the two sets of data compatible. They point out, however, that recent theoretical attempts[8] to motivate a particular connection between the two processes (for example, by symmetry arguments) and therefore eliminate the remaining ambiguities, are in conflict with the experimental results.

The foregoing discussion is based on the assumption that the decay process is $\mu \rightarrow e+\nu+\nu$, where the two neutrinos may be either identical or distinguishable (for $\rho<0.75$ either case is possible). A finite rest mass for the neutral particles would be very hard to detect, since the difference between the observed and expected maximum energies, $\delta=W_0-W_{\text{observed}}$, cannot be measured with much precision unless one has an *a priori* knowledge of ρ; and even a small δ leads to a large value of the mass of the neutrals: $M_{\text{neutrals}}=(2M_\mu\delta/c^2)^{\frac{1}{2}}$. Thus an M_{neutrals} as large as 20 electron masses would go undetected.

V. SUMMARY

A reexamination of the experimental problems relating to a determination of the energy spectrum of positrons from μ^+ decay has shown that the result is critically sensitive to the combination of finite resolution and errors in the energy scale. Our finding is that the spectrum has a large intercept at the upper energy limit; in terms of Michel's parameter, $\rho=0.50\pm0.13$, where the standard deviation includes estimates of the systematic errors.

The often-mentioned striking similarity between μ decay and beta decay is not diminished by this result; however, no satisfactory answer is available to the question of the nature of the relation between the two processes.

ACKNOWLEDGMENTS

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Cosmic Radiation Intensity-Time Variations and Their Origin. IV. Increases Associated with Solar Flares*†

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The distribution on the earth of the impact points for particles of magnetic rigidities 1 to 10 Bv, which originally approach the earth from the direction of the sun, is derived, using principally the published results of numerical integrations of cosmic-ray orbits and model experiments on the motion of charged particles in a dipole magnetic field. Three impact zones for such particles are discussed. Two of these zones include only a small range of local times, and for the special case of the sun in the plane of the geomagnetic equator, are centered near 4 A.M. and 9 A.M. The third zone has no strong local time dependence. Assuming the source of charged particles to subtend a finite angle at the earth, the relative counting rates for detectors in the three zones are estimated. The counting rate due to particles from the sun is expected to be three to seven times larger in the morning zones than in the background, or nonlocal-time-dependent, zone. The morning impact zones are shown to have a seasonal motion of several hours in local time.

Reports of observations made during four large increases of cosmic-ray intensity at the times of solar flares are compared with the distribution predicted for particles from the sun. The observed increases agree with the predicted distribution and counting rate except at very high latitudes on the earth. A possible reason for this discrepancy is suggested.

Cosmic-ray data from the Climax neutron detectors are analyzed for possible increases associated with small solar flares. An increase of ≈ 1 percent is found for flares occurring when the detector is in a morning impact zone for particles from the sun. No increase of more than ≈ 0.3 percent is found for flares occurring when the detector is not in these zones. The mean daily cycle of cosmic-ray intensity is also shown to depend on the rate of flares occurring on the sun. The intensity curve is peaked during the early morning hours for flare periods relative to periods in which few or no flares occurred, in agreement with the supposition that new particles approach the earth from the direction of the sun at the times of flares.

I. INTRODUCTION

A. Time Variations of Cosmic Rays

It has long been known that the cosmic-ray intensity varies with time. Some terrestrial phenomena can be related to the cosmic-ray variations and that part of the variations eliminated (as in the case of the barometric pressure), but after carefully correcting for atmospheric effects there remains to date significant varia-

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tions which are not known to be related to any purely terrestrial phenomena. These residual variations, which may well be due to variations of the primary cosmic rays, can by their periodicities and their statistical associations with astronomical phenomena, give clues to the origin of the cosmic rays, or at least to the solar and other influences on cosmic rays.

In this paper some variations which can be related to visually observed occurrences on the sun will be discussed.

B. Large Solar Flare Effects

On four occasions during the last twelve years the cosmic-ray intensity has been observed[1] to increase sharply for an hour or two following the beginning on the sun of large chromospheric eruptions. In three cases the "solar flare" was actually seen; in all four cases radio fadeouts of the type associated with solar flares were recorded. The cosmic-ray increase began in one case 15 minutes after the beginning of the flare and fadeout. In the other cases the time was perhaps as much as an hour.

A typical solar flare[2–4] is a region in the chromosphere having a projected area of a few hundred millionths of the visible disk of the sun and which emits light in the hydrogen and other lines with a greater intensity than the steady background of the solar disk. Flares usually start suddenly, reach maximum intensity in a few minutes, and disappear within an hour. Many variations from the typical behavior have been observed, for example, "pulsing" flares with repeated maxima of intensity, multiple flares (several separate but simultaneous bright spots), flares lasting several hours, flares reaching maximum intensity an hour or more after their beginning, flares lasting less than five minutes, etc. Observatories usually report the times of beginning, maximum, and end of the flare, the area, the intensity in the center of the H_α line, and the line width of the H_α line. Flares are also given an "importance" rating on a scale of 1,2,3 with sometimes + or − added. This scale is based mainly on area (area between zero and 300 millionths = importance 1, 300 to 750 = importance 2, above 750 = importance 3), but the limits are not rigid and the rating is frequently adjusted if the flare is exceptionally bright or weak for its area. The importance ratings are thus a somewhat subjective measure, but they serve to roughly rank flares as to size and intensity.

The three flares observed at the times of three of the cosmic-ray increases were all larger in area, of higher intensity, and the width of the H_α line was greater than for the average flare. The flare observations for these three events are summarized in Table I.[3,5–11]

The magnitude of the cosmic-ray increase in each of the large events depended on the latitude and longitude of the observing station. None of the increases was observed (with amplitude >2 percent) at Huancayo, near the geomagnetic equator. An ionization chamber at Teloyucan, Mexico (geomagnetic latitude $\lambda=30°$) did not show the increase for the one event occurring during its operation. These facts indicate that the new particles arriving at the top of the atmosphere were charged and that only a small percentage of them had magnetic rigidities (pc/Ze) of more than the cutoff at $\lambda=30°$ (≈ 10 Bv).

For one event a local production neutron monitor and a counter telescope at the same location observed the increase. The counter telescope recorded[12] an increase of ≈ 10 percent while the neutron rate[13] was ≈ 550 percent high. These observations indicate[13] that the new particles have for the most part rigidities of less than 5 Bv.

The close time connection between the solar flare and the cosmic-ray increase in each of these events and the large magnitude of the increases leave no doubt that additional particles are arriving from the region of the sun at these times. We will examine here the question of whether a simple picture—positively charged particles of rigidities 1 to 10 Bv leaving the region of the sun and moving toward the earth under the influence *only* of the earth's dipole magnetic field—can account for the observed facts. Also, using the results of such an analysis, the cosmic-ray intensity recorded by a local production neutron monitor will be examined for increases associated with small solar flares.

C. Related Work

Elliot[14] and Biermann[15] have, in two recent review articles, summarized some of the observations of the four large solar flare effects. Previously an article by Ehmert[16] discussed three of the increases in terms of particles coming from the sun. Ehmert shows, using a few orbits of cosmic-ray particles integrated by Störmer,

[1] Forbush, Stinchcomb, and Schein, Phys. Rev. **79**, 501 (1950).
[2] R. G. Giovanelli, Astrophys. J. **91**, 334 (1940).
[3] M. A. Ellison, Monthly Notices Roy. Astron. Soc. **109**, 3 (1949).
[4] R. S. Richardson, Astrophys. J. **114**, 356 (1951).
[5] International Astronomical Union, *Quarterly Bulletin on Solar Activity* (Eidgen. Sternwarte, Zurich, 1942–49), Nos. 57–88.
[6] H. W. Newton, Observatory **64**, 260 (1942).
[7] M. A. Ellison, Nature **158**, 450 (1946).
[8] R. Muller *et al.*, J. Atm. and Terrest. Phys. **1**, 37 (1950).
[9] A. C. B. Lovell and C. J. Banwell, Nature **158**, 517 (1946).
[10] M. A. Ellison and M. Conway, Observatory **70**, 77 (1950).
[11] Central Radio Propagation Laboratory, "Ionospheric Data," (Natl. Bur. Standards, Washington, D. C., 1949–1953), Nos. F-64 to F-108.
[12] H. Elliot, as reported by E. P. George, *Progress in Cosmic Ray Physics* (North Holland Publishing Company, Amsterdam, 1952), p. 422.
[13] N. Adams and H. J. J. Braddick, Z. Naturforsch. **6a**, 592 (1951).
[14] H. Elliot, *Progress in Cosmic Ray Physics* (North Holland Publishing Company, Amsterdam, 1952), Chap. VIII.
[15] L. Biermann, *Kosmische Strahlung* (Springer-Verlag, Berlin, 1953).
[16] A. Ehmert, Z. Naturforsch. **3a**, 264 (1948).

that the distribution of the increase of 28 February 1942, which was observed in America but not in Germany, indicates that positive particles are arriving from the direction of the sun. Ehmert further examines his counter telescope data for obvious increases lasting a few hours and is able to relate some of them to flares. Clay[17] in Holland also finds many increases and is also able to relate some of them to solar flares.

Schlüter[18] has integrated twenty trajectories of cosmic-ray particles using the method originated by Störmer, in which particles are assumed to be initially moving along a line parallel to the sun-earth line. He concludes from an examination of the impact points on the earth of these orbits that for positive particles from the sun there should be a sharp maximum near 0900 local time, and he regards the observation of one of the large increases in Germany in the afternoon as in disagreement with the theory. Using Störmer's *null-bahnen*, i.e., orbits which would pass through the dipole if extended, as representative of all orbits striking the earth, Schlüter discusses the seasonal change in the impact points on the earth for particles from the sun, as well as the existence of forbidden zones near the poles of the earth for solar particles. The observation of the increases at Godhavn, Greenland ($\lambda = 80°$) he also regards as in disagreement with the theory, since this station lies in such a forbidden region.

II. IMPACT POINTS AND TRAJECTORIES

A. Known Orbits

In order to discuss the distribution on the earth of the solar-flare-connected increases the answer to the following question is sought: If particles leave a point source far from the earth and travel in straight lines until influenced by the earth's magnetic field, where will they strike the earth? The magnetic field of the earth can be represented to a good approximation by the field of a dipole near the center of the earth,[19] and the equations of motion for a charged particle moving in a dipole magnetic field are well known,[20] but no general solution to these equations has been found. However, a partial answer to the above question can be found in terms of numerical integrations of particular trajectories and by model experiments.

Trajectories of charged particles in a dipole magnetic field have been integrated by Störmer,[21] Dwight,[22] and Schlüter,[18] and model experiments have been performed by Malmfors[23] and Brunberg.[24] In the case of the orbits integrated by Dwight and some of the orbits integrated by Störmer, the computation was carried out by considering the path of a negatively charged particle projected vertically away from the earth. A positive particle will follow the same path when approaching the earth. This method of integration insures that the final orbits will be of interest in connection with a cosmic-ray detector deep in the atmosphere, since vertically incident particles are the most efficient in producing counts in such a detector.

In the model experiments electrons were projected away from a uniformly magnetized sphere and the direction of motion of the electrons when far from the sphere measured. Most of the orbits so investigated were vertically "incident" at the sphere. In both the integrations and the model experiments the results are in the form of particular trajectories or impact points on the earth, so it is necessary in order to get a more complete picture to interpolate between the known orbits and, to some extent, to extrapolate beyond the known orbits.

For our purposes an orbit is sufficiently well described by four angles and the rigidity of the particle. The four angles are λ, the latitude of incidence on the earth; λ_s, the latitude of the particle when very far from the earth (Dwight's "latitude of the asymptotic velocity vector," or, more simply, source latitude); β_s, longitude

TABLE I. Observations of three large solar flares.

Date	Observatory	Time of Obs. (UT)	Importance	References
28 Feb. 1942	Arcetri	1100	3	a
	Sherborne	1242–1522	3	a,b
	Greenwich	1415–1505	2	a,c
		Radio fadeout at 1107		c
25 July 1946	Meudon	1504–1830	3+	a
	Sherborne	1513–1527	2	a
	Zurich	1610–1800	3+	a
	Cambridge	1612–1740	3	a
	Sherborne	1615–1810	3+	a,d
	Mt. Wilson	1621–2030	3+	a
		Radio fadeout at 1615		d
		Radio noise burst at 1624		e
19 Nov. 1949	Wendelstein	1029–1119	3	a,f
	Edinburgh	1030–1209	3+	a,g
	Greenwich	1037–1130	3	a
	Ondrejov	1037–1057	2+	a
		Radio fadeout at 1030		f,h
		Solar flare effect in magnetogram		f

[a] See reference 5.
[b] See reference 3.
[c] See reference 6.
[d] See reference 7.
[e] See reference 9.
[f] See reference 8.
[g] See reference 10.
[h] See reference 11.

[17] J. Clay, Proc. Koninkl. Ned. Akad. Wetenschap. **52**, 899 (1949).
[18] A. Schlüter, Z. Naturforsch. **6a**, 613 (1951).
[19] S. Chapman and J. Bartels, *Geomagnetism* (Clarendon Press, Oxford, 1940), Chap. XVIII.
[20] C. Störmer, Z. Astrophys. **3**, 31 (1931).
[21] C. Störmer, Astrophysica Norv. **1**, 1 (1934); *Book of the Opening* (Rice Institute, Houston, 1912), Vol. 3.
[22] K. Dwight, Phys. Rev. **78**, 40 (1950).
[23] K. G. Malmfors, Arkiv. Mat. Astron. Fysik. **A32**, No. 8 (1945).
[24] E. Brunberg, J. Geophys. Research **58**, 272 (1953).

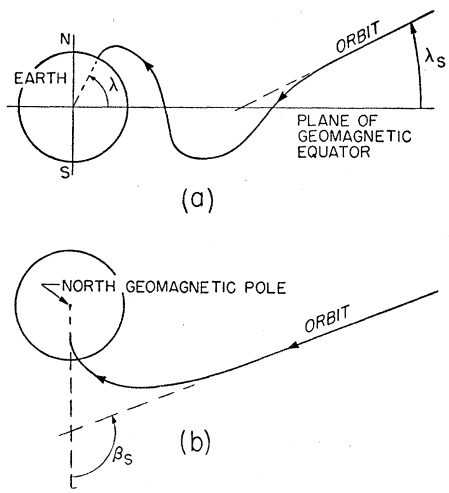

FIG. 1. Angles used to describe cosmic-ray orbits. (a) Orbit in the meridian plane which moves with the particle, showing the latitude of incidence λ and the latitude of the asymptotic velocity vector λ_s. (b) Projection of the orbit on the equatorial plane. Angle β_s is the longitude of impact relative to the source. Orbit shown is one of the 0400 group of paths.

of the source relative to the point of incidence (longitude of the asymptotic velocity vector); and the zenith angle of incidence. The latitudes and longitude, which are shown in Fig. 1, are in geomagnetic coordinates; these may be converted to geographic coordinates by formula or by graphs given by McNish.[25]

As a check on the accuracy of the numerical integrations and as an indication of the reliability of the model experiments, the results of the different workers can be compared where their orbits overlap. For example, in Fig. 2 is plotted, for particles of 6-Bv rigidity, the latitude of impact on the earth as a function of the latitude of the source. Points show integrated orbits[26] by Störmer and Dwight and model experiment orbits by Malmfors. Such comparisons indicate that the agreement is always within a degree or two for the integrated orbits and within five degrees for the measured orbits. However, Dwight's *extrapolations* to lower rigidities (2 and 1 Bv) differ by as much as 8 or 9 degrees in the asymptotic latitude from the model experiments of Malmfors. Therefore, a vertically incident orbit of 2-Bv rigidity was numerically integrated, and it was found that the extrapolations in reference 22 are in error and the model experiment orbits in this rigidity range essentially correct. The angles describing the orbit integrated by the present author are $\lambda = 60°$, $\lambda_s = -20.7°$, $\beta_s = 78.4°$.

New curves have therefore been constructed, similar to Figs. 7 and 8 in reference 22, showing the behavior of the impact points on the earth as a function of rigidity and of the latitude of the source. These curves are shown in Figs. 3 and 4. In constructing these curves all of the available orbits (about 80 in all) which arrive vertically have been employed, as well as some of Störmer's *nullbahnen*. The latter are near vertical incidence for the rigidities considered here.

Figure 3 is simply an extended and corrected version of the similar graph in Dwight's paper. Figure 4, however, is somewhat different from the corresponding graph in reference 22. In that paper is plotted the longitude of the source against the latitude of incidence. Here we plot longitude against latitude of source. In the rigidity range 1 to 10 Bv such curves do not depend strongly on rigidity and form a narrow band, only about an hour wide. This band, essentially the envelope of the 1- to 10-Bv curves, is what is shown in Fig. 4. In this paper we will always be interested in impact "zones" on the earth for particles from the sun, and these zones will be several hours wide. Hence a plot such as Fig. 4, which does not have rigidity as a parameter, is useful in easily constructing impact zones for various situations.

To determine the impact point on the earth for a particle of a certain rigidity leaving a point source far from the earth one notes in Fig. 3 the intersection of the line representing the latitude of the source with the curve of orbits of the desired rigidity. The abscissas of the intersections give the latitudes on the earth of possible impact points. Then using these latitudes and Fig. 7 of Dwight's paper, or using Fig. 4 of this paper, one gets the longitudes, relative to the source, of the impact points.

In Fig. 5 are plotted as smooth curves the impact points in the northern hemisphere for particles leaving a point source far from the earth and in the plane of the geomagnetic equator, and arriving at the earth with vertical or near vertical incidence. Also shown are the impact points of some orbits integrated by Schlüter which arrive with large zenith angles. The line attached

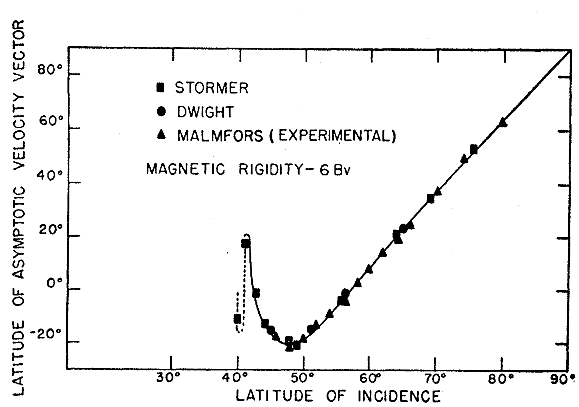

FIG. 2. Example of comparison of the cosmic-ray orbits derived by different workers. The Störmer and the Dwight orbits were obtained from numerical integrations of the equations of motion; the Malmfors orbits are from model experiments.

[25] A. G. McNish, Terrestrial Magnetism and Atm. Elec. 41, 37 (1936).

[26] It is necessary, when making these comparisons, to reduce all of the orbits given by the different workers to a common value of dipole moment for the earth. Störmer and Schlüter used an older value (8.4×10^{25} gauss-cm^3), whereas the others used 8.1×10^{25}.

to each Schlüter orbit in Fig. 5 is a projection on the earth's surface of the velocity vector of the particle at the time of arrival. The length marked "E" in the figure gives the reference length of the velocity vector. Later we wish to identify the source with the sun, so in Fig. 5 the lower longitude scale is marked in units of hours local time, the source being at local noon.

B. Groups of Impact Points

In Fig. 5 one sees the division of the impact points into three groups. The late morning group ($\approx$0900 local time) represents orbits that remain north of the equatorial plane; the early morning ($\approx$0400) orbits pass once through the equatorial plane; the late evening group ($\approx$2000) contains orbits passing twice through this plane, and so on. The three curves in Fig. 5 do not exhaust the possible impact points for vertically incident particles in the 1- to 10-Bv range. Störmer[27] points out that one can find an infinite number of families of impact points on the earth by considering orbits with increasingly more complicated paths near the earth. This can be seen in Fig. 4, where a line representing a particular source latitude, within certain limits, has an infinite number of intersections with the impact curve, since, as Störmer points out, this curve continues to oscillate back and forth through $\lambda_s=0$ for increasing longitude. These groups of impact points, not shown in Fig. 5, have latitude distributions similar to the 2000 group.

For the purpose of constructing Fig. 5 the source was considered to be in the plane of the geomagnetic equator. If the source is at some angle, λ_s, away from the plane of the geomagnetic equator an impact point plot can easily be made using Figs. 3 and 4. As the source is moved south of the equator the two morning groups of impact points in the northern hemisphere move

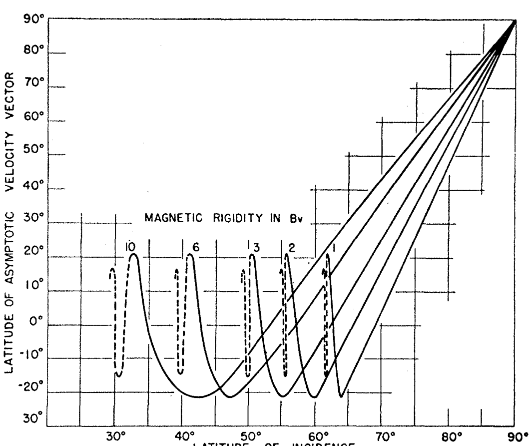

FIG. 3. Geomagnetic latitude of impact on the earth of particles arriving vertically with magnetic rigidities of 1–10 Bv as a function of the geomagnetic latitude of the source.

[27] C. Störmer, Astrophys. Norv. **1**, 115 (1934); Terrestrial Magnetism and Atm. Elec. **22**, 23 (1917).

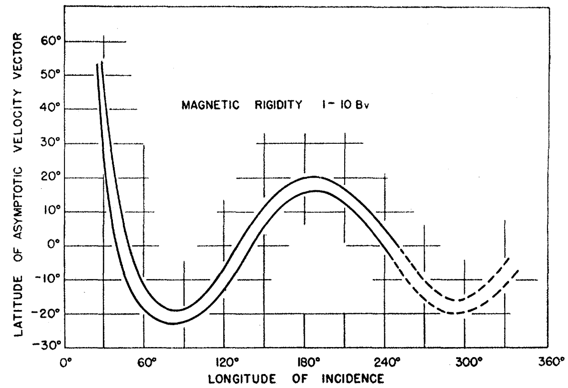

FIG. 4. Geomagnetic longitude of impact on the earth of particles with magnetic rigidities of 1–10 Bv. Curves shown are the envelope of the individual curves for each rigidity.

closer together, and the evening group moves toward earlier evening. The motion is reversed for the source north of the equator. When the source is identified with the sun this motion of the impact points or zones will appear as a seasonal effect.

Instead of considering only particles coming from a point source, it is perhaps more realistic to consider that the source of charged particles (the sun) subtends a finite angle at the earth, perhaps larger than the visible sun. Strong local magnetic fields are known to exist in sunspots, and particles of rigidities below 10 Bv would be appreciably deflected by these fields, even when several sun's radii away from the spot. This assumes that the magnetic fields of spots are not "shielded" by the high conductivity gases of the sun. However, so little is known of the magnetic (and electric) fields in the solar corona that we will just keep in mind that we are considering a finite source and later see if the experimental data place some limits on the size of the source.

The effect of a finite particle source on the impact point diagram can be seen in terms of the change in the impact points as the (point) source moves off the equator, which was discussed above. The rate of change of latitude of impact for a 3-Bv particle as the source latitude changes (see Fig. 3) is 0.3 degree per degree for the 0900 impact point, -0.1 for the 0400 point, and 0.0 for all other points. The rates of longitude change with change of source latitude from Fig. 4 are, respectively (longitude measured in local time), -0.07, $+0.12$, and -0.14 hr/degree. Thus a particle source of finite size would produce impact *zones* instead of the lines of impact points as shown in Fig. 5. These zones are about an hour wide for a source 10° in diameter. The 0900 zone has the least spread, while the 2000 zone, and presumably all of the similar zones, are the widest. Since each of the latter is at a larger longitude than the preceding one, this infinity of impact zones will fill the whole range of local times between the latitudes of 25° to 60° for 1- to 10-Bv particles. We are

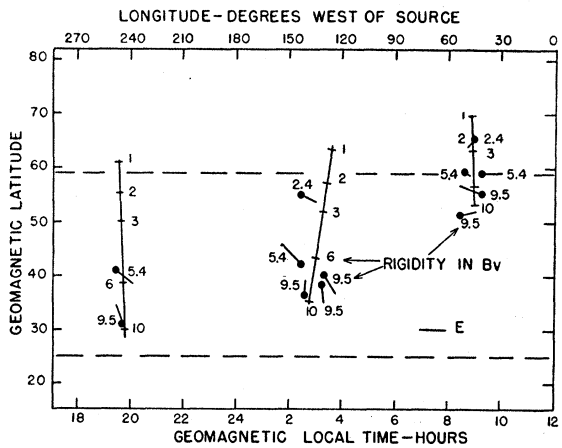

FIG. 5. Impact points on the earth for particles approaching in the equatorial plane. The solid lines show the impact points for particles arriving vertically. The circles give the impact points for some orbits which arrive with large zenith angles. The line attached to each of the latter shows the azimuth and zenith angles of arrival. This line is the projection on the earth's surface of the velocity vector, length "E," at the time of arrival. The longitude scale in hours local time assumes the source of particles to be at noon local time. The dashed lines indicate the band of latitudes which is filled with impact points of 1- to 10-Bv particles.

left then with only three distinct zones—the 0900, the 0400, and a background zone covering all local times.

C. Intensity in Impact Zones

The methods used in selecting the initial conditions for the numerically integrated orbits and the agreement with the model experiment orbits insure that the orbits are not "singular," i.e., there are similar orbits infinitely near to the computed orbits. An application of Liouville's theorem shows, then, that the intensity of particles in a small rigidity range striking a small area around the impact point must be the same as the intensity at the source. An infinitesimally small detector with a small angular aperture would receive (if outside the earth's atmosphere) the source intensity if the detector happened to be at an impact point and if the aperture opened along the orbit. The measured counting rate R_m for a real detector in the atmosphere thus depends on the fraction of the aperture which is filled with orbits from the source, as well as the zenith angles of the allowed directions and the rigidity range which can reach the detector.

The counting rate $R_m(P)$ due to particles of rigidity P is given by

$$R_m(P)=\sum\int I_s(P)S(x,P,\theta,\phi)\,\sin\theta d\theta d\phi, \qquad (1)$$

where $I_s(P)$ is the intensity near the source, x is the atmospheric depth, $S(x,P,\theta,\phi)$ is the yield function[28] appropriate for the detector considered, and θ and ϕ are the zenith and azimuth angles describing the direction of arrival of the particle. The integral is taken over all directions from which particles of rigidity P can arrive at the detector from the source. The sum is taken over all kinds of particles emitted by the source. The total measured counting rate is then given by

$$R_m=\int R_m(P)dP, \qquad (2)$$

where the integral is taken over all rigidities arriving at the detector from the source.

In order to compute the counting rate measured by a particular detector from Eqs. (1) and (2), it is necessary to know all the possible orbits connecting the sun and the detector. Since relatively few orbits are known the calculation cannot be performed, but some general conclusions concerning the relative counting rates in the different zones can be reached.

In Eq. (1) the integration is made over all directions from which particles can arrive at the detector from the sun. Malmfors[23] found in his model experiments that for the 0900 group of impact points practically the whole sky was filled with orbits from a small source. For the 0400 zone and other zones the proportion of the sky which is "allowed" is not known, but cannot be larger than for the 0900 zone. The quantity $R_m(P)$ would therefore remain constant or become smaller as we move from the 0900 zone to the 0400 zone or to the background zone.

From Eq. (2), where the integration is taken over all rigidities arriving at the detector, one expects a difference in the counting rate measured in the different zones, due to the integral being taken over different ranges of rigidity for the different zones. Two factors contribute to this range of rigidities: (1) For particles which arrive vertically the finite size of the source will cause a finite range of rigidities ΔP_f to reach a point on the earth; and (2) particles arriving with nonzero zenith angles may have a different rigidity from the vertical particles and so contribute a range, ΔP_a, to the integral. The total rigidity range will be $\Delta P_f+\Delta P_a$.

The first of these ranges may be estimated by use of Figs. 3 and 5. From Fig. 3 we get the rate of change of latitude of impact with changing source latitude, and from Fig. 5 we get the rate of change of rigidity with latitude on the earth. Then we have

$$P_f=(dP/D\lambda)(d\lambda/d\lambda_s)\Delta\lambda_s,$$

where $\Delta\lambda_s$ is the angular diameter of the source. For a point near the 3-Bv impact point $\Delta P_f=3$ Bv for the 0900 zone, 0.5 Bv for the 0400 zone, and 0.0 Bv for the background zone, if we take $\Delta\lambda_s\approx 15°$.

We may estimate the range of rigidites associated with the range of zenith angles in the following manner. Störmer has shown[27] that the asymptotic latitude of an orbit is determined almost solely by the value of the

[28] S. B. Treiman, Phys. Rev. 86, 917 (1952).

constant of the motion γ, given by

$$\gamma=-\tfrac{1}{2}[r\cos\lambda\cos x+(\cos^2\lambda)/r], \qquad (3)$$

where r is the distance of the particle from the dipole in Störmer units, λ is the latitude of the particle, and x is the angle the velocity vector of the particle makes with a vector pointing west. Stated differently, only particles of a small range of γ can hit the earth for rigidities less than 10 Bv. The values of γ appropriate to a source in the plane of the geomagnetic equator are -0.46 for the 0900 zone, -0.86 for the 0400 zone, and -0.93 for the background zone.[27] The range of γ around these values which may hit the earth with x between 0 and π seems to be[27] only ± 0.01 for the last two zones and somewhat larger for the 0900 zone.

Differentiating (3) and rearranging, we have

$$d\gamma/dx-A\cos\lambda\sin x=[(\cos^2\lambda)/A^2-\cos\lambda\cos x]dA, \qquad (4)$$

in which we have set r at the earth equal to A. Using 8.1×10^{25} gauss-cm^3 for the earth's dipole moment, the rigidity of the particle in Bv is given by $P=60A^2$. So the rate of change of rigidity with angle x is

$$dP/dx\approx(120A^4\sin x)/(A^2\cos x-\cos\lambda). \qquad (5)$$

We have neglected $d\gamma/dx$ since it is only about 1/20 as large as the other term on the left in Eq. (4). Then a formula for ΔP_a, the range of rigidities associated with a range of x from $\pi/2$ (particles arriving in the meridian plane) to $\pi/2\pm\alpha$, is conveniently obtained by assuming $A=$constant in (5) and integrating. This yields

$$\Delta P_a\approx 120A^2\ln\frac{\cos\lambda}{\cos\lambda\pm A^2\sin\alpha}.$$

For a 3-Bv particle ($A=0.224$) arriving at $\cos\lambda=0.645$ the range of rigidities for $\alpha=30°$ is 0.48 Bv. The value 30° is, of course, arbitrary, but it represents the openings of typical counter telescopes. A similar estimate of the range of rigidities due to the spread in zenith angles be obtained brom an examination of curves of asymptotic latitude as a function of azimuth and zenith angles given by Malmfors.[23]

Thus the total range of rigidities to be integrated over in Eq. (2) is about 3.5 Bv for the 0900 zone, 1.0 Bv for the 0400 zone, and 0.5 Bv for the background zone. Assuming that the rigidity spectrum of the new particles is not rapidly varying, the expected counting rates near the 3-Bv impact point in the 0900, 0400, and background zones are roughly in the ratio 7:2:1. If the allowed directions in Eq. (1) vary greatly from one zone to another these ratios may be higher. This estimate does not depend strongly on the assumption of a particular angular opening for the detector nor on a source 15° in diameter. For example, if a 30° source is assumed, the predicted ratio becomes 7:3:1. Since later it is indicated that the larger source is appropriate, we will use the later ratio.

D. Summary on Orbits

From the above discussion it is possible to predict the distribution on the earth of particles from the region of the sun if those particles are deflected only by the earth's dipole magnetic field. If the sun, while near the geomagnetic equator, emits a pulse of particles with rigidities up to 10 Bv, identical detectors scattered over the earth's surface would see the following:

1. Detectors located at latitudes less than 25° would receive no new particles.[29]
2. Detectors between 25° and 35° would see an increase in counting rate. This increase would be due to the background zone and would have no strong longitude (local time) dependence.
3. Detectors above 35° would see an increase as in 2, but in addition those detectors at local times around 0400 would see an increase about three times as large as in 2.
4. Detectors above 50° would see an increase as in 2, but detectors near 0400 or 0900 would see additional increases, up to seven times as large as in 2.

The highest latitude at which detectors would see increases, either the background type as in 2 or the strongly local time dependent increase as in 3 and 4, would depend on the lowest rigidity particles to which the detector was sensitive.

In summary, we have predicted, using a simple model, the geographical distribution of the increase in cosmic-ray intensity associated with solar flares. This distribution differs from that arrived at in earlier work[18] in several ways; most importantly, the existence of a background zone, or a band of latitudes in which the solar flare effect will have no strong local time dependence, is pointed out. Further, a rough estimate of the relative intensities in the different zones is made, and the effect of a finite source, larger than the visible sun, is considered. Earlier work[16,18] has considered only a source of particles about the size of the earth.

III. THE FOUR LARGE EVENTS

A. General

The flare observations for the four large events are summarized in Table I. In Table II is given a list of the cosmic-ray stations reporting on one or more of the large increases associated with these flares and references to the reports.

The observed increases will be compared with the predicted distribution by simply constructing an impact zone diagram appropriate for the position of the sun at the time of the increase, using Figs. 3 and 4, and marking on the plot the positions of the stations reporting on the increase. It is then possible to compare the size of the increase observed by a station with its position relative to the impact zones.

[29] The exact latitudes mentioned here are of course dependent on our assumption that there are no new particles with $P>10$ Bv.

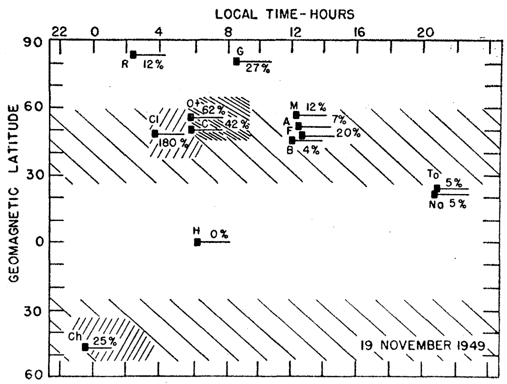

FIG. 6. Impact zones on the earth at the time of one of the large cosmic-ray increases—1100 UT on 19 November 1949. The crosshatching indicates the positions of the zones with the density of crosshatching giving roughly the relative intensities predicted for the different zones. The cosmic-ray stations are indicated by solid squares; the lines attached to each station shows its motion during the increase. Near each station is an identifying letter (see Table II) and the percentage increase observed.

The increases in the cosmic-ray intensity were quite sharp, remaining at maximum intensity for only a few minutes. Thus the size of the increase reported will depend on the length of the time intervals used for averaging the counting rate and how the intervals were related in time to the peak intensity. So, in comparing data from two observers, it is desirable to use similar time intervals similarly centered. The reports in the literature do not always make this possible.

Observations made in Germany[8] during one of the events with both counter telescopes and ion chambers indicate that the magnitude of the increase does not depend strongly on the directional properties of the detector, so observations of both directional and non-directional detectors will be used here. Only reports of charged particle detectors will be used, since the yield function for neutron detectors differs greatly from that for charged particle detectors,[30] and only one report from a neutron detector is available for these four events.

B. November 19, 1949

The latest and best known large cosmic-ray increase occurred[1,8] on November 19, 1949, following a large flare and a radio fadeout, both of which began very nearly at 1030 UT. Figure 6 shows a rectangular projection of the earth at this time, with the impact zones which are predicted as discussed above indicated by crosshatching. The density of the crosshatching indicates roughly the relative intensities to be expected in the different zones. The lack of symmetry between the zones in the northern and southern hemispheres is an example of the seasonal effect mentioned earlier. The small squares are the positions of the cosmic-ray stations reporting the increase (or its absence), with the line attached to each indicating its motion during the increase. Near each station is marked the percentage increase observed using for the most part short time intervals (5 to 15 minutes). The zones were constructed assuming a source 15° in diameter.

It is seen in Fig. 6. that there is a clear tendency for the stations in the morning impact zones to show the largest increase. In particular we note that the station in Ottawa, in the 0900 zone, recorded an increase about five times as large as that at Manchester, located in the background zone. This is consistent with the ratio seven predicted above. The 0900 and 0400 zones may be compared by using Cheltingham and Christchurch, giving a ratio of about two, consistent with the predicted 7:3. The 20 percent increase at Freiburg seems large compared with the other European observations and is probably due to the fact that this figure is derived from a very short time interval at the peak intensity. Similarly, the 7 percent at Amsterdam is a one hour average and should be made somewhat larger for comparison with other stations. Two German stations,[8] not shown in Fig. 6 for lack of room, gave increases of 15 percent for each of two similar counter telescopes and 17 percent for a shielded ion chamber. The very large increase at Climax can in part be

TABLE II. Observations of large cosmic-ray increases.

Station	Symbol used here	λ (degrees)	Altitude[a] (meters)	References 28 Feb. 1942	7 Mar. 1942	25 Jul. 1946	19 Nov. 1949
Amsterdam	A	54N		b	b	c	d
Bagneres	B	46N	550	...	...	...	e
Bargteheide		54N		...	...	...	f
Cheltingham	C	50N		g	g	g	g
Christchurch	Ch	48S		g	g	...	g
Climax	Cl	48N	3500	...	...	...	g
Darmstadt		50N		...	...	...	f
Freiburg / Friedrichshafen	F	48N		h	h	...	f
Godhavn	G	80N		g	g	g	g
Huancayo	H	1S	3350	g	g	g	g
London	L	54N		i	i	...	...
Manchester	M	57N		...	...	j	k
Nagoya	Na	25N		...	...	...	l
Norfolk	N	49N		m	...	...	...
Ottawa	Ot	56N		...	...	...	n
Resolute	R	83N		...	...	...	n
Teloyucan	T	30N	2285	g	...	...	...
Tokyo	To	25N		o	o	...	p
Weissenau		49N		...	...	...	f
Mt. Wilson		43N	1800	...	...	q	...

[a] Altitude listed only for mountain stations.
[b] Clay, Jongen, and Dijker, Proc. Koninkl. Ned. Akad. Wetenschap. **52**, 923 (1949).
[c] See reference 17.
[d] J. Clay and H. F. Jongen, Phys. Rev. **79**, 908 (1950).
[e] A. Dauvillier, Compt. rend. **229**, 1096 (1949).
[f] See reference 8.
[g] See reference 1.
[h] See reference 16.
[i] A. Duprerier, Proc. Phys. Soc. (London) **57**, 468 (1945).
[j] D. W. N. Dolbear and H. Elliot, Nature **159**, 58 (1947).
[k] See references 12 and 13.
[l] Sakido, Kodama, and Yagi, Rept. Ionos. Research Japan **4**, 207 (1950).
[m] E. B. Berry and V. F. Hess, Terrestrial Magnetism Atm. Elec. **47**, 251 (1942).
[n] D. C. Rose, Can. J. Phys. **29**, 227 (1951).
[o] J. Nishimura, J. Geomag. Geoelec. **2**, 121 (1950); Sekido, Yoshida, and Kamiya, Rept. Ionos. Research Japan **6**, 195 (1952).
[p] Miyazaki, Wada, and Kondo, Rept. Ionos. Research Japan **4**, 176 (1950).
[q] H. V. Neher and W. C. Roesch, Revs. Modern Phys. **20**, 350 (1948).

[30] W. H. Fonger, Phys. Rev. **91**, 351 (1953).

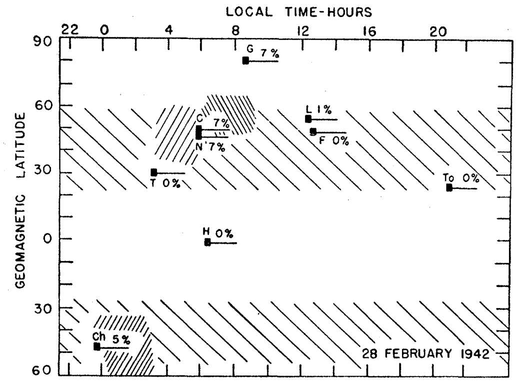

FIG. 7. Impact zones and cosmic-ray stations at 1100 UT on 28 February 1942. Symbols same as in Fig. 6.

attributed to the high altitude of that station. A reasonable altitude correction to sea level lowers the percentage increase to about the same value as at Cheltingham.[1]

The high latitude stations, Resolute and Godhavn, recorded increases although they were not in any impact zone.

C. February 28, 1942

The first large cosmic-ray increase to be noticed was reported by Berry and Hess (see Table II) in 1942. This increase followed a flare and fadeout beginning around 1100 UT on February 28 of that year. Figure 7, similar to Fig. 6, shows the earth at that time, with the positions of the impact zones and stations. In this case the increases marked in the figure are for one hour averages centered on the half hour. It is seen (with Godhavn again the possible exception) that the distribution of the increase is again consistent with positive particles arriving at the earth from the direction of the sun. All of the increases for this event began roughly an hour after the flare began.[31] The ratio of the increases in and out of the morning impact zones is, in this case, seven or greater.

D. March 7, 1942

For the second solar flare-type increase to be observed the flare was not seen, but the characteristic radio fadeout was recorded.[1] Figure 8 shows the impact zones at 0400 UT on March 7, 1942, when the increase occurred, and the increases in the one hour averages. Once again the largest increase was in the morning impact zones.

E. July 25, 1946

The third large increase of the solar flare type was recorded on July 25, 1946 at around 1700 UT. No report has been found from a cosmic-ray station which was in the morning impact zones at this time. The increase was seen by five stations (see Table II), all with roughly the same amplitude of about 15 percent. No increase was seen at Huancayo. These observations again agree with the predicted distribution. For this event the maximum of the cosmic-ray increase was about two hours later than the maximum of the flare.

F. Conclusions on Big Events

From the above discussion and Figs. 6, 7, and 8 it is seen that the middle and low latitude observations of the four large cosmic-ray increases are consistent with positive particles with magnetic rigidities of less than 10 Bv approaching the earth along the sun-earth line and being deflected only by the earth's dipole magnetic field. The relative magnitudes of the increases at different stations is in rough agreement with the estimate based on general properties of the cosmic-ray orbits.

Although the above comparison was made assuming that the source of particles is $\approx 15°$ in diameter, none of the results are changed if one takes a source twice as large.

The observations of the increases at very high latitudes (Resolute and Godhavn) are not consistent with the predictions of the simple model used here, unless there exists a whole family of orbits and impact points, having small values of γ, which have been overlooked by all workers in the field. As this is unlikely, and as the simple model gives good agreement at lower latitudes, it seems reasonable to examine the simplifying assumptions made in setting up the simple model to find one that could produce the high-latitude disagreement.

In particular it is suggested that the deviations of the earth's magnetic field from that of a dipole may produce high latitude impact zones. Particles contributing to the background zone travel large angles around the earth at distances where the nondipole terms in the earth's field amount to a few percent of the dipole field, and a small perturbation in the path of a particle at one point can produce a large change in the orbit by

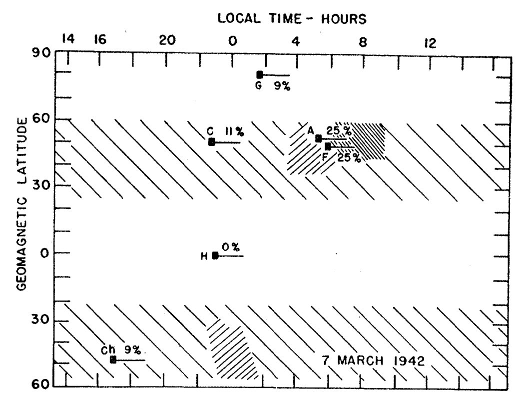

FIG. 8. Impact zones and cosmic-ray stations at 0400 UT on 7 March 1942. Symbols same as in Fig. 6.

[31] In reference 1 and elsewhere the flare is listed as having started *after* the cosmic-ray increase. Apparently the report of an observation by the Arcetri Observatory of a flare in progress at 1100 UT, before the increase, has been overlooked. See Table I.

time the particle has made a circuit of the earth. Thus particles may be deflected to points nearer the poles than is predicted by the simple theory.

This possibility for explaining the high-latitude observations could be checked by a model experiment such as Malmfors', but with a more complicated magnetic field. Also, the equations of motion could be integrated numerically, preferably with a digital computer. It would also be helpful if, during the next large increase, there were a variety of detectors (neutron monitor, shielded ion chamber and so on) at a high-latitude station so that the energy of the new particles arriving there could be extimated.

IV. EFFECTS OF SMALL FLARES

In the preceding sections it has been shown that the simple model adopted here gives a fairly consistent picture of the solar-flare-connected increases of cosmic-ray intensity. If, then, a small increase associated with a small solar flare is sought, the preferred local times of arrival for particles from the sun should be taken into consideration. It was shown in the discussion of impact zones that an increase due to particles from the sun might be seen at any local time in the middle latitudes, but that a higher intensity is expected at certain times.

We will use pressure corrected hourly averages of cosmic ray intensity from the Climax neutron detector, which has been described earlier.[32] Neutron detectors are particularly suited for observing solar flare effects because most of the counts recorded by such a detector are due to particles of low rigidities (less than 13 Bv).[32]

This detector is at a geomagnetic latitude of 48°. For latitudes less than 50° the 0900 impact zone is of little importance, since it stays for the most part farther north. So for Climax the preferred local times for observing solar flare effects are largely determined by the 0400 zone. For a given declination of the sun and Greenwich time the magnetic latitude of the sun can be found from McNish's graphs.[25] Then, from Figs. 3 and 4, the impact zones on the earth can be found. In particular, at Climax, the centers of the zones pass over at times varying from 0300 to 0700. The details are given in Table III. The dates listed there are, of course, approximate.

TABLE III. Times of impact zones at Climax.

Dates From	Dates To	Type of zone	Center of zone to nearest hour (local time)
1 Apr.	10 Sept.	0400	0300
21 Feb.	31 Mar.	0400	0400
11 Sept.	21 Oct.		
22 Oct.	10 Dec.	0400	0500
1 Jan.	20 Feb.		
11 Dec.	31 Dec.	0400	0600
21 Nov.	21 Jan.	0900	0700

[32] Simpson, Fonger, and Treiman, Phys. Rev. **90**, 934 (1953).

TABLE IV. Small solar flare data.

Date	Time[a] (UT)	No. of observations	Importance	Group
1951				
13 May	0943	1	2	*A*
15 May	1127	2	2+,2	*A*
17 May	0947	2	1+,1	*A*
18 May	1020	9	3,2,2,3,3,3,2+,3,2	*A*
20 May	0817	3	2,1,1+	*A*
16 June	0901	2	1,2	*A*
28 July	0841	1	1+	*A*
12 Aug.	0837	3	1+,1,2	*A*
3 Sept.	1012	1	1+	*A*
7 Sept.	1108	2	1,1+	*A*
18 Sept.	1145	1	1+	*A*
22 Dec.	1058	1	1+	*A*
8 May	1505	3	2,2,1	*B*
14 May	1545	1	2	*B*
17 May	1754	2	2,2	*B*
18 May	1956	2	2+,1	*B*
19 May	1949	1	3−	*B*
6 June	1240	1	2	*B*
15 July	2316	1	2	*B*
28 July	1535	3	1,2,2	*B*
3 Sept.	1308	4	3,3,2,2	*B*
14 Sept.	1338	6	2,2,1+,2,2,1	*B*
15 Sept.	1505	4	2+,2,2,1	*B*
23 Sept.	2032	3	1,2,2	*B*
1952				
22 Apr.	1155	1	2	*A*
1 May	1037	2	2,1	*A*
27 Mar.	2300	1	1+	*B*
30 Mar.	0034	1	1+	*B*
4 Apr.	0403	1	2	*B*
11 Apr.	0545	2	2,2	*B*
1 June	1629	1	2	*B*
12 July	1450	1	2	*B*
25 Oct.	1945	2	2,2	*B*
18 Nov.	2045	1	2	*B*
1953				
25 June	1000	1	1+	*A*
20 July	1048	1	2	*A*
1 Jan.	2054	1	2	*B*
15 July	1418	1	1+	*B*
21 July	1424	1	1+	*B*
22 July	1532	1	1+	*B*

[a] Time given is either first observation or beginning of flare. For sources of data see references 5, 11, 33, and 34.

Since the Climax (*D*-1) detector has been in operation (May, 1951) no changes in intensity of more than a few percent in an hour have been observed. Any intensity changes associated with solar flares, therefore, must be separated from other changes of about the same magnitude, such as the 24-hour cycle[30] and the 27-day-recurring[30] changes. The latter offer no particular difficulty, since they occur slowly, but correction for the 24-hour cycle may be necessary.

To look for a small cosmic-ray increase at the time of small solar flares the following analysis has been performed. Flares which were reported[5,11,33] as occurring in 1951 and which were rated as importance 1+ or higher were placed in one of two groups. Group *A* contained those flares the starting time of which put Climax in a morning impact zone, the zones considered

[33] K. O. Kiepenheuer (editor), Sonnen-Zirkular, published quarterly by the Fraunhofer Institute, Freiburg-in-Baden, Germany, 1951–53.

to be four hours wide. Group B contained those flares for which Climax was at least an hour away from the edge of a morning impact zone. The cosmic-ray data for each group were superimposed so that the average cosmic-ray intensity for the hour of the flare, the hour before, the hour after, etc., were obtained for each group. Table IV gives the data concerning the flares used, and Fig. 9 shows the average cosmic-ray behavior during flares of the two groups. A correction for mean daily cycle has been applied to the data of Fig. 9, but in this case the correction is small and does not change any essential feature of the curves. It is seen that for Group A flares there is a small increase during the hour of the flare with a return to normal in two hours. The Group B points are consistent with a much smaller, or no, increase.

In seeking a more detailed relationship between the Group A flares and the cosmic-ray increases we ask whether the size of the flare and the magnitude of the cosmic-ray increase are related for the individual events. We take as the size of the cosmic-ray increase the difference between the mean of the hourly counting rates for the two hours during and after the flare, and the hourly average just before the flare. As the size of the flare we take its "average importance," that is, the average of the importance ratings given to the flare by the different observatories which reported the flare. The importance rating is, as mentioned earlier, a somewhat subjective measure of the flare size, but it is the only measure that is always reported. As an indication of how well different observatories agree in their rating of a flare we may inspect the importance ratings in Table IV for those flares seen by two or more observers. The correlation coefficient of flare size and cosmic-ray increase for the events in Group A is $+0.6\pm0.2$, indicating that the two sizes, with good probability, are related, the larger flares yielding the larger increases.

A similar analysis can be made for the 1952 and part of 1953 data,[34] although flares of any size were much less frequent in these years than in 1951. This decline in the rate of occurrence of flares is associated with the general decline in the level of solar activity, part of the 11-year "solar cycle." Only four flares could be found that could be placed in Group A. The results for 1952–1953 are also shown in Fig. 9, and are similar to the 1951 results, although much less conclusive. Table IV gives the data on the flares.

It has been assumed in this method of examining the cosmic ray data that the impact zones are about four hours wide. No attempt has been made to narrow the zones further, since the number of events in Group A would become too small. The question of the time width of the zones, however, has been examined in the following manner. A flare activity index has been published[35] giving values for each day during 1951, 1952, and part of 1953. This index is intended to be proportional to the energy radiated per unit time during the day in H_α light by flares occurring on the visible hemisphere of the sun. During periods when flare observations are made every day, this index is a slowly varying function of time. It will gradually increase in value for several days and then decrease in a like manner. This behavior is a result of the fact that flares usually occur in certain active regions on the sun, and, as such a region comes over the limb, flares in it begin to be observed, slowly increasing the index. These regions vary with time in their flare-producing activity, but this change is also usually slow. Hence, this flare index represents the likelihood of flares occurring in the early morning hours, even if the index for the day is derived from observations made at some other time. If small flares are associated with new cosmic-ray particles approaching the earth from the direction of the sun, the cosmic-ray intensity for days of high flare index should then be peaked in the early morning hours relative to days of low flare index. In Fig. 10 is seen that such is the case. The plotted

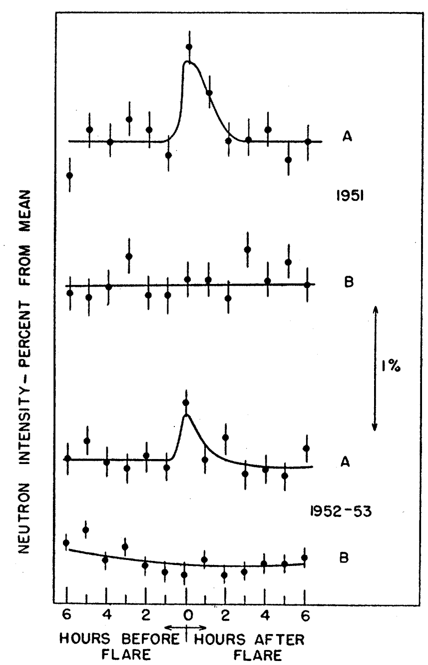

FIG. 9. Cosmic-ray intensity during times of small solar flares. Curves A show behavior during flares which occurred when the detector was in a morning impact zone for particles from the sun. Curves B show cosmic-ray behavior for flares occurring when the detector was *not* in a morning impact zone. Errors shown are estimated standard deviations.

[34] We thank Dr. Yngve Ohman of the Swedish Solar Station on Capri for communicating to us the results of his flare observations for the summer, 1953, prior to publication.

[35] D. E. Trotter and W. O. Roberts, Flare Activity Index, Report No. HAO-NBS 20, High Altitude Observatory, Boulder, Colorado, 1953 (unpublished). Preliminary values of the flare index are given in Preliminary Chart of Solar Activity, issued weekly by the High Altitude Observatory.

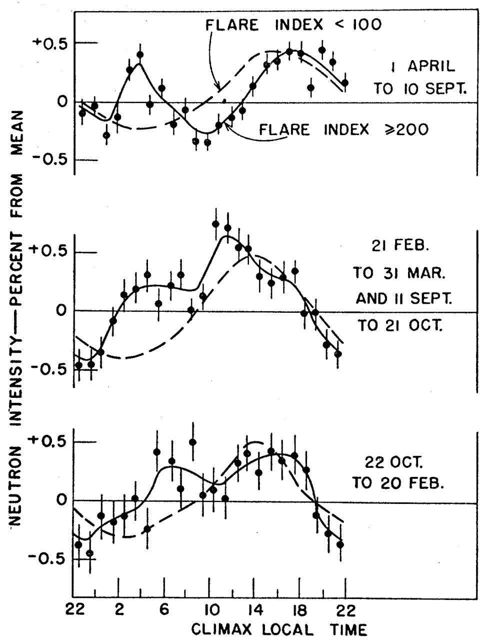

FIG. 10. Mean daily cycle of cosmic-ray intensity for days of many flares (solid curve) and for days of few flares (dashed curve). No points or errors are shown for the dashed curve since the errors are much smaller than for the solid curve. Data used are for the period May, 1951, to August, 1953, and the dashed and solid curves are matched at 1600 hours. The solid line is a smooth line drawn through the mean of the 3-hour and 1-hour running averages.

points and the solid lines are the mean daily behavior of the Climax hourly averages for days of flare index ≥ 200. The dashed line is the mean daily cycle for days with flare index <100. Cosmic-ray data for the period May, 1951–August, 1953 are included. No points or errors are shown for the dashed curves since they are based on ≈ 200 days each and have very small statistical errors as compared with the solid curves. The solid curves are based on ≈ 20 days each.

The morning peak in Fig. 10, at least for the summer and winter curves, is indeed about four hours wide, as assumed above. The spring and fall curve seems to have a wider peak, but not significantly so. The winter peak in Fig. 10 may be several hours later than the summer peak, a fact which is suggestive in view of the seasonal motion of the impact zones discussed above. It must be pointed out, however, that implicit in this comparison of high-index days with low-index days is the assumption that the shape of the mean daily cycle outside of the early morning hours is unaffected by varying states of activity on the sun. Since changes in the daily cycle associated with earth's magnetic field disturbances, which in turn are related to solar activity, have been reported[36–38] this assumption seems doubtful and results dependent upon it must be used with caution. On the other hand, if the small-solar-flare effect discussed here actually exists, then workers seeking associations between cosmic-ray changes and magnetic field disturbances must take care that the effects of the early morning peak in statistical analyses of the daily cycle (shifting the phase of the first harmonic to earlier morning, increasing the amplitude of the second harmonic, etc.) are not attributed to magnetic field changes.

Some limits can now be placed on the angular size of the particle source, using the experimental result that the impact zone at Climax is about four hours wide. Clearly a line source, 60° in longitude and small in latitude would give such a time spread. Similarly, in Fig. 4, one finds that a source 30° in latitude and small in longitude would give such a spread. So our results limit the source to an elongated region of the sky, containing the sun, which has its longest dimension (about 60°) parallel to the plane of the geomagnetic equator and with a width of about 30°.

V. CONCLUSIONS

From the results discussed above it is concluded that the large cosmic-ray increases associated with solar flares are mainly the result of positive particles which approach the earth from the direction of the sun. We further find that small solar flares produce similar cosmic ray effects to the big flares, but considerably smaller in magnitude. The results suggest that perhaps all flares are associated with additional cosmic-ray particles approaching the earth. In both small flare and large flare events the results are consistent with a source of particles located in the direction of the sun and 60° or less in longitude and 30° or less in latitude.

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[36] Y. Sekido and S. Yoshida, Rept. Ionos. Research Japan **4**, 37 (1950).
[37] H. Elliot and D. W. N. Dolbear, J. Atm. and Terrest. Phys. **1**, 205 (1951).
[38] A. Ehmert and A. Sittkus, Z. Naturforsch. **6a**, 618 (1951).