these times are so different.

McCracken, K. G.: I would like you to amplify the details of your model in relation to the following experimental facts.

1) For an axially symmetric magnetic field, the direction of the diurnal anisotropy will be either 90° to the east, or the west of the sun. In fact, it takes intermediate values on a great number of occasions. In particular, there was a continuous migration of this direction from approximately towards the sun, to one 90° east of the sun between 1954 and 1958.

2) For those events for which sufficient data are available to permit positive identification, the arrival directions for cosmic rays generated in solar flares lie close to the plane of the ecliptic, and furthermore, are inclined by some 50° to the west of the sun. For a "dipole like" field, I would think that we would expect the solar cosmic rays to come from directions roughly perpendicular to the plane of the ecliptic.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-5-18. Morphology of Solar Flare Effects on Cosmic Rays and Sub-Cosmic Rays

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Morphological studies of energetic solar protons are presented in an energy range of Mev to GeV by using cosmic ray records and polar cap absorption data. The solar protons could be classified by order of energy into the four groups: (1) cosmic ray unusual increase, (2) cosmic ray small increase and polar cap absorption of (3) fast and (4) slow types, being classified, respectively, in terms of the propagation time of the particles from the sun toward the earth. A clear distinction is recognized on their characters between a group of the unusual increase and the fast-type PCA and another group of the small increase and the slow-type PCA. These two groups are related to different solar regions where different accelerations of particles occur. This conclusion is based on characteristics of the solar radio noise outbursts associated with these solar proton events and also solar cycle dependencies of the events.

Introduction

This is a review of the morphological studies of energetic solar protons, such as cosmic ray unusual increase, small increase and polar cap absorption events, which were mainly given by several Japanese workers. We have a lot of data concerning the solar flare events by means of the world-wide network of observatories distributed during the IGY 1957–58. Although many interesting studies on the solar flare effects have been made so far, most of them were apt to be restricted to either region of cosmic rays or sub-cosmic rays such as PCA event. If not so, then the studies have concentrated on a special event, for examples, July 1959 event or November 1960 event. At least, the statistical study so as to deal with all of the solar flare events throughout both regions scarecely exists.

The purpose of this report is to investigate the various characteristics of solar cosmic ray particles and solar sub-cosmic ray particles and then to discuss their acceleration in the solar region and their propagation process in the interplanetary space. Analyses of data were carried out from the following three viewpoints: first, relationship between the propagation time of solar particles and the flare position, second, characteristics of the solar radio outbursts associated with solar particles and lastly, solar cycle dependency of occurring frequency of solar proton events.

The data obtained on the ground level were used for the above purposes. Of course, we must remember the important informations given by balloon or rocket experiments, especially as regards energy spectrum of solar particles. But the statistical treatment is rather suitable to the ground level data, so no data from balloons and rockets are included here.

Classification of Energetic Solar Protons

For convenience, let us first classify the energetic solar protons into the five types as shown in Table I. The cosmic ray increase, the maximum enhanced intensity of which is larger than about 100%, is defined as unusual increase (hereafter say U.I.). This event was observed eight times since 1942. Next, we say cosmic ray increase, the maximum enhanced intensity of which is of order of 0.1 to 1%, as small increase. This is classified furthermore into two kinds of increase, one is individually detectable (S.I.-I.) and the other statistically detectable (S.I.-S). PCA events also are divided in to two types according to propagation times of particles, namely, the one that it is below 6 hrs. (F-type) and the other above 6 hrs. (S-type). Maximum energies of five types of solar protons are roughly given in second coloumn of Table I, where several factors attached to respective values are omitted.

No small increase had been found before the beginning of observations of cosmic ray neutron component. Table II gives six S.I.-I events occurred from 1956 to 1961. These events show a maximum intensity enhancement of several % which can be clearly distinguished from U.I. Details of S.I.-S will be given in later.

PCA events during 1956–60 are 33 events accompanied by type IV radio outbursts which were given by Hakura[1,2]. Among them, 22 events belong to F-type and 11 events S-type

Table I. A classification of energetic solar protons

	Maximum energy (BeV)	Maximum enhanced intensity (%)	Propagation time (hrs)
C.R. unusual increase (U.I.)	~10	≳100	
C.R. small increase individual (S.I.-I)	~ 1	~1	
C.R. small increase statistical (S.I.-S)	~ 1	~0.1	
Fast type of PCA (F-type)	~0.1		<6
Slow type of PCA (S-type)	~0.01		≥6

Table II. List of cosmic ray small increases.

	Solar Flare		SSC	Enhanced C.R. Intensity (%)	ΔT_m (hrs)	ΔT_p (hrs)	Refs.
	Start	Position					
Aug. 31, 1956	1228	18N, 12E	2nd, 0230	2	38	0.3	a
July 17, 1959	2115	8N, 26W	17th, 1638	10	19	15	b
Sept. 3, 1960	0040	17N, 90E	4th, 0230	4	26	6	c
Nov. 20, 1960	2022	25N, 120W	21st, 0632	5	10	1.5	d
July 18, 1961	0929	8S, 59W	20th, 0248	15	41	2	e
July 20, 1961	1550	6S, 90W		4		0.4	e

a) K. G. McCracken: Nuovo Cimento **13** (1959) 1074.
b) M. Kodama: Helsinki Symposium (1960).
c) J. R. Winckler *et al*: Phys. Rev. Lett. **6** (1961) 488.
d) H. Carmichael *et al*: Phys. Rev. Lett. **6** (1961) 49.
e) H. Carmichael: private communication.

respectively.

Part 1

Fig. 1 is a familiar diagram that the propagation time of solar particles is given with a heliographic longitude of the corresponding solar flare. The propagation time means, in case of cosmic ray events, the difference between the starting time of solar flare and the time of maximum cosmic ray intensity. In case of PCA events, it is the difference between the both beginning times of the type IV radio outburst and PCA event.

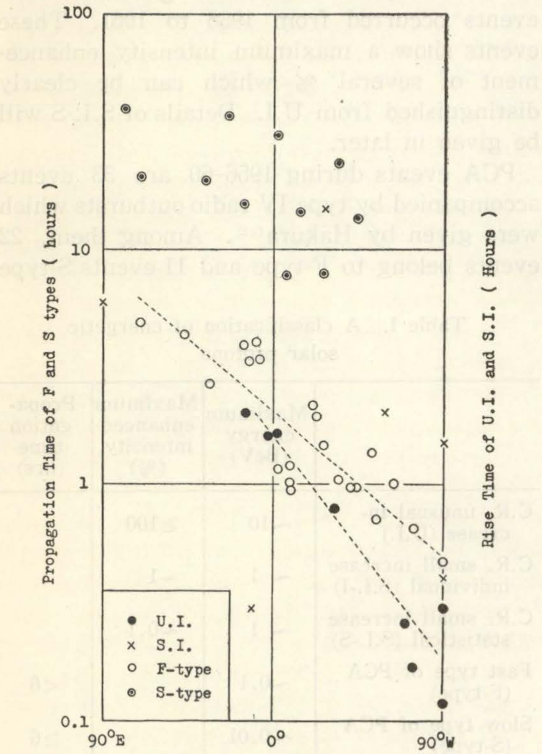

Fig. 1. Heliographic distributions of the propagation times of solar particles.

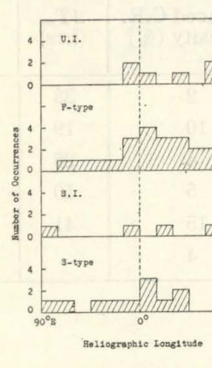

Fig. 2. Heliographic distributions of occurring frequencies of solar proton events.

Double circles seen in the upper part of the figure are for S-type PCA and clearly separated from a group of E-type PCA by assuming a border line on 6 hours of the propagation time. It can be seen from this figure that a feature of so-called western excess in propagation time is remarkable in both cases of U.I. and F-type PCA, while rather obscure in other two cases.

The histogram in Fig. 2 gives a longitude dependence of occurring frequency of the above each event. Similarily, the western excess is apparent in both U.I. and F-type, whereas not so clear in both S.I.-I and S-type PCA. These facts lead us to a simple assumption that U.I. has a close relation with F-type PCA and S.I.-I is related with S-type PCA, but these two groups are different types of events from each other.

Part 2

Here, we must remember characteristics of the solar radio outbursts associated with these solar proton events. From the diagrams of Hakura[3], we can see some examples of frequency spectra of such radio outbursts. Figs. 3 and 4 correspond to the events accompanied by F-type and S-type PCAs. In the former case, the radio outburst arises

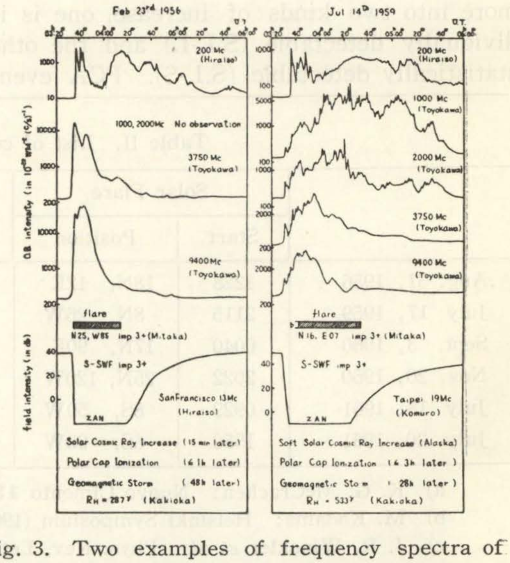

Fig. 3. Two examples of frequency spectra of the radio outbursts associated with fast type PCA events (by Y. Hakura).

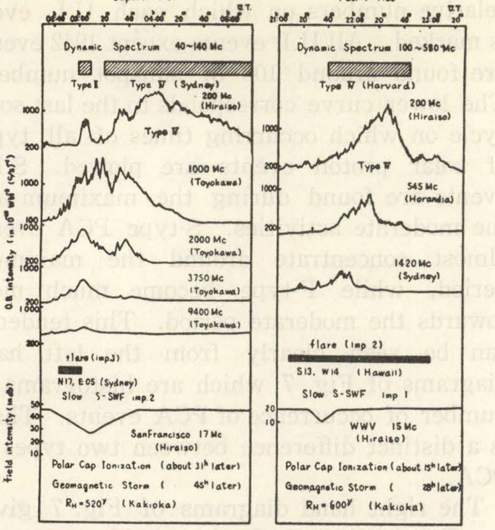

Fig. 4. Two examples of frequency spectra of the radio outbursts associated with slow type PCA events (by Y. Hakura).

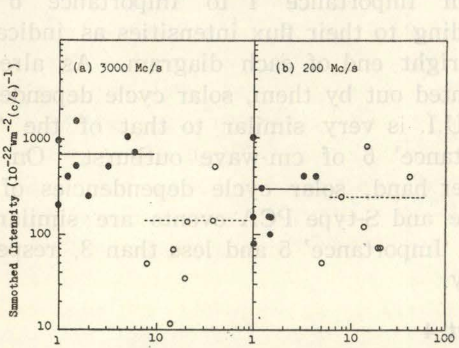

Fig. 5. Relation of radio outburst smoothed flux intensities to the time delays (ΔT) from the onset of radio outbursts to the arrival of PCA particles. ●: Time delay <6 hrs. ○: Time delay ≧6 hrs. Dotted lines are mean intensities (by Sakurai *et al.*).

over all frequency bands, especially predominant in cm-wave band. On the other hand, Fig. 4 shows that cm-wave outburst is far smaller than in other wave bands.

According to the results by Sakurai and Maeda[4], flux intensities of the radio outbursts associated with F-type are larger than those associated with S-type. Fig. 5 is their reproduced figure where black and open circles correspond to F-type and S-type PCAs, respectively. Comparing two diagrams regarding the same type of circles, we can say that flux intensity of the outbursts corresponding to F-type PCA is larger in cm-wave band than in m-wave band, while that corresponding to S-type PCA is equal in both bands, or rather larger in m-wave band.

Next, let us examine the frequency spectrum of the radio outburst associated with S.I.-I. The smoothed flux intensities of four events excepting July 1961 events are given in Table III, the largest intensity is not seen in cm-wave band but in dm-wave band. But the last example, Nov. 20, 1960 event, may be an exceptional case because the solar flare occurred behind the west limb, 120°W.

Saying on U.I., we know from the observed records after Feb. 23, 1956 event the fact that it begins simultaneously with the starting time of very intense cm-wave outburst.

From the above mentioned results, one finds that both U.I. and F-type PCA have a close relation with cm-wave radio outburst while both S.I.-I and S-type PCA are connected to dm- or m-wave outburst.

Part 3

When we study on the solar flare effect, it is one of the important problems to investi-

Table III. SMD. flux of the solar radio outbursts associated with S.I.-I.

Wave	Frequency	Aug. 31 1956	July 16 1959	Sept. 3 1960	Nov. 20 1960	Mean flux	Obs.
cm	9400 Mc/s		640	30		200	a
	3750		1500	70		800	a
	2800	>340*			400*	400	b
dm	2000		2350	153		1300	a
	1500	4900*				4900	c
	1000		6500	47200		26800	a
	545	1700*	1000		40*	900	d
m	200	7500*	150		100*	2600	d

a) Toyokawa, b) Ottawa, c) Heinrich-Hertz, d) NERA All flux values are given in units of 10^{-22} mW^{-2} (c/s)$^{-1}$, where, * is peak flux.

gate how it is modulated with solar cycles. The most remarkable fact is that all of U.I. events occur in the period of moderate solar activity, avoiding periods of maximum and minimum solar activities. An upper diagram

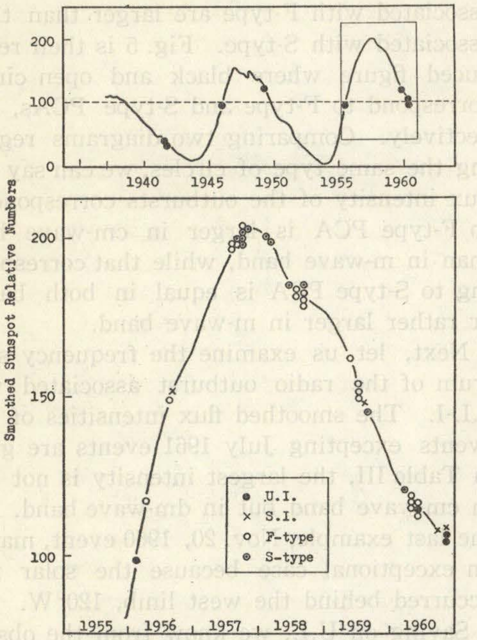

Fig. 6. Solar cycle dependence of occurring times of all solar proton events.

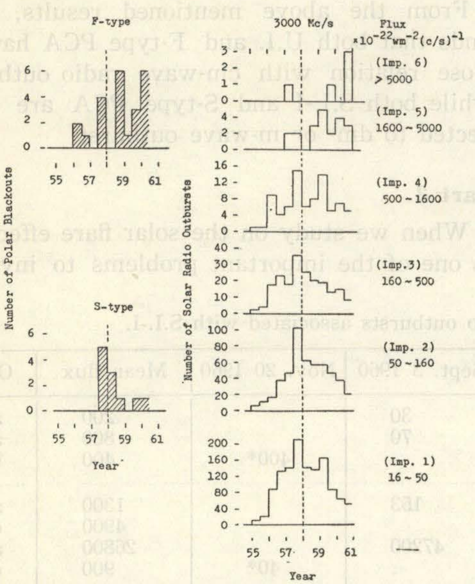

Fig. 7. Left hand: Histograms of occurring frequencies of PCA events. Right hand: Histograms of number of radio outbursts divided into six classes (by Takakura and Ono).

of Fig. 6 shows a smoothed curve of sunspot relative numbers on which each U.I. event is marked. All U.I. events except 1942 events are found around 100 of sunspot numbers. The lower curve corresponds to the last solar cycle on which occurring times of all types of solar proton events are plotted. S.I.-I events are found during the maximum and the moderate activities. S-type PCA events almost concentrate around the maximum period, while F-type become much more towards the moderate period. This tendency can be seen clearly from the left hand diagrams of Fig. 7 which are histograms of number of occurrence of PCA events. There is a distinct difference between two types of PCA.

The right hand diagrams of Fig. 7 given by Takakura and Ono[5] are histograms of occurring frequencies of cm-wave radio outbursts. They are classified into six groups from 'Importance' 1 to 'Importance' 6 according to their flux intensities as indicated in right end of each diagram. As already pointed out by them, solar cycle dependency of U.I. is very similar to that of the 'Importance' 6 of cm-wave outburst. On the other hand, solar cycle dependencies of F-type and S-type PCA events are similar to the 'Importance' 5 and less than 3, respectively.

Part 4

Now we wish to mention about cosmic ray small increase statistically detectable, S.I.-S. The past many works regarding S.I.-S have been made by taking the flare time as 'epoch' of the Chree's method. But it is more important to know characteristics of the radio

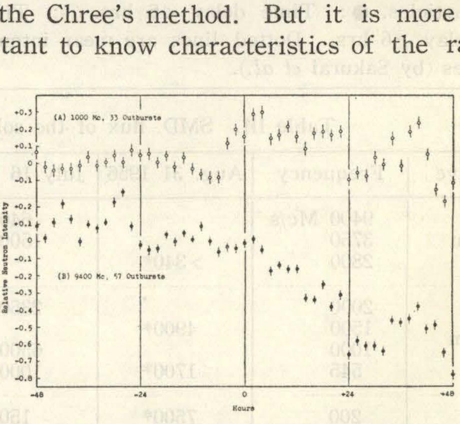

Fig. 8. Time variations of cosmic ray neutron intensities before and after the times of maximum intensities of radio outbursts.

outbursts associated with solar flares. Therefore, we classified the radio outbursts into two groups according to their frequency spectrum: One is the outburst in which the largest intensity is found in 1000 Mc band and the other in 9400 Mc band. Outburst data from Toyokawa during IGY were used and cosmic ray neutron data from Sulphur Mt. corresponding to these outbursts were superposed by taking the time of maximum intensity of the outbursts as '0-hour' of the Chree's method.

Fig. 8 shows thus obtained results corrected for diurnal variation in cosmic rays. The correction was made by using a mean diurnal curve deduced from the whole data during four days. A significant intensity enhancement is found in the upper curve, that is, in case of the radio outburst in which flux intensity is largest in dm-wave band. Dividing these

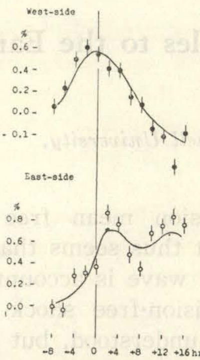

Fig. 9. Time variations of cosmic ray neutron intensities before and after the times of maximum intensities of the radio outbursts which were divided into the one occurring in west longitude and the other in east.

outbursts, furthermore, into two; the one occurred in the western longitude on the sun and the other in the eastern side, results from respective Chree's method are given in Fig. 9. The upper curve shows intensity enhancement earlier than in the lower. In other words, there exists a feature of the western early in the propagation time.

Summary

Table IV is a summary of the above mentioned results. Let us consider these results together with the dynamic spectrum of solar radio outburst given by Takakura. According to his consideration[6], three types of type IV outbursts, cm-wave, dm-wave and m-wave, attributed to synchrotron radiations occur in different heights above the associating flares and the energies of electrons radiating respective outbursts are different from each other.

The following conclusions are deduced by combining Table IV and Fig. 10.

1. Both solar protons of cosmic ray unusual increase and fast type PCA are accelerated in the same solar region simultaneously

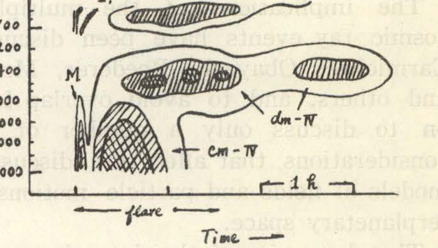

Fig. 10. A schematic dynamic spectrum of an intense outburst complex (by Takakura).

Table IV. Summary

	ΔT_p-φ Relation		Associated solar radio outbursts		Corresponding solar activity
	Western early	Western excess	Type	Intensity	
U.I.	yes	yes	cm	$>10^{4}$*	moderate
F-type	yes	yes	cm	$>10^{2}$	moderate
S.I.-I	(yes)	(yes)	(dm)	$>10^{3}$	moderate
S.I.-S	yes	no	dm	$>10^{2}$	max.-moderate†
S-type	(yes)	no	m	$<10^{3}$	maximum

ΔT_p: Propagation time of solar particles, φ: Heliographic longitude, *: $10^{-22}\,\mathrm{wm^{-2}\,(c/s)^{-1}}$, ( ): Subjected to uncertainties, †: Deduced from the past other results, for examples, by Firor or Kolomeets.

with cm-wave radio outbursts. The difference in energy among them is attributed to different efficiencies of accelerations.

2. Both solar protons of cosmic ray small increase and slow type PCA are generated in the same region from which dm-wave or m-wave outbursts are emitted. The different efficiencies of accelerations produce different energies of protons, but long delay time of S-type PCA is due to propagation process as acceleration mechanism.

3. Solar cycle dependencies of all solar proton events are subjected to acceleration mechanisms rather than propagation processes in the interplanetary space.

In conclusion, the author acknowledges the benefit of discussions with Dr. Y. Hakura.

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II-5-19. The Propagation of Solar Particles to the Earth

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The implications of the multiple solar cosmic ray events have been discussed by Carmichael, Obayashi, Roederer, McCracken and others, and to avoid overlap I will go on to discuss only a number of further considerations that affect the discussions of models of fields and particle motions in interplanetary space.

The sharp rise of the interplanetary pressure implied by a Sudden Commencement forces one to identify this with some kind of a shock wave. An expansion of a gas cloud into a vacuum would develop a much more diffuse front and the continuous collimation of the front by a resisting medium is necessary to account for the suddenness of the effect. My suggestion in 1953 that such a shock wave must exist and derive its sharpness from an electromagnetic interaction (rather than from particle collisions which would be much too infrequent) was taken up chiefly by Dr. A. Kantrowitz and his group. They have demonstrated experimentally that indeed wave fronts can be set up in a magnetized plasma that are very much narrower than the collision mean free path in the medium, and it thus seems that the sudden commencement wave is accounted for. The theory of collision-free shock waves is not yet completely understood, but most workers in the field are agreed that a sharp but collision-free wave front will exist.

There is no reasonable doubt now that such shock waves go through interplanetary space. There are still differences of opinion, however, how much of the modulation effects of galactic and solar cosmic rays should be attributed to the effects of the shock wave and how much should be attributed to the direct changes in the magnetic configurations in space which the varying motions of gas masses must produce.

We feel sure for many reasons now, including the famous results of Pioneer V, that we must consider the strong field case: by that I mean that the fields in space are all the time strong enough to deflect solar energetic particles into a spiral motion. We do not have the case of a weak enough field to allow any solar particles to come to us