Development of microwave telescopes for detection of Molecular Bremsstrahlung Radiation from EAS of UHECR

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Abstract: Multi-pixel microwave telescope system is under a development for a detection of Molecular Bremsstrahlung Radiation (MBR) from Extensive Air Showers. This system is composed of 12 parabolas fixed on a roof of Konan university in Kobe Japan. Diameter of the parabola is equivalent to 1.2 m. Each parabola has a single feed horn with 12GHz receiver on the focal point. The details of this system are reported.

Keywords: MBR UHECR detection

1 Introduction

With unprecedented precision and accuracy, UHECR sky is being observed by the Pierre Auger Observatory on the southern sky. The northern sky is observed by the Telescope Array observatory simultaneously. These observations, as well as precedent measurements, indicate that the CR energy spectrum get steeper around 10^{20} eV which is consistent with the expectation so called GZK steepening [1]. Also possible detection of anisotropy on the UHECR sky has been reported by the Auger Collaboration [2]. Nevertheless, the sources of the UHECRs are not identified yet.

It is clear that UHECR measurements with higher statistics and same or better accuracy are necessary to identify the UHECR sources. It may be possible to develop higher statistics with low resolution or better resolution with similar statistics in current technology. Question is how to develop next generation detector for the UHECR observation with higher statistics and better accuracy with limited budget.

Current observatories achieved its sensitivity utilizing hybrid observation i.e. surface array overlooked by fluorescence telescopes. The surface array is composed of a grid of particle detectors. Advantage of this detector is 100 % of duty cycle so that large statistics can be achieved. On the other hand, surface array measures only portion of Extensive Air Showers (EAS). Therefore amount of energy of EAS has to be estimated based on a conversion function of size parameter of EAS and the energy. The fluorescence telescope measures longitudinal development of

EAS. Therefore calorimetric measurement of CR energy is available in principal but duty cycle is $\sim$10% because it works only moonless clear night.

Detection of radiowaves from EAS may improve this situation. Especially microwave emission from low energy electrons in the EAS through MBR is expected to have the advantages of the surface array and the fluorescence telescopes.

High energy electrons in the EAS make huge amount of lower energy electrons through electro-magnetic cascades in the atmosphere. If the energy of the electron gets lower than 84 MeV, which is critical energy of electron in the air, the electron stops the development of the air shower. Electrons also lose energy through ionization. In this process, huge number of omnidirectional free electrons are created in the atmosphere. These low energy electrons are scattered by the molecular of atmosphere to the random direction and emit microwave by MBR. The microwave radiation is expected to be isotropic as well as fluorescence radiation. If this is the case, measurement of microwave by MBR should improve UHECR observation dramatically because

- 100 % duty cycle just like the surface array.

- Measurement of longitudinal development of EAS from remote detector just like the fluorescence telescope.

Detection of MBR from EAS was originally proposed and reported in Gorham et al [3]. Their results indicate MBR from EAS is strong enough to detect from remote tele-

scopes. Motivated by their results, we are developing a multi-pixel microwave telescopes. The detail of this telescopes will be reported in this conference.
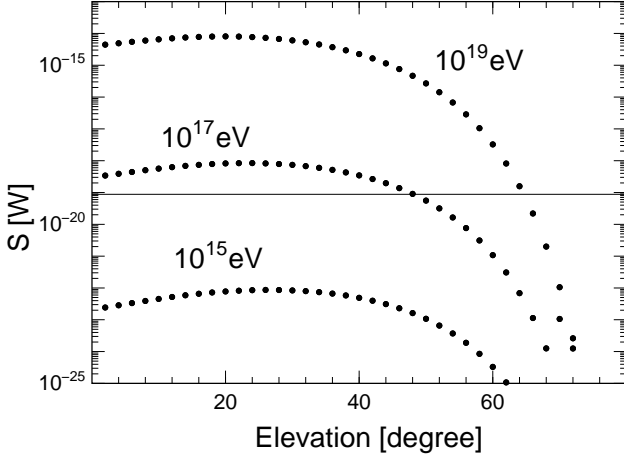
2 Design of Telescopes

Figure 1: Expected signal intensity of MBR from vertical airshowers at a distance of 7 km from telescopes. The telescope is assumed to be composed of 1.2 diameter dish with 12 GHz receiver. X-axis is elevation angle of telescopes. Solid line indicates threshold of signal assuming $T_{sys} = 150K$.

Aiming for the detection MBR from EAS, we have developed a simple simulation code to estimate signal intensity at a remote telescope. This simulation is based on the results of electron beam measurements by P.W.Gorham et al. [3]. They have measured 3.8GHz microwave from electron beam of which intensity is equivalent to a shower maximum induced by a 3.36×10^{17} eV CR. Deferential signal intensity I_{f0} from the electron beam with 0.65 [m] in length at a distance of 0.5 [m] on the ground was $I_{f0} = 4 \times 10^{-16}[W/m^2/Hz/s]$. Decay time of this microwave signal was reported as $\tau = 10^{-8}$ [s]. Based on this results, signal intensity from an air shower at a parabola antenna can be estimated with simple assumptions.

Intensity of MBR was assumed to be proportional to the atmospheric density. The atmospheric density ρ as assumed as follows.

$$\rho = \rho_0 exp\left(-\frac{z}{H}\right) \quad (1)$$

where ρ_0 is atmospheric density on the ground and H is scale hight of atmosphere and z is altitude of the observed point on the airshower axis. Then expected microwave intensity $I_{f,exp}$ from the maximum of the airshower with energy of 3.36×10^{17} eV is

$$I_{f,exp} = I_{f0}\frac{c\tau}{0.65[m]}\frac{\rho}{\rho_0}\left(\frac{R}{0.5[m]}\right)^2 [W/m^2/Hz/s] \quad (2)$$
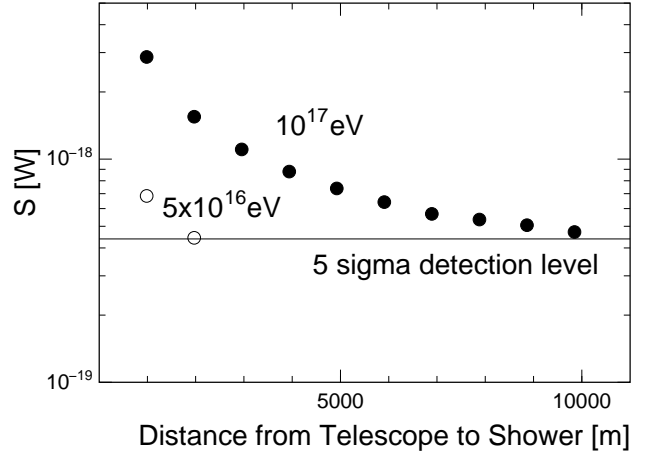

Figure 2: Expected signal intensity from vertical airshowers as a function of distance from telescope to the showers. Same telescopes with elevation angle of 10 degrees are assumed. Solid line indicates 5 sigma detection level.

where R is distance between the shower maximum and detector.

The size of plasma of the airshower depends on its stage of longitudinal development. Gaisser-Hillas function is used for this correction as follows.

$$N_e = \left(\frac{X - X_0}{X_{max} - X_0}\right)^{\frac{X_{max}-X}{\Lambda}} exp\left(\frac{Xmax - X}{\Lambda}\right) \quad (3)$$

where X is atmospheric depth of the airshower and X_0 is first interaction point of CR with atmosphere which is fixed on 10 [g/cm^2] and does not affect to the N_e very much. X_{max} is atmospheric depth of shower maximum which was assumed depending on CR energy as follows.

$$X_{max}[g] = 300 \times log_{10}\left(\frac{E}{1[eV]}\right) + 1800 \quad (4)$$

where E is energy of CR. Λ was assumed to be $700[g/cm^2]$.

Then signal intensity I_{obs} at the detector is scaled as

$$I_{obs} = I_{f,exp} \times N_E \times \left(\frac{E}{3.36 \times 10^{17}[eV]}\right)^n \quad (5)$$

where n is assumed to be 1 in this simulation.

Field of view of the feedhorn mounted on the focal point of parabola $\Delta\theta$ is estimated as

$$\Delta\theta = 1.22\frac{\lambda}{D} \quad (6)$$

where D is diameter of parabola and λ is wave length of the microwave. Therefore length of shower in the field of view L_{sh} is

$$L_{sh} = \frac{R\Delta\theta}{sin\left(\chi\right)} \quad (7)$$

where χ is angle of shower axis to the line of sight of parabola. Then expected signal intensity S on the receiver is

$$S = I_{obs} \times \eta\pi\left(\frac{D}{2}\right)^2 \times \frac{L_{sh}}{c} \times \Delta f \qquad (8)$$

where η is efficiency of the feed horn and Δf is bandwidth of receiver.

Detection threshold of intensity of MBR I_{th} is estimated as follows.

$$I_{th} = \frac{k_B T_{sys}}{\eta\pi\left(\frac{D}{2}\right)^2 \sqrt{\frac{L_{sh}}{c}\Delta f}} \qquad (9)$$

where T_{sys} is system temperature of the parabola and DAQ system.

Based on above estimation, we have calculated expected signal from EAS. Figure 1 shows a result of this simulation. Expected signal intensities S from Equation 8 are shown. Vertical showers with energy of 10^{15} eV, 10^{17} eV, 10^{19} eV at a distance of 7 km from telescopes are simulated. Telescope is assumed to have 1.2 diameter parabola with $\eta = 0.8$ and detection band is from 12.25 to 12.75 [GHz]. Signal threshold is also shown in this figure which indicates air showers with energy of $> 10^{17}$ eV can be detected by the assumed observation system.

Same telescopes are assumed in Figure 2 which shows expected signal intensity from vertical showers as a function of distance from telescope to the showers. 5 sigma detection level is also indicated. This figure indicates that vertical airshowers with energy above 10^{17} eV are detectable by a microwave antenna with 1.2 m diameter parabola.

3 Detector

Figure 3: Photograph of the parabola for detection of MBR from EAS. 12 parabolas are located on a roof of university building.

Based on the results from the simulation described above, we have developed an MBR observation system. This system composed of 12 off axis parabolas (NIPPON ANTENNA CS-S120K). Diameter of this parabola is equivalent to 1.2 m which is decided to maximize signal to budget ratio. 1000 kg of concrete pad is constructed to mount each parabola. All of the 12 parabolas and concrete pads are located on a roof of university where the Pacific is overlooked beyond Kobe city (Figure 3). Ku band is selected to be measured to avoid strong noise caused by communication devices in Kobe city. In this wave length, signal rapidly attenuates at off axis of parabola. Therefore only one receiver (NIPPON ANTENNA FOC-ASJ5) is mounted on the focal point of each parabola. Each receiver has two antennas to detect vertical and horizontal polarization separately. Band width of these receivers is 500 MHz from 12.25 to 12.75 GHz. The signal is down-converted to around 1GHz in the receiver. All of these equipments are commercial products for satellite TV receiver. Amount of 24 channel signals run through power detectors and proceeded in 66 MHz sampling ADC modules of VEM standard.

Field of view of each feedhorn is about 1.3 degrees. 3.9 degrees (horizontal) times 5.2 degrees (vertical) on the sky is covered by the 12 parabolas. Center of field of view is fixed on south because it is convenient to adjust its direction using Sun. Elevation angle of the center of the field of view is 15 degrees. System temperature of this system is about 150 K as assumed in the simulation. Based on the above simulation, expected detection rate above 10^{17} eV is estimated as 40 events in a day.

4 Summary

MBR detection system is under development in the Konan University in Kobe Japan. This system has 12 parabola which is equivalent of 1.2 m in diameter. Each parabola has a single receiver which measures microwave from 12.25 to 12.75 GHz. Signals from the receivers are to be digitized and processed by 66 MHz sampling ADC modules. Development of data acquisition system is going on.

References

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