what upper limit can you place on their relative flux?

Ney, E. P.: No electrons have been detected with certainty yet. The upper limit at late times is about 10% of the proton flux. However no flights during early stages when type IV was being radiated have been available.

Singer, S. F.: Your particular acceleration mechanism may have much wider application, e. g. for electrons in the radiation belt. (The general idea of repeated acceleration with subsequent redistribution of degrees of freedom (magnetic pumping) was first suggested by Alfvén). We have considered your mechanism but find that energy loss is too important at relativistic energies. We prefer to believe that (at least for the radiation belt electrons) a push-pull acceleration mechanism of the general type suggested by Fan is applicable.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-II, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3B-25. Geomagnetic and Interplanetary Effects on Solar Cosmic Rays

J. R. WINCKLER

University of Minnesota, Minneapolis, Minnesota, U.S.A.

The energy spectra and the time variations for many of the larger solar cosmic ray events from 1958 to the present have been directly measured with balloons, satellites, and space probes. The direct measurements cover the range 10–300 Mev and show spectra to be characteristically steep compared with galactic protons. Small differences in the spectral shape and intensity determine whether the solar cosmic rays will be detected at sea level or only at high altitude. Spectra measured on the earth reflect energy sensitive propagation as well as the characteristics of the source. Large differences exist in the time variations of the flare particles. Direct and rapid propagation from the sun is frequently accompanied by a slow decay. Delayed propagation even in the high energy region appears in many events. These delays seem associated with complex propagation routes from the flare region to the earth, frequently because of magnetic plasma clouds in interplanetary space. The lowering of Störmer cutoffs during strong geomagnetic storms is shown by many events studied and occurs coincident with the main phase of storms. Periodic intensity variations of solar cosmic rays have been observed at Minneapolis which may be caused by large-scale oscillations in the main field of the earth.

Introduction

In the last three years, progress in the understanding of the production of cosmic rays by the sun has been rapid. This is because the period of high solar activity provided a large variety of events to study and because many new types of measurements were developed. At the present time we have data obtained on the solar cosmic rays at high altitude with nuclear emulsions both in balloons and rockets, Wilson cloud chambers carried in balloons, many types of counting instruments at various latitudes and longitudes, and, in a number of cases, with counters in an earth satellite. The cosmic rays have also been measured in space 5,000,000 km from earth with a space probe.

Table I. Solar cosmic ray energy spectra.

Event No.	Flare Date, Time UT	Spectra Measurement Date, Time UT	ΔT hrs	$N(>E)=CE^{-\gamma}$ (Mev) Eqn. of Spectra C	γ	Literature Source	Notes
(1)	23 Mar 1958 0950	26 Mar-1300-1800	78	7.2×10^5	2.7	(a) (c)	Flare assignment tentative. First P. C. A. on 25 Mar at time of S. C. indicating cosmic rays contained in magnetic solar cloud. Spectra from nuclear emulsions at Mpls
(2)	22 Aug 1958 1417	23 Aug-0500	15	8.0×10^7	4	(b)	Spectra from counters on ascent at Ft. Churchill.
(3)	10 May 1959 2055	12 May-0500	32	2.5×10^9	6	(c) (d)	Spectra from counters on ascent. Emulsions give $\gamma=5$ as average.
(4)	10 July 1959 0210	11 July-1800-1600	30-38 av. 34	—	—	(e)	Spectra falls off at low energies. Not a simple power law. Exponential fit is good.
(5)	14 July 1959	15 July-1030	31	1.1×10^8	2.9	(f)	Spectra from counters on ascent. Approximate agreement with emulsions averaged from 0900-1430 UT 15 July.
(6)	16 July 1959 2114					(f)	Produced sea level effect.
(7)	1 Apr 1960 0843	1 Apr-0945	1		2.4	(g) (h) (i)	Spectrum from balloon and satellite counters—measured simultaneously.
(8)	5 Apr 1960	5-6 Apr				(h) (i)	Spectrum probably similar to (7). Seen only by satellite and space probe.
(9)	28 Apr 1960 0130					(g)	Spectra not measured for these events.
(10)	29 Apr 1960 0107					(g)	Spectra not measured for these events.
(11)	4 May 1900 1020	4 May-1700-2500	7-15 av. 11	—	—	(j)	Not a power law spectrum. Has exponential form.
(12)	3 Sept 1960 0040	3 Sept-1400	13			(k) (l)	Region 10<E<100 Mev from rocket. 100<E<300 balloons at two latitudes
(13)	12 Nov 1960 1322	13 Nov-2000	31			(m)	Emulsion spectra. Short balloon exposure.
(14)	15 Nov 1960			—			

Literature Source:
(a) P. S. Freier, E. P. Ney, and J. R. Winckler, *J. Geophys. Research* **64** (1959) 685-688.
(b) K. A. Anderson, R. Arnoldy, R. Hoffman, L. Peterson, and J. R. Winckler, *J. Geophys. Research* **64** (1959) 1133-1147.
(c) E. P. Ney, J. R. Winckler, and P. S. Freier, *Phys. Rev. Letters* **3** (1959) 183-185.
(d) J. R. Winckler, and P. D. Bhavsar, *J. Geophys. Research* **65** (1960) 2637-2655.
(e) P. S. Freier, and E. P. Ney (Private Communication).
(f) J. R. Winckler, P. D. Bhavsar, and L. Peterson, *J. Geophys. Research* **66** (1961) 995-1022.
(g) A. J. Masley *Cosmic Ray Tech. Rept. No. CR*-**35**, School of Physics, University of Minnesota, Minneapolis, 1961.
(h) J. A. Van Allen, and Wei Ching Liu, *J. Geophys. Research* **65** (1960) 2998-3003.
(i) R. L. Arnoldy, R. Hoffman, and J. R. Winckler. *J. Geophys. Researdh*, **65** (1960) 3004-3007,
(j) "The High-Energy Cosmic-Ray Flare of May 4, 1960. Part I. High-Altitude Ionization and Counter Measurements," J. R. Winckler, A. J. Masley, and T. C. May. "Part II. Emulsion Measurements," S. Biswas, and P. S. Freier, *J. Geophys. Research* **66** (1961) 1023-1033.
(k) J. R. Winckler, P. D. Bhavsar, A. J. Masley, and T. C. May. *Phys. Rev. Letters*, **6** (1961) 488-401.
(l) L. R. Davis, C. E. Fichtel, D. E. Guss, and K. W. Ogilvie. *Phys. Rev. Letters* **6** (1961) 492-495.
(m) E. P. Ney, and W. Stein, International Conference on Cosmic Rays and the Earth Storm September 8, 1961, Kyoto, Japan.

Although most of the solar cosmic ray particles have been identified as protons, analysis of nuclear emulsions exposed under proper conditions has shown α-particles and heavy nuclei up to $Z=16$ in the solar beams. Details of the heavy components are given elsewhere in this symposium by Ney[1]. The propagation from the sun to the earth has shown complex features associated with magnetic fields in space. These magnetic fields in one case have now been directly observed with space probes. Associations between the propagation of the solar cosmic rays from the sun to the earth, and the modulation by the solar-produced magnetic fields of the galactic cosmic radiation have now been found.

Despite the abundance of solar data and the knowledge of the composition and energy spectrum of the cosmic rays, the details of the acceleration mechanism on the sun remain obscure.

In this paper we will summarize certain kinds of knowledge about a series of 14 solar cosmic ray events. These events are selected because direct measurements have been made on the primary particles with balloons or rockets. The list of 14 includes most of the larger events of the period from 1958 through 1960. Complete lists of the occurrence of all events, numbering about 50 of all sizes determined by polar cap ionospheric effects, are available elsewhere (Obayashi and Hakura, 1960[2]; Reid and Leinbach, 1959[3]. The present list of events is given in Table I. We propose to discuss the following features for this symposium:

(1) energy spectra of the solar protons
(2) the time variations and the resulting implications about propagation from sun to earth
(3) the interaction of the solar cosmic rays with the geomagnetic field, particularly during disturbed periods.

Energy Spectra

The available integral energy spectra of the series of events are given in Fig. 1. These spectra are for protons which are known to be the principle component of the solar cosmic ray events. The numbers refer to Table I where details of the source of the spectra are given. These spectra are measured under various circumstances with balloons, rockets, and satellites. Because the spectra are determined either at high latitude, or at low latitude when the geomagnetic cutoffs were very low, they may be assumed to represent the spectra in space near the earth at the times given in Table I. As will be discussed later (for example event No. 12 on September 3, 1960), the energy dispersion in the propagation from sun to earth may modify the spectra considerably in all energy regions and these spectra are thus not necessarily the source spectra. Because the spectra are measured at various times with respect to the flares which are the source of the particles, the relative intensities are not necessarily in the proper order for the events. This feature will become clearer in the next section on the time history of the events, (See Fig. 2 and Table I). Nevertheless, it can be seen in Fig. 1 that the intensities vary over wide limits from event to event, and in general the spectra are much steeper than the galactic cosmic ray spectra. Some of these events, namely No. 6 (July, 1960, 1959), No. 11 (May 4, 1960), No. 12 (September 3, 1960), No. 13 (November 12, 1960), No. 14 (November 15, 1960), and the

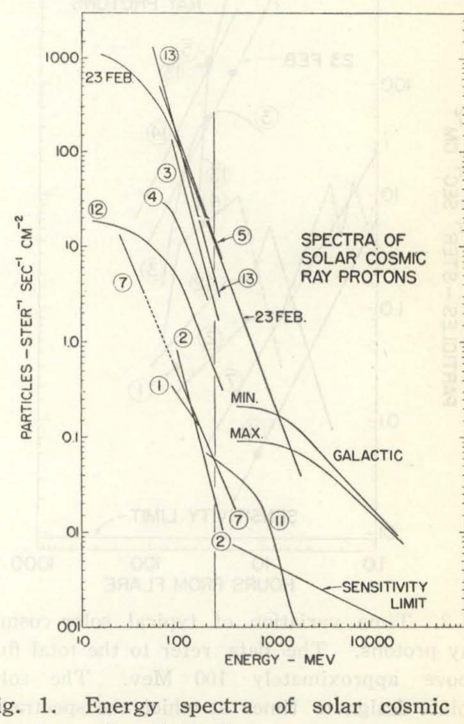

Fig. 1. Energy spectra of solar cosmic ray protons. See Table I.

event on February 23, 1956, were detected by sea level monitors. Due to the uncertain neutron yield function in the 1 bev and lower region, the sea level data cannot be used with certainty at present to extend these spectra to intermediate energies, *i.e.* above 400 Mev where balloon data end. Since the detection of these events by neutron monitors depends sensitively on the solar cosmic ray flux in the galactic range of energies, a small decrease in slope of the spectra in Fig. 1 may result in a "high energy" flare event. High energy events thus do not seem unique in any way, but represent less frequent cases of spectra dropping off somewhat less rapidly with increasing energy. However, the relativistic particles from the sun provide better probes for studying interplanetary fields than the lower rigidity particles (Steljes, Carmichael and McCracken, 1961[4]). This is because impact zone effects on the earth cannot be distinguished for particles with rigidity much below 1 B.V. Furthermore strong directional effects in space may be expected only if the radii of curvature of the solar particles is larger than the scale of irregularities in the

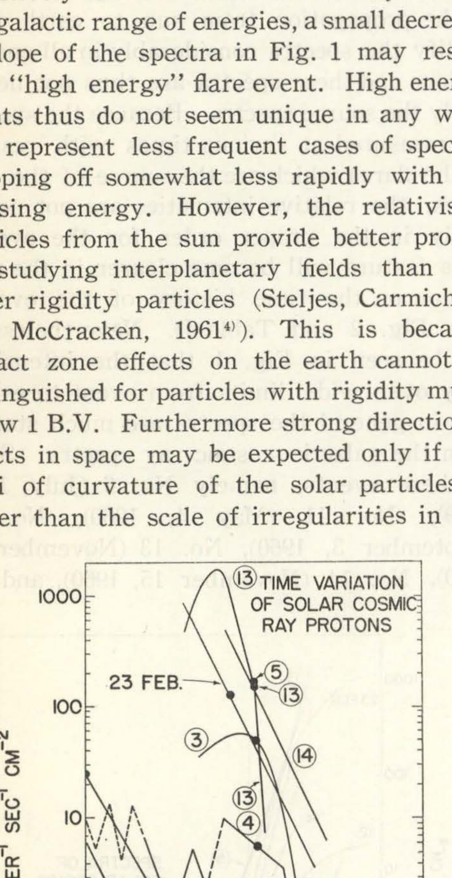

Fig. 2. Time variation of typical solar cosmic ray protons. The data refer to the total flux above approximately 100 Mev. The solid points designate times at which the spectra in Figure 1 were measured.

interplanetary fields. In certain cases the relativistic flare particles above 1 B.V. obviously meet this criterion. It is difficult to find any evidence for similar effects in the particles studied here below 0.8 B.V. rigidity.

The various spectra in Fig. 1 show marked differences as follows which may be explained entirely by propagation effects:

(1) Certain spectra bend over at low energies, e.g. 23 February, No. 4, No. 11 and No. 12. There are apparent exceptions, however, e.g. No. 7 and No. 13.

(2) Frequently the most intense low energy events contain negligible numbers of relativistic particles, e.g. Nos. 2, 3, 4, and 5.

(3) Some relativistic events are markedly deficient in low energy particles, e.g. 23 February and No. 11 (May 4, 1960).

An examination of the 12 known cases to date of sea level cosmic ray flare increases shows that with one exception (September 3, 1960) the flares are in the center or western sectors of the solar disc and, in fact, are concentrated near the west limb (Ellison, 1961[5]). This asymmetry can only be a propagation effect which effectively screens from the earth relativistic particles from flares near the center or east sector. Low energy events, e.g. polar cap increases without sea-level effects, show no asymmetry and are arrayed symmetrically on each side of solar meridian.

From the above facts one finds the clue to the peculiar "low energy" type event seen frequently during the IGY and later periods which is not detected at sea level. The non-relativistic particles are able to reach the earth readily either because their energy density is high compared to the magnetic field energy density in space, or because the small gyro radius permits the particles' easy passage through complex fields. The relativistic component is diverted eastward from the sun and is excluded from the earth from center or east sector flares. On the other hand, the low energy protons from west limb relativistic events may escape into the solar system in a beam or cloud aimed completely away from the earth, accounting for the February 23 and May 4 events which are deficient in low energy particles but show strong relativistic effects.

The relative proportions in the spectra may change with time so that low energy protons are delayed. This will be discussed in the next section, but contributes to the observed bending over of the spectrum at low energies.

Free Space Time Variations

The time variations collected in Fig. 2 will now be discussed. These data are mainly from high latitude results and should represent the free space intensity near the earth. This figure is an estimate of the changes in the integral intensity above 100 Mev as a function of time from the start of the flare. The black points are the times at which the various spectra in Fig. 1 are measured. The curves of Fig. 2 have been normalized at 100 Mev using these spectra. In some cases the integral intensity at 100 Mev is not known within a few hours of the flare but decays in a regular fashion at later times, e.g. February 23, 1956. Observations back to within one hour of the time of the flare for cases 7 and 11 show a continual decay following approximately the power law $I=I_0T^{-\alpha}$, where I_0 is the intensity at 1 hour from the flare and α 2. A number of cases show striking delays in which the intensity rises to a maximum 10 to 15 hours after the flare, and then drops away. In constructing Fig. 2 we have made use of the results of Anderson[7], of D'Arcy[11] and of Charckhchian[12].

Time-intensity curves as shown in Fig. 2 are in a sense special cases since they represent integral intensities. An observation has been made of the complete spectral changes in the early stages of an east-limb flare increase on September 3, 1960. A detailed description of the event is given in a paper by Bhavsar[6] in this symposium. The correlation of balloon and rocket measurements in this event gave the spectra and its time dependence over wide limits from 10 to 400 Mev. It was observed that 14 hours after the flare in the region from 10-50 Mev the intensity was rising when the BV rigidity particles detected at sea level were well into the decay mode. The time history above 100 Mev for this event is shown in curve 12, Fig. 2.

The most rapidly rising event of the 14 studied in the 100 Mev range was detected by Anderson at Churchill in 1958 (Anderson and co-workers, 1959[7]). Protons arrived with the direct transit time of about 20 minutes from a central meridian flare. No effect was detected above 1.2 BV rigidity.

The interplanetary and solar conditions leading to direct or delayed propagation for 100-Mev particles are not easy to identify. We do not propose to offer any detailed theory or models of interplanetary field accountings for the time variation summarized in Fig. 2.

Time Variations at Minneapolis and Geomagnetic Effects.

(a) The "Normal" Cut-off

The time variations seen at the intermediate latitude of Minneapolis during solar cosmic ray events are mainly associated with magnetic storm effects. However, if the incident spectrum contains enough flux above the "normal" Störmer cut-off then the free space time variations may be seen early in some of the events.

If the equatorial magnetic field is not appreciably disturbed, we assume that "normal" Störmer cutoff rigidity values apply. It has been suggested by MacDonald (1957)[8] as a result of measurements on galactic primaries that this "normal" cutoff rigidity is about 0.75 B.V. However, there are two kinds of evidence from solar events that indicate a higher value. First, if we consider the free space spectra shown in Fig. 1 and assume 0.75 B.V. (250 Mev KE for protons) for the local cutoff then for many events a large flux above the "sensitivity limit" value for an ion chamber should have been observed at Minneapolis ($\lambda=55°$). A careful analysis of all events shows that a value near 1.0 or 1.2 B.V. must be assumed to account for the complete absence of any particles at Minneapolis although large fluxes were simultaneously observed at high latitude during many events.

Further, in all cases following flares that particles were seen at Minneapolis during "normal" cutoff conditions as shown by no large disturbances of the main field of the earth, a reponse was obtained at sea level on high latitude neutron monitors. This indicates that the atmospheric outoff for a neutron monitor (*i.e.* about 1 B.V.) is close

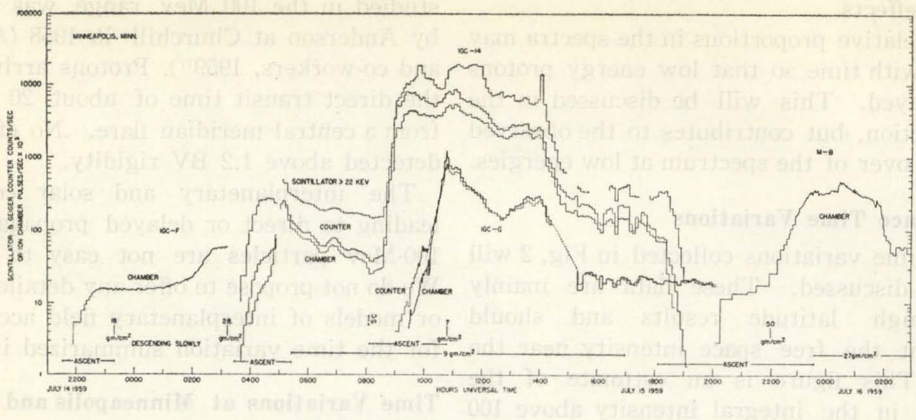

Fig. 3. Time history of solar cosmic rays at Minneapolis during the magnetic storm of July 15, 1959. Note the large increase 30 minutes after the S. C. at 0804 U. T. July 15.

to the "normal" geomagnetic cutoff at Minneapolis.

This result is on closer agreement with the value recently suggested by Quenby and Wenk[9] for Minneapolis of 1.43 B.V.

(b) The disturbed cutoff

Direct spectral measurements and relative intensity values both clearly show that during magnetic storms the solar cosmic ray spectrum down to energies below nominal air cutoff (80 Mev or 0.4 B.V. rigidity) may be incident at Minneapolis.

Fig. 3 shows an example of the complex variation seen during the strong storm and solar proton event on July 15, 1959. In Fig. 3 note the very large increase in flux about 0.5 hr. after the S.C. Comparison of the cosmic ray fluxes and the earth's main field shows that the drop in Störmer cutoff occurs *at the time of the main phase* and not at the time of S.C. In Figs. 4 and 5 are shown two correlations of flux and magnetic field. Note that although the time delay between S.C. and main phase varies from 0.5 to 7 hours, the cosmic ray increase occurs at the main phase.

So far we have found no exceptions to the main phase cutoff correlation. In Table II is summarized data on this effect for the 14 events studied in this paper. Note that the low energy increase either occurs at the time of the main phase, or if a main phase is already in progress, occurs at the time of the flare. Elsewhere in this symposium Kellogg and Winckler[10] have presented a theory which explains the altered Störmer cutoffs in terms of the main phase ring current. Because the altered cutoffs return to normal, long before the main storm field at the earth's surface, it is necessary to assume that the ring current

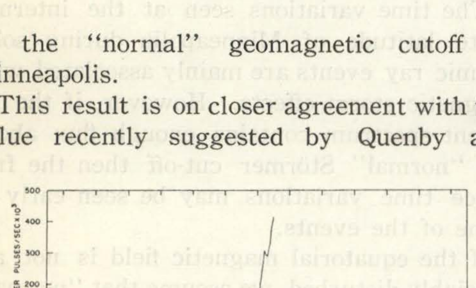

Fig. 4. Solar proton increase at Minneapolis coinciding with a sudden decrease of Störmer cutoff energies at beginning of main phase. Note 7 hour delay from the sudden commencement.

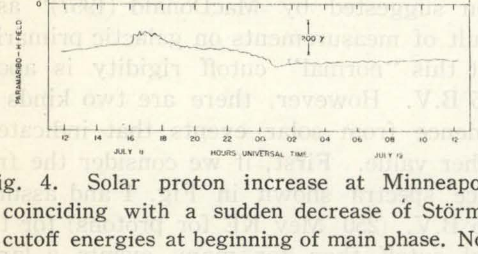

Fig. 5. A very large and sudden increase in intensity corresponding to main phase. Delay from S. C. was only 30 minutes. In this case, and also Figure 4, the polar intensity was continuously high and showed no such fluctuations.

Table II. Correlation of cutoff changes and magnetic field at Minneapolis.

Event No.	Cosmic Ray Flare Date	Time	Related Sudden Commencement Date	Time	Begin Negative Phase Date	Time	Low Energy Cosmic Ray Increase Date	Time	Notes
1	23 Mar 1958	0950	25 Mar	1540	26 Mar	1300	26 Mar	1330	*Event includes evidence for trapping in solar cloud
2	22 Aug 1958	1417	24 Aug	0140	24 Aug	0330	Undetected		Free space intensity probably too low to detect during main phase
3	10 May 1959	2055	11 May	2320	12 May	0430	12 May	0400-0500	Inferred from total differerence between two flights
4	10 July 1959	0210	11 July	1623	11 July	2300	11 July	2330	
5	14 July 1959	0325	15 July	0802	15 July	0830	15 July	0830	
6	16 July 1959	2114	17 July	1638	17 July	1900	17 July	1900	
7	1 April 1960	0843	31 Mar	0800	31 Mar	1600	1 April	0945	Main phase already in progress at time of cosmic ray flare
8	5 April 1960	0215	None		None		Untetected		Although free space rates high, no cosmic rays at Minneapolis
9	28 April 1960	0130	27 April	2000	27 April	2100	28 April	0315	Main phase in progress at time of cosmic ray flare
10	29 April 1960	0107	30 April	0130	30 April	0330	30 Apr before 0600		Very weak event in >100 Mev range
11	4 May 1960	1340	None		None		No low energy particles		All particles measured were above normal cutoff
12	3 Sept 1960	0040	4 Sept	0230	4 Sept	0400	4 Sept about 0400		
13	12 Nov 1960	1322	12 Nov	1348	12 Nov	1740	12 Nov before 2000		*Main phase in progress at time of blloon ascent
14	15 Nov 1960	0207	15 Nov	1303	Uncertain	1400	15 Nov	1400-1500	*Sudden commencement and storm from previous flare. Interpretation difficult

* Evidence indicates trapping in solar cloud, producing possible increases at time of sudden commencement associated with beam in space.

Time in UT

shrinks inward as the main phase progresses so that the magnetic moment decreases but the surface field remains constant.

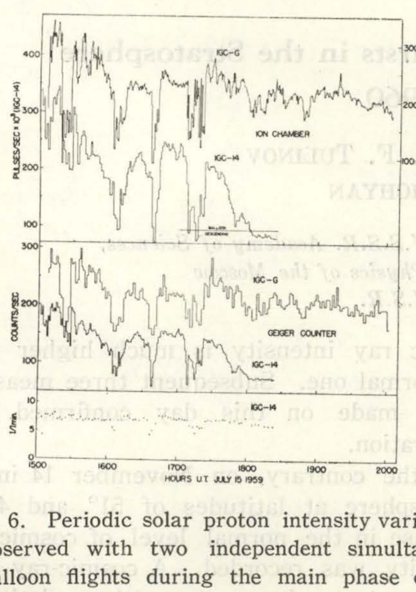

Fig. 6. Periodic solar proton intensity variations observed with two independent simultaneous balloon flights during the main phase of the July 15, 1959 magnetic storm.

Finally, besides giving indirect but very plausible evidence for a main phase ring current, the possible presence of standing waves or oscillations in the main field of the earth or of the ring has also been detected. Fig. 6 shows the ionization and count rate records from two independent but simultaneous balloon flights near Minneapolis during the strong July 15, 1959 solar proton event. At least 5 cycles of an oscillation with a period of about 0.5 hrs. are clearly evident. This period is similar to the travel time around the earth of a hydro-magnetic wave at a distance of 7 to 10 earth radii. The intensity variation in the solar protons would then be produced by a periodic alteration of the geomagnetic cutoffs by this wave motion.

References

1) E. P. Ney, International Conference on Cosmic Rays and the Earth Storm, Kyoto, Japan, 1961.

2) T. Obayashi and Y. Hakura, J. Radio Research Labs, **7** (1960) 27.
T. Obayashi and Y. Hakura, J. Geophys. Research, **65** (1960) 3143.
3) G. C. Reid and H. Leinbach, J. Geophys. Research, **64** (1959) 1801.
4) J. F. Steljes, H. Carmichael and K. G. McCracken, J. Geophys. Research, **66** (1961) 1363.
5) M. A. Ellison, S. M. P. McKenna and J. H. Reid, Dunsink Observatory Publications, **1** (1961) 3.
6) P. D. Bhavsar, International Conference on Cosmic Rays and the Earth Storm, Kyoto, Japan, 1961.
7) K. A. Anderson, R. Arnoldy, R. Hoffman, L. Peterson and J. R. Winckler, J. Geophys. Research, **64** (1959) 1133.
8) F. B. McDonald, Phys. Rev. **107** (1957) 1386.
9) J. J. Quenby and G. J. Wenk, Cosmic Ray Group Report, Imperial College of Science and Technology, London England.
10) P. J. Kellogg and J. R. Winckler, International Conference on Cosmic Rays and the Earth Storm, Kyoto, Japan, 1961.
11) R. G. D'Arcy, Ph. D. Thesis. University of California, Berkeley, 1960.
12) A. N. Charakhchian, V. F. Tulinov and T. N. Charakhchian, Space Research, Proc. First International Space Science Symposium, Nice, North Holland Publishing Co., Amsterdam, 1960.

Discussion

Carmichael, H.: In a slide which I did not have time to show a periodic fluctuation similar to that shown by Dr. Winckler was shown at sea level during the late part of the November 12, 1960 event. The pulsation were observed only by the European stations and Climax in U.S.A. Dr. Webber has stated that the pulsations appeared to be correlated with pulsation seen in the value of H measured by equatorial stations.

Singer, S. F.: Theoretical remark on the apparent flattering of the spectrum of solar cosmic rays at low energies. Such an effect would be expected by the application of the expected Liouville theorem (Swann, Nagashima) if diffusive deceleration is experienced by the particles in propagating from sun to earth (see paper II-5-16).

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-II, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3B-26. Cosmic Ray Intensity Bursts in the Stratosphere in November 1960

A. N. CHARAKHCHYAN, V. F. TULINOV and T. N. CHARAKHCHYAN

The P. N. Lebedev Physical Institute of the U.S.S.R. Academy of Sciences, The Research Institute for Nuclear Physics of the Moscow State University, U.S.S.R.

According to our data in November 1960 there were recorded three cosmic ray intensity bursts in the stratosphere on the 14th, 15th and 21th of November.

The general picture of cosmic-ray flares is the following. A measurement carried out on November 14 at 7 hours (universal time) in the stratosphere at a latitude of 64° (the Murmansk region) showed that the cosmic ray intensity is much higher than the normal one. Subsequent three measurements made on this day confirmed this observation.

On the contrary, on November 14 in the stratosphere at latitudes of 51° and 41° a decrease in the normal level of cosmic ray intensity was recorded. A cosmic-ray flare in the stratosphere at northern latitudes