Letters to the Editor

COSMIC-RAY EQUATOR ACCORDING TO THE DATA FROM THE SECOND SOVIET SPACESHIP

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THE knowledge of the geographical position of the line of minimum primary cosmic-ray intensity (cosmic-ray equator) permits a study of the character and structure of the geomagnetic field and a check of the theoretical and empirical approximations of this field.

The use of satellites for the determination of the cosmic-ray equator has a number of advantages over earth-based investigations: 1) a large number of crossings of the equator at various points, 2) the practically simultaneous crossing of the equator over the whole globe, 3) a direct detection of the primary component of cosmic radiation. These advantages provide the possibility of studying in detail the cosmic-ray equator at various periods of time, and in particular of studying the influence of various geophysical effects on its position. It becomes unnecessary to introduce barometric and temperature corrections, or corrections for time variations.

The ionizing-radiation detectors on the second spaceship included a gas-discharge counter. The pulses from the counter were fed to a scaler which was interrogated by an independent daily memory device once every three minutes. This information was recalled and transmitted to the earth stations by means of telemetry controlled from the earth. The daily memory made it possible to measure the latitude dependence of the primary cosmic radiation for each crossing of the equator. Since, at high latitudes, the spaceship often passed through radiation belts, we have used only the experimental points for latitudes lower than 40° in constructing the empirical formula for the latitude dependence by the least-squares method. A quadratic parabola was used as the approximating function.

From 22 latitude curves obtained at different crossings of the geographic equator region, we have determined the position of the minima of cosmic-ray intensity (see figure).

The cosmic-ray equator obtained is not compatible with the idea of a dipole geomagnetic field.[1-6] The comparison of the cosmic-ray equator with the equator calculated by Quenby and Webber taking into account both the dipole and nondipole components of the geomagnetic field,[7] and also with the equator calculated by Kellog and Schwartz using the octupole approximation,[8] gives a sufficiently good agreement within the limits of experimental accuracy. A more detailed comparison would be possible if the experimental errors could be decreased.

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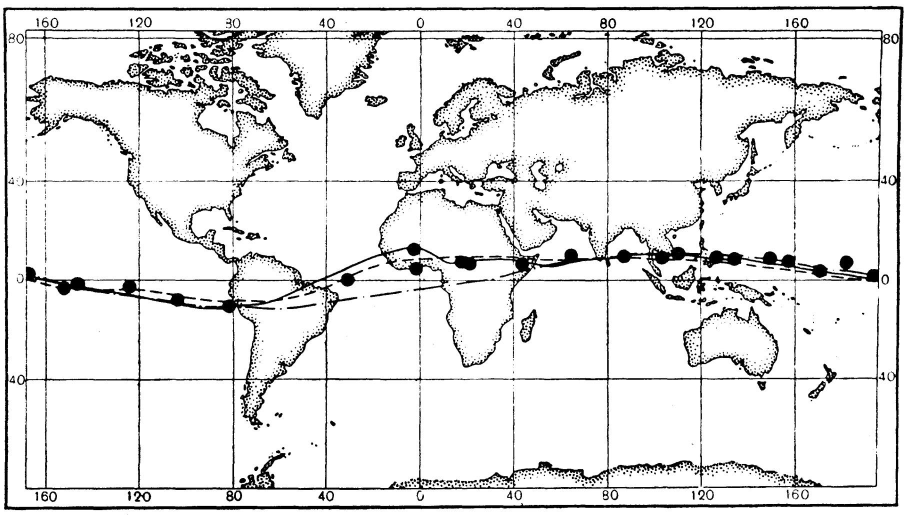

Cosmic-ray equator. Dash-dot line – geomagnetic equator of the dipole field, dotted line – equator calculated taking into account the dipole and nondipole components of the internal geomagnetic field,[7] solid-broken line – equator calculated using the octupole approximation,[8] ● – data obtained by the second spaceship.

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NONLINEAR PROPERTIES OF THREE-LEVEL SYSTEMS

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As is well known, the three-level system* is the basic element of quantum amplifiers and oscillators-masers. It is of interest to consider other possible physical applications of three-level systems, in particular, applications that derive from their nonlinear properties.

A manifestation of the nonlinear properties of a three-level system would be the response of the system (for example, the polarization P) to two monochromatic signals. Let E_1, E_2 and E_3 be the three levels of the quantum system and suppose that an external field (electric or magnetic) acts on the system

$$F = E_{13}\cos\Omega_{31}t + E_{23}\cos\Omega_{32}t, \tag{1}$$

where $\Omega_{31} \approx (E_3 - E_1)/\hbar$ and $\Omega_{32} \approx (E_3 - E_2)/\hbar$.

To find the system polarization produced by the field (1) we use the equation for the density matrix ρ_{mn}:[1,2]

$$\frac{\partial\rho_{mn}}{\partial t} + i\omega_{mn}\rho_{mn} = \frac{i}{\hbar}F\sum_{l=1}^{3}(\mu_{ml}\rho_{ln} - \rho_{ml}\mu_{ln}) - [\tau^{-1}(\rho-\rho_0)]_{mn};$$

$$[\tau^{-1}(\rho-\rho_0)]_{mn} = \begin{cases}\tau_1^{-1}(\rho-\rho_0)_{mm} & \text{for } m=n\\ \tau_2^{-1}\rho_{mn} & \text{for } m\neq n\end{cases}, \tag{2}$$

where the μ_{ml} are the dipole moment matrix elements, τ_1 and τ_2 are the longitudinal and transverse relaxation times, and ρ_{0mn} is the density matrix corresponding to instantaneous equilibrium at time t, when the field is given by F(t). The polarization of the system is

$$P = \mathrm{Sp}\,(\hat{\rho}\hat{\mu}). \tag{3}$$

In solving Eq. (2) we keep only the resonance terms[2] at frequencies Ω_{32}, Ω_{31}, and $\Omega_{31} - \Omega_{32}$, thereby obtaining the corresponding system of algebraic equations[2] that yields the following expression:

$$P = \bar{\rho}_{31}\mu_{13}e^{-i\Omega_{31}t} + \bar{\rho}_{32}\mu_{23}e^{-i\Omega_{32}t} + \bar{\rho}_{21}\mu_{12}e^{-i(\Omega_{31}-\Omega_{32})t} + \text{c.c.}, \tag{4}$$

if $\Omega_{31} = (E_3 - E_1)/\hbar$ and $\Omega_{32} = (E_3 - E_2)/\hbar$,

$$\bar{\rho}_{31} = 2i\gamma_{31}\Delta^{-1}\{D_{13}^{(0)}[4(\tau_2^{-1} + \gamma_{23}^2\tau_1) + \tau_2\gamma_{13}^2] - D_{23}^{(0)}(2\tau_1 + \tau_2)\gamma_{23}^2\},$$

$$\bar{\rho}_{32} = 2i\gamma_{32}\Delta^{-1}\{D_{23}^{(0)}[4(\tau_2^{-1} + \gamma_{13}^2\tau_1) + \tau_2\gamma_{23}^2] - D_{13}^{(0)}(2\tau_1 + \tau_2)\gamma_{13}^2\},$$

$$\bar{\rho}_{21} = \frac{1}{2}i\tau_2\gamma_{13}\gamma_{23}(\bar{\rho}_{32}/\gamma_{32} + \bar{\rho}_{31}/\gamma_{13}) = -2\gamma_{13}\gamma_{23}\tau_2\Delta^{-1}\{D_{13}^{(0)}[2(\tau_2^{-1}+\tau_1\gamma_{23}^2)-\tau_1\gamma_{13}^2] + D_{23}^{(0)}[2(\tau_2^{-1} + \gamma_{13}^2\tau_1) - \tau_1\gamma_{23}^2]\};$$

$$\Delta = [4(\tau_2^{-1} + \gamma_{23}^2\tau_1) + \tau_2\gamma_{13}^2][4(\tau_2^{-1} + \gamma_{13}^2\tau_1) + \tau_2\gamma_{23}^2] - (2\tau_1 + \tau_2)^2\gamma_{13}^2\gamma_{23}^2;$$

$$\gamma_{13} = \mu_{13}E_{13}/\hbar = \gamma_{31}, \qquad \gamma_{23} = \mu_{23}E_{23}/\hbar = \gamma_{32};$$

where $D_{13}^{(0)}$ and $D_{23}^{(0)}$ are the corresponding equilibrium population differences in the levels.

It is evident from Eq. (4) that the response of the system to two monochromatic signals contains a term at the combination frequency $\Omega_{12} = \Omega_{13} - \Omega_{23}$; this term results from the nonlinearity of the system.† In particular, in the case of practical interest, where one of the applied signals is large (for example, $\gamma_{13}\tau_2 > 1$), it turns out that $|\rho_{12}|/|\rho_{23}| > 1$. This result indicates the possibility of building a quantum frequency converter with appreciable conversion gain. From the point of view of noise characteristics it would appear that the quantum converter can compete with quantum amplifiers. Special interest attaches to the case in which Ω_{12} is a very low frequency and can be used directly as the intermediate frequency.

We note that in principle it is possible for oscillations to occur at the frequencies Ω_{13} and Ω_{23} when a three-level maser is used as an oscillator or as an amplifier. It then follows that a maser can produce a signal at frequency Ω_{12} even if the populations in levels E_1 and E_2 are not inverted.

The principle of quantum frequency conversion can also be used in the optical region. It would appear that the monochromatic light signals re-