SIDEREAL COSMIC RAY VARIATION AND ITS RELATION WITH THE INTERPLANETARY MAGNETIC FIELD POLARITY

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RESUMEN

Datos de la componente mesónica de la intensidad de la radiación cósmica, registrada a diferentes profundidades, han sido comparados con las predicciones del modelo propuesto por Swinson. Las observaciones en la superficie y a profundidades moderadas muestran un efecto dependiente de la polaridad del campo del tipo propuesto por Swinson. Las observaciones a profundidades mayores de 40 metros de agua equivalente no muestran dicho efecto.

Se da una explicación en términos de la función de respuesta del detector. La pequeña variación sideral observada a 60 metros de agua equivalente se explica en base al movimiento del sistema solar relativo a estrellas cercanas.

ABSTRACT

Data from μ-meson telescopes, at different underground depths, have been compared with the predictions of a solar-controlled mechanism proposed by Swinson. The observations at ground level and at moderate depths show a significant field-polarity dependent effect of the kind envisaged by Swinson. The observations at depths greater than 40 m.w.e. do not show an obvious Swinson effect. An explanation is given in terms of the response function of the recorders. The small sidereal variation observed at 60 m.w.e. is explained in terms of the motion of the solar system relative to nearby stars.

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INTRODUCTION

Recently, Swinson (1969, 1971) has proposed a solar controlled mechanism for generating a spurious sidereal variation in the cosmic-ray intensity and suggests that previous experimentally observed sidereal variations are due to this process. According to Swinson an apparent sidereal variation would arise from the combined effects of the interplanetary magnetic field, a radial gradient of the cosmic-ray flux in interplanetary space and the inclination of the axis of rotation of the earth to the normal to the ecliptic plane. It is also dependent on the polarity of the interplanetary magnetic field. Elliot et al. (1972) and Thomson (1973) have both pointed out that this mechanism is applicable to the low rigidity end of the cosmic-ray spectrum $\leqslant$ 100 GV, where the solar modulation processes operate and a heliocentric radial gradient exists, but should not be apparent at high rigidities beyond the limit of solar modulation. Thus, Swinson effect should clearly be seen, when the data are separated into two groups according to the polarity of the interplanetary magnetic field, at a ground level or moderate depth underground detector, but should not be apparent at a deep underground detector like London (60 m. w.e.).

PREVIOUS RESULTS

Several people has now tested the Swinson effect by dividing the data from meson telescopes, at different underground levels, into two groups corresponding to positive and negative polarities of the interplanetary magnetic field. This has been done with the aid either of direct measurements of the interplanetary magnetic field made in space (Wilcox and Colburn, 1969, 1970, 1972) or by indirect methods of inference of the polarity of the interplanetary magnetic field (Svalgaard, 1972). The results of some of these studies have been summarized in Table I.

Table I

Station	Depth (m.w.e.)	Data period	Amplitude Δa (%)	Reference
Makerere	0	68-69	0.08 ± 0.02	Thomson (1973)
Chacaltaya	25	67-68	0.11 ± 0.03	Swinson (1971)
Hobart	36	64-69	0.05 ± 0.01	Humble *et al.* (1973)
Embudo	40	65-68	0.05 ± 0.02	Swinson (1971)
Kilembe	50	70-71	0.02 ± 0.03	Thomson (1973)
London	60	65-69	0.02 ± 0.02	Otaola (1973)
London	60	65-71	0.01 ± 0.01	Humble *et al.* (1973)

Where Δa is the difference in amplitude for the two field directions

$$\Delta a = a^{-} + a^{+}$$

According to Swinson, a^{-} and a^{+} differ in phase by 180° in sidereal time.

From the above table it can be seen that data from surface and shallow depths show a clear evidence for a field-polarity dependent effect of the type proposed by Swinson, while data from stations at depths $\geqslant 50$ m.w.e. do not observe the Swinson effect, in agreement with both Elliot *et al.* and Thomson's suggestions.

UNDERGROUND RESPONSE FUNCTION

The fact that Swinson has ascribed various experimentally observed sidereal variations, including those carried out in London (Elliot *et al.*, 1970), to his proposed mechanism it can be explained in terms of the underground response function that he employed to make quantitative predictions regarding the response of the detector to a variation expected on the basis of his proposed solar-controlled mechanism. This response function, derived by Ahluwalia and Eriksen (1971), overestimates the contribution to the counting rate by low-rigidity primaries.

Figure 1 shows a comparison between the integral response functions that have been derived for the London recorder at a depth of 60 m.w.e. Curve A has been derived by using a primary integral spectrum of the form $E^{-1.67}$ and the Trilling formula for pion multiplicity (Peacock, 1970). At high energies this formula approaches a pion multiplicity proportional to E where E is the energy per nucleon. Curve B has been derived by A. W. Wolfendale (private communication) and is based on an integral energy spectrum of the form $E^{-1.5}$, a pion multiplicity given by $M_{\pi} = E_p{}^{1/2}$ (where E_p is in GeV) and the CKP model of high energy interactions. Curve C is based on a work of Turver and Earnshaw using Monte Carlo calculations of atmospheric meson production and quoted by Thomson. Finally, curve D is the response function derived by Ahluwalia and Erikson. In each instance the response is expressed in terms of magnetic rigidity of the primaries, where due account has been taken of those nuclei in the primary beam with $Z/A = 1/2$.

We believe that curve D places much greater weight on the contribution to the counting rate by low rigidity primaries and that curves B or C are probably the best representation. Curve B has been used in this paper. If the median primary rigidity of response of the London recorder were of the order of what Ahluwalia (1971) claims to be, 130 GV instead of 257 GV as obtained from curve B, then primaries with rigidity below 100 GV, a fraction of approximately 41% of the detector counting rate, would be appreciably modulated by processes of non-sidereal origin like the one proposed by Swinson. As the amplitude of sidereal daily variation, due to the anisotropy expected on the basis of Swinson's model, is proportional to the percentage of the detector's counting rate, it means that a variations of this kind would be easily observed in the London data, which have a statistical error of the order of 0.005%, after four years of uninterrupted records. The small apparent sidereal variation with amplitude of 0.010%, and statistical significance corresponding to 2.5 σ, over a period of 10 years, that is present in the London data and that has been ascribed to the motion of the solar system relative to the galactic rotation frame in our neighborhood, would, on the basis of Swinson's model, imply an apparent sidereal variation at all rigidities less than 75 GV, the upper limit of the Swinson effect, of 0.10% if curve B is used and a corresponding figure of 0.05% if we use curve D. Nagashinna *et al.* (1962), using 21 years of Carnegie Institute ionization chamber data, found an average apparent sidereal variation with an amplitude of 0.021% for Chaltenham and 0.025% for Christchurch, which relate to primaries in the energy range 10^{10} to 10" eV. Both values lie well below the lower limit estimated above from the measured London value and curve D. Conversely if the ion-chamber date are accepted as giving a time measure of the Swinson effect, the maximum spurious variation to be expected at 60 m.w.e. would be ~ 0.005% which is not significantly greater than the statistical error for the London data.

SIDEREAL DAILY VARIATION

From the results shown in Table I it is clear that in order to avoid spurious solar effects in an experiment designed to look for a genuine sidereal anisotropy, it is necessary to make use of a detector that would carry out measurements at magnetic rigidities well above the solar modulation limit. This would also minimize the smearing out of the genuine sidereal anisotropy by the effects of scattering of cosmic rays by the interplanetary magnetic field.

By using the secondary muon flux at a depth of 60 m.w.e. at London, it has been possible to study the sidereal daily variation during the last 13 years (Miyazaki, 1973). The only well established result is that this variation has an amplitude of less than 0.1% for primaries in the rigidity range 10" to 10^{12} V.

The absence of any large anisotropy outside the solar system can be explained in terms of the galactic magnetic field. Since this field has a strenght of the order of 10^{-6} gauss, it is capable of containing particles of momentum up to 10^{17} to 10^{18} eV/c, and therefore, any conceivable source distribution, inside or outside the galaxy, will be effectively obscured by the complexity of the particle trajectories in the field.

However, even if the galactic magnetic field renders the cosmic rays completely isotropic, there will be a small affect due to the motion of the solar system relative to nearby stars. Measured relative to galactic rotation, the solar system has a velocity of ~ 20 km/sec in the direction of the constellation Hercules. Because of this motion an observer on the Earth should see a sidereal daily variation in intensity of two or three parts in 10^4.

On these basis, assuming that the radiation is completely isotropic in the frame of reference of galactic rotation, i.e., the cosmic rays corotate with the galaxy, then the angular distribution seen by an observer in the solar system is given by

$$I = I_o \left[1 + (2 + \gamma)\right] \frac{v}{c} \cos \alpha$$

where I_o is the meson intensity; γ is the exponent of the differential energy spectrum, which will be taken as 2.5; v is the velocity of the solar system relative to the rotation frame and α is the angle between the asymptotic cosmic ray direction and the solar apex at R. A. = 18 hs, $\delta = 34°$N.

Figure 2 shows the variations in sidereal time of cos α when the Earth is at the mid-point of a magnetic sector. Use was made of the asymptotic directions determined by Speller (private communication) for primaries with magnetic rigidity 100, 150, 200, 300, 500 and 9 000 GV. The curves drawn are the best fitting sine curves through the weighted mean values. The weights were assigned according to the value of the rigidity and the response function of curve B (Fig. 1). From this figure it can be seen that there is no significant difference between the two variations.

The mean values of cos α together with the response function of curve B, and the expression given above, have been used to compute the expected sidereal variation in London when the Earth is within positive and negative magnetic sectors.

These variations are represented in Figure 3. According to these curves, the vertical underground telescope at Holborn should see a variation with a Maximum at 1800 hrs (local sidereal time) and an amplitude of 0.010% above the mean intensity for both polarities of the interplanetary magnetic field. Now, if one takes into account that the interplanetary field is equally likely to be directed either toward the sun or away from it throughout the year, then the expected sidereal variation at Holborn over a long period of time, should have an average amplitude of ~ 0.010% with a time of maximum at 1 800 hrs (L. Sid. T.) irrespective of the polarity of the field. This is in agreement with previously reported results (Dutt, 1965; Peacock, 1967; Elliot *et al.*, 1970; Speller *et al.*, 1972; Miyazaki, 1973).

An additional objection to Swinson's model is that it is now known that the radial gradient in cosmic ray flux is too small to produce the required effect (Lentz *et al.*, 1973).

CONCLUSIONS

It is concluded that, a spurious solar-controlled sidereal daily variation in the cosmic ray intensity, of the type proposed by Swinson, exists at shallow depths and at ground level, but, up to the present limits of accuracy, there is no reason to believe that this effect is present in the data at depths $\geqslant$ 50 m.w.e. It seems that the explanation of the observed sidereal daily variation at 60 m.w.e. in London in termes of the known motion of the solar system relative to the local galactic rotation frame is the more likely one.

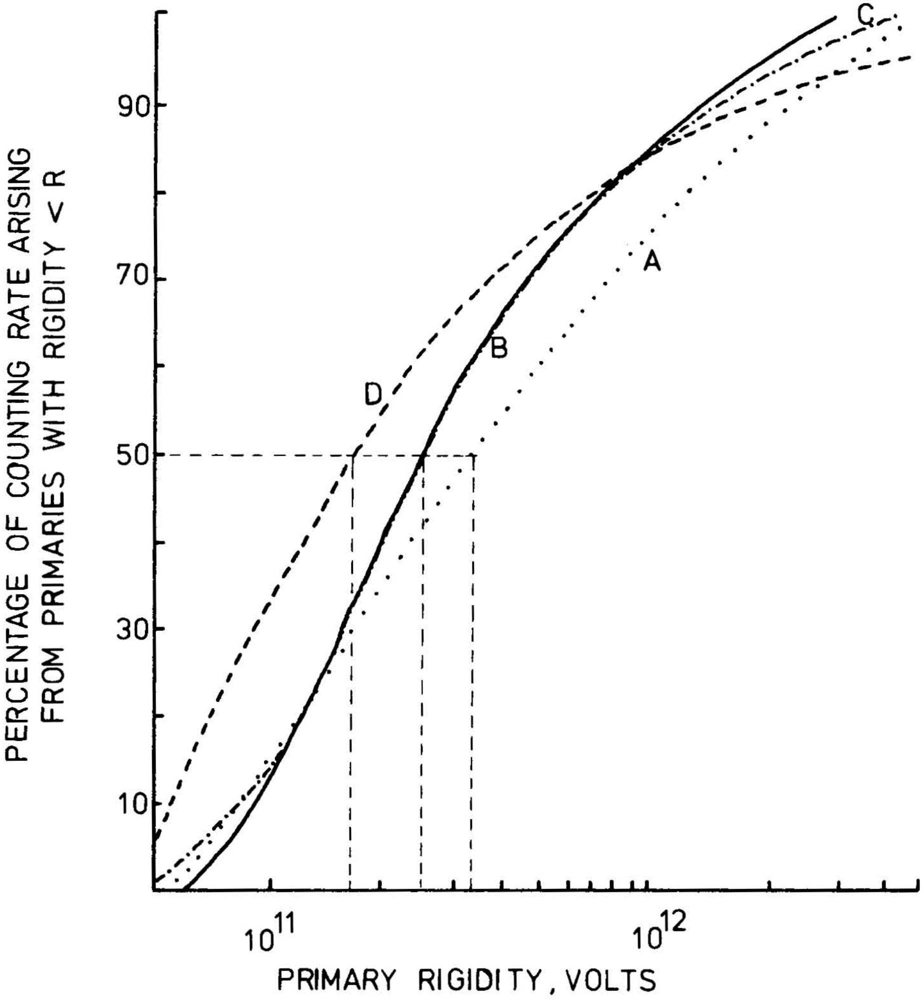

Figure 1. Integral response functions for a muon detector at 60 m.w.e. Curve A (Peacock), curve B (Wolfendale), curve C (Turver and Earnshaw), curve D (Ahluwalia and Ericksen).

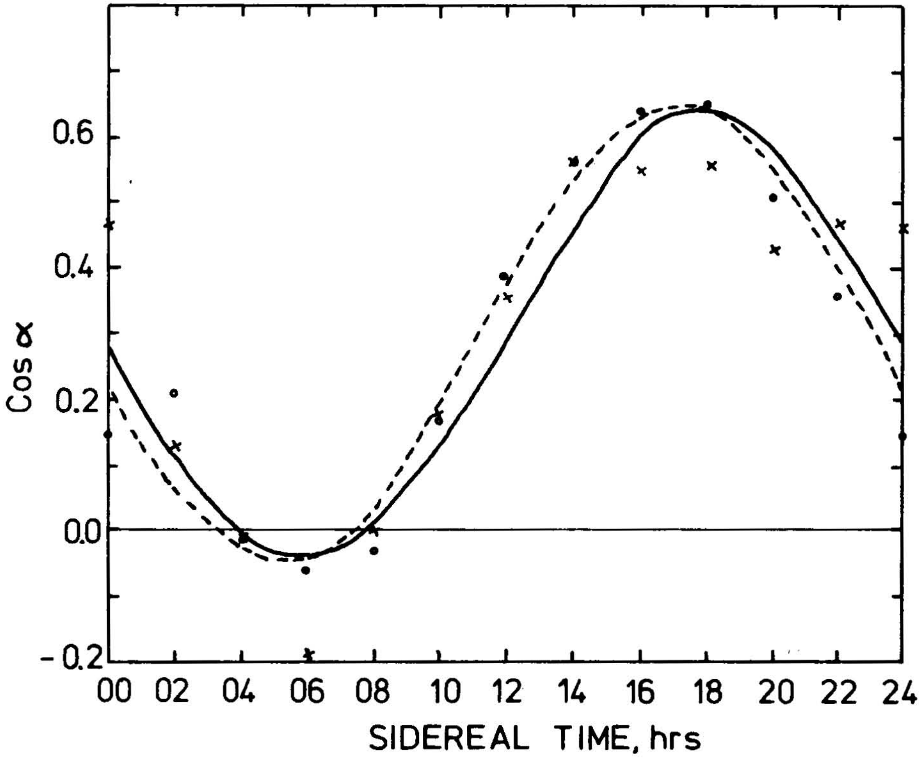

Figure 2. Angular scan of the muon telescope relative to the solar apex when the Earth is at the mid-point of a negative sector (dashed line) and at the mid-point of a positive sector (solid line). Both lines are the best sine curves through the mean values indicated by o for negative sectors and x for positive sectors.

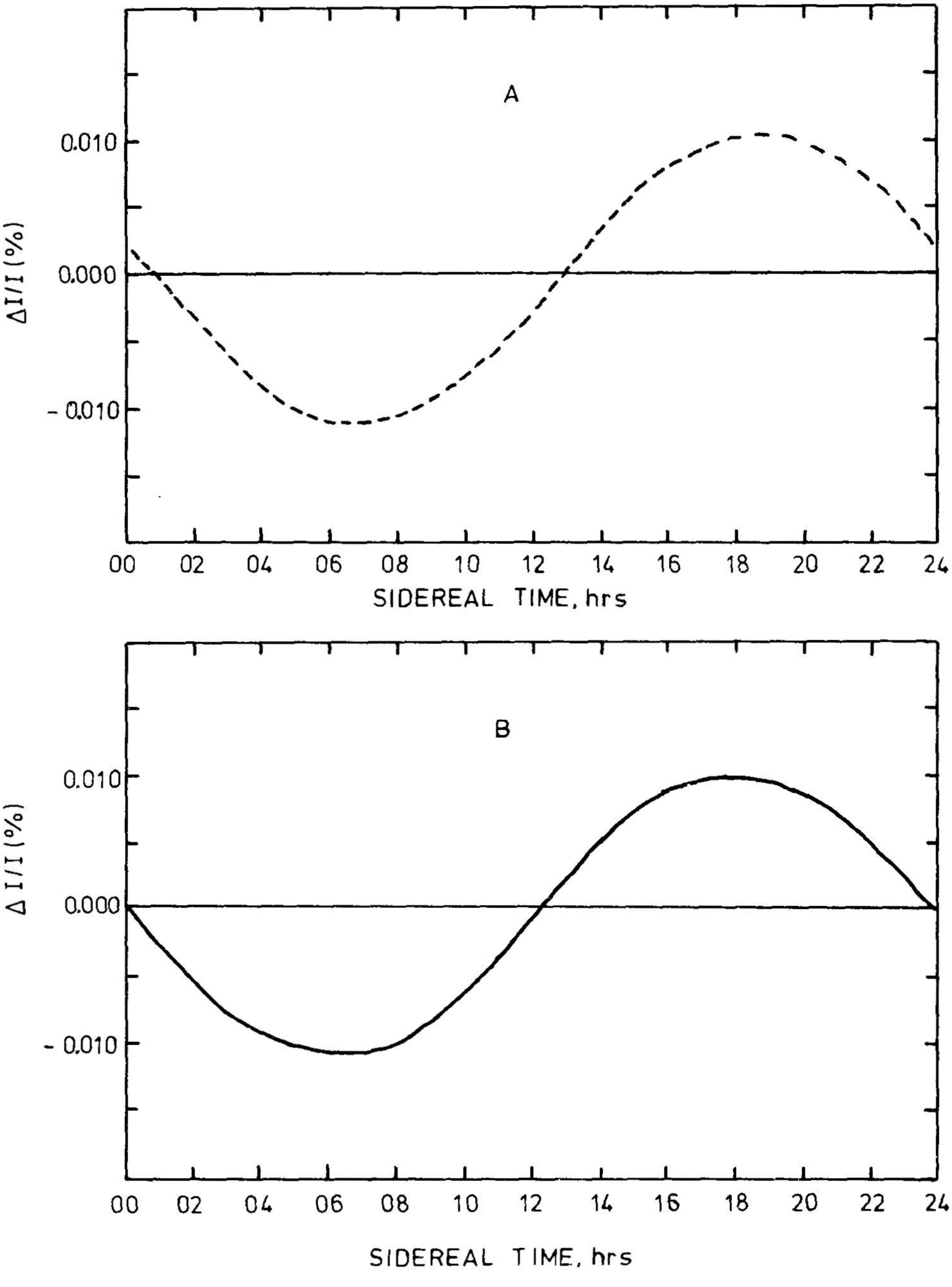

Figure 3. Expected sidereal daily variation at 60 m.w.e. when the Earth is at the mid-point of a: (A) positive sector, and (B) negative sector.

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