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A study of sidereal anisotropy of Cosmic rays with GRAPES-3 Muon Telescopes

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We have observed the cosmic rays with GRAPES-3 multi-directional muon telescope (total area of 560m^2) at Ooty (11.4 N latitude and 76.7 E longitude, 2200m altitude), India. We have analyzed muon intensity variation over a period of 5 years (2000-2004). The results obtained on with sidereal anisotropy are summarized. Currently the so called "Tail-IN and Loss-cone" model proposed by the Nagashima et al. (1998) is largely describes the sidereal anisotropy. Our analysis shows the existence of Tail-IN , but absence of Loss-cone feature.

1. Introduction

Observation of sidereal time anisotropy of the cosmic ray is an effective method for determining the electromagnetic environment in the interstellar space near boundary of the heliosphere which is not understood very well. 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) [3]. 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 [4].

We have been operating a large area muon telescope (560 m^2) ar part of the GRAPES-3 air shower experiment for the past 5 years and measure the incident angle of muons above 1 GeV which correspond to a primary cosmic ray of median energy 60 GeV. Five years of data, from January, 2000 to December, 2004 were analyzed to obtain the sidereal time variation of primary cosmic rays. Our results have been compared with those of Nagashima et al. [3]. and Hall et al. [4]. Although the TI anisotropy was observed in our data, the LC anisotropy was not seen clearly. This indicates that there are different causes for these two anisotropies. The results are shown and discussed in detail in the following section.

2. Analysis and results

Using Using data of five years (2000-2004) from GRAPES-3 muon telescopes, we obtained the sidereal time variation of primary cosmic rays. Our muon telescopes are able to measure the incidence direction of the cosmic ray with rather good accuracy (7 degrees). The data were classified according to the direction (polarity) (Toward and Away) of IMF. The polarity of each day was determined from the satellite data of ACE level 2. Calculating the 72 hour running average we adopted the value of 22h UT for the polarity of the corresponding day. The muon telescope consists of a total of 16 modules (each module has an effective area of 35 m^2 , total area of 560 m^2) resulting in smallest statistical error among all instruments operating in the world. The data for each direction is summed for one hour and the resulting counting rate is normalized by average value for the day and also corrected for barometric pressure [6]. In addition, in order to remove various systematic errors, we adopted the so called E-W method (refer to [2] for details) to obtain the sidereal time variation [5]. For a median energy of 60 GeV the sidereal time variation, there would be contamination due to the daily variation of pseudo sidereal time anisotropy called Swinson flow [1].
This anisotropy arises due to the gradient of cosmic rays in the vicinity of the Earth and the polarity (Toward, Away) of IMF. The amplitude (about 0.07%) of anisotropy due to Swinson flow is larger than the expected genuine sidereal time anisotropy (about 0.03%). The average anisotropy by Swinson flow should show the same variation with a phase difference of 12 hours with respect to the polarity of IMF. So, if we take average of the intensity for both polarities (T+A)/2, then pseudo anisotropy due to Swinson flow can be cancelled and only a genuine anisotropy would be left in the data.

In case of (T-A)/2 thie effect of the original Swinson flow would be enhanced by a factor of 2. These two sets of data namely, (T-A)/2 and (T+A)/2 observed by the GRAPES-3 muon telescopes, are shown in Fig. 1 and Fig. 2 for 5 years from 2000 to 2004. Each panel shows the sidereal time variation in an individual year. As one can see in these two figures that for each year the value fluctuates considerably. In the case of (T-A)/2 "Swinson flow" intensity variation should follow a sinusoidal wave with a maximum at a phase at 18 hours and a minimum at 6 hours for a long-term time average. The daily variation for each year is distorted in due to effect of "Swinson flow" in the case of single year data. It implies that single year data cannot be used to judge the genuine sidereal anisotropy. Therefore avaerage of five years of data is taken and is shown for (T-A)/2 in Fig. 3 and (T+A)/2 in Fig. 4. As can be seen in Fig. 3, (T-A)/2, the phase of the minimum appears around 6 hours and the maximum near 18 hours. Thus averaging over five years has resulted in effect of Swinson flow being smoothed into a sine wave and the effect of pseudo sidereal anisotropy could be largely cancelled. Same is true for the genuine sidereal anisotropy as well. As seen in Fig. 4 for (T+A)/2, there exist a clear excess at 6 hours, but no other clear excess or deficit can be seen in present analysis.

3. Conclusions

Present analysis shows the existence of Tail-IN excess, but the Loss-cone deficit is not clearly seen. Since three years out of total of five years observation period happen to fall in the maximum phase of Solar activity, a strong disturbance due to this Solar activity might have been hiding the Loss-cone type anisotropy. The energy of the cosmic rays connected with Tail-IN is considered to be lower than Loss-cone. The fact that the anisotropy is seen only at low energy in present analysis is somewhat difficult to understand. One of the possible explanation for this kind of Tail-IN anisotropy could be the difference between the "Nose" and "Tail" structure of the heliosphere which exists considerably deeper in the heliosphere than usually expected.

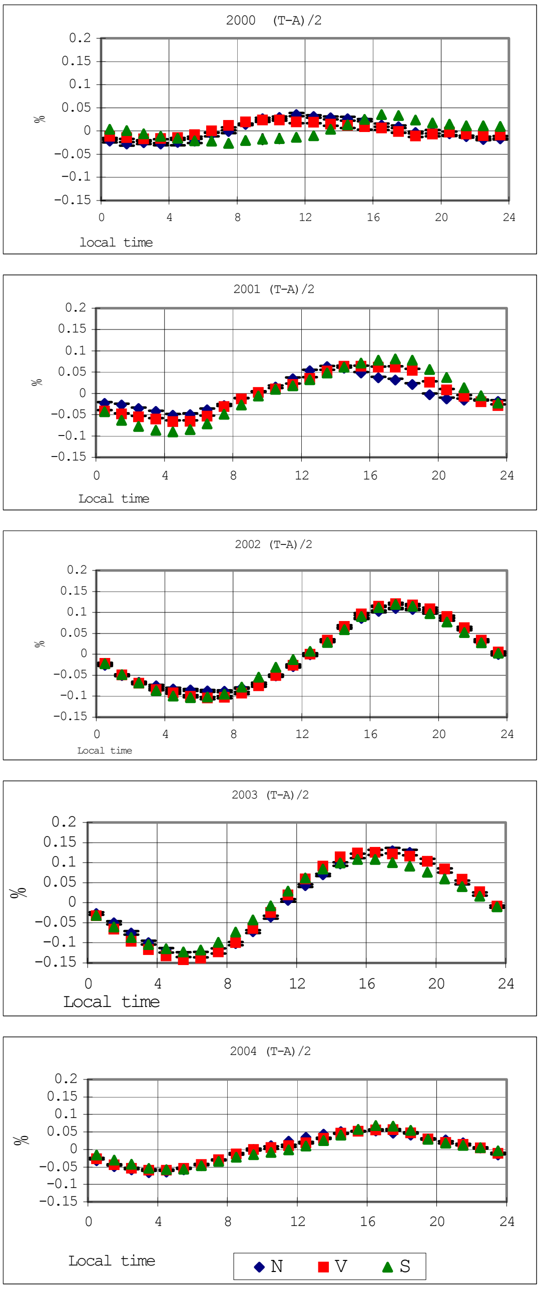

Fig 1 .(Toward-Away)/2 in the every each year from 2000 to 2004.

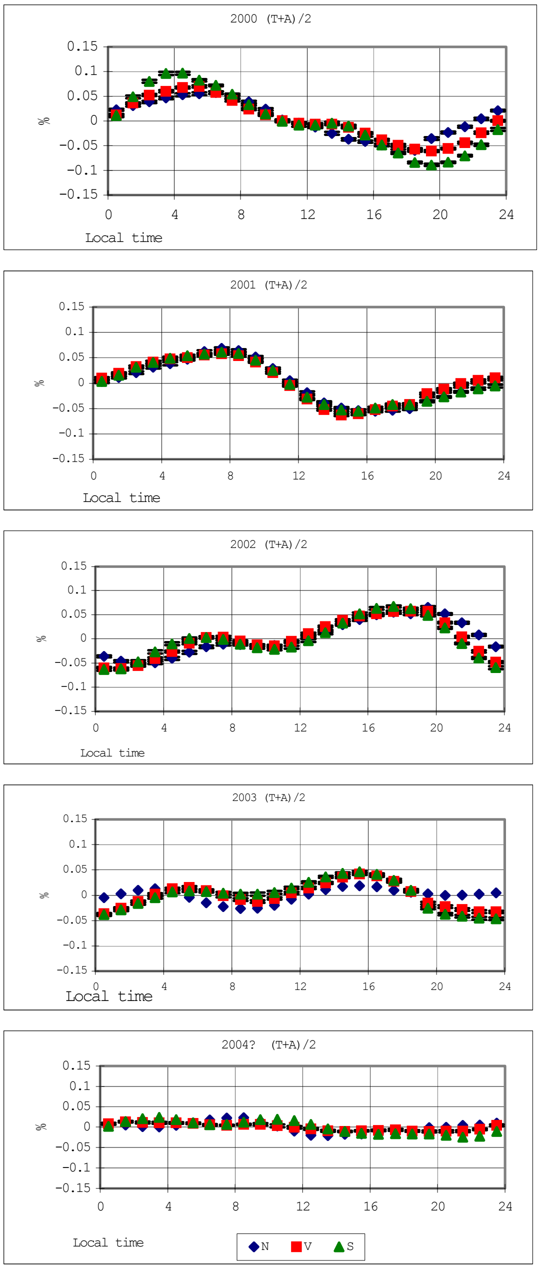

Fig 2 .(Toward+Away)/2 in the every each year from 2000 to 2004.

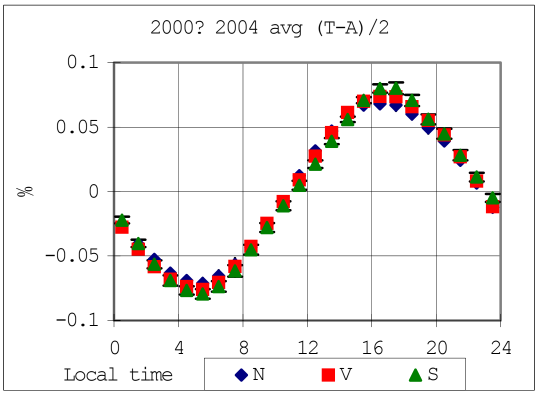

Fig 3 .(Toward-Away)/2 in 5year average from 2000 to 2004.

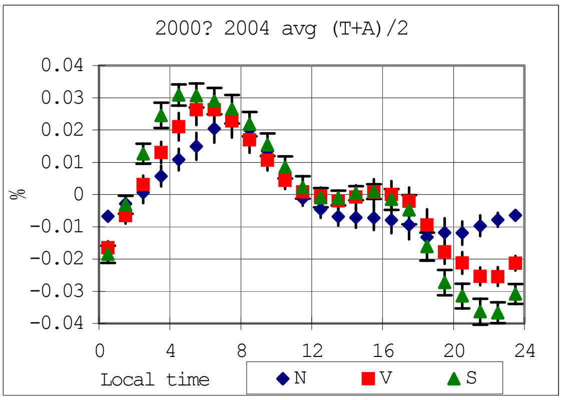

Fig 4. (Toward+Away)/2 in 5 year average from 2000 to 2004.

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