Cosmic-Ray Sidereal Daily Variation, Showing of the Coexistence of the Galactic and Heliomagnetotail-In Anisotropies

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Abstract

It is shown that the cosmic-ray sidereal daily variation in the energy region less than $E_U \sim 10^4$GeV is due to two kinds of anisotropy, one is the galactic anisotropy from the direction of the right ascension α_G=0h and the declination $\delta_G = -20^o$ and can be observed even in the energy region as low as ~60GeV with the same form and almost the same phase as observed by the small air showers with $\sim E_U$ (Nagashima et al., 1989). The other is a newly discovered directional excess flux confined in a narrow cone with a half opening angle of $\sim 68^o$ from the direction ($\alpha_T \sim$6h; $\delta_T \sim -24^o$) and observed only in the energy region less than E_U. It is suggested that the excess flux is solar origin and the direction toward it seems to coincide with the expected heliomagnetotail direction (α_{TP}=6.0h; $\delta_{TP} = -29.2^o$) opposite to the proper motion of the solar system, but does not coincide with the expected tail direction (α_{TN}=4.8~7.2h; $\delta_{TN} = 15^o \sim 17^o$) opposite to the relative motion of the system to the neutral gas.
This paper is called hereafter Paper (1).

1. Sidereal daily variation

The cosmic-ray data used for the present analysis are those of the muon telescopes at the underground stations Sakashita (latitude $\lambda=36^o$N, longitude $\phi=138^o$E, depth d=80 hg/cm^2) and Hobart ($\lambda=43^o$S, $\phi=147^o$E, d=36 hg/cm^2) and at the ground station Nagoya ($\lambda=35^o$N, $\phi=137^o$E). The characteristics of the telescopes are shown in Table 1, together with those of three-fold ($F3$) small air showers at Mt. Norikura ($\lambda=36^o$N, $\phi=138^o$E, height=2776 m above sea level).

The sidereal daily variation $SI(t)$ in local time (t) observed at low energies is influenced by the systematic annual variation of the solar daily variation. The influence can be eliminated as follow: The above annual variation produces also the anti-sidereal daily variation $ASI(t_a)$ with frequency of 364 cycles/year expressed by the anti-sidereal local time (t_a=1,2,$\cdots$,24h), which is measured in units of 'anti-sidereal hour' defined by 1 year/364/24. The influence of the solar disturbance to the sidereal variation can be eliminated by subtracting from the observed $SI(t)$ the modified anti-sidereal variation $ASI(t)_{mod}$ as $0.948 \cdot ASI(t_a$-4.53h), (Nagasima et al., 1983). Figure 1 shows some examples of the corrected $SI(t)$ together with that of the air showers due to the galactic anisotropy from α=0h (Nagashima et al., 1989).

2. Galactic and tail-in anisotropies

The sidereal variations in Fig. 1 are characterazed with the narrow peak and/or the deep valley, their centres being nearly at 6h and 12h, respectively.

The peak almost disappears for the northernmost pointing N_{NAG}-telescope, while the valley loses its similarity to others for the southernmost V_{HOB}-telescope. This suggests the peak and valley are of different origins.

It is emphasized that all the valleys except at Hobart are very similar to that of the air showers ($F3$) with almost no phase difference. Futhermore, it cannot be emphasized much that the entire time profile of $SI(t)^{N}_{NAG}$ for the northernmost-looking N_{NAG}-telescope almost completely coincides in shape with that of SI^{F3}_{NOR} as can be seen in Fig. 2. This implies that the galactic anisotropy, observed by the air showers with the median energy (E_m~10^4GeV), can be observed even at very low energies of ~60GeV without any deformation in shape and with almost no phase difference with the air showers. Other $SI(t)$s except for $SI(t)^{V}_{HOB}$ also coincide with that of the air showers fairly well but partly, as can be seen by the examples of the superposition in Fig. 2. Such a sidereal variation of galactic origin as characterized with the broad plateau and the narrow valley with its minimum near 12h is called the G-variation or $G(t)$, hereafter. According to the previous analysis of the sidereal variation of the air showers (Nagashima et al., 1989), the space distribution of the galactic anisotropy responsible for $G(t)$ can be expressed by the deficit flux confined in the narrow cone with the half oppening angle (χ_G=57°) from the direction of $\overline{\alpha}_G$=12h and $\overline{\delta}_G$=20°, which is the reversal of the direction (α_G=0h and δ_G=−20°) of the galactic anisotropy. As the deficit flux inside the cone can not be observed by the V_{HOB}-telescope (λ_C=43°S), the deep and narrow valley characteristic of $G(t)$ does not appear in $SI(t)^{V}_{HOB}$.

Therefore, $SI(t)^{V}_{HOB}$, characterized with a narrow peak with the maximum at ~6h and almost a flat backgroung, should be regarded as being due to another anisotropy. In contrast with $G(t)$, it is called the T-variation or $T(t)$. Other $SI(t)$s except for $SI(t)^{N}_{NAG}$ in Fig. 1 are the superposition between the T- and G-variations. The full view of $T(t)$ for other telescopes than V_{HOB} is given by the deviation between two superposed curves as shown in Fig. 2. The anisotropy producing $T(t)$ can be determined as follows:

Figure 3 shows the amplitude and phase of the first harmonic vector (T_1) of $T(t)$ as a function of E_m. The three vectors in higher energy region (>180GeV) shows almost the same phase of about 6h. As the geomagnetic deflection of cosmic rays in the energy region is almost negligible, the direction of the anisotropy responsible for $T(t)$ would be in the meridian plane of α_T~6h. The energy spectrum of the amplitude can be estimated by using $T_1,^{V}_{NAG}$ (E_m=60GeV, λ_C=35°N) and $T_1,^{V}_{SAK}$ (E_m=331GeV, λ_C=36°N) in Fig. 3. As these amplitudes depend on E_m only, their power spectrum can be given by the solid line through these two points on the graph. On the other hand, the amplitudes of $T_1,^{V}_{HOB}$ and $T_1,^{S}_{SAK}$ remarkably deviate from the solid line. This can be attributed to the difference of λ. As λ_C of V_{HOB}- and S_{SAK}-telescopes has the inverce sign to that of V_{NAG}- and V_{SAK}-telescopes, the above relation indicates the north-south (NS-) asymmetry of the amplitude. This implies that the anisotropy responsible for $T(t)$ must have a space distribution characterized with the directional excess flux confined in a narrow cone with its half opening angle (χ_T) less than $\pi/2$ from the direction in the southern hemisphere. The declination (δ_T) of the direction of the anisotropy can be fortunately estimated by the comparison between $T_1,^{V}_{HOB}$ (λ_C=43°S;

E_m=184GeV) and $T1,^S_{SAK}$ (λ_C=5°S; E_m=387GeV). As their amplitudes are almost equalized by chance to each other by the mutual energy normalization according to the above spectrum (cf. dashed line parallel to the solid line in Fig. 3), δ_T must be the middle point (−24°) of λ_C=5°S and 43°S, so as to satisfy the above equality. Finally, the half opening angle (χ_T) of the excess cone from the direction of δ_T=−24° and α_T=6h can be determines so as to satisfy the condition that the direction inside the cone can be looked at by the telescope through the duration period of the peak of $T(t)$. As $T(t)^S_{SAK}$ and $T(t)^V_{HOB}$ have very clear peak with its width of about 9 hours, χ_T is estimated at about 68°.

On the basis of the above analysis, it has become clear that the anisotropy in question has the space distribution characterized with the directional excess flux confined in the cone with the half opening angle (χ_T) of about 68° from the direction of α_T~6h and δ_T~−24°, and its energy spectrum increases with energy.

It is emphasized that the direction (α_T~6h; δ_T~−24°) toward the anisotropy responsible for $T(t)$ approximately coincides with the inferred heliomagnetotail direction (α_{TP}=6.0h; δ_{TP}=−29.2°) opposite to the proper motion of the solar system (Mihalas, 1968), but does not coincide with the inferred tail direction (α_{TN}=4.8~7.2h; δ_{TN}=15°~17°) opposite to the relative motion of the system the neutral gas (McClintock et al., 1978; Ajello, 1978). Hereafter, we call this anisotropy the heliomagnetotail-in (or simply tail-in) anisotropy.

The space distribution of the tail-in anisotropy is shown on the map in Fig. 4, together with the distribution of the galactic anisotropy. In the figure, the excess cone of the tail-in anisotropy, within which all the directional excess flux is confined, is shown bounded by the thick line. A thinner line bounds the deficit cone of the galactic anisotropy, in which all the directional deficit flux is confined.

References

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Telescope	Centre direct. of viewing λ_C(°)	ϕ_C(°)	Median Energy E_m(GeV)	Counting Rate 10^4/h	Period
Nagoya N	65N	137E	66	125	'71-'93
V	35N	137E	60	276	
Sakashita V	36N	138E	331	39	'78-'93
S	5S	147E	387	6.7	
Hobart V	43S	147E	184	11.5	'58-'83
Mt. Norikura Air showers (F3)	36N	138E	$1.5\cdot10^4$	3.7	'73-'87

Table 1
Characteristics of the telescopes.

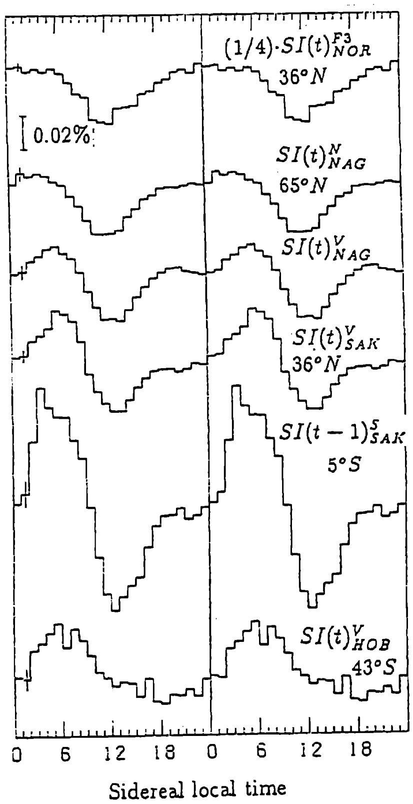

Fig. 1 Cosmic-ray sidereal daily variation $SI(t)$. The super- and sub-script indicate the telescope and station, respectively.

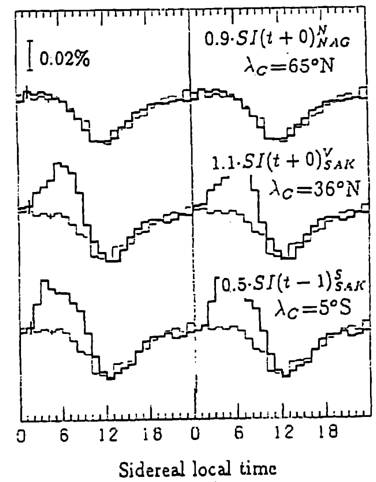

Fig.2
The superposition of $f\cdot SI(t+\Delta t)$ of the muon telescope (thick line) on $(1/4)\cdot SI(t)^{F3}_{NOR}$ of the air showers (thin line).

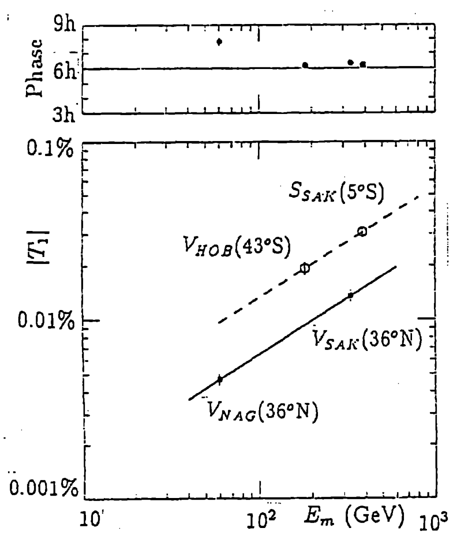

Fig. 3 Amplitude and phase of the first harmonic vector (T_1) of the $T(t)$ as a function of the median energy (E_m).
The solid line in the lower figure expresses the energy spectrum and the dashed line is parallel to the solid line through a point V_{HOB}.

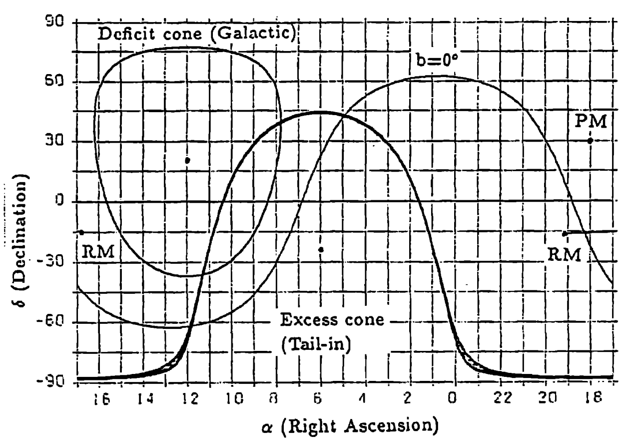

Fig. 4 The distribution of the tail-in and galactic anisotropies on the equatorial coordinate grid.
PM: Direction of proper motion of the solar system, RM: Direction of relative motion of the system to the neutral gas, b=0°: Galactic equater.