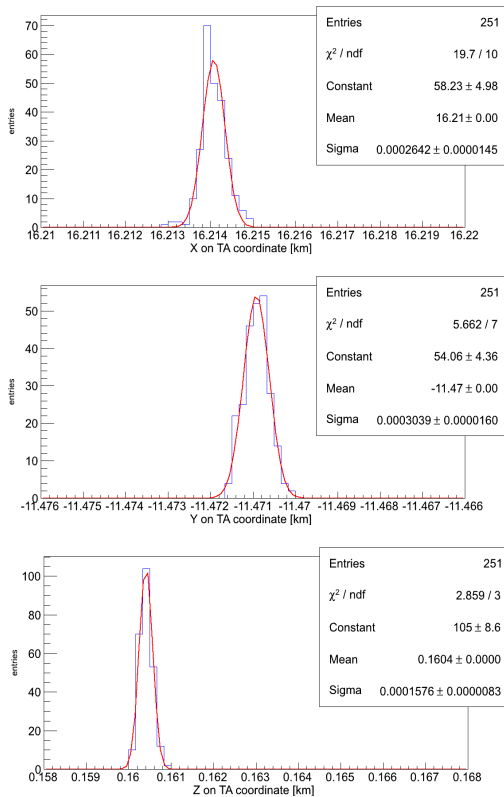


Figure 5: The example of the distribution of the flight position in CLF coordinate. X(km)(top), Y(km)(middle) and Z(km)(bottom)

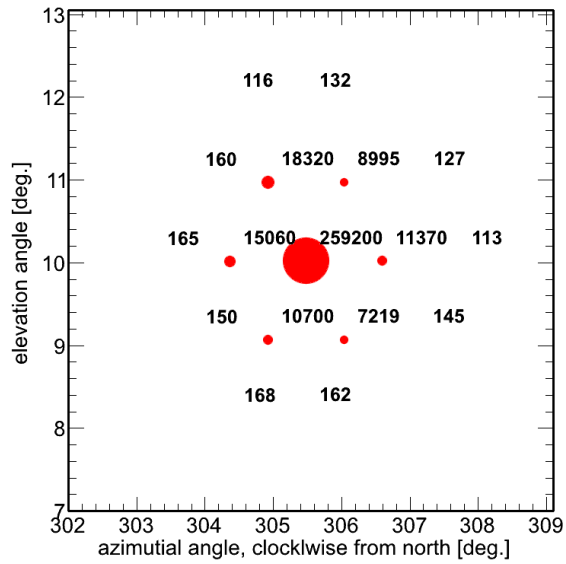


Figure 6: Average number of the photo-electrons for PMTs (187 shots) in camera 07. The radius of the red circle depend on log(number of the photo-electrons), large red circle shows the center PMT (PMT 77) and the small number on the upper right of the red circle shows average number of the photo-electrons for that PMT.

PMT77	photons		Ratio	
	Total(6P)	Total(7P)	Center/7P	6P/7P
2.471E+05	8.907E+04	3.362E+05	0.735	0.265
2.592E+05	7.166E+04	3.309E+05	0.783	0.217
2.085E+05	7.221E+04	2.807E+05	0.743	0.257
1.102E+05	3.867E+04	1.489E+05	0.740	0.260

Figure 7: Left side : Number of the photo-electrons for the center PMT 77 and 6 PMTs around the center PMT 77. Right side : The ratio of the photo-electrons to the top flight data.

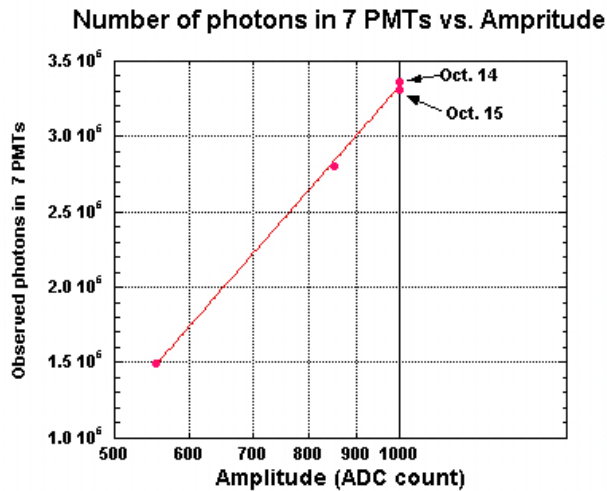


Figure 8: The number of the photo-electrons in 7 PMTs vs. Amplitude (ADC count)

The two red point at Amplitude=997 in this figure are slight defferent number of the photo-electrons. The intensity on 14 Oct. is slight larger than one on 15 Oct. The intensity of the light source is depend on the temperature at the light source. The temperature at the light source is recorded for each shot during the flight operation with the accuracy of 1 degree. The average temperature at the light source is 7.43°C on 14 Oct. and 12.0°C on 14 Oct.. The difference of the intensity of the photo-electrons be indicated that a part of the difference intensity will be come from the inverse dependence on the temperature at the light source.

3 Summary

The first trial octocopter calibration had been done with 20 flights in TA site on Oct. 14, 15, and 16 in last year. We had analyzed the four calibration operation data to the center PMT 77 in camera 07 which the distance between the octocopter and the mirror is about 1.0 km. The standard deviation of the octocopter position for the flights are less than about ± 30 cm for X, Y and Z coordinate in TA site. The ratio of the center PMT 77 for total the photo-electrons is 75%, 25% for 6 PMTs around the center PMT, the light source is distributed to 7 PMTs. The intensity of the photo-electrons is depend on the amplitude ADC count of the light source, one is described with the linear logarithmic function of the amplitude. The inverse dependence on the temperature at the light source will be expected.

References

- [1] Felix Werner, Design and Test of a Flying Light Source for the Calibration of the Auger Fluorescence Telescopes, Thesis, Karlsruhe Institute of Technology, 2010.
- [2] Julia Parrisius, Test of the Calibration of the Auger Fluorescence Telescopes with an Isotropic UV Light Source, Thesis, Karlsruhe Institute of Technology, 2009.
- [3] www.mikrokoetter.de
- [4] www.mikrocontroller.com (product id=396)
- [5] J.N. Mattews, ICRC 2013,id=1218

[6] S. Kawana, et al., Nuclear Instruments and Methods in Physics Research Section A 681 (2012) 68-77