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Simultaneous Detection Of The Loss-Cone Anisotropy With Ooty And Akeno Muon Telescopes.

T.Nonaka[a] S.K.Gupta[b] Y.Hayashi[a] N.Hayashida[c] K.Honda[d] N.Ito[a] A.Jain[b] A.V.John[b] S.Karthikeyan[b] S.Kawakami[a] H.Kojima[e] K.Matsumoto[a] Y.Matsumoto[a] T.Matsuyama[a] D.K.Mohanty[b] P.K.Mohanty[b] S.D.Morris[b] K.Munakata[f] T.Okuda[a] A.Oshima[a] B.S.Rao[b] K.C.Ravindran[b] K.Sivaprasad[b] B.V.Sreekantan[b] K.Takizawa[f] H.Tanaka[a] S.C.Tonwar[b]K.Viswanathan[b]T.Yoshikoshi[a]

(a) Graduate School of Science, Osaka City University, Osaka 558-8585, Japan
(b) Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400005, India
(c) Institute of Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 277-8582, Japan
(d) Faculty of Engineering, Yamanashi University, Kofu, 400-8521, Japan
(e) Nagoya Women's University, Nagoya 467-8610, Japan
(f) Physics Department, Shinshu University, Matsumoto 390-8621, Japan
Presenter: Toshiyuki Nonaka (nonaka@alpha.sci.osaka-cu.ac.jp), jap-nonaka-T-abs2-sh26-poster

A new technique to observe cosmic ray anisotropy with multi-directional muon telescope were developed using Muon detectors of GRAPES-3 air shower experiment at Ooty (N11.4,E76.7 and 2230m altitude). The muon telescope has an area of 560 m^2 and threshold energy of 1.0 GeV. The statistical accuracy enables to obtain 2-dimensional map of cosmic ray intensity variation. The coverage of field of view along longitudinal direction is important to observe local anisotropy(eg. Loss-Cone precursor decrease) emerges in short time ($\leq$1 day). To expand field of view of the GRAPES-3 Muon telescope along longitude with keeping overlapping region through energy range of their response, new muon telescopes were developed at Akeno observatory (N35.8,E138.5 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 muon telescope and Akeno Muon telescope, it becomes possible to observe time profile of local anisotropy like Loss-Cone Precursor decrease for around 9 hours. We report first simultaneous detection and interpretations of Loss Cone anisotropy events using over lapping field of view between two muon telescopes.

1. Introduction

It is known that local (small scale) anisotropy emerges due to combinations of interplanetary magnetic field (IMF) and cosmic ray density gradient. One example is loss-cone precursor anisotropy which emerges while approaching of interplanetary shock derived by earth directed CME [1]. This kind of phenomena have been mainly investigated by using muon or neutron monitors those have relatively less angular resolutions. But to observe structure of the anisotropy,more angular resolution and higher density of viewing directions is required. The GRAPES-3 muon telescopes[2] located at Ooty in India (N12.0 E74.0 2200m asl) are observing intensity of atmospheric muon($E_\mu \geq 1GeV$)with angular resolution of $\sim 7^\circ$. The current observation have been running since year 2001. Till now several events of Loss-Cone(LC) anisotropy have been clearly detected in it's Field of View(FOV). As a next step, for observation of time profile of such a local anisotropy,it is required to expand field of view along longitude direction with keeping overlap region in Field Of View in each telescopes.

2. Akeno Muon Telescopes

New Muon telescopes were constructed at Akeno Observatory in Japan (N35.8,E138.5). Detector module are mounted under 2 m of concrete absorber to achieve an energy threshold of 1 GeV for total energy of vertical muon. The telescope is consisted of proportional counters which have dimensions 10cm×10cm×500cm. Each detector module have 4 layers of 49 proportional counters. Layers are alternately placed in crossing configuration to enable determination of arrival direction of penetrating muon. Between 2nd and 3rd layer,steel pipes with total hight of 30cm are inserted as spacer. This configuration gives same angular resolution and size of FOV with those of GRAPES-3 Telescope. Arrival direction of detected muon are categorized into 15×15 direction by using hit pattern marked by muon. Counting rate are 2100Hz with 1 module observation ($25m^2$). Total 3 modules of telescope have already been constructed. Now 2 module are in observation. Fig. 1 represents FOV which is consisted of 15×15 cells. According to statistics, We can arrange these cells into 7×7 or some other configurations instead of 15×15 . In Fig. 1,there an example of division of FOV (3×3) which is used in this analysis is also shown.

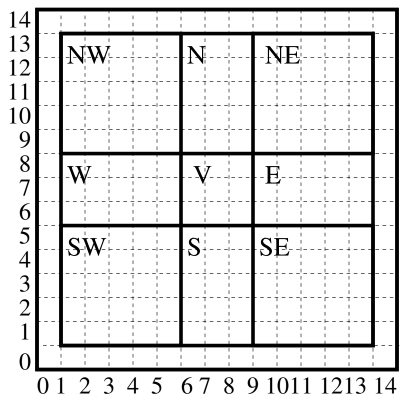

Figure 1. 15×15cells in FOV.

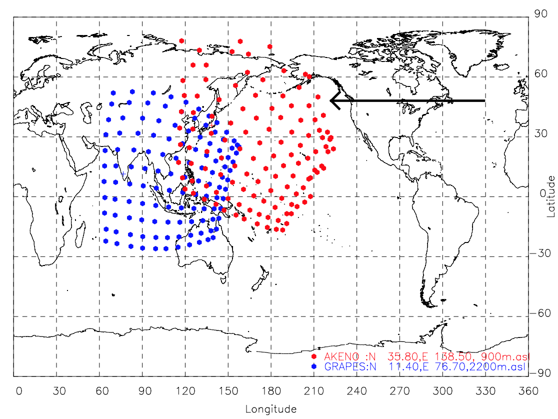

Figure 2. Observing directions of two muon telescopes.

Response of Muon Telescopes and Combined Field Of View:
Primary proton spectrum for detecting muon were estimated using CORSIKA 5.62(QGSJET + GHEISHA). On the calculation,detector structure and online data taking process were also taken into account. Assuming primary spectrum index as -2.7, response functions for individual cell's in FOV at each telescope were obtained. 2 Muon telescopes in Akeno and Ooty(GRAPES-3) has quite similar response except a difference in geomagnetic cut off rigidity. Median rigidity of primary proton for all observing muon at Akeno and Ooty(GRAPES-3) were 63.5 and 65.5 GV respectively.
If the observing direction were defined as a direction of asymptotic direction of median rigidity particle,the projected observing direction will be as shown in Fig. 2. There one can see overlapping region between FOV of two telescope. By combining GRAPES-3 muon telescope and Akeno Muon telescope, the total FOV has a width of $\sim 150°$ along longitudinal direction.

3. Observation and Analysis

A local anisotropy were observed at both of GRAPES-3 telescopes and Akeno telescopes. The anisotropy emerged on 30 July 2004. It was a period of recovery phase of a large Forbush decrease which started at around UT 0h on 27 July 2004. Dividing FOV into 9 directions as defined in Fig. 1, the variation observed in each direction is plotted in center and right panel of Fig. 3. For this analysis, all telescopes in Ooty and one telescope ($25m^2$) in Akeno were used. One can see clearly a difference between S(south) and N(north) direction of GRAPES-3 telescope. Assuming the 24 hour averaged trend in South telescope of GRAPES-3 as cosmic ray density variation, it was concluded that the periodic minimum those are visible around UT22∼4h in North side data from 30 July to 1 August is a local anisotropy with deficit of cosmic ray intensity.

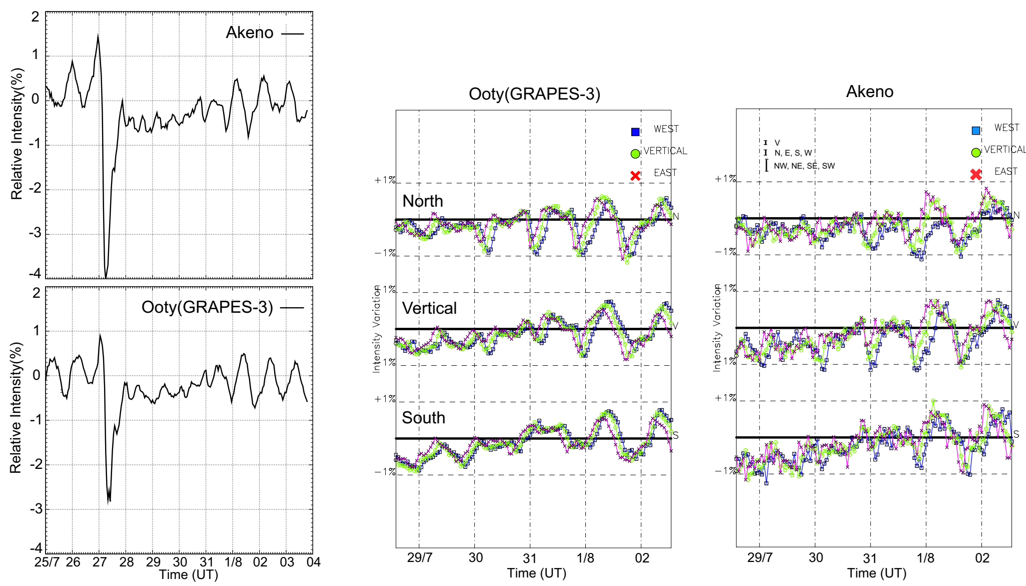

Figure 3. Relative muon intensity at Akeno and Ooty(Grapes-3) Muon Telescopes. Left: Variation in total muon count observed at GRAPES and Akeno observatory were shown. Statistical error in GRAPES and Akeno are 0.036% and 0.01% respectively. Center: Variation in 9 direction at GRAPES-3 were shown. Statistical error for each series is 0.018% to 0.029%. Right:Variation in 9 direction at GRAPES-3 were shown. Statistical error for each series is 0.09% to 0.15%.

Fig. 4 is relative intensity map of cosmic ray observed at Akeno Telescope and GRAPES-3 telescopes from 30 to 31 July 2004. The relative intensity variations are indicated 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 average among surrounding cells since statistical accuracy was not sufficient. Opening angle between IMF direction and viewing direction are shown in red colored contour line. Each division in the contour corresponds 15°.

The intensity map of both GRAPES-3 Telescope and Akeno Telescope are consistent each other and additionally the deficit direction are well correlated with Sun-ward of IMF direction. By using viewing direction of cells and intensity map of Fig. 2, it is possible to estimate position of the anisotropy. If we estimate trajectory of the center of the anisotropy roughly from Fig. 4, it will be the direction of arrow indicated in Fig. 2. The geographical latitude of the anisotropy is around $35° \sim 55°$ in this estimation.

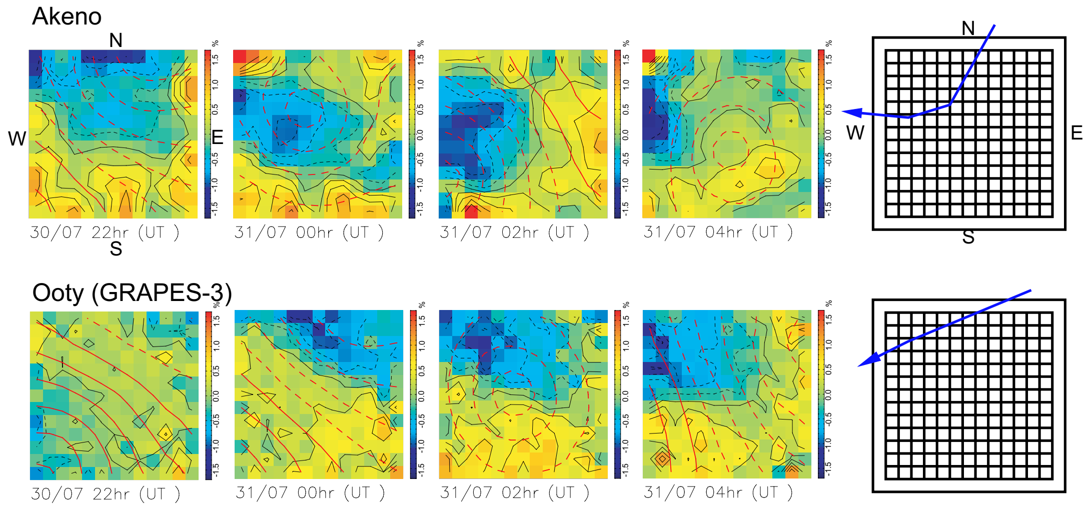

Figure 4. Intensity map in FOV at Akeno and Grapes-3 muon telescopes. Right panel shows path of deficit cone in FOV at each telescope.

4. Discussion and Summary

The Forbush decrease on 27 July 2004 looks to be a result of M1/sf flare occurred in UT 15:14 25 July 2004 and associated CME. After The flare, the active region placed at N08W35 was generating activities when rotating towards west side of the Sun. So the anisotropy around IMF direction can be a result of Loss-Cone effect between earth and region of low cosmic ray density which places far west direction in interplanetary space.
Omnidirectional muon flux displayed in left side panel of Fig. 3 shows large daily variation after the emerging Loss-cone anisotropy. The amplitude of diurnal variation seems to increase as the width of Loss-Cone becomes wider. This implies that some of high amplitude diurnal variation events [3] corresponds to this kind of phenomena found in this observation.

5. Acknowledgements

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