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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3B-5. Solar Active Regions and Solar Cosmic Rays

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A study has been made of solar active regions in which occurred flares which produced solar cosmic rays — primarily protons in the energy range of a few Mev to a few Bev — during the period July 1957-December 1960. Of 40 solar cosmic ray events that occurred during this period, 35 could be attributed to 26 active regions. The regions producing the majority of the 35 events were characterized (not necessarily simultaneously) by $\beta\gamma$ or γ sunspot magnetic complexity, sunspot areas $>200\times10^{-6}$ of the solar hemisphere and five or more flares of importance ≥2. Over two-thirds of the flares producing the cosmic rays occurred (a) in the northern solar hemisphere, (b) west of the central meridian, and (c) on first or second rotation of the parent active region. However, some significantly strong events did not fall in with the majority. The strength of polar cap absorption, measured by riometers in db, was correlated to some extent with the strength of related geomagnetic storm, although anomalies existed.

On the average, active regions producing solar protons form a part of a larger population of the most active solar regions. However, aside from the average trend noted, none of the gross characteristics of the proton-producing regions distinguished them from other regions. It is suggested that other features of a finer nature — magnetic and thermodynamic details — make the difference between cosmic ray flares and non-cosmic-ray flares.

Introduction

This paper extends the investigation of solar cosmic rays — herein understood to consist primarily of energetic protons with energies from a few Mev to a few Bev — which have been studied in recent years by many investigators[1-5], to the solar active regions in which they were produced, with the objective of determining if there existed features unique with these regions which distinguished them from active regions not producing solar protons detected at the earth. It is possible that such information may be useful in the prediction of occurrence of cosmic ray flares in the future.

During the period July 1957-December 1960, 40 cases of solar protons incident on the earth were detected by polar cap absorption (PCA) of cosmic radio noise, measured by riometers. Some of these events were also detected by other means. These events are tabulated in Table I along with other data to be discussed. Of these events, 35 could be assigned with reasonable certainty to specific solar active regions. The 35 events were related to flares in 26 active regions or sunspot groups, counted separately per appearance on the visible solar disk.

The following data pertinent to the cosmic ray events and their parent active regions were obtained (for sources see footnote, Table I): magnetic characteristics, age, area, location, associated flare and radio activity, and strength of associated magnetic storm. An arbitrary classification of strength of PCA event was adopted for comparison purposes and defined in terms of maximum high latitude absorption in db on 27 mc/s riometers, as follows: weak, <5 db; moderate, 5-15 db; strong, >15 db.

Results

The distributions in the characteristics mentioned in the preceding paragraph of parent active regions and of individual solar events which produced protons detected at the earth are shown in Figs. 1 to 10. Pertinent facts are given in the captions of the figures.

The relationship between strength of PCA

Table I.[a] Polar Cap Absorption Events, July 1957—December 1960

PCA[b]				Flare			Region					
Date	Start UT	Intensity db	Duration>, hrs.	Imp.	Location	Start[c] UT	Mc-Math	HAO	Helio. Long.	Mag.[f] Class.	Sunspot Area[d]	Mag. Storm[e]
1957 July 3	<1100	6	46	3+	N10 W42	0830	4039	57QC-1	70	αp	750	M
24	2015	2	11	3	S24 W27	1801	4070	57JA-3	135	βp	680	none
Aug. 9	<2245	2.5	24									
29	1300	9	49	3	S31 E33	0913+	4125	57JL-1	350	γ	1050	S
31	<1500	5	45	3	N25 W02	1257	4124	57JG-2	330	$\beta\gamma$	2660	G
Sept. 2	<2100	9	32	1+	N10 W26	1257	4124	57JG-2	330	$\beta\gamma$	2660	G
12	<1200	0.5	18	3	N13 W02	0236+	4134	57JH-2	195	$\beta\gamma$	1780	G
21	<1930	5	31	3	N10 W06	1330	4152	57QD-3	90	$\beta\gamma$	2160	G
26	<2315	2	29	3	N22 E15	1907	4129	57JG-3	330	αp	1890	G
Oct. 21	<0700	5	13	3+	S26 W45	1637+	4189	57JU-1	70	βf	3580	S
1958 Feb. 10	<0700	>12	30	2+	S12 W14	2108+	4400	58B-2	20	β	2380	G
Mar. 25	<2230	12	96	3+	S14 E78	0947++	4476	58J-2	90	$\beta\gamma$	2170	S
Apr. 10	1130	4.5	40									
June 6	1345	small		2	N16 W78	0436	4578	58K-1	345	β	900	M*
July 7	0130	>15	120	3+	N25 W08	0020	4634	58P-2	205	βf	860	G
29	0405	1.5	30	3	S14 W44	0259	4659	58S-2	320	$\beta\gamma$	3480	none
Aug. 16	0600	>15	60	3+	S14 W50	0433	4686	58BC-2	85	$\beta\gamma$	2180	M
21	1500	3	19									
22	<1700	>10	80	3	N18 W10	1428	4708	58BF-1	310	$\beta\gamma$	1540	M
26	0100	>13	89	3	N20 W54	0005	4708	58BF-1	310	$\beta\gamma$	1540	M
Sept. 22	1430	4	82	2	S19 W42	0738	4765	58CA-2	290	βp	2110	M
1959 May 11	0130	>15	200	3+	N18 E47	2102+	5148	58BT-6	60	$\beta\gamma$	2390	G
June 13	<1330	1.5	48									
July. 10	0700	>15	90	3+	N20 E60	0206	5265	59Q-3	330	γ	2040	S
14	<0700	>15	51	3+	N17 E04	0325	5265	59Q-3	330	γ	2040	G
16	<2250	>15	120	3+	N16 W31	2114	5265	59Q-3	330	γ	2040	G
Aug. 18	<1100	1	60	3	N12 W33	1014	5323	59L-4	255	β	1240	S
Sept. 2		very small										
1960 Mar. 31	<0730	7	14	2	N12 E15	1455+	5615	60H-1	135	γ	2270	G*
Apr. 1	0945	3	86	3	N13 W09	0845	5615	60H-1	135	γ	2270	M
5	<0800	3	40	2	N12 W62	0207	5615	60H-1	135	γ	2270	none
28	0500	3	24	3	S05 E34	0130	5645	60K-2	90	βp	570	S**
29	<0600	14	114	2+	N12 W21	0138	5642	60H-2	135	γ	1120	G
May 4	1044	5	49	3(?)	N12 W90	1015	5642	60H-2	135	γ	1120	M
6	<1830	>15	101	3+	S10 E08	1404	5653	60L-2	350	αp	680	G
13	0620	4.5	65	3	N30 W64	0522	5654	60M-1	350	γ	2300	S*
Sept. 3	<1400	2	48	3(?)	N17 W90	0037	5837	60X-3	150	γ	920	S**
Nov. 12	1400	>15	61	3+	N27 W01	1315	5925	60HH-1	35	$\beta\gamma$	2330	G
15	<0800	>15	~100	3+	N26 W33	0207	5925	60HH-1	35	$\beta\gamma$	2330	M
20	3		~48	3(?)	N25 W90	1955	5925	60HH-1	35	$\beta\gamma$	2330	S*

Notes: a. Data (not PCA) from CRPL Solar-Geophysical Data, HAO Quarterly Summary of Solar Activity, IAV. Quarterlp Bulletin of Solar Activity, IGY Solar Activity, Reports 12 and 15; D. E. Trotter (unpublished).

b. PCA data: Reid and Leinbach[2]; H. Leinbach, T. R. Hartz (unpublished)

c. + and ++ signify one and two days earlier than PCA event

d. Maximum area in units of 10^{-6} of solar hemisphere

e. G, great; M, moderate; S, small, as defined by Bell.[3] (8) See Table II. * association uncertain; ** preceded or followed by another storm

f. Data from Mount Wilson Observatory

Table II. Relation between PCA and Related Magnetic Storm

PCA	Magnetic Storm			
	Great	Moderate	Small	None
Strong	6	2	1	0
Moderate	5+1?	4	3	0
Weak	2	2+1?	1+4?	3

Numbers are total cases of correspondence between pairs of events. Some numbers questioned because of uncertain association oroverlapping storm.

PCA: Strong, >15 db; moderate, 5-15 db; weak, <5 db.

Magnetic Storm[13]: Great, Ap$\geqq$100 and/or one 3 hr. Kp$\geqq 9^-$; Moderate, Ap$\geqq$50 and/or one 3 hr. Kp$\geqq 7^+$; Small, Ap, ΣKp both $\geqq$25 on at least one of three days following flare.

event and strength of geomagnetic storm associated with the same flare is shown in Table II.

Discussion

The data in the figures show that the majority of solar proton events during the period investigated, and the majority of strong events as well, were due to flares in active regions characterized by (not necessarily all simultaneously) magnetic complexity, few rotations, relatively large sunspot area and many major flares. However, these same conditions obtain for many features of solar activity in general. Richardson[14)] has shown that over a 14-year period, $\beta\gamma$ and γ groups constituted 56% of all groups producing five or more flares. Thus the fact that the proton-producing groups were primarily $\beta\gamma$ or γ may reflect the fact that, in general, flares form more frequently in such groups.

With respect to age and area, it is well known that spots form and develop early in the history of an active region, often in bipolar form, later becoming unipolar. Flare frequency is related to both the area and the rate of change of area of spots[15)]. However, the largest flares tend to occur when the spot areas are near maximum, even though the rate of change is then small[16)]. This is consistent with the behavior of the proton-producing flares, as a detailed examination showed.

The proton-producing groups, then, did not

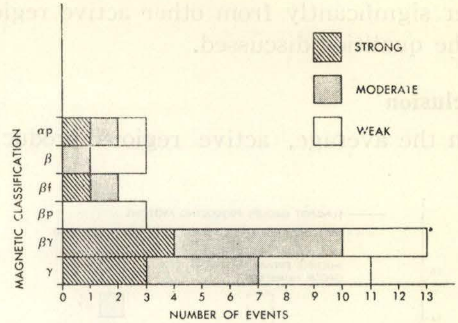

Fig. 1. Number of solar proton events versus average magnetic classification (6) of parent spot group. The thirty-five events were related to 26 spot groups distributed by magnetic classification as follows: $3\alpha p$, 3β, $2\beta f$, $3\beta p$, $9\beta\gamma$, 6γ (α, unipolar; β, simple bipolar; $\beta\gamma$, complex bipolar; γ, complex multipolar). The distribution of events is as follows: α, 9%; β, 23%; $\beta\gamma$,: 37%; γ, 31%. The distribution of all (1223) non-transient spot groups in this period was α, 35%; β, 59%; $\beta\gamma$, 5%; γ, 1%. The 24 cases of solar protons identified with $\beta\gamma$ and γ groups came from 15 regions, about 20% of all $\beta\gamma$ and γ regions during the report period.

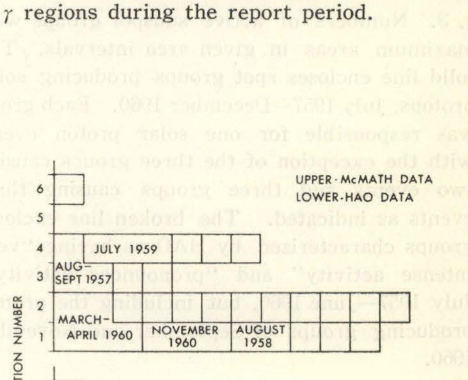

Fig. 2. Number of solar proton events versus age in rotations of parent active region. The rotation number based on McMath-Hulbert plage age is shown in the upper figure, and based on High Altitude Observatory data in the lower figure. Multiple events due to one sunspot group, or in two cases (September 1957, April 1960) to its return on the next rotation, are indicated by the name of the month. All multiple events occurred in sunspot groups of $\beta\gamma$ or γ classification.

differ significantly from other active regions in the qualities discussed.

Conclusion

On the average, active regions producing solar protons form a part of a larger population of the most active solar regions. Not all of the most active regions produced detectable protons; and several strong events originated in regions not noted for high ac-

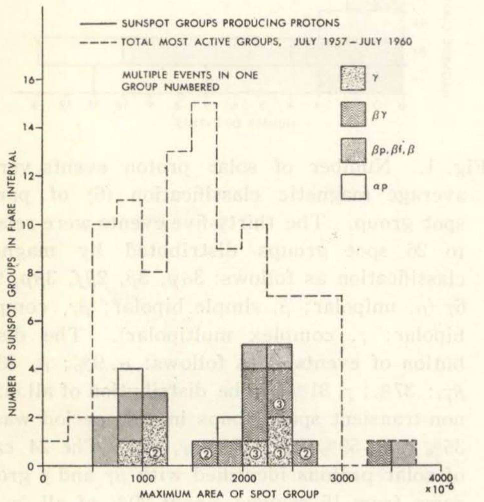

Fig. 3. Numbers of active sunspot groups with maximum areas in given area intervals. The solid line encloses spot groups producing solar protons, July 1957—December 1960. Each group was responsible for one solar proton event, with the exception of the three groups causing two events and three groups causing three events as indicated. The broken line encloses groups characterized by HAO as having "very intense activity" and "pronounced activity," July 1957—June 1960, but including the proton-producing groups of September and November 1960.

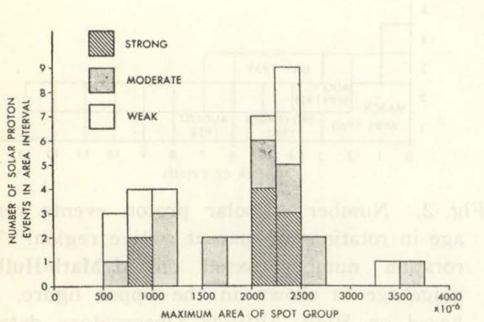

Fig. 4. Numbers of solar proton events originating in sunspot groups having maximum areas in given area intervals. Strong, moderate, and weak refer to 27 mc/s riometer maximum absorption > 15 db, 5—15 db, < 5 db respectively.

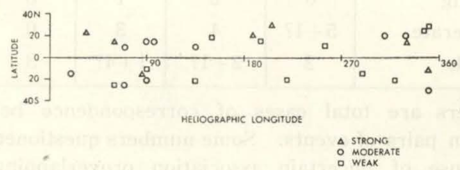

Fig. 5.

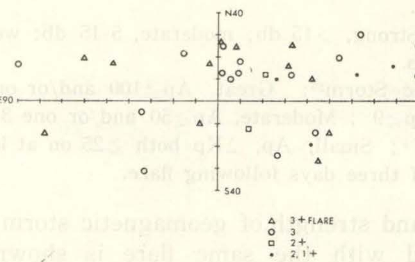

Fig. 6.

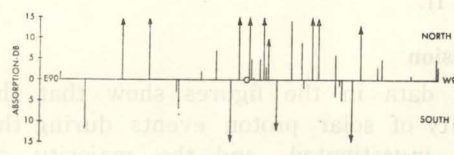

Fig. 7.

Fig. 5. Heliographic longitude (based on epoch of January 1, 1854) and latitude of active regions producing solar protons. Sunspot groups producing protons on two successive rotations are indicated only once each. The greatest degree of riometer absorption is indicated in the case of multiple events due to one region. Parent regions for events of February 23, 1956; August 31, 1956; January 20, 1957; and April 3, 1957 (2 North, 2 South) are included in addition to events from July 1957 through December 1960. (14 North, 10 South). Although the statistics are poor there appear to be two intervals in longitude, 60°—100° and 310°—350°, in which these active regions showed some concentration. A tendency for active regions to occur non-randomly but in preferred intervals of longitude has been noted before. (7-9)

Fig. 6. Distribution in latitude and central meridian distance of flares producing solar proton events.

Fig. 7. Maximum riometer absorption in db resulting from protons from solar flares having indicated heliographic distribution. Events above and below the line are due to flares north and south of the solar equator respectively. Arrow heads indicate that maximum absorption was greater than the indicated value.

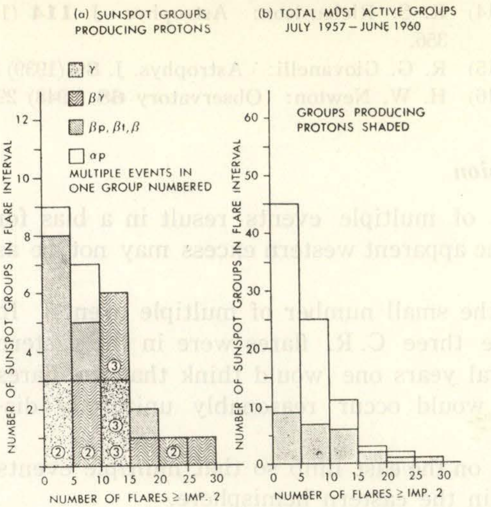

Fig. 8. Numbers of sunspot groups having flares of importance ≥ 2.

a) Sunspot groups producing solar protons, July 1957—December 1960. The number of multiple events in a group is indicated.

b) Total groups characterized by HAO as having "very intense activity" and "pronounced activity," July 1957—June 1960, but including the proton-producing groups of September and November 1960.

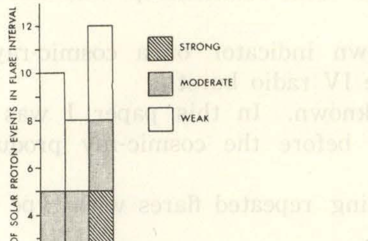

Fig. 9. Numbers of solar proton events due to sunspot groups having flares of importance ≤ 2. Maximum 27 mc/s riometer absorption indicated by strong, moderate, and weak, for >15 db, 5—15 db, <5 db respectively.

tivity. None of the gross characteristics of the proton-producing regions uniquely distinguished them from other regions, aside from the average trend noted.

It is suggested that other features of a finer nature—magnetic and thermodynamic details, for example, in the chromosphere and corona — not examined here, make the

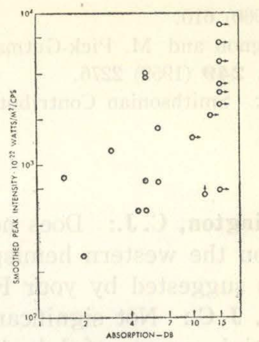

Fig. 10. Smoothed intensity of Type IV 10 cm emission associated with certain of the solar proton events (10—12) versus db absorption on 27 mc/s riometer. Arrows indicate that numerical values are greater than shown.

difference between cosmic-ray flares and non-cosmic-ray flares. These same details are most probably the ones necessary for the production of Type IV radiation, since such radiation is so closely associated with solar cosmic rays.

Acknowledgments

Grateful acknowledgment is made to Mount Wilson Observatory for granting access to its sunspot records, and in particular to T.A. Cragg for helpful discussions concerning sunspot magnetic classifications; and to H. Leinbach, M. Pick, and D.E. Trotter for unpublished data.

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Discussion

Waddington, C. J.: Does not the inclusion of multiple events result in a bias for events on the western hemisphere so that the apparent western excess may not be as great as suggested by your Figures?

Noyes, J. C.: Not significantly, in view of the small number of multiple events. In the multiple events of July 1959, two of the three C. R. flares were in the eastern solar hemisphere. Over a period of several years one would think that the flares which potentially could produce cosmic rays would occur reasonably uniformly distributed in longitude.

Also, a developed active center can appear on the east limb so that multiple events from such a region could potentially appear in the eastern hemisphere.

During the IGY the C. R. sources were more numerous in the western hemisphere, but this appears to be a statistical fluctuation which was smoothed out during the next two years.

Cook, F. E.: One possible criterion (for separating possible event producing regions) may be meter-wave radio emission. R. T. Hansen also came to the same conclusions as those given here, with respect to 8-type magnetic classification.

Noyes: In this connection also Mme Pick of Meudon has indicated a close correlation between small high-temperature coronal condensation at 3 cm and Type IV radiation. Because of the close correlation between solar cosmic rays and Type IV radiation, a relation between cosmic-ray producing region and region with such high temperature condensations might be inferred. This relationship was not examined in this paper.

Wild, J. P.: There is surely one well-known indicator of a cosmic-ray or solar proton flare—namely the occurrence of a type IV radio burst.

Noyes: This radiation is of course well known. In this paper I was referring more to conditions in the centre of activity before the cosmic-ray producing flare occurs.

Biermann, L.: A centre of activity producing repeated flares with type IV bursts should then be an indicator of solar protons.

Athay, R. G.: It is well known that sunspot regions of complex magnetic structure statistically produce more flares and are larger than regions of simple polarity.

Does not this explain your conclusions regarding the importance of magnetic classification and sunspot group area as indicators of cosmic ray production?

Also, since most active regions have lifetimes of less than three rotations, your conclusion that cosmic rays are produced most often during the first two rotations must follow.

Noyes: Yes, in general, but with a few notable exceptions. The solar regions that produced cosmic rays were of the class of the most active solar regions, that is, characterized by magnetic complexity, large area, and few rotations. And as noted, not all of the most active regions produced cosmic rays. My principal conclusion is that certain details of magnetic or thermodynamic configurations are necessary for cosmic ray flares at distance from other flares to occur. Such details may be present with greater probability in regions of the majority type described earlier. (note added later) Since non C. R. flares and regions were not examined in detail. I cannot at this time compare on a "per flare" basis regions producing cosmic rays and those not doing so.

Biermann: In order to improve the statistics, it might be useful to take into account the distinction, (introduced first, I believe, by Denisse) between radio-active regions and others. Only in the former group ($\times 1/5$ of all) flares may be accompanied by acceleration processes which produce relativistic electrons or energetic protons.

Noyes: 21-cm scans from Sydney were examined for the period July 1957 — December 1958. These data showed the same general trend stated in the conclusions previously given: that many of the cosmic ray producing groups were characterized by high brightness temperatures at 21 cm, but not all high temperature groups produced cosmic rays. Since such data were not available to me after 1958, for consistency I used none of the data.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3B-6. Intensity of Solar Proton Emissions

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The intensity of proton emissions associated with solar flares has been studied over the period of maximum activity for solar cycle 19. During this period, from 23 February 1956 to 3 September 1960, there were 43 events in which there was experimental evidence for solar proton emission. Using the published data for these events we have estimated the *time integrated free space proton flux* for several of the events. For those events observed only by riometers the integrated flux was determined by taking the proton intensity to depend quadratically on the riometer absorption and assuming that the time history for all events is similar.

A summary is given of the estimated integrated flux (size) for 36 of the events. This data is then used to determine the integral size-frequency distribution, giving the average rate of occurrence, during solar maximum, of events larger than any specified size. The relatively flat size spectrum and the corresponding intensity spectrum have a shape approximating an inverse power law. It is suggested that this observation may be interpreted as defining a general property that any theory must possess which attempts to explain the acceleration of energetic protons during flares. The size distribution may also be used for estimating the hazard for a manned space system.

Introduction

The discovery, during the IGY, of the relatively frequent low energy solar proton emissions following solar flares has been followed by many investigations to elucidate the basic phenomena of cosmic ray production by the sun. The intensity of these events is of fundamental interest for cosmic-ray and solar physicists and also now of considerable practical interest.

The purpose of this study has been to use the available experimental data on the flare associated proton production by the sun over the period of solar maximum (cycle 19) to deduce the total integrated proton flux (protons/cm^2) received near the earth. During