Study of Cosmic Ray Short Term Variations Using GRAPES-3 Muon Telescopes

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Abstract

We are operating a large area multi directional muon telescope as a part of the GRAPES-3 air shower experiment at Ooty (N 11.4, E 76.7 and 2200 m altitude). The muon detector has an area of 560 m^2 and threshold energy of 1.0 GeV. Due to the large detector size, we are observing a very large number of muons, $1.8X10^8$/hour. The design of the muon detector allow us to measure muon intensity from 225 directions simultaneously. Therefore we are able to make a 2-dimensional map of cosmic ray intensity for protons of energy 65 GeV. Using the response functions for the these 225 elements of the muon telescope,observed intensity variation was analyzed especially around the period of disturbance. And several Precursor variations which can be explained with Loss Cone model were founded.

1. GRAPES-3 Muon detector

GRAPES-3 multi directional muon telescope is consisted of proportional counters which have dimensions 10cm×10cm×600cm. Each detector module have 4layers of 58 proportional counters. Each layer are placed in crossing configuration. This configuration enable us to measure arrival direction of penetrating muon. Threshold energy for vertically penetrating muon is around 1GeV. We are counting penetrating muon and categorizing into 15x15 direction by using hit pattern marked by muon. There are 16 muon detectors. Total area of detector is 560m^2. Fig. 1 shows the schematic view of module.[5]

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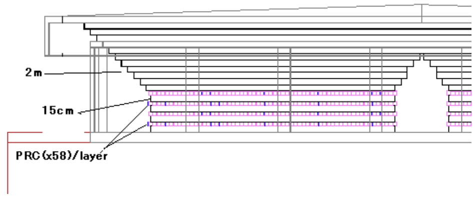

Fig. 1. Side view of GRAPES-3 Muon detector module. Each module are consisted of 4 layers of 58 proportional counters. 2m thick concrete were put on the top of Module and 15cm concrete were mounted between each layers.

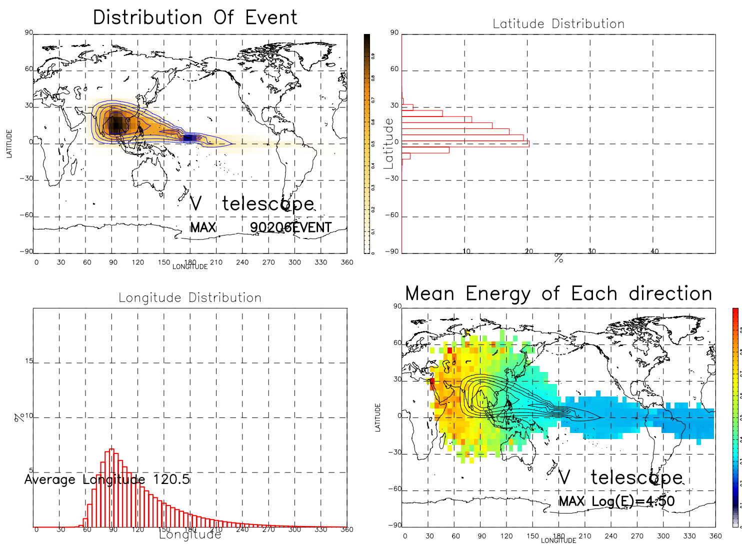

Fig. 2. Calculated response function of Vertical telescope[5]. Distribution of asymptotic direction were shown in top-left panel and corresponding average energy were shown in bottom-right panel.Degree of color is corresponding to $\log E_{(GeV)}$ and have range of 1GeV to 30TeV(no color mens no event).Other two panels shows projected histograms of distribution of asymptotic direction along longitude and latitude.

2. Calculation of response function

Muons were generated with monte-carlo simulation CORSIKA5.62 (QGSJET-GHEISHA model)[1]. Geometry effect and algorithm for angle determination were considered within detector simulation. We selected primaries which created 4layer penetrating muon. To know asymptotic arrival direction,these primary particles were traced back in Earth's magnetic field up to 25×Earth radius[2]. Fig. 2 is the example of response function calculated by this method.

3. Data analysis

Hourly counting rate were used for this analysis. To pickup event showing short term variation, we selected the days which shows standard deviation

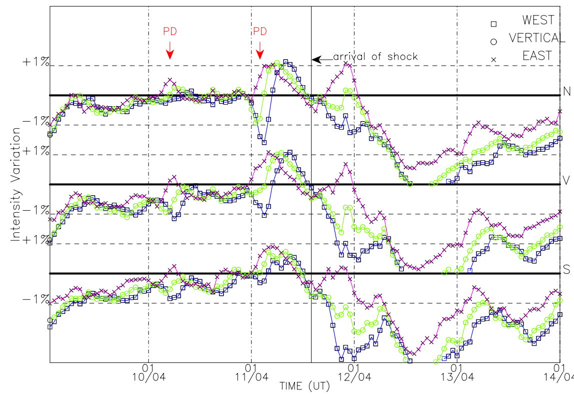

Fig. 3. Intensity variation observed in 9 categorized direction[5].Here intensity of 9-16 direction were summarized into NW,N,NE,W,V,E,SW,S and SE direction and plotted along time.Statistical error of each point is less than 0.03%.

grater than 0.4% from each module individually. To avoid false event with some artificial cause,those short term variation has to be seen in all 16 modules. As a result,around 30 candidate events were found in 2001 and 2002 data set. Some of event contain series of Forbush decreases. From these data set we searched for events which have correlation with Inter-planetary Magnetic Field. Fig. 4 is an example of observed intensity map and pitch angle contour map. Each cell(13×13) shows intensity variation of central 169 directions. In this figure horizontal axis are corresponding west to east direction and vertical axis are corresponding south to north direction. The statistical error of each intensity data are 0.06 to 0.30%. Pitch angle between each direction(13×13) and IMF were calculated using simulated response function at median rigidity. These value are also shown by contour line (15°/line) on the same figure. We examined this kind of map hour by hour.

4. Result

Some of events were having good correlation between IMF direction. We observed dip in intensity map which seems to keep correlation for more than 24hrs on 10^{th}Apr 2001 and 11^{th}Apr 2001. Fig. 3 is time profiles of the variation observed in 9 categorized direction. The variation which we are paying attention is around UT04 10^{th}Apr 2001 and UT03 11^{th}Apr 2001. In Fig. 4 intensity variation of each direction around these period were plotted. 4maps those placed upside is variation of 10^{th}Apr bottom side is variation of 11^{th}Apr. In Fig. 3 We can see Forbush decrease on 11^{th}Apr. It seems to be the result of flares occurred UT0526 10^{th}Apr and UT1534 9^{th}Apr and associating CMEs. At this event geomagnetic storm started around UT1500 11^{th}Apr after an observation of inter planeterly shock at UT1300 11^{th}Apr.[4]

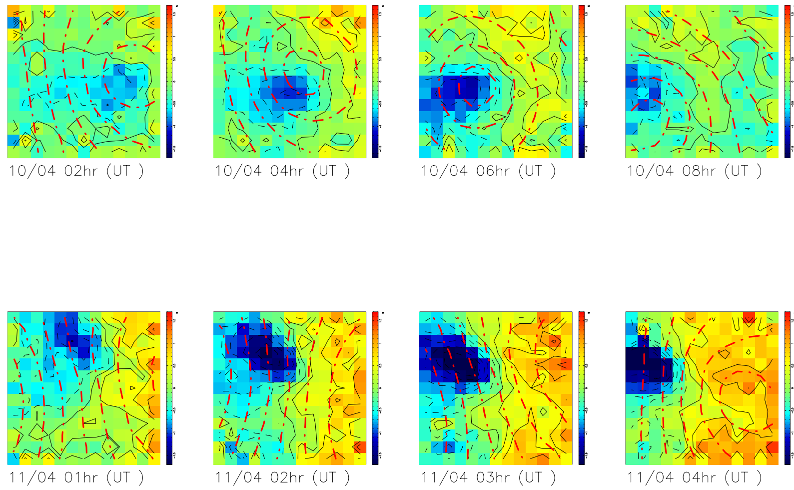

Fig. 4. Degree of intensity variation were shown by contour line drawn at each 0.3%.Range of color scale is -1.7% to +1.7%. Pitch angle between IMF field line(toward to sun) were drawn with dash-dot line at each 15°.

5. Discussion and summary

Considering these situations,it is natural to understand variations on 10^{th} Apr 2001 and 11^{th}Apr 2001 as a precursor phenomena of arrival of shock. The deficits before shock was enough large to discuss the structure. Loss cone model[3] can well describe these two dips with structural features. Deficit on 10^{th}Apr seems to have a good correlation with IMF direction at median rigidity. Though dip in 11^{th}Apr didn't show good correlation with IMF at median rigidity,the structure of dips looks very similar to each other and the amplitude of 11^{th} are quite large,nearly 1.8%. There is two possible explanations for this difference between two loss cone. One is that on 11^{th},distance from position of IMF structure which is responsible for loss cone was so close that original direction of loss cone didn't align toward direction of IMF near Earth. Another is that the rigidity spectrum of loss cone may softer than 10^{th}Apr. We think it is interesting to search best fit loss cone parameters on 10^{th} and 11^{th}Apr and comparing each other. We will continue to search consecutive precursors which shows this kind of behavior.

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1. Heck D.et al. . 1998, FZKA 6019, Forschungszentrum Karlsruhe
2. A.Inoue.et al. . 1981,Institute of space and Aeronautical science report V1,79
3. K.Nagashima K.Fujimo.et al. . 1992, planet.space.sci.,Vol.40,No 8,1109
4. SEC Majordomo Archives . http://www.sel.noaa.gov
5. S.Kawakami.et al. . 2001, proc.27^{th}ICRC(Humburg),V9,3473