IMF-SENSE-DEPENDENT COSMIC RAY ANISOTROPY PRODUCED FROM DIFFUSION-CONVECTION IN HELIOSPHERE

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1. Introduction. An IMF-sense-dependent first order anisotropy of solar origin, which is produced perpendicularly to the ecliptic plane from the radial density gradient, was first pointed out by Swinson.

In addition to this anisotropy, the existence of IMF-sense-dependent higher order anisotropies has recently been suggested by Munakata and Nagashima(1), based on the simulation of cosmic ray diffusion-convection in the heliomagnetosphere.

In this paper, we discuss the characteristics of the daily variations caused by the IMF-sense-dependent second order anisotropy obtained on the same condition as adopted by Munakata and Nagashima(1). A brief comparison of these variations with observations will also be made in order to demonstrate their existence.

2. Daily Variation and its Seasonal Variation. Munakata and Nagashima obtained a stationary cosmic ray anisotropy of solar origin which is expressed in the IMF-polar-coordinate system defined at any point fixed in space (cf. fig. 1), as

\[ \eta(r,p) = \sum_{n=1}^{\infty} \sum_{m=0}^{n} \left[ n_{\text{nc}}^{m}(r,p) \cos m \Phi' + n_{\text{ns}}^{m}(r,p) \sin m \Phi' \right] P_{\text{n}}^{m} (\cos \Theta'), \]

where the angles \( \Theta' \) and \( \Phi' \) express the incident direction of cosmic rays with momentum \( p \) at a point \( r \), and \( P_{\text{n}}^{m} (\cos \Theta') \) is the semi-normalized associate Legendre function(3).

![Fig. 1. The IMF-POLAR-COORDINATE SYSTEM.](https://ntrs.nasa.gov/search.jsp?R=19850026681)

The terms with coefficients \( n_{\text{ns}}^{m} \) in eq. (1) are called IMF-sense-dependent terms, because \( n_{\text{ns}}^{m} \)'s change their sign according to the sense of IMF: The IMF-sense-dependent second order anisotropy is composed of two kinds of term \( \langle n_{\text{nc}}^{m} P_{\text{n}}^{m} (\cos \Theta') \sin m \Phi' \rangle ; m=1,2 \) which are not symmetric for an arbitrary rotation around any axis. This anisotropy produces two kinds of daily variation at the Earth: one is a solar(SO) diurnal variation and the other is an extended sidereal(\( S1/2 \)) semi-diurnal variation(2).

The solar diurnal variation changes the sign for a sign change of the
geographic latitude ($\phi - \theta$) of the viewing direction of the telescope. We call this type of variation the north-south (N-S) asymmetric type or $P_2^1(\cos \theta)$-type. For the positive and negative polarity states, fig. 2(a) shows the dependence of the solar diurnal space harmonic vector ($\hat{S}$) on the diffusion parameters ($\lambda_0$ and $a_\lambda$) which are related to the scattering m.f.p ($\lambda$) as,

$$\lambda = \lambda_0 (R/GV) \exp \left( \frac{r-r_e}{33a.u.} \right) (1 + a_\lambda \cos \theta_H).$$

In the equation, $R$ is the cosmic ray rigidity, $r_e$=1a.u. and $\theta_H$ is the heliographic co-latitude. In fig. 2, the arabic numerals express the values of $a_\lambda$ and the roman numerals I and II express, respectively, the cases of $\lambda_0=0.016a.u.$ and $\lambda_0=0.032a.u.$

On the other hand, the extended sidereal semi-diurnal variation is N-S symmetric or $P_2^0(\cos \theta)$-type and represents the annual variation of the solar semi-diurnal variation whose yearly average is zero. This space harmonic vector ($\hat{S}$) is also shown in fig. 2(b).

It is noteworthy that these two kinds of vector show remarkable polarity state dependences (cf. fig. 2).

3. Comparison with Observations. Fig. 3 shows the observed $SO$ difference vectors (T-A) between the corresponding harmonic vectors in the toward (T) and away (A) sectors in the positive polarity state (1971-1979) of the multi-directional muon telescope at Nagoya. In the figure, the symbols (V,N,S,E,...) denote respectively the 17 directional component telescopes ($^4$).

The theoretical $SO$ vectors to be compared with the observed vectors are shown in fig. 4 and are obtained by assuming that the phase of space harmonic vector is $0hr^4$.

The relative configuration of the observed vectors in fig. 3 bears a
striking resemblance to that of $P_2^1(\cos \theta)$-type not to that of $P_1^1(\cos \theta)$-type (N-S symmetric) shown in fig.4.

Fig. 3.

The spectrum of the vector is assumed to be of power-type \((R/1000)^{0.6}\) with upper limiting rigidity (1000 GV).

In addition to the above solar diurnal variation, the present anisotropy produces also \(S_{1/2}\) vector. Fig. 5 shows the T-A vectors in positive polarity state, and the theoretical vectors are shown in fig.6 in the same manner of fig.4. Although the observed vectors \(S_{1/2}\)'s are not very significant statistically, their relative configuration is systematic and bears a resemblance to that of $P_2^2(\cos \theta)$-type in fig.6(a) not to that of $P_3^3(\cos \theta)$-type (N-S asymmetric).

In fig. 5, we show also the observed \(A_{1/2}\) vectors which must be very small (\(\sim\) one sixth) in comparison with \(S_{1/2}\) vectors from the theoretical point of view. The observed vectors \(A_{1/2}\)'s are evidently small as expected.

These comparison with observations strongly suggest the existence of the 2nd order IMF-sense-dependent anisotropy. For confirmation, however, detailed analysis of the observed vectors \(S_0\) and \(S_{1/2}\) is required.
4. Conclusion. It has been demonstrated that an IMF-sense-dependent 2nd order anisotropy is produced by the diffusion-convection of cosmic rays in the heliomagnetosphere. The result implies that the anisotropy cannot be expressed only by the pitch angle ($\mu = \cos \theta$) with respect to the IMF-axis (cf. eq. (1)). In this respect, it is not suitable to discuss the 2nd and 3rd order anisotropies, based on the diffusion equation with respect to the pitch angle ($\cos \theta$).

Fig. 5.
EXTENDED
SIDEREAL ($SI_{1/2}$)
AND
ANTI-SIDEREAL:
($AS_{1/2}$) SEMI-DIURNAL
'TOWARD-MINUS-AWAY'
HARMONIC VECTORS (T-A)
OBSERVED BY
MULTI-DIRECTIONAL
MUON TELESCOPE AT
NAGOYA
FOR THE PERIOD OF

Fig. 6.
RELATIVE CONFIGURATION OF EXPECTED
SEMIDIURNAL
HARMONIC VECTORS OF
$P_2^2(\cos \theta)$- AND
$P_3^2(\cos \theta)$-TYPE FOR
COMPONENT TELESCOPES
OF MULTI-DIRECTIONAL
MUON TELESCOPE AT
NAGOYA.
The spectrum of the
vector is assumed to
be of power-type
[$(R/100GV)^{0.5}$]
with upper limiting
rigidity ($100GV$).

References

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