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THE ANISOTROPY OF PRIMARY COSMIC RADIATION AND THE ELECTROMAGNETIC STATE IN INTERPLANETARY SPACE

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ABSTRACT

Study of the anisotropy of cosmic rays from the measurement of the daily variation of meson intensity has demonstrated that there are significant day-to-day changes in the anisotropy of the radiation. New experimental data pertaining to these changes and their solar and terrestrial relationships are discussed.

An interpretation of these changes of anisotropy in terms of the modulation of cosmic rays by streams of matter emitted by the sun is given. In particular, an explanation for the existence of the recently discovered types of daily variations exhibiting day and night maxima respectively, can be found by an extension of some ideas of Alfvén, Nagashima, and Davies. An integrated attempt is made to interpret the known features of the variation of cosmic ray intensity in conformity with ideas developed above.

The study of the daily variation of cosmic ray intensity provides a unique tool for the evaluation of the anisotropy of the primary cosmic radiation, and changes occurring in it. Since the anisotropy is related to theories of the origin of cosmic radiation and to the electromagnetic state in interplanetary space, it is of importance to summarize the current status of our knowledge derived from measurements of the daily variation of cosmic ray intensity.

1. The daily variation of cosmic rays and the anisotropy of the primary radiation is of a highly variable character. This is seen in large long-term changes of the 12-monthly mean daily variation of meson intensity (Sarabhai and Kane [1], Sarabhai, Desai and Venkatesan [2], Thambyahpillai and Elliott [3], Steinmaurer and Gheri [4]), the day-to-day changes correlated with magnetic character figure and the occurrence of large amplitudes of the daily variation of meson intensity on groups of days

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(Sittkus [5], Remy and Sittkus [6]). It is seen from Fig. 1 that on these same days the daily variation at Amsterdam (H. F. Jongen, private communication) at $\lambda = 54°$ N, at Ahmedabad (U. D. Desai) $\lambda = 13°$ N show similar features. However, Kodaikanal (D. Venkatesan) on the magnetic equator

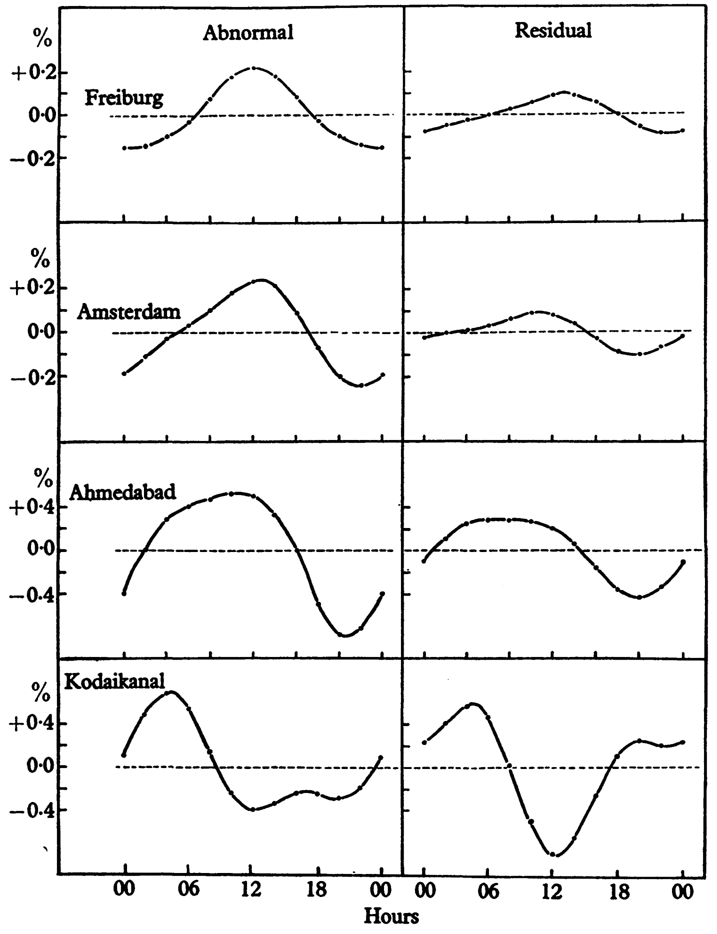

Fig. 1. Comparison of the daily variation at Freiburg (Sittkus), Amsterdam (Jongen), Ahmedabad (Desai) and Kodaikanal (Ventakesan) on days of abnormal amplitudes at Freiburg with the daily variation on residual days.

does not exhibit any marked difference on days on which Sittkus gets abnormal amplitudes.

2. During several years the daily variation, particularly at low latitudes, exhibits two maxima instead of one. This is seen not only in data from Huancayo during 1937–52 (Sarabhai, Desai and Venkatesan [2]) but also

in data at Ahmedabad, Kodaikanal (Venkatesan and Sastry) and Trivandrum (Duggal) during 1950–5 as shown in Fig. 2. The changes of the daily variation indicate that they are primarily due to two types of anisotropies

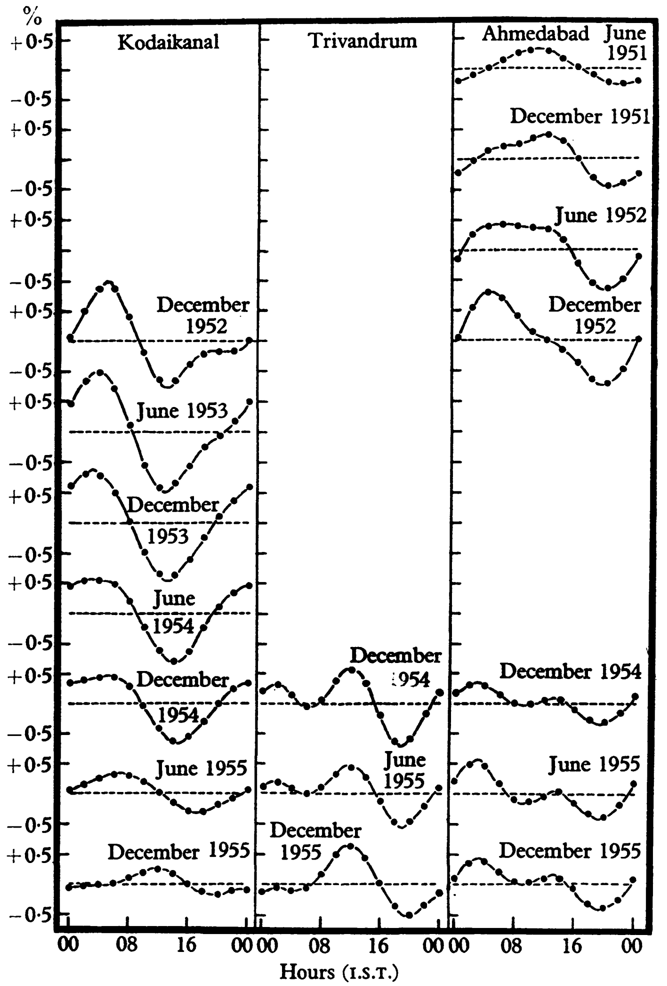

Fig. 2. Twelve-monthly mean daily variation of meson intensity at Ahmedabad, Kodaikanal and Trivandrum centred at six-monthly intervals 1950–5.

which correspond to maxima at 03.00 and 11.00 hours local time respectively (Sarabhai, Desai and Venkatesan [2]).

3. The daily variation of radiation incident in directions very close to the vertical is characterized by large amplitudes and undergoes large changes (Ehmert [7], Sarabhai and Nerurkar [8]). For stations in low

latitudes it exhibits maxima centred at 11.00 hours or 03.00 hours on a majority of days. On some days, which appear to be associated with low values of K_p, the daily variation has two maxima instead of one. The cone within which the radiation with large amplitude appears to be incident is restricted to a semi-angle of about 5° around the vertical. The semi-angle of the cone is however variable, so that during different periods the ratio of the amplitude in narrow angle and in wide angle telescopes varies, as shown in Table 1 (Ehmert [7], Sarabhai and Nerurkar [8]).

Table 1. *The ratio of the diurnal amplitudes measured with telescopes of different semi-angles on identical days during different periods*

	1954					1955								
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Total	Reference
(±5°) / ±15°)	1·52	1·79	1·72	1·74	2·17	2·40	1·83	1·65	1·68	0·79	1·18	1·04	1·60	10
±45°) / *IC*	—	—	—	—	—	—	—	—	—	—	—	—	1·5:1 to 2·4:1	7

ıe recorders are designated by IC for ionization chamber and CT (±x°) for counter telescope of semi-
: x° in the east–west plane.

4. The comparison of the daily variations with telescopes pointing to the vertical, the east and the west directions indicates that the spread of times of maxima in the three directions is much less than is expected. This is seen in the curves of the daily variation and the harmonic components shown on harmonic dials in Fig. 3 (*a*) and (*b*). These relate to a study made by Nerurkar at Ahmedabad with telescopes pointing to directions inclined at 45° to the vertical.

5. The long-term changes appear to follow the 22-year cycle of solar activity (Thambyahpillai and Elliot [3], Steinmaurer and Gheri [4], Sarabhai, Desai and Venkatesan [2]). The occurrence of the anisotropy which gives a maximum near noon and the anisotropy which gives a maximum at night-time is on groups of days which have a 27-day recurrence tendency.

If we consider the above facts, the most important conclusion is that at the present moment our knowledge of the characteristics of a permanent anisotropy, if indeed such exists, is very meagre. Initially, it is appropriate to consider for interpretation only the variable anisotropy about which we have now a number of well-established experimental facts and solar and terrestrial relationships. Theories which have been advanced in the past to explain only the average characteristics of the diurnal component of the daily variation, and those which do not take into consideration the existence of the two types of anisotropies which produce daily variations with maxima separated by approximately 8–10 hr are clearly inadequate. A theory which explains the variable anisotropy by a modulation of the primary intensity seems most promising in this context.

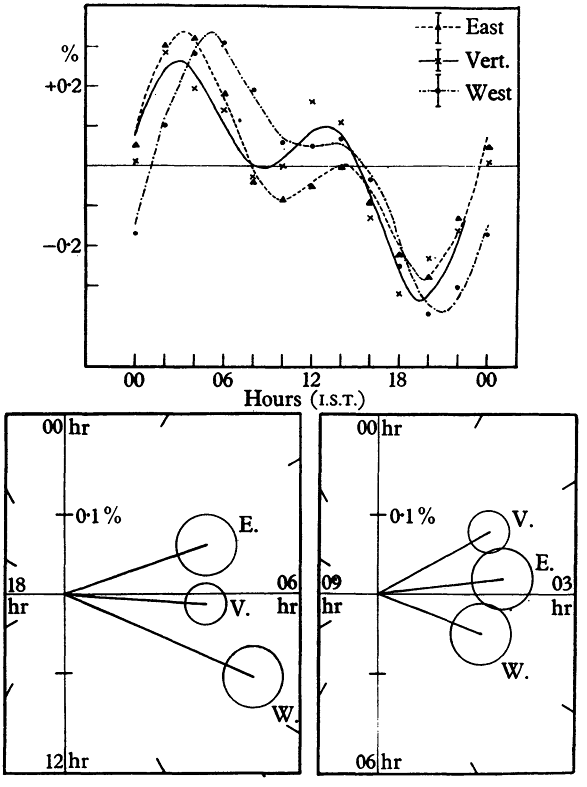

Fig. 3 (*a*, upper). The daily variation at Ahmedabad in the vertical, the east and the west pointing telescopes. (*b*, lower), harmonic dials showing the diurnal and the semi-diurnal components of the daily variation in the three telescopes at Ahmedabad.

Nagashima [9] has proposed a theory to explain the magnetic-storm type anisotropy which is directed towards the 12-hr direction. His theory postulates neutral beams of ionized particles ejected from the sun. These carry with them a trapped magnetic field derived from the solar dipole field. The charge separation which occurs in the beams as viewed from the earth, creates an electric field across the beams so that cosmic rays which traverse the beams and come to the earth suffer an acceleration or a

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deceleration depending on the orientation of the beam and the earth. Nerurkar [10] has studied the implications of an extension of Nagashima's ideas. If the magnetic field trapped within a beam is derived from the high local magnetic field in the neighbourhood of the active region from which the beam is ejected, it would be possible to expect a magnetic field frozen within the beam but having no preferred orientation in relation to the solar dipole field. For the purpose of the theory, the author has assumed that the solar beam would have an outward radial velocity of from 500 to 2000 km/sec, a width of about 5×10^{12} cm and a magnetic field of from 10^{-5} to 5×10^{-6} gauss at the distance of the earth from the sun. These values are consistent with theories of geomagnetic disturbances involving neutral but ionized streams of matter ejected from the sun.

With the daily variation of cosmic ray intensity which arises as an observational effect due to the spinning of the earth, it is only possible to study the anisotropy in the east–west plane. We have therefore to consider the electric field produced in the beam in the east–west plane due to the component of the magnetic field in the direction perpendicular to this plane. We have also to consider the situation that arises because the beam has an angular velocity derived from the spinning of the sun and it approaches the earth, envelops it and then recedes from it. These three cases are illustrated in Fig. 4 (*a*), (*b*) and (*c*) respectively. The top and the bottom series of diagrams of the figure relate to the reversal in direction of the component of the magnetic field perpendicular to the ecliptic. The diagrams illustrate the directions in space, as viewed from the earth, along which cosmic rays suffer acceleration or deceleration after traversing the beam. They also show in a schematic manner the increase or decrease according to local time of mean intensity of a definite primary region due to the spinning of the earth. Some of the consequences of the theory are as follows:

(1) While in the case of particles being accelerated we get an increase of intensity, there is a decrease when particles are decelerated. However, the time of occurrence of the increase and the decrease is separated by 12 hr. Therefore, the maximum of the daily variation occurs at approximately the same time irrespective of the relative position of the beam with respect to the earth.

(2) Depending on the negative or positive sign of the component of the trapped magnetic field, an anisotropy is produced which would give a maximum in the daily variation either at about 08.00 or at about 16.00 hours before deflexion in the geomagnetic field. The measured time of maximum depends on the correction to be applied for bending of the trajectories in the geomagnetic field.

(3) The magnitude of the anisotropy would vary in relation to the magnitude of the component of the trapped magnetic field in the direction perpendicular to the east–west plane. For different orientation of the trapped field of varying magnitude, we can expect the average anisotropy to correspond to a daily variation at low latitude having a most probable time of maximum 03.00 hours or 11.00 hours respectively, even though the

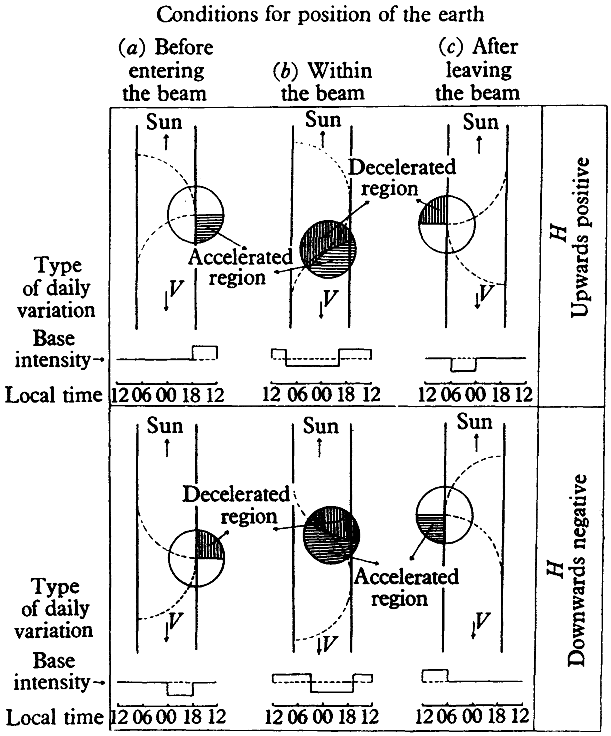

Fig. 4. Accelerated and decelerated regions and the type of daily variation for positive primaries of energy $=2E_{\min}$ when the earth is (*a*) on the right side, (*b*) within, and (*c*) on the left side of the beam. The component of the trapped magnetic field perpendicular to the plane of the paper is positive and towards the reader in upper figures and negative and away from the reader in lower figures.

time of maximum as well as the amplitude on each particular occasion would be different. Table 2 indicates the expected amplitude and time of maximum of the diurnal component of the daily variation at low latitudes.

(4) The anisotropy is only produced for primary cosmic rays of energy above a certain minimum value $E_{\min}$. $E_{\min}$ depends on the width of the beam, the magnitude of the trapped magnetic field and its orientation in

Table 2. *The percent amplitude and the time of maximum of the diurnal component of the daily variation of meson intensity in equatorial latitudes.*

Width of the beam $= 5\times10^{12}$ cm				When H is positive		When H is negative	
H (gauss)	Velocity (cm/sec)	Change in energy (eV)	E_{min} (Bev)	Amplitude (%)	Time of maximum (hr)	Amplitude (%)	Time of maximum (hr)
10^{-5}	2×10^{8}	$1{\cdot}3\times10^{8}$	10	0·65	1030	0·65	0300
10^{-5}	10^{8}	$0{\cdot}65\times10^{8}$	10	0·33	1030	0·33	0300
10^{-5}	5×10^{7}	$0{\cdot}33\times10^{8}$	10	0·16	1030	0·16	0300
5×10^{-6}	2×10^{8}	$0{\cdot}65\times10^{8}$	5	0·44	1130	0·39	0130
5×10^{-6}	10^{8}	$0{\cdot}33\times10^{8}$	5	0·22	1130	0·20	0130
5×10^{-6}	5×10^{7}	$0{\cdot}17\times10^{8}$	5	0·11	1130	0·10	0130

respect to the east–west plane. No appreciable anisotropy is produced for cosmic ray particles of energy less than E_{min}, while for increasing energy above E_{min}, the per cent anisotropy goes on diminishing. This explains why averaged over long periods the amplitude of the daily variation measured with a neutron monitor is about the same at Huancayo as it is at Climax, even though the mean energy of primary radiation is 19 Bev and 7 Bev respectively (Firor, Fonger and Simpson [11]). Similarly there is almost no latitude effect observable in the amplitude of the daily variation measured with ionization chambers at Huancayo, Cheltenham and Christchurch. Comparison between a neutron monitor and a meson detector cannot be made directly on account of the differences in the response functions of the instruments with respect to directions of arrival of particles. The energy dependence of the anisotropy also reconciles with theory the experimentally observed small change in time of maximum of the daily variation measured in the east and the west directions.

The special properties of the daily variation of intensity measured with narrow angle telescopes pointing towards vertical require much further consideration for experimental study and interpretation.

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