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Observation of Cosmic Ray Anisotropy with Large Area Air Shower Experiments

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Abstract: The sidereal anisotropy of galactic cosmic rays with energy in the range $10^{14} \sim 10^{16}$eV was measured by using extensive air showers (EAS) detected with the Large Area Air Shower (LAAS) experiments. The anisotropy amplitude onto the right ascension axis for EAS arrival directions, was obtained as $(2.04\pm0.50)\times10^{-3}$ with a phase -0.1 ± 1.6 hour. The celestial map in equatorial coordinates indicates, however, an isotropic distribution of cosmic rays in this energy region.

Introduction

Measuring the anisotropy amplitude of the galactic cosmic ray intensity provides one mean to explore the propagation process of the galactic cosmic rays. In recent results on the anisotropy analysis[1, 2], provides very precise information for 10TeV-100TeV energy regions. They reported 10^{-4} amplitude of anisotropy for underground muons and EAS less than 300 TeV.

The celestial information of the cosmic ray anisotropy enables to study galactic magnetic field structures and relative motion of cosmic rays between observers and the system of whole galactic cosmic rays, such as the Compton-Getting (CG) effects [3].

In this article, we present results on the one and two dimensional analyses of arrival direction anisotropy of galactic cosmic rays observed by LAAS EAS arrays.

LAAS Array and Data Set

The typical EAS array using LAAS observatories[4] is made of 8 modules of scintillation detectors, 0.25m^2, distributed over 200 m^2. The trigger condition is provided by the fivefold coincidence or any threefold coincidence of 8 modules, of which discrimination level are set at ~ 0.5 m.i.p.. The trigger rate is typically 0.05 Hz at each EAS array. In the simulation study of array performances[4], EAS arrival direction is determined with accuracy of 6 degree. In order to monitor the atmospheric effect for cosmic ray intensity modulation, data archives from Japan Meteorology Agency are used at each EAS observatory. The EAS array profiles of geographical

Table 1: Each EAS array profiles of geographical latitude and longitude, data period and the number of scintillation counters. HU, NUI, KU, OUS and OU are abbreviated names of each institute respectively.

Abbrev.	Lat. (N)	Lon. (E)	scintillation detectors	period
HU	40°35'	140°29'	8	11/13/98-01/02/07
NUI	34°35'	135°41'	8	08/26/96-05/10/06
KU	34°39'	135°36'	8	09/01/96-05/23/06
OUS1	34°42'	133°56'	8	09/02/96-07/30/06
OUS2	34°42'	133°56'	8	04/23/02-12/05/06
OUS3	34°42'	133°56'	5	12/29/02-07/30/06
OU	34°41'	133°55'	8	09/12/96-07/30/06

location, data period and instrumental setup are summarized in Table. 1

The EAS events were selected under some criteria such as the number of coincidence detector ≥ 5, and their zenith angle $\leq 45^\circ$, the uniform observation carried out over one sidereal day and intensity variation per solar day $\leq 3\sigma$. The data period and event statistics summed up among 7 EAS arrays, are 14,920 days and 74M events, respectively.

The performance of LAAS arrays have been evaluated using CORSIKA [5] simulation code. The primary energy range observed was estimated to be 10 TeV to 10 PeV with a mean energy of 600 TeV [4, 6].

Analysis and Results

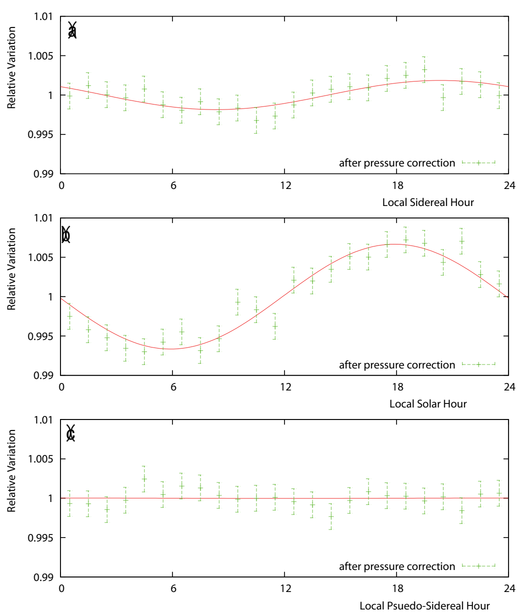
To eliminate spurious variations of observed cosmic ray intensity, due to atmospheric effects, barometric pressure monitored at each site were corrected and the typical value of a regression factor is -0.75%/hPa. This regression factor can be converted to shower absorption length $\lambda'_{abs} = 120 \pm 20$ g/cm^2. The atmospheric temperature effect is not corrected because the LAAS observation for averaged over 10 years periods make the spurious variation due to seasonal effects largely cancel out.

In one dimensional anisotropy analysis, we applied the method proposed by Farley and Storey [7] to estimate the amplitude and phase in order to obtain both solar modulation and solar variation, and sidereal variation. The right ascension of each EAS event is used for the one dimensional analysis. The results on right ascension distribution are shown in Fig. 1 with the best fit curve of the first harmonic function to data. The anisotropy amplitudes and phases obtained from EAS right ascension and local sidereal time are summarized in Table 2. The amplitude obtained by LAAS arrays are consistent with other experiments and evaluated index value of the power law dependence of the amplitude on primary energy is consistent with the diffusive propagation models with the parameter $\alpha = \frac{1}{3}$[8].

The anisotropy maps in an equatorial coordinate and a galactic one are obtained by making right ascension(α) distributions with binning width 10 degree in each declination(δ) band, of which width is 10 degree, because of poor angular resolution of EAS array performance. The obtained maps in an equatorial coordinate and galactic one are shown in Fig. 2. Each pixel shows significance value from isotropic cases in every 10 degree strips of declination. In the energy ranges of 10^{13}eV to10^{16}eV, the obtained maps are partially unlikely to come from the random fluctuations of an isotropic distribution. The equatorial map shows small region of deficit of cosmic ray intensity around $(\alpha, \delta) = (150^\circ, 10\ ^\circ)$. However, the significance levels in these maps exist within 3 σ level. The Tibet EAS experiments[9] excluded the existence of the galactic Compton-Getting effect around ~ 300 TeV energy. If galactic Compton-Getting effect exists, it predicts 4.7×10^{-4} amplitude with primary energy spectral index -2.7 and minimize at (135 °, -40 °). In our results, no signal from galactic Compton-Getting effect is observed.

In the galactic coordinate map, this deficit region lies around the galactic north pole, but their significance levels are also within 3 σ levels. The clear evidence of excess regions along by the galactic plane is not observed in this energy regions.

Figure 1: The right ascension distribution. Data points were plotted as a function of (a)local sidereal time(=right ascension), (b)local solar hour and (c)local pseudo sidereal time based on 364.24cycles per year. The solid lines represent the best fit curve of the first harmonic functions. The error bars came from statistics.



Conclusions

The anisotropy amplitude and phase of galactic cosmic ray intensity were derived from EAS arrival direction analyses, of which values are $(2.04 \pm 0.50) \times 10^{-3}$ and -0.1 ± 1.6 hour in primary energy region of 10 TeV to 10 PeV. The small region of deficit around (α, δ)=(150 ˚, 10 ˚) was seen in the celestial map, but it is not significant to conclude. The significant feature of excess and deficit was not observed in the equatorial coordinate map. In the galactic map, the galactic north to south anisotropy which came from the solar system location in the galactic plane, would not be indicated in our results, that was pointed out in [2].

Acknowledgments

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Table 2: The anisotropy amplitude and phase obtained from right ascension analysis and local sidereal time analysis.

Method	amplitude($\times 10^{-3}$)	Phase(hour)	statistics
Local Sidereal Time(LST)	1.87 ± 0.42	-0.1 ± 1.6	18M
Right Ascension Angle	2.04 ± 0.50	-0.1 ± 1.6	12M
previous work[10] (LST)	2.30 ± 0.04	0.4 ± 0.7	12M

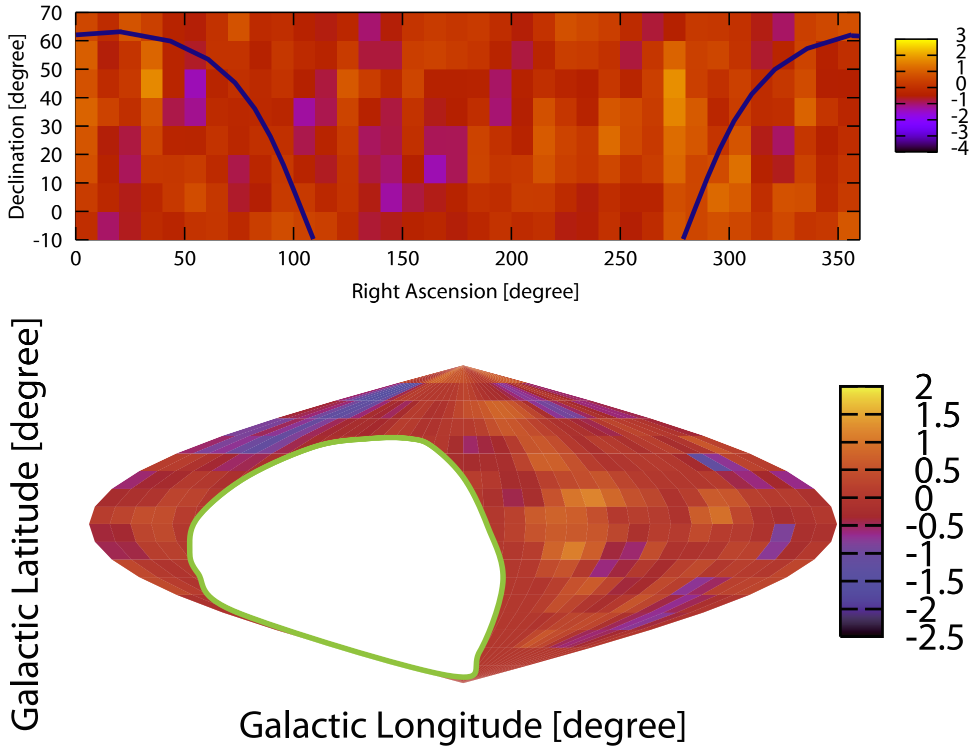

Figure 2: The celestial map of anisotropy significance of galactic cosmic rays in an equatorial coordinate and a galactic one. The solid line represents the galactic plane.