NOTAS DE FÍSICA
VOLUME VII
Nº 10

COMPARISON OF SOLAR COSMIC RAYS INJECTION INCLUDING JULY 17, 1959, AND MAY 4, 1960

by

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CENTRO BRASILEIRO DE PESQUISAS FÍSICAS
Av. Wenceslau Braz, 71
RIO DE JANEIRO
1961

COMPARISON OF SOLAR COSMIC RAYS INJECTION INCLUDING JULY 17, 1959, AND MAY 4, 1960*

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(Received October 13, 1960)

ABSTRACT. Using neutron monitor data obtained at high latitudes, it is shown in Part 1 that cosmic-ray particles of rigidity > 1 bv were produced by the solar flare that occurred at 2115 UT on July 16, 1959. The exponent of the integral rigidity spectrum of the radiation was ≤ -8.0. The temporal dependence of the flare radiation was unlike that of earlier flare effects, the intensity requiring ~ 7 hours to reach its maximum value. No impact zones were observed. In Part 2, meson data obtained at the time of the flare effect starting at 1031 UT on May 4, 1960, are presented. In Part 3, by considering the above-mentioned flare effects, and those observed previously, it is shown that

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* Published in Journal of Geophysical Research, 65, 9, 1960.

** This work was performed when one of the authors (R.A.R.P.) was at the M.I.T.

the time scale of the cosmic-ray flare effect is a highly variable quantity, varying by a factor as great as 36 from event to event. The flares responsible for the four flare effects with the shortest time scales occurred on the western solar limb; those resulting in the flare effects with the longest time scales occurred near the center of the solar disk. In Part 4 the above facts are shown to support the theoretical model proposed by Piddington.

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1. THE FLARE EFFECT OF JULY 17, 1959.

Introduction. Over a period of 23 years, six cases have been observed in which an intense solar flare was followed within a few hours by a marked enhancement in the cosmic-ray intensity at the surface of the earth [Dorman, 1957; McCracken, 1959]. These six events showed a number of marked similarities, and it seemed reasonable to list the characteristics of solar flares as follows:

a) The cosmic-ray intensity increases rapidly, maximum intensity occurring within about 15 to 100 minutes of the observation of the electromagnetic radiation from the flare. Once the maximum is reached, the intensity commences a smooth decline to the pre-event level. The time required to attain maximum intensity is considerably less than that required for the intensity to return to the pre-event level.

b) The integral rigidity spectrum of the flare-produced cosmic radiation is very steep, varying approximately as $(\text{rigidity})^{-7}$.

c) The event occurs at roughly the same time at all points on the earth. The small differences in onset time ($\sim$10 minutes) that do occur can be explained as follows [Lust and Simpson, 1957]. The higher-rigidity particles arrive at the earth first, and appear to come from within a relatively small solid angle in the direction of the sun. Thus, at first, only stations within several limited regions (impact zones) on the earth's surface observe a cosmic-ray enhancement. With the passage of time, lower-rigidity particles arrive, the radiation becomes isotropic, and all stations for which the rigidity cutoff is low enough observe an intensity enhancement.

In what follows, we consider an intensity enhancement which followed soon after an intense 3+ flare, but which, while fulfilling criteria (b) and (c), failed to fulfill criterion (a). In particular, the period of increasing intensity was of at least 6 hours' duration, maximum intensity occurring some 8 hours after the maximum output of visible light from the flare. We interpret this event as being a genuine case of the production of relativistic particles at the sun, and suggest that the atypical time behavior was the result of a disordered magnetic field between the earth and the sun, the cosmic-ray particles being required to diffuse through this field.

Observations. The cosmic-ray neutron data obtained at Mawson, Antarctica, and Herstmonceux, England, during the period July 14-18, 1959, are displayed in Figure 1. The Herstmonceux data show that two very large Forbush-type decreases occurred, one early on July 15, the other late on July 17. It can be seen that the Mawson curve tracks with the Herstmonceux curve quite well except during the period 02 to 16 UT on July 17. This failure to track can be seen to be due to a sudden change in slope in the Mawson curve, the intensity at that station increasing by about 8 per cent within a period of about 4 hours.

The neutron data obtained at 31 observatories were examined, and the data from many of them were plotted as in Figure 1. Separate graphs were prepared for the longitude zones centered on Europe, the Americas, and Australia, this procedure being adopted as it is known that during the recovery phase of a Forbush decrease there are differences in the behavior of the cosmic-ray intensity at different longitudes. It was seen from these graphs that the intensity changes at a number of observatories were similar to those at Herstmonceux: that is, a typical recovery from the Forbush decrease on July 15 preceded the Forbush decrease on July 17.

The data from another group of stations failed to track with those from the first group. This failure to track was invariably due to a sudden intensity increase at about 02 UT on July 17, the curves being very similar to those for Mawson. The increment was not present in the meson data from these observatories. This fact by itself has already prompted a number of investigators to speculate that the neutron enhancement was due to solar-produced radiation [Carmichael and Steljes, 1959; Bailey and Pomerantz, 1960]; however, the fact that the time changes during the event were unlike those of earlier flare effects has thrown some doubt on this interpretation. It is clear that we must investigate other characteristics of the anomalous increase to see whether they support the hypothesis of solar production.

In Table 1, some of the stations whose data we have examined are listed in order of increasing cutoff rigidity N. The cutoff rigidities calculated by Quenby and Webber [1959] were employed. It is immediately clear that every station for which N was 1.13 bv or less observed the enhancement, but it was not seen by any station for which N was 1.15 bv or more. This suggests that the rigidity spectrum of the enhanced radiation was very steep. Furthermore, it can be seen from the table that, if the enhancement was observed, it commenced between 01 and 04 UT irrespective of the longitude of the station.

To obtain some quantitative data on the exponent of the rigidity spectrum the data from Herstmonceux, Uppsala, and Bergen have been considered. The fact that these stations are quite close to one another gives us confidence that, even if there are errors in the assigned cutoff rigidities, they will be of approximately the same magnitude, and that therefore the ratio of the cutoff rigidities appropriate to any two stations will be approximately correct. It is also known that, during Forbush decreases, the percentage changes in intensity at these three stations are approximately equal, and consequently, as Herstmonceux did not see the enhanced radiation, it was possible to remove the variations due to the Forbush decrease from the Bergen and Uppsala data by subtraction of the percentage variations observed at Herstmonceux from the percentage variations observed at the other two stations. The results of these calculations are plotted in Figure 2. Averaging over the period during which Bergen saw the enhanced radiation, we find the amplitude to be 4.5 per cent at Bergen and 0.3 per cent at Uppsala. Assuming a power law, with exponent $-\beta$, for the integral rigidity spectrum of the enhanced radiation, the above values set a lower limit of 8.1 for β. An upper limit cannot be set on account of the statistically insignificant increase at Uppsala. The fact that the atmospheric cutoff is in the vicinity of 1 bv means that the effective cutoff at Bergen may be greater than the value used (0.94 bv), and consequently $\beta = 8.1$ may be an underestimate of the lower limit for β.

A further check on the value of the exponent was obtained by comparison of the enhancements observed at the mountain stations of Mt. Washington (1910 meters altitude, 1.03 bv vertical cutoff rigidity) and Sulphur Mountain (2280 m, 0.98 bv). It was known from the stations in the Americas that did not observe the increment (Chicago, Berkeley, Buenos Aires) that at these longitudes the recovery of the Forbush decrease during July 17 approximated quite well to a linear extrapolation of the recovery during July 16. Using this approximation, the intensity of the enhanced radiation at stations in the Americas was derived, the data from three stations being given in Figure 3. The data from Deep River and Sulphur Mountain were used to derive the attenuation length of the enhanced radiation, a value of 89 g cm^{-2} being obtained. This in itself suggests that the enhancement was not merely a modulation of the galactic radiation, as the value of the attenuation length applicable to the galactic radiation is 138 g cm^{-2}. Taking the value 89 g cm^{-2} for the attenuation length, the Sulphur Mountain observations were used to estimate the enhancement that would have been observed at an altitude of 1910 m at Sulphur Mountain. This value, and the data obtained at the same altitude at Mt. Washington, gave a spectral exponent of 9.3 ± 2.0.

Thus the criteria (b) (steep rigidity spectrum) and (c) (approximate simultaneity) listed in the Introduction were fulfilled by the intensity enhancement observed on July 17, 1959. As the enhancement, and the associated ionospheric effects [Bailey and Pomerantz, 1960; Reid and Leinbach, 1959] indicative of the arrival of lower-rigidity particles occurred soon after the observation of a 3+ flare (at 2115 UT on July 16 at a point 30° west of the central solar meridian [National Bureau of Standards, 1959], there is little doubt that the sea-level enhancement was of the nature of a solar flare increase.

Isotropy of the flare radiation. During previous examples of the solar flare effect, the cosmic-ray intensity within the '9 o'clock impact zone' was greater than that in the 'background zone' by a factor of 2 or more [Lüst and Simpson, 1957; Firor, 1954]. This inequality persisted for an hour or so after the maxima of the flare effects, and was consistent with a short-lived source in the direction of the sun. Assuming an apparent source of 40° in latitude and 80° in longitude, centered on the sun, it was found that both Mawson and Bergen would have been within the 9 o'clock zone during the period 02 to 06 UT on July 17. The event amplitudes at these two stations and the detailed shapes of the increasing intensity phases were not significantly different from those observed at sea level at other points on the earth's surface, leading to the conclusion that impact zones were not formed. It therefore seems that by 03 UT, about 2 hours before maximum intensity was attained, the radiation was already isotropic. The data are not sufficiently accurate to determine whether the radiation was isotropic before 03 UT. The arrival of flare radiation at Thule, Resolute, and Churchill also requires isotropy by about 03 UT.

Temporal dependence of the enhanced radiation. The maximum emission of Hα radiation occurred at 2230 UT on July 16, and the first ionospheric effect indicative of the arrival of corpuscular radiation at the earth commenced at 2250 UT. The Sulphur Mountain and Deep River data, that is, the neutron data with the best statistics, show the first noticeable flare effect between 01 and 02 UT, or ~ 2 hours after the commencement of the ionospheric effect. The neutron data from Sulphur Mountain and Deep River indicate that the flux of solar cosmic radiation continued to increase until about 05 UT. To understand the difference in the times of onset of the ionospheric and neutron effects, we must consider the sensitivity of the two types of measurement to low-rigidity solar protons.

Using the primary proton spectrum found by McDonald and Webber [1959], and the dependence of neutron intensity upon latitude observed by Rose, Fenton, Katzman, and Simpson [1956], the specific yield function [Fonger, 1953] for 1-bv protons was calculated, and used to estimate that it would require a flux of ~15 protons m^{-2} $ster^{-1}$ sec^{-1} $(100\ Mv)^{-1}$ in the rigidity range 0.95 to 1.1 bv to produce a 0.5 per cent, and hence barely detectable, increase in the neutron counting rate at a station at a high latitude. On the other hand, Reid and Leinbach [1959] estimate that a riomater can readily detect a flux of 10^5 protons m^{-2} sec^{-1} if the protons are in the rigidity range 0.05 to 0.3 bv. Using this value, and the observed integral rigidity spectrum of the solar cosmic radiation (going as the reciprocal of the eighth power of the rigidity above 0.3 bv), we have estimated that this threshold flux for the riometer corresponds to 1 proton m^{-2} sec^{-1} $ster^{-1}$ $(100\ Mv)^{-1}$ at 1 bv, that is, a flux which is a factor of 15 below the neutron monitor threshold.

These considerations show that there is no inconsistency between the riometer and neutron data, a plausible reason for the difference in times of onset being that a riometer can detect a much smaller flux of solar protons than a neutron monitor. It is concluded that the solar cosmic radiation first arrived at the earth at 2250 UT, the flux continuing to increase until a maximum was reached at about 05 UT on July 17, that is, 8 hours after the maximum emission of $H\alpha$ by the flare. This slow rise in cosmic-ray intensity is in marked contrast to the abruptness noticed during previous flare effects.

2. THE FLARE EFFECT OF MAY 4, 1960.

While this paper was in the final stages of preparation, another flare effect was observed by ground-level cosmic-ray detectors. As this flare effect adds considerably to the experimental data to be considered in the next section, we thought it advisable to rewrite a part of this paper in order to include the new observations. As the discussion in the next section will be largely concerned with the time scales of flare effects, we will use the meson data obtained at MIT for the sole purpose of establishing the time scale of the May 4 event.

Figure 4 displays the sum of the counting rates observed by the three large meson telescopes at MIT. The instruments have been described elsewhere [Palmeira and Williams, 1958], and it suffices to point out that there is now 7.5 cm of lead between the upper and lower scintillators. Each telescope has a counting rate of about 300 $\sec^{-1}$.

The cosmic-ray flare effect can be seen to have commenced at about 1031 UT. This would place MIT in the background zone [Firor, 1954][1]. A preliminary report [National Bureau of Standards, 1960] indicates that a solar flare of importance 2 was observed to start at about 1020 UT in the vicinity of a sunspot group 90° west of the central solar meridian. It was not followed by a Forbush decrease. At the time of occurrence of the flare, the terrestrial cosmic-ray intensity was recovering from a Forbush decrease which commenced on April 30.

3. THE TIME SCALES OF FLARE EFFECTS.

In Figures 5 and 6 are displayed the meson and neutron data obtained at background zone stations during the July 1946, February 1956, July 1959, and May 1960 flare effects [Forbush, Stinchcomb, and Schein, 1950; Forbush and Burke, 1956; Rose and Katzman, 1956]. Visual comparison of these graphs shows that the time scales of the events differ markedly; this will now be established in a more quantitative manner. It is known that the observations of any single flare effect can have time scales differing by a factor of approximately 2, depending on the type of instrument used, the cutoff rigidities of the stations, and the type of flare effect zone in which the stations lay (impact, background, or forbidden polar zone). Consequently, in order to avoid uncertainties in the comparisons between different events, we have, wherever possible, compared data obtained by similar instruments, situated at stations in the background zones where the cutoff rigidities are roughly the same.

For convenience, the interval between the commencement of the intensity enhancement and the time at which the maximum intensity was attained will be called the rise time of the event. The interval over which the enhanced intensity subsequently decreased by half will be called the 50 per cent decay time.

Camparing the MIT, Derwood, and Cheltenham meson data (Fig. 5), the rise times of the 1960, 1956, and 1946 events are found to be ~ 7 minutes < 30 minutes, and ~ 120 minutes, and the 50 per cent decay times to be ~ 8 minutes, ~ 40 minutes, and ~ 180 minutes, respectively. That is, the time scales of the rising intensity phases of these three events are in the ratio 1:4:17; the time scales of the decreasing intensity phases are in the ratio 1 : 5 : 22. Comparing the Ottawa and Sulphur Mountain neutron data (Fig. 6), the rise time of the 1956 and 1959 events are found to be $\sim$45 minutes and $\sim$7 hours; that is, the time scales are in the ratio 1 : 9. The fact that a Forbush decrease commenced on July 17, 1959, prevents a determination of the 50 per cent decay time of the 1959 event.

Combining the above data, it is found that the rise times of the May 1960, February 1956, July 1946, and July 1959 events are in the ratio 1 : 4 : 17 : 36. Furthermore, the evidence suggests that the 50 per cent decay times exhibit approximately the same ratio. That is, whereas the time scales of flare effects can differ from event to event, the rise time, measured relative to the 50 per cent decay time, is a constant. This fact would seem to be an important clue to the nature of the mechanism responsible for the observed temporal dependence of flare effects.

For completeness, the time scales of the February 1942, March 1942, and November 1949 events [Dorman, 1957] have been compared with those of the May 1960 event. The values of the rise times are listed in Table 2. For the February 1942 event, the rise time had to be determined from data obtained at a station in the main impact zone (Cheltenham). To permit comparison with the other determinations, the rise time so found was multiplied by a factor of 2(the data obtained during the February 1956 flare effect suggesting that this is a reasonable value for the time scale of an event observed in the background zone when measured relative to the time scale of the same event as observed in the main impact zone). It is found that in all cases the ratio of the rise time to the 50 per cent decay time is approximately constant.

4. DISCUSSION.

The solar flare effect, the Forbush-type decrease, and the 11-year cycle of cosmic-ray intensity are responsible for introducing the greatest changes into the terrestrial cosmic-ray intensity. An understanding of these three effects will take us a long way toward an understanding of the whole field of cosmic-ray variations. Clearly any satisfactory theory must explain the observations obtained when two or three of the effects are superposed. The superposition of a flare effect upon one or both of the other two is especially valuable, as the time of flight of the cosmic radiation and the degree of isotropy upon arrival at the earth are indicative of the electromagnetic conditions in interplanetary space, and therefore permit a test to be made of any models that may be proposed to explain the Forbush-type decrease and the 11-year cycle of intensity change. Such a test will now be applied to a model suggested by theoretical studies.

The model we will examine is essentially that proposed by Piddington [1958] and, in part, by others [Morrison, 1956; Parker, 1958; Cocconi, Greisen, Morrison, Gold, and Hayakawa, 1958]. It is suggested that during a period of solar activity the sun is surrounded by an extended region containing a disordered magnetic field (10^{-5} gauss), generated in a manner to be described later. When a large solar flare occurs in an active sunspot region, matter is ejected, which, on account of its high electrical conductivity, carries part of the sunspot magnetic field with it. Whitin the cloud of matter, there will be chaotic material motions, and the magnetic field will be fairly strong ($\gtrsim 10^{-4}$ gauss) and disordered. However, there will be lines of force connecting the cloud to the sunspot magnetic field, and these lines will be relatively ordered, and radial, as shown in Figure 9. The radial magnetic field remains rooted in the sunspot group, and, consequently, the rotation of the sun causes it to become twisted as shown in Figure 7 some days after the occurrence of the flare. In an active sunspot group, there is a more or less continual outflow of matter, which, though not as energetic as the matter ejected in a large flare, nevertheless establishes an ordered field stretching out from the sun. With the passage of time, instabilities destroy the ordered nature of the radial field, the disordered remnants contributing to the general disordered field postulated previously.

It has been shown that mechanisms based upon particle diffusion through disordered magnetic fields might be responsible for the 11-year and Forbush-type variations [Morrison, 1956; Parker, 1958]. In the present model, it is proposed that the weak but extensive general disordered field is responsible for the 11-year variation, while the stronger, chaotic fields in a cloud of matter ejected by a large solar flare are responsible for the Forbush-type decrease.

We shall now consider the consequences predicted by this model in the event of sudden production of cosmic radiation in a solar flare. Consider the three cases that follow:

Case A (Fig. 7): An active group has passed across the solar disk and is now on the western limb. Matter ejected by the group has established an essentially radial field enveloping the earth. If a solar flare did occur while the active center was near central meridian passage (c.m.p.), the highly chaotic matter and fields have by now passed the earth, and the field near the earth is essentially radial.

In such a case, cosmic rays produced by a solar flare in the active region would gain almost immediate access to the earth by spiraling along the lines of force of the radial field. The small irregularities that would undoubtedly be present in the radial field would alter the pitch angles of the cosmic radiation, thereby producing small time delays and dispersion of the high- and low-energy parts of the cosmic-ray spectrum (as the change in pitch angle would be an energy-dependent function). The first particles to arrive at the earth would be those moving roughly parallel to the radial magnetic field, and, consequently, there would be an apparent source in the direction of the sun during the early stages of the cosmic-ray enhancement. At later times, radiation scattered by the irregularities in the radial field would cause the radiation at the earth to become roughly isotropic.

Case B (Fig. 8): An active sunspot group is within about 40° of c.m.p. A radial magnetic field has been established; however, it does not at present contain the earth, which is still surrounded by the general disordered field.

Cosmic rays produced in a flare in such a sunspot group would not have an easy route of access to the earth defined for them by the magnetic fields in space. To reach the earth, the radiation would have to diffuse through the general disordered field. As a result of this diffusion, the time scale of the rising intensity phase would be greater than if direct access (case A) were possible. Furthermore, the fact that the earth is surrounded by scattering centers would cause the radiation to appear to come from all directions quite early during the flare effect. That is, the apparent source would be broader, and the radiation would appear to become isotropic more rapidly than in case A.

Case C (Fig. 9): An active sunspot group is within 40° of c.m.p., and a large flare has occurred in the group a day or two previously. The cloud of matter, with its entrained disordered magnetic fields, surrounds the earth, and the terrestrial cosmic-ray intensity is consequently depressed by the early stages of a Forbush decrease.

If another flare in the sunspot group were to generate cosmic radiation, the radial magnetic field would define an easy route for part of the distance to the earth. For the remainder of their journey to the earth, however, the particles would have to diffuse through the strong, disordered fields associated with the Forbush decrease. This diffusion would delay the arrival of the radiation at the earth and would lengthen the time scale of the increasing intensity phase of the flare effect. The relatively strong field, and its chaotic nature, would result in a mean free path for scattering which would be shorter than that in the general disordered field. Consequently, the time required for the radiation to diffuse to the vicinity of the earth and the time scale of the increasing intensity phase could be considerably greater than in case B. Furthermore, the radiation would appear to reach isotropy very rapidly.

In Table 2 the seven largest flare effects observed by ground-level detectors have been listed, together with the position on the solar disk at which the flare occurred and the prevailing terrestrial cosmic-ray conditions at the time. On the basis of these data, we have determined which of the previously considered cases fits the actual conditions most closely. For example, the July 1959 event occurred when the flare-producing center was about 30° from c.m.p., and soon after a Forbush decrease, and hence fitted case C. We wish to emphasize that the class to which a flare effect was assigned was determined solely by the conditions existing in the solar system prior to the occurrence of the solar flare.

Comparing the last two columns of Table 2, assigned class and relative time scale, we find good agreement with the predictions, for it can be seen that the four events with the shortest rise times were assigned to class A, the two events with the next longest rise times to class B, and the event with the longest time scale to class C. In addition, it was shown in section 1 that impact zones were not observed during the July 1959 event, an observation in accord with the predictions for class C.[2]

The rise times of the seven largest flare effects are therefore in good agreement with the theoretical model. Recently it has been shown [Reid and Leinbach, 1959] that radio techniques can be used to detect the arrival at the earth of cosmic rays produced in solar flares. This method reveals that a relatively large number of flares produce some cosmic radiation, and therefore a further test of the theoretical model is possible. To this end, Figure 10 shows the delay observed between the occurrence of a flare and the first indication of the arrival of cosmic radiation at the earth, plotted against the position on the solar disk at which the flare was observed (data derived from Reid and Leinbach, [1959]). It can be seen that the delays tend to be greatest for flares on the eastern half of the solar disk and least for flares near the western limb. With regard to the four events indicated by the open circles, their great deviation from the region occupied by the remainder of the points makes them somewhat suspect. The abnormally long delay of the September 2, 1957, event might possibly be due to the fact that it occurred when the terrestrial cosmic-ray intensity was greatly depressed by a Forbush decrease (case C), but no such explanation can be given for the other three anomalous events.

Fifty per cent decay time. It was demonstrated in section 3 that the rise and 50 per cent decay times vary from event to event by approximately the same factor. Clearly, two separate mechanisms, one to explain the rise time and the other to explain the decay time, would not, in general, predict such a behavior. The most natural explanation of the observed fact would be that a single feature of interplanetary space determines the time scales of both the rising and the decaying intensity phases of a flare effect.

Consider case A of the model we have been examining. The motion of cosmic-ray particles through a radial field in which there are irregularities approximates roughly to a random walk in which the motions perpendicular to the lines of force are eliminated by spiraling about the lines of force. In cases B and C the particle motion also approximates to a diffusion process. Simplifying the problem by considering it to be diffusion in a semi-infinite, one-dimensional medium [Carslaw and Jaeger, 1947], the cosmic-ray intensity at a distance x from the sun, at time t after injection, would be proportional to $(kt)^{-\frac{1}{2}} \exp(-x^2/4kt)$, where k is the diffusion coefficient in the direction of the lines of force. Since k and t only appear as the product kt, the shape of this intensity against time curve is not affected by the value of k. But the rise and 50 per cent decay times are individually changed by the same factor: thus, if t_1 is the time giving maximum intensity when $k = k_1$ then, for $k = k_2$, the maximum intensity occurs at $t_2 = k_1 t_1/k_2$.

The above very naive treatment, though predicting the observed correlation between the changes in the rise and 50 per cent decay times, fails in that it predicts a $t^{-\frac{1}{2}}$ dependence of the intensity during the decreasing intensity phase, whereas a decay going as $t^{-3/2}$ has been observed [Meyer, Parker, and Simpson, 1956]. A more rigorous treatment of the actual three-dimensional problem might remove this difficulty and consequently provide a good confirmation of the correctness of the proposed model.

Concluding remarks. Without invoking any models, certain properties of the solar flare effect have been demonstrated in this paper. Although the model we have considered may prove to be incorrect, these experimental facts appear to be well founded and must consequently be explained by any satisfactory theory. In summary, the experimental facts are:

1. The time scale of the solar effect is a highly variable quantity, varying by a factor as great as 36 from event to event.

2. The ratio of the rise time of a solar flare increase to the 50 per cent decay time is roughly constant. That is, the shape of the intensity against time curve is roughly the same for all flares effects.

3. The flares resulting in the four flare effects with the shortest time scales occurred on the western solar limb; those with the longest time scales occurred near the center of the solar disk.

4. No impact zones were observed at the time of the flare effect that showed the greatest time scale.

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ACKNOWLEDGMENTS

We are grateful to the many investigators who supplied data obtained during July 1959. In particular, we desire to thank the Astronomer Royal, Dr. H. Carmichael, Dr. A. G. Fenton, Dr. J. A. Lockwood, Dr. P. L. Marsden, Dr. B. Meyer, Dr. M. A. Pomerantz, Dr. D. C. Rose, Dr. A. E. Sandstrom, Prof. J. A. Simpson, and Prof. B. Trumpy for the data presented in this paper. We should like to thank Prof. B. Rossi for discussion during the course of this work. R. A. R. Palmeira was supported by a fellowship from Conselho Nacional de Pesquisas (Brazil). K. G. McCracken was sponsored by the World Wide Research Scientists project of the U. S. Government (International Co-operation Administration).

This work is supported in part through AEC contract AT(30-1)-2098, by funds provided by the U.S. Atomic Energy Commission, the Office of Naval Research, and the Air Force Office of Scientific Research; and in part, also, by a grant from the National Science Foundation.

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1. Note added in proof. The result that MIT lay in the background zone during the May 4, 1960 event was based on the assumption of an apparent source in the direction of the sun. However, analysis of the observations made at many points on the earth's surface has led to the conclusion that MIT did in fact lie in the 9 o'clock (primary) impact zone, and that the apparent source of solar cosmic radiation was displaced from the direction to the sun by a considerable angle (approximately 70° to the west). This result does not alter the conclusions of this paper for, allowing a factor of two for the ratio of the times scales applicable to the background, and primary impact zones, it is still true that the May 4, 1960 event had the shortest time scale of any of the observed flare effects.

2. Note added in proof. For class A of our model, the shortest time scales would occur when the magnetic field contained few scattering centers. This would also result in the radiation arriving at the earth being well collimated along the magnetic lines of force and, consequently, impact zones would be well defined. A recent analysis has shown that during the May 4, 1960 flare event, impact zones were very well defined, in good agreement with theory. However, the analysis has suggested that at the time of the May 4 event, the lines of force in the ordered field were not radial but inclined to the sun-earth line by about 70° to the west in the plane of the ecliptic.

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Table 1

Details of the Anomalous Cosmic Ray Events Observed at High Latitude Stations during 17th July, 1959

Station	Cut off Rigidity (B.V.)	Anomalous Event Seen	Amplitude (%)	Onset Time (G.M.T.)
Thule (a)	< 0.10	Yes	5.0	01 - 02
Resolute	< 0.10	Yes	5.0	about 04
Churchill	0.11	Yes	5.0	02 - 04
Mawson	0.75	Yes	5.0	03 - 04
Bergen	0.94	Yes	4.7	about 04
Ottawa	0.96	Yes	4.0	03 - 05
Deep River	0.97	Yes	4.5	01 - 02
Sulphur Mt.	0.98	Yes	11.0	01 - 02
Mt. Washington	1.03	Yes	4.5	02 - 04
Ellsworth (b)	1.13	Yes	4.5	02 - 04
Uppsala	1.15	No		
Chicago	1.54	No		
Hobart	1.70	No		
Leeds	1.77	No		
Herstmonceux	2.25	No		
Gottingen	2.42	No		

(a) Wilson, B. G., D. C. Rose, and M. A. Pomerantz, Can. J. Phys. 38, 328-331 (1960).

(b) Roederer, J. G., O. R. Santochi, J. C. Anderson, J. M. Cardoso, and J. R. Manzano, to be published.

Table 2

Details of the seven largest cosmic ray increases. The time scales are those derived from the rise times, and are relative to that of the May 1960 event.

Event	Position of Flare on Solar Disc	Cosmic Ray Conditions (Period since previous Forbush decrease)	Assigned Class	Time Scale
May 1960	90° W	5 days	A	1
February 1956	80° W	5 days	A	4
November 1949	70° W	- - -	A	6
March 1942	90° W	7 days	A	7
February 1942	4° E	- - -	B	13
July 1946	15° E	- - -	B	17
July 1959	30° W	1 1/2 days	C	36

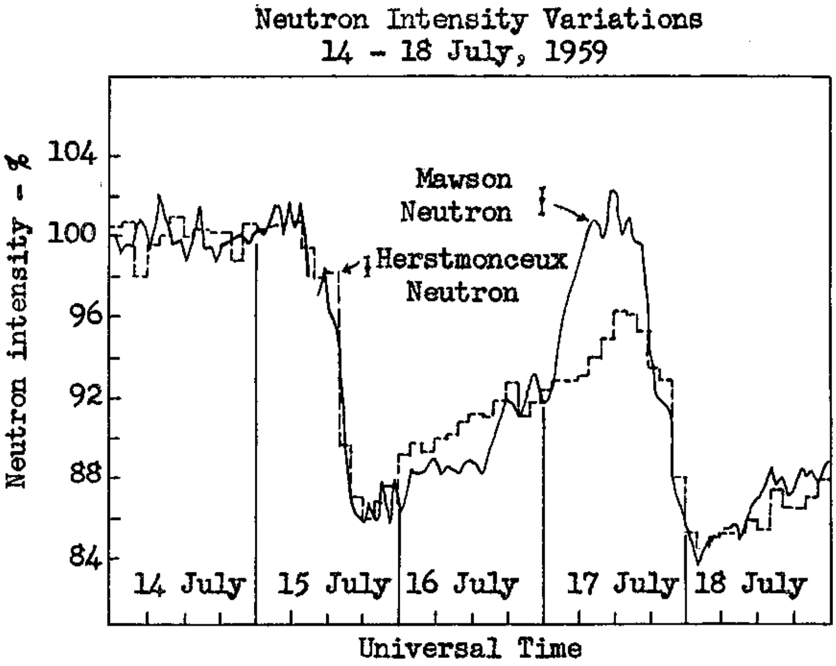

Fig. 1. Neutron monitor data from Mawson and Herstmonceux for the period July 14-18, 1959

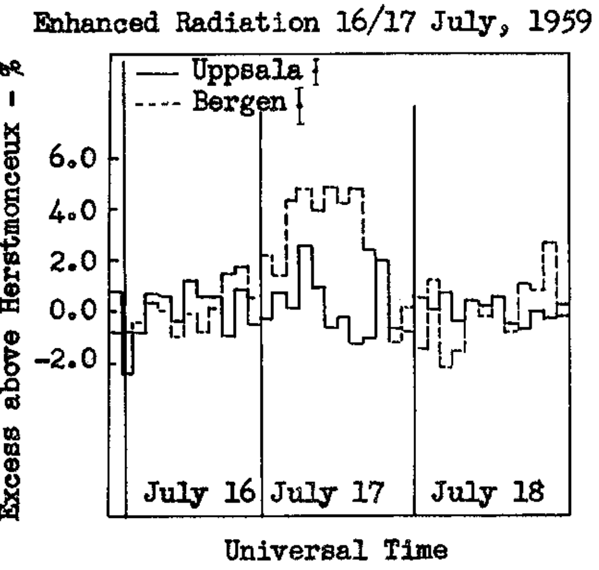

Fig. 2. Enhanced radiation at Bergen and Uppsala measured as an excess above the cosmic-ray back-ground as measured at Herstmonceux.

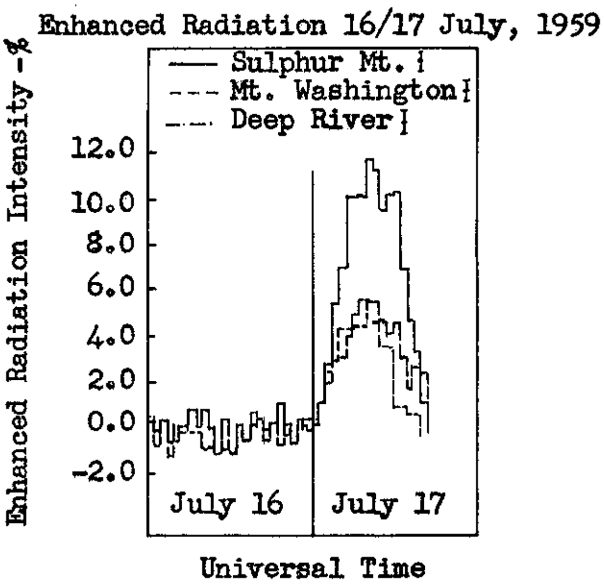

Fig. 3. Enhanced radiation at Sulphur Mt., Mt. Washington, and Deep River measured as an excess above the cosmic-ray back-ground estimated for each station.

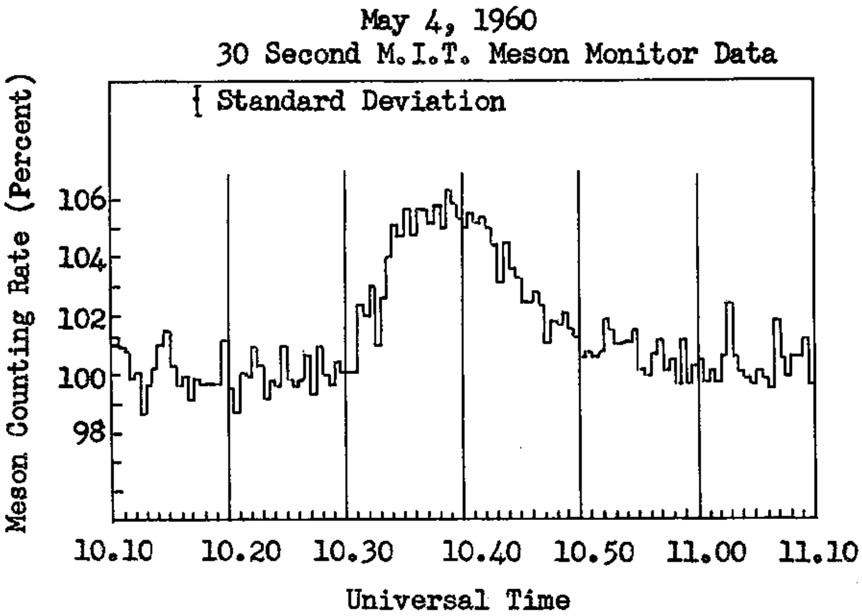

Fig. 4. The solar flare cosmic-ray increase on May 4, 1960, as observed by the MIT meson detector

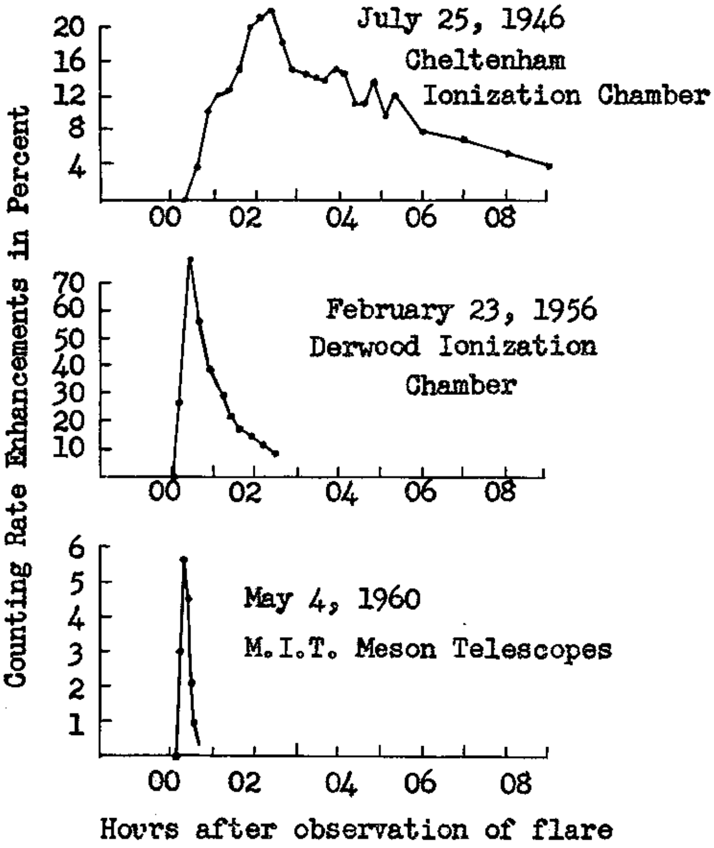

Fig. 5. Meson data for the solar flare cosmic-ray increases of July 1946, February 1956, and May 1960.

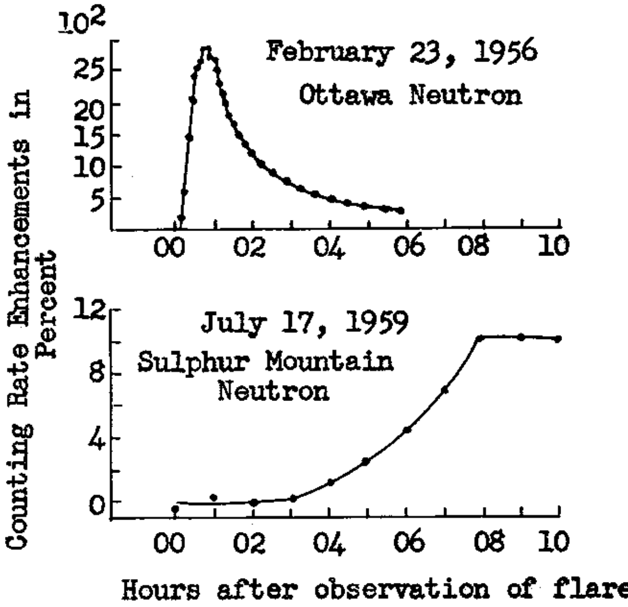

Fig. 6. Neutron data for the solar flare cosmic-ray increases of February 1956 and July 1959.

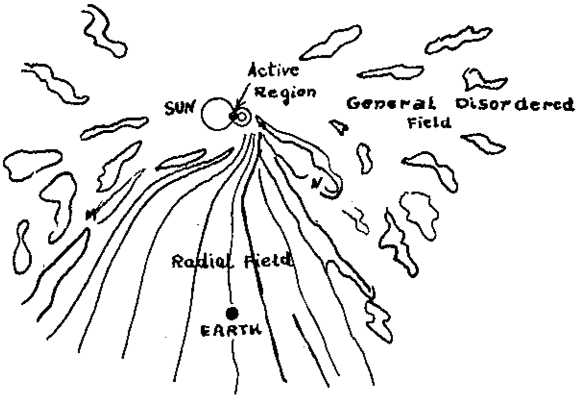

Fig. 7. Case A of the proposed model for the magnetic fields in the sun-earth region. In region N, matter ejected by the sun is stretching out the solar magnetic fields, thereby forming an essentially radial field. In region M, instabilities are destroying the radial field.

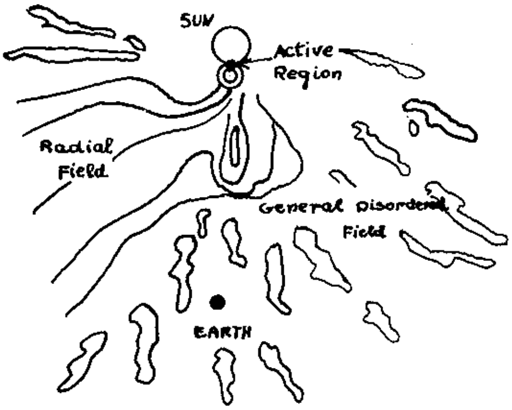

Fig. 8. Case B of the proposed model for the magnetic fields in the sun-earth region.

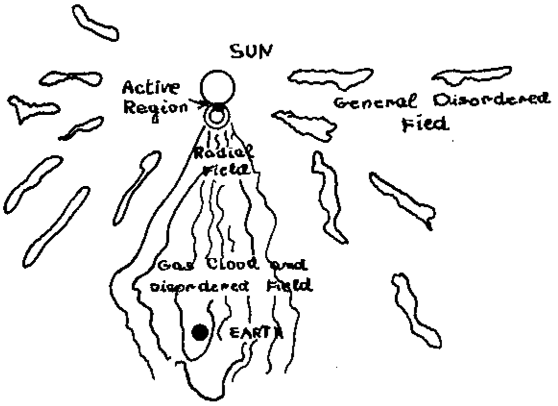

Fig. 9. Case C of the proposed model for the magnetic fields in the sun-earth region.

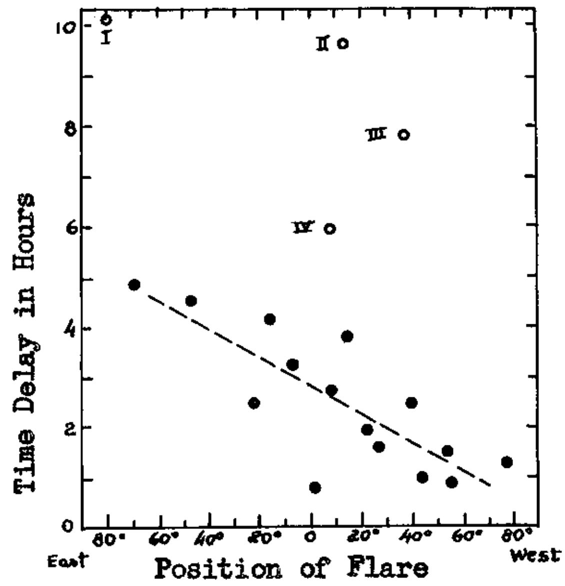

Fig. 10. The time delay between the visual observation of a flare and the start of the subsequent polar-cap blackout, plotted against the position of the flare on the solar disk. The four events represented by the open circles occurred on the following dates: I, March 23, 1958; II, February 10, 1958; III, September 2, 1957; IV, September 21, 1957.