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Simultaneous Detection of the Loss-Cone Anisotropy with Ooty and Akeno Muon Telescopes.

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A new technique to observe cosmic ray anisotropy with multi-directional muon telescope was developed using Muon detectors of GRAPES-3 air shower experiment at Ooty (11.4°N, 76.7°E and 2230m altitude). The muon telescope has an area of 560 m^2 and a threshold energy of 1 GeV. The statistical accuracy of data enables us to obtain 2-dimensional map of cosmic ray intensity variation. The coverage of field of view (FOV) along longitudinal direction is important to observe local anisotropy (e.g. Loss-Cone precursor decrease) which emerge in short time ($\leq$1 day). To expand the FOV of the GRAPES-3 Muon telescope along longitude in overlapping regions through energy range of their response, new muon telescopes were developed at Akeno observatory (35.8°N, 138.5°E and 900m altitude) using muon detectors operated as a part of Akeno air shower experiment. The new muon telescope has total area of 50(75)m^2 and threshold energy of 1 GeV. By combining GRAPES-3 and Akeno Muon telescopes, it is possible to observe time profile of local anisotropy like Loss-Cone Precursor decrease for $\sim$ 9 hours. Here we report first simultaneous detection and interpretations of Loss Cone anisotropy events using overlapping FOV between two muon telescopes.

1. Introduction

It is well-known that local (small-scale) anisotropies emerge due to a combination of interplanetary magnetic field (IMF) and cosmic ray density gradient. One example is loss-cone precursor anisotropy which emerges when an interplanetary shock due to CME arrives at the Earth [1]. This phenomenon has been mainly investigated by using muon or neutron monitors having relatively poor angular resolution. To observe structure of the anisotropy, better angular resolution over a wider field of view (FOV) is required. The GRAPES-3 muon telescopes [2] observe the flux of atmospheric muon ($E_\mu \geq$1 GeV) with an angular resolution of $\sim$ 7°. During the data taking since 2001, several events of Loss-Cone (LC) anisotropy have been detected. As a next step, for observation of time profile of such a local anisotropy,it is required to expand FOV along longitude direction with sufficient overlap of FOV among the telescopes.

2. Akeno Muon Telescopes

New muon telescopes were constructed at the Akeno observatory in Japan. The detector modules are mounted under 2 m of concrete absorber to achieve an energy threshold of 1 GeV for vertical muons. The telescope consists of proportional counters, 10cm×10cm×500cm in size. Each detector module has 4 layers of 49 proportional counters and the alternate layers are placed in orthogonal directions for determination of arrival direction of muon. Between the 2^{nd} and 3^{rd} layers, steel pipes with a height of 30 cm are inserted as spacers. This configuration gives same angular resolution and FOV as those of the GRAPES-3 muon telescope. The muon direction is binned into 15×15 directional cells by using proportional counters hit. Observed muon rate is ∼2100 Hz with single module ($25m^2$). A total of 3 modules have already been constructed and 2 of them are collecting data. Fig. 1 represents FOV of 15×15 cells. According to statistics required these cells can be combined into fewer number of cells. In Fig. 1 the FOV which was divided into 3×3 cells for the present work also shown.

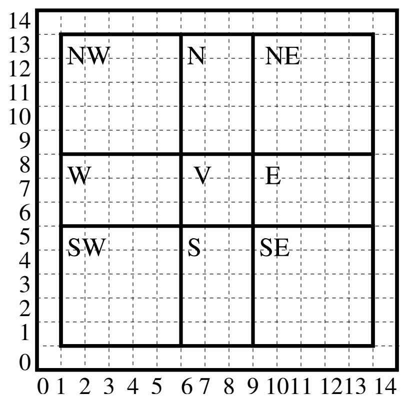

Figure 1. 15×15 cells in the FOV.

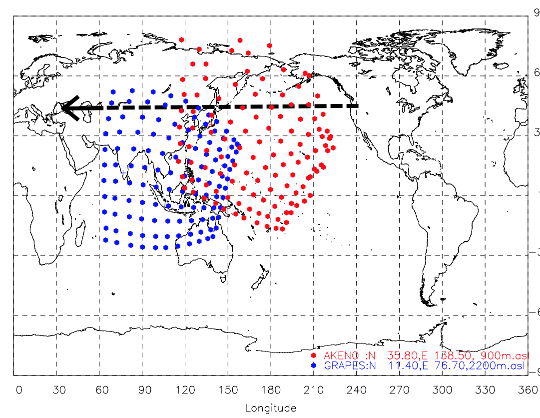

Figure 2. Observed directions of 2 muon telescopes.

2.1 Response of Muon Telescopes and Combined Field Of View

CORSIKA 5.62 (QGSJET + GHEISHA) code was used to estimate the muon flux from primary proton spectrum. On the calculation,detector structure and online data taking process were also taken into account. Assuming a primary spectrum index of -2.7, the response functions for individual cells in FOV of each telescope were obtained. The two muon telescopes at Akeno and GRAPES-3 have similar response except for a difference in the geomagnetic cutoff rigidity. Median rigidity of primary proton for observed muons at Akeno and GRAPES-3 were 63.5 and 65.5 GV respectively. While the observed direction is defined as the asymptotic direction of median rigidity particle, then the projected observed direction will be as shown in Fig. 2. One can clearly see overlap between FOV of the two telescopes. By combining GRAPES-3 and Akeno Muon telescopes, the combined FOV has a width of $\sim 150°$ along the longitudinal direction.

3. Observation and Analysis

A local anisotropy was observed at both of GRAPES-3 telescopes and Akeno telescopes. The anisotropy emerged at 30th Jul2004. It was a period of recovery after a large Forbush decrease which started at UTC ∼ 3h on 27 July 2004. Dividing FOV into 9 directions as shown in Fig.1, the variation observed in each direction is plotted, in center and right panels of Fig. 3. For this analysis, all telescopes in GRAPES-3 and one telescope ($25m^2$) in Akeno was used. One can see clearly a difference between S(south) and N(north) directions of GRAPES-3 telescope. Assuming a 24 hour averaged trend in S telescope of GRAPES-3 as cosmic ray density variation, it is concluded that the periodic minimum visible around UTC 22∼4h in North side data from 30 July to 1 August is a local anisotropy with deficit of cosmic ray intensity.

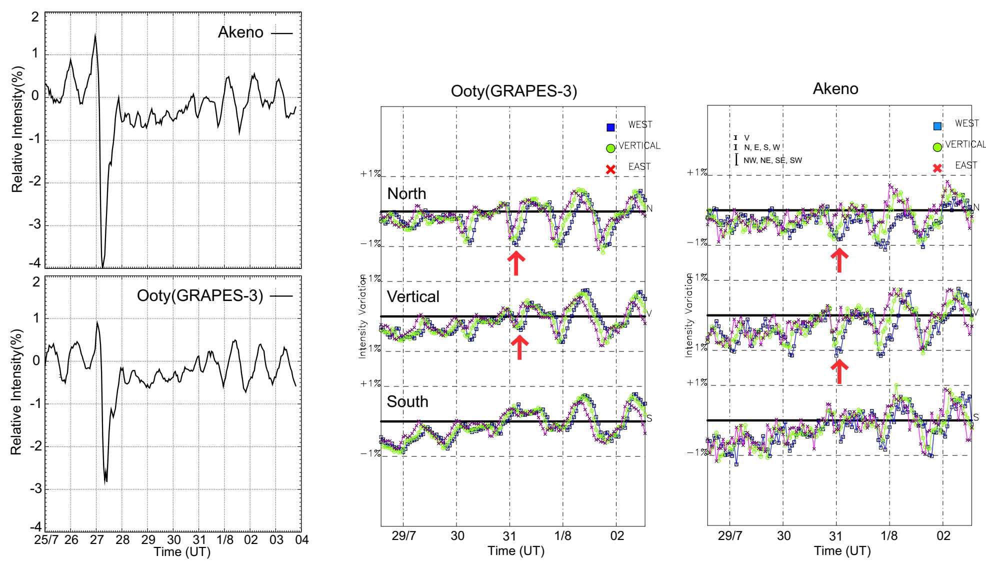

Figure 3. Relative muon intensity at Akeno and Grapes-3 muon telescopes. Left: Variation in muon rate observed at GRAPES-3 and Akeno are shown. Statistical errors in GRAPES and Akeno are 0.036% and 0.01% respectively. Center: Variation in 9 direction at GRAPES-3 are shown. Statistical error for each series is 0.09% to 0.15%. Right: Variation in 9 direction at Akeno are shown. Statistical error for each series is 0.018% to 0.029%.

In Fig. 4 the relative intensity of cosmic ray muons observed at Akeno and GRAPES-3 telescope from 30 to 31 July 2005 are shown. The relative intensity variations are coded in a color map. The color range corresponds to relative intensity of -1.7% ∼ +1.7%. Statistical accuracy of each cell in FOV are 0.1% at center and 0.3% at corner of View in GRAPES-3 data. In Akeno data, relative intensity of each cell was smoothed by taking weighted mean among surrounding cells, since the statistical accuracy of 0.25% at center of FOV was not sufficient for plot clear map. Opening angle between IMF and viewing directions are shown with red colored contour line. Each contour corresponds to an angle of 15°.

The intensity map for both GRAPES-3 and Akeno telescopes are consistent with each other and additionally the deficit directions are well correlated with IMF direction towards the Sun. By using the observed direction of cells and intensity map from Fig. 2, it is possible to estimate position of the anisotropy. The estimated trajectory of the center of the anisotropy, derived from Fig. 4, is shown by the direction of arrow indicated in Fig. 2. The geographical latitude of the anisotropy is around 35° ∼ 55° according to our estimate.

4. Discussion and Summary

The Forbush decrease on 27 July 2004 looks to be a result of M1/sf flare occurred at UTC 15:14 Hrs on 25 July 2004 and associated CME. After the flare the active region at N08W35 continued to be active while rotating towards west side of the Sun. Thus the anisotropy around IMF direction can be a result of Loss-Cone effect between the Earth and region of low cosmic ray density located in the western direction in the interplanetary

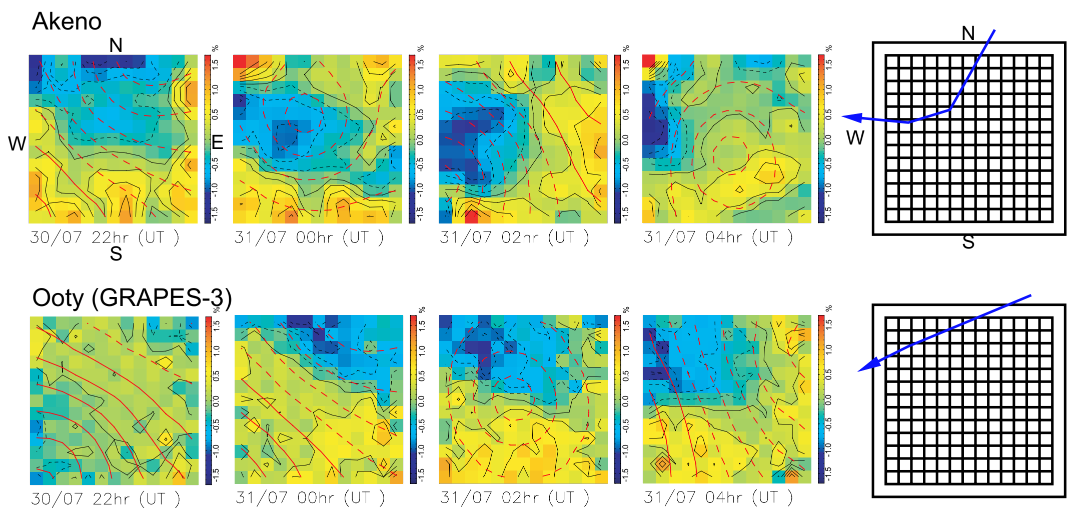

Figure 4. Intensity map in FOV of Akeno and Grapes-3 muon telescopes. Right panel shows path of deficit cone in FOV of each telescope.

space.

Omni-directional muon flux displayed in left panel of Fig3 showed large daily variation after emerging the Loss-cone anisotropy. The observed amplitude of diurnal variation seems to be becoming larger while the Loss-Cone anisotropy persists. This implies that some of high amplitude diurnal variation event[3] are corresponding to this kind of phenomena found in this observation.

5. Acknowledgements

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