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Cosmic ray anisotropy observed by GRAPES-3 air shower array

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Abstract: So far a genuine sidereal anisotropy of galactic cosmic rays was reported by Nagashima et al. and Hall et al., more recently by Milagro and Tibet groups in sub-TeV energy region. We have also reported a sidereal anisotropy of low energy cosmic rays in GeV energy region observed by GRAPES-3 large tracking muon detector. GRAPES-3 muon detector is also used to measure muon content of an air shower which is induced by high energy galactic cosmic ray of $\geq$10TeV. Here we report a sidereal anisotropy of both charged cosmic rays and gamma rays observed by GRAPES-3 air shower array in combination with muon detector using the data from 2000 to 2006.

Keywords: anisotropy, sidereal, cosmic ray

1 Introduction

Observation of sidereal time anisotropy of the cosmic ray is an effective method for determining the structure of magnetic field in the interstellar space near boundary of the heliosphere which is not understood yet very well. A possible anisotropy would reflect the general charactaristic of propagation of cosmic rays in the galactic magnetic fields. Nagashima et al. have studied sidereal time variation for various energies of cosmic rays. A number of experiment such as air shower measurements at Mt. Norikura (2750 m a.s.l), muon intensity measurements at Nagoya (sea level), muon measurements at Sakashita (underground) and Hobart(underground, Australia). These meaurements have indicated the existence of two kinds of sidereal time anisotropies, namely an intensity excess at sidereal time of 6 hour RA and deficit at 12 hour RA. These are respectively called Tail-IN (TI) and Loss-cone (LC) anisotropies. In addition, Hall et al. (1999) have analyzed the data from many muon stations all over the world (sea level and underground) and have obtained results similar to that of Nagashima et al. and have displayed their results in the form of a contour map on the celestial sphere.

The observation of the sidereal variation at low rigidities is indispensable for the determination of the three dimensional direction of galactic anisotropy, which cannot be realized by observations only in the high rigidity region. From this point of view, it is worthshile to examine the existence of the sidereal daily variation of galactic cosmic rays.

The anisotropy of galactic cosmic ray intensity in the energy region of $\geq$ 10 TeV gives us an important information on the structure of magnetic field of the heliosphere and the local interstellar space around the heliosphere, where cosmic rays propagate to the Earth. The anisotropy of galactic cosmic rays were measured via the sidereal daily variation of cosmic ray intensity by several experiments. On the basis of the sidereal variation observed in the TeV region, most of the previous investigations reported that small amplitude and a phase of maximum somewhere between 23-3hours in the local sidereal time(LST). these observations are consistent with the large scale diffusive propagation of

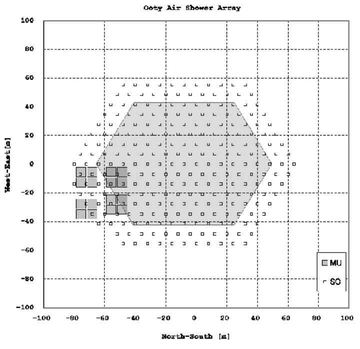

Figure 1: The GRAPES-3 experimental system with 257 scintillator detectors and 16 muon detector modules

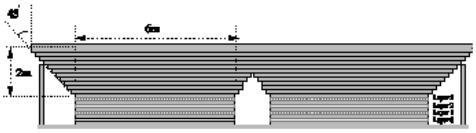

Figure 2: A muon station has four muon detector modules each consisting of 232 proportional counters. There are four muon stations inside the air shower array (Fig. 1).

cosmic rays.

Here we present the results of a sidereal variation of the galactic cosmic rays using air shower data of 7-years. Cosmic rays observed here should be galactic origin. Using the ability of measuring muon content by muon station, we tried to study the sidereal variation for several primary groups such as gamma, proton, heavy.

2 GRAPES-3 experiment

The experimental system of the GRAPES-3 (**G**amma **R**ay **A**stronomy at **P**eV **E**nergy**S** Phase-**3**) experiment consists of a densely packed array of scintillator detectors and a large area tracking muon detector. The EAS array consists of 257 plastic scintillator detectors shown in Fig. 1, each of 1 m^2 in area. These detectors are deployed with an inter-detector separation of only 8 m. The array is being operated at Ooty in south India (11.4°N, 76.7°E, 2200 m altitude).

In order to achieve the lowest possible energy threshold, a simple 3-line coincidence of detectors has been used to generate the Level-0 trigger, which acts as the fast GATE and START for the analog to digital and time to digital converters (ADCs and TDCs), respectively. As expected, this trigger selects a large number of very small and local showers and also larger showers whose cores land very far from the physical area of the array. Therefore, it is also required that at least 10 out of the inner 127 detectors should have triggered their discriminators within 1 μs of the Level-0 trigger. This Level-1 trigger with an observed EAS rate of 13 Hz is used to record the charge (ADC) and the arrival time (TDC) of the pulses from each detector [5]. The pulse charge is later converted into the equivalent number of minimum-ionizing particles (MIPS) using the most probable charge for a single MIP measured using the trigger from a small area (20×20 cm^2) scintillation counter telescope.

The 560 m^2 GRAPES-3 muon detector [10] consists of 4 super-modules in Fig. 2 , each in turn having 4 modules. Each module with a sensitive area of 35 m^2 consists of a total of 232 proportional counters (PRCs) arranged in 4 layers, with alternate layers placed in orthogonal directions. Two successive layers of PRCs are separated by 15 cm thick concrete. The energy threshold of 1 GeV for vertical muons, has been achieved by placing a total of 15 layers of concrete blocks (total absorber thickness $\sim$550 $g.cm^{-2}$) above the Layer-1. The concrete blocks have been arranged in the shape of an inverted pyramid to provide adequate shielding up to a zenith angle of 45°.

One of the most critical parameter in the study of direction of primary cosmic rays using a particle detectorarray is good angular resolution. This requires an accurate determination of the relative arrival time of the shower frontat various detectors. The high density of the detectors in GRAPES-3 enabled an angular resolution of 0.7° to be obtained at energies as low as 30 TeV. Angular resolution of the GRAPES-3 was estimated by 2-D Gaussian fit to the Moon shadow data.

3 Data and Analysis

A total of 1.9×10^9 showers have been collected over a total live time of 11.9×10^7 s, spread over a 7-year period, from 2000 to 2006. For each EAS, the core location, the shower age 's' representing the steepness of the Nishimura-Kamata-Greisen (NKG) lateral distribution function and the shower size N_e have been determined using the observed particle densities, following the minimization procedure discussed in detail by Tanaka et al [7]. Also, for each shower, the zenith (θ) and the azimuth (ϕ) angles have been calculated using the time information from the TDCs, also following the minimization procedure described by Tanaka et al [7].

Fig. 3-5 show charactalistic shower particle pattern for different primaries each shower was produced by simulation using CORSIKA code. As mentioned above, muon station of GRAPES-3 can measure muon content of a shower. Lateral distribution for each gamma and proton primary of energy of 10^{14}eV are shown in Fig. 6-7. Because number of muon could is different from each primary species in general, Using the ability of measuring muon content by muon station, we tried to study the sidereal variation for several

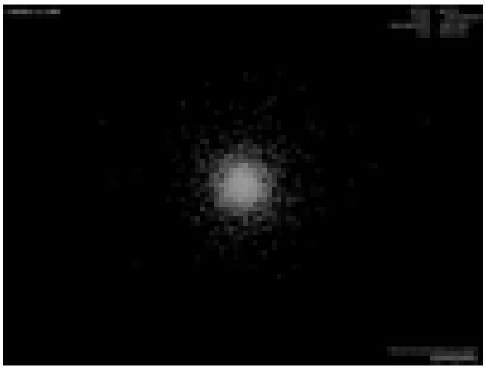

Figure 3: Shower particle pattern of a gamma primary

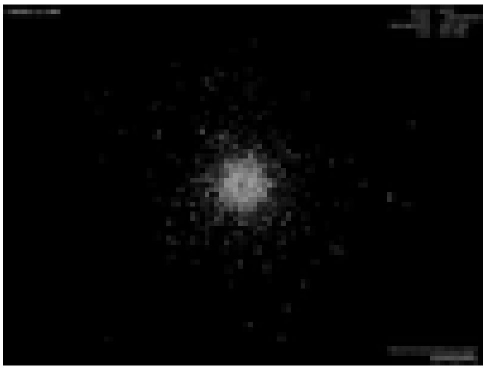

Figure 4: Shower particle pattern of a proton primary

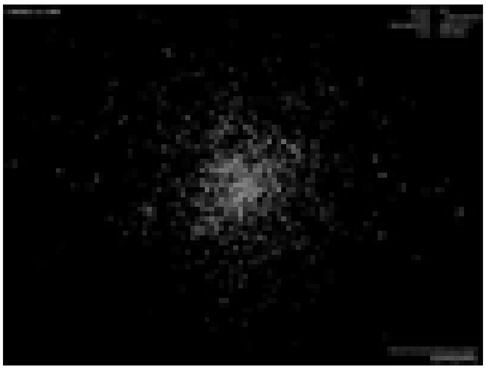

Figure 5: Shower particle pattern of a iron primary

primary groups such as gamma, proton, heavy.

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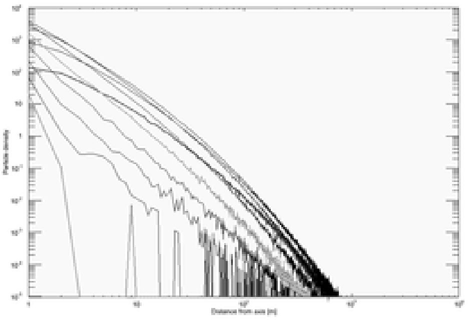

Figure 6: Lateral distribution of a gamma induced airshower for several observation level, 10^{14}eV

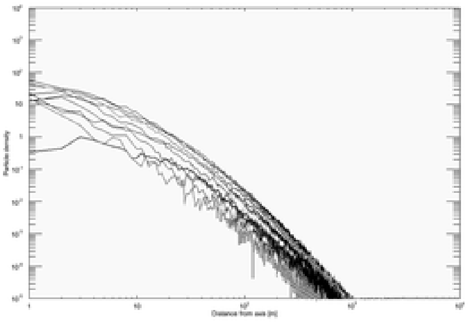

Figure 7: Lateral distribution of a proton induced airshower for several observation level, 10^{14}eV

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