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Observation of cosmic ray sidereal time variation by GRAPES III muon telescope at Ooty

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Abstract. We analyzed the sidereal time variation on the data of muons counting rate observed by the large muon telescope of GRAPES III (total area 560 m^2 , muon's energy > 1GeV) over 3 years at Ooty (11.4deg latitude, 76.7deg longitude). Their counting rate is around 53,000 counts /sec and this high counting rate is great advantage for modulation measurement. The analysis based on the data of such high-statistics enable us to compare the sidereal diurnal variation even with each single year's result. We observed the Tail-in and Loss corn anisotropies through detailed analysis. We newly started the measurement of direction of individual muons with accuracy of about 8 degrees from 1999. We present some results on the sidereal daily variation obtained by this system too.

1. Introduction

There are several reports on sidereal time variation of the cosmic ray, 10^{10}eV~10^{13}eV, so far. Swinson(1969) analyzed the intensity variation of the cosmic rays with energy 10^{11}eV-10^{12}eV and he reported that there are some days which have the maximum peak at local sidereal time 18 and other days have it at 6 hour. These two different timing of peak position is due to polarity change (Tword, Away) of interplanetary magnetic field. This is based on the flow of the cosmic ray which is perpendicular to ecliptic plane and existence of the radial density gradient of cosmic ray in interplanetary magnetic field near Earth. Thus these sidereal time anisotropy comes from local helio-magnetosphere.

Many other groups also reported the possible existence of the cosmic ray anisotropy caused by outside helio-magnetosphere.

Alexeenko and Navara(1985) proposed the existence of the anisotropy by the flow of the high energy diffusion gamma-rays which are confined in our galactic disk, from the result of the air shower experiment (<10^{13}eV) in Baksan. They insisted such anisotropy should make the peak at 0 hour local sidereal time in northern hemisphere. If there is such gamma rays flow, there should be peak at 12 hour local time in southern hemisphere.

On the other hand, Nagashima and Fujimoto et al(1989) analyzed the data of air shower direction (>10^{13}eV) in Mt. Norikura, and have shown the minimum intensity occurs at local sidereal time of 12 hour. They proposed that the minimum intensity occurs at 12 hour local sidereal time in the northern hemisphere rather than maximum occur at 0 hour which is shown by Alexeenko et al.

Considering there is no peak in the southern hemisphere at sidereal time of 12 hour, they proposed the following model: the intensity loss comes from loss cone which is created by the interaction between cosmic rays and magnetic field of the interstellar space. In addition to the Mt Norikuraata's air shower data, Nagashima Fujimoto and Jacklyn (1998) analyzed the data on Hobart and Sakashita's underground muon telescope

While the solar system moves in our galaxy, the helio-magnetosphere has the bow shock structure.

The cosmic rays are easy to infiltrate from tail direction of this structure.

This lead to another anisotropy which shows maximum at 6 hour local sidereal time for the energy around 10^{12} eV of cosmic rays entering from southern hemisphere. These two anisotropy are respectively called loss cone (LC) and tail in (TI).

The GRAPES III muon telescope is situated in Ooty (11.4 deg. latitude, 76.7deg. longitude) and the cosmic ray of the energy above 10^{11}eV is observed . This telescope is very much suitable to observe sidereal time anisotropy. We are hoping to clarify the coordinate of excess and deficiency of cosmic rays due to LC and TI more clearly by adding the recent results which are obtained by angle measurement of muons.

2. Analysis and result

We analyzed the data of the muon observed by the GRAPES III muon telescope and obtained the sidereal time anisotropy of the primary cosmic ray, the energy about 10^{11}eV from. (total area of 560 m^2, muon energy > 1GeV). The observation period omni directional observation is 3 years from April, 1998 to March, 2001 .

Total counting rate is 53,000/sec. for omni-directional measurement with all the modules. This high counting rate assures us very small statistical error (0.02% with 10min. data).

The process of our basic analysis is the followings

1. Data are analyzed in terms of one month after correcting barometric pressure and normalized by one month average.
2. This monthly data is categorized into two groups with their polarity of Interplanetary Magnetic Field (IMF). This polarity is calculated by the following method. We calculated the averaged IMF value at UT 20 hour for different polarity. It is obtained by getting 72 hour running average of one hour value of GSM coordinate, using level-2 data of ACE SCIENCE CENTER.
3. We make two separate dataset on sidereal time variation, one is for 'toward ' polarity and other is 'away'.
4. Final results are obtained by making mean value of these two sets .

One of the reason that we use the average of these monthly dataset is due to large fluctuation and unbalance in number of days of different polarity. Another reason is that there is rather big Solar anisotropy (with amplitude around 0.4%) and these seasonal change may cause significant distortion on the sidereal daily variation. So we estimate that the mean value from the monthly dataset would be better than the simple darly mean. There seems to be systematic another seasonal effect which arises from the stationery solar time anisotropy. To avoid this, anti-siderial time correction were done. (Nagasima et al,1983) Those results are shown in Fig 1.

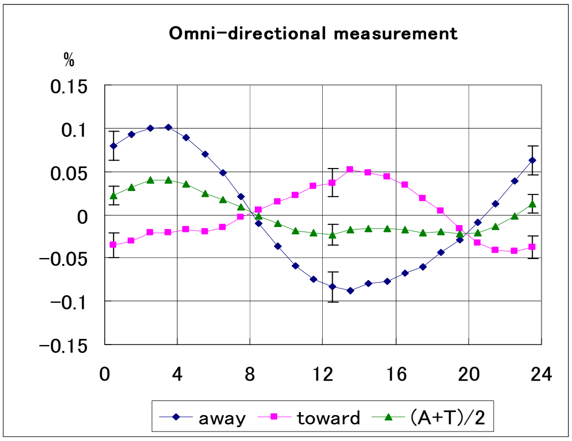

Fig 1 Siderial time anisotropy of the omni-directional measurement at Ooty

IMF polarity dependence of the sidereal anisotropy is clearly seen from these results. This inversion is indicated by Swinson(1969). This anisotropy which seems to be the Tail In (TI) effect, proposed by Nagashima, Fujimoto and Jacklyn(1998), is observed from the averaging of toward and away.

However, the maximum intensity occurs about 2 hours earlier than expected timing. This can be well explained, if we consider the deflection of the cosmic rays by earth's magnetism. Though the Loss Cone (LC) anisotropy can not be clearly confirmed, this might be due to the difference in direction or energy of the primary cosmic rays.

We have started the angle measurement on individual muon from March 1999 with one module of 35m^2 area and 12 modules (420m^2) are operational now. The analysis was carried out for one module for 2 years data , April 1999 to March 2001. Though our measuring system has an accuracy of 7 to 8 degrees in order to gain enough statistics we have summed some of the data and arranged in six directions of North East (NE), North West (NW), East(E), West(W), SE and SW. Finally they are further added into three groups of northern, zenithal and southern direction. The difference in E and W was taken on each group every hour. using this differential method, the systematic errors such as characteristics of the equipment, temperature effect and even barometric pressure effect can be removed without further correction. We constructed the sidereal daily variation for these three groups. We have analyzed these directional data following same manor as omni directional data. The results are shown in Fig2.

As it can be seen clearly in fig.2 in each groups results, the maximum phase occur difference of around 12 hours in case of Toward and Away.

If we consider that this results came from only one module and observation time of 2 years and compare with omni directional observation, it is quite satisfactory.

There are some difference in amplitude of averages value (T+A)/2 among the three groups. Though it is not so significant to say , our results are indicating the intensity asymmetry due to L.C. and T.I. anisotropy, the tendency of revealing these anisotropy can be seen. Since the analysis of directional muon observation is carried out only for one module so far we could not achieve sufficient statistical accuracy yet. But we are operating 12 modules at present, we are hoping expected that the structure of L.C. and T.I. anisotropy can be clarified in detail within one to two year time.

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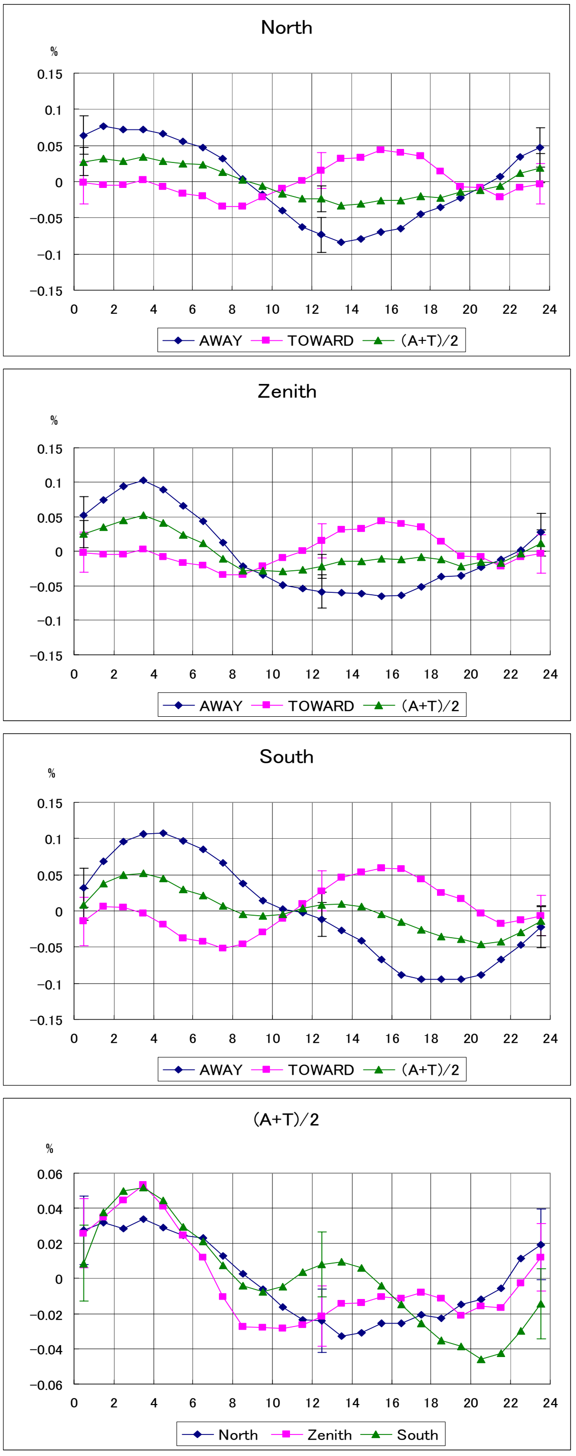

Fig 2

Sidereal time anisotropy of the directional telescopes (north, zenith, south) and (A+T) /2 of three directional compornent at Ooty