Search for molecular bremsstrahlung radiation signals in Ku band with coincidental operations of radio telescopes with air shower detectors

S Ogio\textsuperscript{1}, T Yamamoto\textsuperscript{2}, K Kuramoto\textsuperscript{1}, T Iijima\textsuperscript{2}, H Akimune\textsuperscript{2}, T Fujii\textsuperscript{1}, N Sakurai\textsuperscript{1}, M Fukushima\textsuperscript{3}, H Sagawa\textsuperscript{3}

\textsuperscript{1} Graduate School of Science, Osaka City University, Osaka 558-8585, Japan
\textsuperscript{2} Faculty of Science and Engineering, Konan University, Kobe 658-8501, Japan
\textsuperscript{3} Institute for Cosmic Ray Research, University of Tokyo, Kashiwa-shi, Chiba 277-8582, Japan

E-mail: sogio@sci.osaka-cu.ac.jp

Abstract. Microwave radiation from extensive air showers is expected to provide a new technique to observe UHECR. We developed three set of radio telescopes in Osaka, in Kobe and at Telescope Array site in Utah, USA. In Osaka, we are coincidentally operating two Ku band radio telescopes with an air shower array which consists of nine plastic scintillators with about 10 m separation. In Kobe, we have started the operation of twelve radio telescopes of 1.2 m diameter in March 2012. In Utah, we installed two telescopes just beside the Black Rock Mesa fluorescence detector (FD) station of the Telescope Array experiment, and we operated the radio telescopes coincidentally with FD event triggers. We report the experimental setups and the results of these measurements.

1. Introduction

In order to develop a new generation of UHECR detectors with several orders of magnitude bigger target volume, the most actively studied and most promised method is related to techniques at radio wavelength band \cite{1,2}. Radiations in some specific frequency bands have a better transmittance and a longer mean free path in the air than visible light and charged particles.

Here we report our research into detections of microwave radiations from extensive air showers (EAS) in Ku (\(\sim 12\) GHz) band. The method of shower detections in this band has some remarkable feature, a small expected angular resolution of 1\(^\circ\) and negligibly small atmospheric attenuation of radiation. Moreover, since operations of the array are unaffected by we can expect calorimetric measurements with 100 \% duty factor.

2. Experiment at Osaka City University

In order to detect and study microwave signals coincident with EAS, we operated radio telescopes with an air shower array. In this experiment, we used the air shower array is located in Sugimoto campus of Osaka City University. The array consists of nine surface scintillation detectors of 0.5 m\(^2\) area. The detectors are arranged in three rows, and the spacing of the detectors are about 7 m to north-south and about 10 m to east-west directions. The total effective area of the array is about 294 m\(^2\). All the detectors are calibrated to be a same hit rate of about 200 Hz. This array makes a trigger by a four fold coincidence of the detectors at the corners of the alignment.
Simultaneously working microwave radio telescope system for this study consists of two parabolic antennas with LNBF for Ku-band, power sensors, a digital oscilloscope and a PC for controlling and recording data. The Ku-band antenna with LNBF which is CBS45AST made by Nippon Antenna, which is 45 cm diameter, the received frequency of 11.7-12.75 GHz and the converter output frequency of 1032-2072 MHz. In the experiment one antenna, called “ON-AXIS”, pointed to zenith and was covered by microwave absorbent materials (IR-K150 by TDK-EPC), and the other, called “OFF-AXIS”, pointed to north-west with 30° elevation. The noise temperature are measured as 182.9K and 201.4K for ON and OFF telescopes, respectively. Output of each LNBF is connected to a power sensor, ZX47-60-S+ by Mini-Circuits laboratory, Inc., through a bias-tee which is ZX85-12G-S+ by the same company. The digital oscilloscope is TDS 3032 by Tektronix, Inc. operated with a sampling frequency of 100 MHz and a record length of 10,000 samples. A block diagram of the experimental setup is shown in Figure 1.

The observation period is from Jun. 30th, 2011 to Dec. 12th of the same year, and the total observation time is 2664.0 hours. Although the number of EAS triggers is 235,860, the number of recorded events is 114,265 because of a large dead time in DAQ process of the oscilloscope.

![Figure 1](image_url). The experimental setup of the microwave antennas with the EAS array at Osaka City University.

Every recorded waveform has 100 µs length, and for the signal search analysis a waveform was divided into three regions. “BEFORE”, which is 40 µs range before the trigger, “COINC.”, 10 µs range after the trigger, and “FAR LATER”, which is the other region of 50 µs length. Then in each region for every waveform the maximum amplitude was determined and the significance relative to an averaged fluctuation was calculated. The histograms for the significance values for ON- and OFF-AXIS telescopes are shown in Figure 2. Comparing the histograms we found excess between 5.5 and 6.0 sigma on the ON-AXIS “COINC.”. However, radio signals are expected to be appeared in “BEFORE” region from delay time measurements of the array and the telescopes, so then we cannot conclude the excess caused by radiations induced by EAS particles.

The improvements on analog electronics (shorten the rise time and optimized output load) and on the DAQ system had been finished, and then we have restarted observations from May 2012.

### 3. Experiment at the Telescope Array site

We brought the radio telescope system to the Telescope Array site at Delta, Utah, and we installed it just beside the south-east FD station building, called “Black Rock Mesa (BRM) station” [3]. A photograph is shown in Figure 3. The system, block diagram is shown in Figure 4, is almost same as used in Osaka, but a high pass filter with the cutoff frequency of 33 kHz and an amplifier installed in the signal line. Moreover the data recording system was changed to an ADC module attached on PC-card bus, CSI-320110 by Interface, Inc., which has two input
channels with a sampling frequency of 40MHz, 10bits for ±1 V input range and 4M sample/ch record length.

Figure 2. Histograms of the significance values in three different ranges in the waveforms.

Figure 3. The two antennas are installed just beside the BRM station building. Behind the antennas and the fence the ELS buildings are seen in this photo.

Figure 4. The experimental setup at the Telescope Array site.

After test operations for several nights, in March 17, 2012, we operated the system simultaneously with electron beams emitted by the Electron Light Source (ELS), which is a 40 MeV electron linac installed at 100 m away in front of the BRM station [4]. A radio telescope was point to 30° above the ELS beam muzzle and its output signals were recorded with the FD triggers induced by ELS beams [5]. The other ADC channel was recorded ELS trigger signals. The total recorded waveforms coincident with ELS triggers was 1,782.
The ELS pulse duration is 1 µs and the estimated delay of radio signal is 6.8 µs, equivalent to 270 samples after the rising edge of ELS trigger pulses. We have not yet found significant microwave signals coincident with ELS beams. The Telescope Array’s ELS team is planning to change the beam width, to be shorter than 1 µs. After this improvement we also plan radio telescope operations again in this summer.

4. Experiment at Konan University

Besides the experiments at Osaka and at Utah with small dish (45 cm) antennas, we constructed multi-antenna system that consists with twelve 1.2 m dishes in Kobe, shown in Figure 5. Each dish has two LNBFs connected to the same power detectors, and signals are recorded with 65MS/s 12bit ADCs. Operations have started in February 2012. An air shower array, which consists of 16 surface scintillation detectors with covering 1,600 m², simultaneously working with the antennas are planed to be constructed beside the system in this year.

Figure 5. Ku band antennas installed in Konan University. Each of telescopes has two LNBF for two different linear polarization. The sensitive band of the LNBF is 12.25-12.75 GHz, and the beam width is about 1.5°.

Acknowledgments

The authors thank CROME and MIDAS collaborations, specially Prof. Ralph Engel, Dr. Radomir Smida and Prof. Paolo Privitera for the useful discussions and advices. We also thank all the members of Telescope Array collaboration, specially Dr. Tatsunobu Shibata, for their kind and helpful supports. This work is supported by the Ministry of Education, Culture, Sports, Science and Technology, Japan, Grant-in-Aid for Challenging Exploratory Research, 21654036, 2009, and Grant-in-Aid for Scientific Research (B), 24340059, 2012. It also partly supported by the Inter-University Research Program of the Institute of Cosmic Ray Research, University of Tokyo. We gratefully acknowledge the contributions from the research and the technical staffs of our home institutions.

References

[1] Gorham P W, et al. 2007 Phys. Rev. D 78 032007
[2] Privitera P 2011 Proc. Int. Sym. on Recent Progress of UHECR Observation (Aichi, Japan) (AIP Conf. Proc. 1367) p 137
[3] Tokuno H, et al. 2012 Nucl. Inst. and Meth. A 676 54
[4] Shibata T, et al. 2008 Nucl. Inst. and Meth. A 597 61
[5] Tameda Y, et al. 2009 Nucl. Inst. and Meth. A 609 227