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Abstract

Various geophysical phenomena are produced by both wave and particle emissions from solar flares. In understanding these phenomena, it is necessary to investigate the nature of these emissions and solar flare phenomena. Using the observed data for these emissions, a review is given on the nature of solar flares and their development. Geophysical phenomena are discussed by referring to the results for solar flare phenomena.

1. Introduction

Sudden ionospheric disturbances (SID's) are always associated with solar flares,which emit X-rays of wavelength shorter than about 5 $\mathring{A}$ (e.g., Friedman, 1963, 1964; Neupert, 1969). These X-rays ionize the atmospheric constituents of the lower region of the ionosphere, in particular, the D and E regions. At present, it is known that various wave and particle emissions are associated with solar flares: hard and soft X-ray bursts, EUV emissions, radio bursts of spectral types II, III, IV and V, microwave-impulsive bursts, solar cosmic ray protons, heavier nuclei and electrons, corpuscular clouds and shock waves (e.g., Sakurai, 1973a).

Although every flare is not accompanied by all of these emissions just mentioned, a major flare of importance 4B (or 3+) generally produces all of these emissions. It is now known that solar cosmic rays of Mev energy and corpuscular clouds are the sources for the polar cap absorption and geomagnetic storms, respectively. Shock waves associated with flares tend to propagate outward from the flare region and seem to reach sometimes near the earth's orbit or beyond. When they encounter the earth, SSC's are often observed at

the earth. These SSC's are also observed by satellites as the jump of magnetic field intensity, plasma flow speeds and other factors (e.g., Hundhausen, 1970; Chao et al., 1973).

Those geophysical phenomena are all of solar flare origin (Warwick, 1965; Mitra, 1970). Thus it seems very important to investigate the development of solar flares and their associated phenomena. At present, solar flares are usually observed by the hydrogen Balmer alpha line ($H\alpha$, λ = 6563$\overset{\circ}{A}$), which gives us an important information for the structure of flares in the chromospheric regions of the sun (Smith and Smith, 1963; Hess, 1964). In addition to this line, several other lines like $H\beta$, Ca II H and K are used in accordance with different purposes for the flare investigation. At present, we have methods to observe flares by using various wave emissions other than these spectral lines. For instance, solar X-ray and radio emissions associated with flares give many important informations on the development of flares and its relation to these emissions. These informations are also very important to study the mechanism of flares.

Though indirectly studied, SID's are also useful to study the development and mechanism of flares, because we are able to find a clue to estimate the time profiles of X-ray and EUV emission intensities which give additional informations to direct observations by satellites and rockets. Since, at present, we do not know yet the mechanism of solar flares and its relation to the particle acceleration processes, it is still necessary to take every possibility for observations in order to understand solar flares and associated phenomena.

The study of geomagnetic and cosmic ray storms enables us to estimate the propagation pattern of interplanetary disturbances associated with flares. This problem is under study by taking into account the magnetic and plasma data obtained by satellites and deep spacecrafts (e.g., Akasofu and Chapman, 1971; Hundhausen, 1972).

In this paper, we shall first review the observational results on solar terrestrial relationships and then consider solar flare phenomena and their relation to geophysical events. By taking into account the development of flares and various associated emissions, flare-associated disturbances at the

earth will be interpreted. Forecasting technique of flare

occurrences will also be discussed briefly to give an in-

sight to search for the cause of geophysical phenomena.

2.   Geophysical Disturbances Associated with Solar Flares

Solar flares, in general, produce both waves and particle

emissions. Among these emissions, X-rays and EUV rays are

responsible for SID phenomena, while Mev-particles emitted

by flares produce the polar cap absorption. In association

with flares, shock waves and corpuscular clouds are often

generated in the flare regions. After ejection, these waves

and clouds sometimes approach the earth's orbit and then

generate SSC's and geomagnetic storms, respectively. In

this section, we shall therefore, review these three emissions

from the sun by referring to the results observed on the

earth. Detailed descriptions for these results are useful to

further study of solar terrestrial relationships.

1)   SID's

SID's are generated as a result of the sudden increase

of the ionization density in the lower region of the ionosphere

except for SFD and the increase of the critical frequency

foF2. As shown in Fig. 1, for instance, various phenomena

occurred in association with the flare of 16 August 1958

(Hakura, 1958, 1961). In this figure, SEA (Sudden enhancement

of atmospherics), SWF (Short wave fade-out), SCNA (Sudden

cosmic noise absorption) and sfe (Solar flare effect on

geomagnetism) are described with the flare duration and the

time-profile of type IV radio burst at 200 MHz. These

phenomena associated with ionospheric disturbances are

called SID's.

In addition to the phenomena shown in Fig. 1, it is

known that SFD (Sudden frequency deviation), SPA (Sudden

phase anomaly), f-min increase and the increase of foF2 are

often associated with flares. SID's such as SEA, SCNA, SWF,

sfe and SPA are generated as a result of increased ionization

of the lower regions of the ionosphere, i.e., the ionospheric

D and E regions, whereas SFD and the foF2 increase are related

to the increase of the ionization density in the lower portion

of the ionospheric F2 region. This indicates that the cause

of both SFD and the foF2 increase is different from those

which produce other SID phenomena; that is, the cause is

dependent on the depth of the penetration of solar emissions

into the ionospheric regions. Therefore, the investigation

of SID's can give important clue to clarify the spectral distribution of flare-associated emissions responsible for ionizing the ionosphere.

2) PCA

The solar flare of 16 August 1958 was also accompanied by the polar cap absorption, which was detected as the increase of f-min (see Fig. 2) (Obayashi and Hakura, 1960). Several hours after the onset of this flare, the ionosonde at Alert, Canada, recorded the increase of f-min for about several hours. Almost simultaneously with this ground-based observation, the satellite, Explorer 2 just detected Mev solar particles (Rothwell and McIlwain, 1959). These solar particles were emitted from the flare described in this figure, which occurred at 0432 UT of 16 August. This flare was associated with type II burst at metric frequencies and type IV radio burst of wide frequency band.

This polar cap absorption is produced by the enhanced ionization in the upper atmosphere (50 - 100 Km high) over the polar cap regions due to the invasion of Mev solar cosmic ray particles (e.g., Obayashi and Hakura, 1960; Webber, 1962; Reid and Leinbach, 1959; Hultquist, 1959, 1965).

Because of this ionization, the commercial and standard

VLF radio waves of the polar routs is affected in a way

similar to SEA and SPA as described in subsection 1) (see

Egeland et al., 1961; Hakura et al., 1972). Phase

variation of these waves is clearly observed just after

the invasion of Mev solar cosmic ray particles starts.

During the IGY and IGC, several polar ionospheric

observing stations equipped the riometers to measure the

cosmic noise absorption due to ionospheric disturbances.

Later on, the riometers were shown to be useful to study

solar cosmic ray events because the enhanced ionization

by solar cosmic ray invasion produces sudden cosmic noise

absorptions (SCNA) for the riometer absorption records

(e.g., Reid and Leinbach, 1959; Leinbach, 1962; Reid, 1964,

1970). Leinbach (1962) extensively studied the patterns

of the development of this absorption and made clear that

the processes of solar cosmic ray invasion over the polar

cap regions are classified to several types; they are

currently called F, F*, S and mixed types, as shown in

Fig. 3 (Obayashi, 1964).

The cause of these types of events is related to the difference of the propagation mechanism of these solar cosmic rays in interplanetary space. This problem has been extensively investigated by many authors (e.g., Hakura, 1967a,b; Sakurai, 1965a, 1971a; Leinbach, 1962; Obayashi, 1962). At present, it is known that the chemical composition of solar cosmic rays plays an important role on the formation of the developmental pattern of Mev solar cosmic ray events (Hakura, 1967a,b; Sakurai, 1971a). Hakura (1967a) indicates that, in a typical event, there exist three stages for the development, each of which is closely related to the invasion of electrons, protons and helium nuclei over the polar cap regions. Therefore, the investigation of the developmental pattern of solar cosmic ray events gives us some important information for the acceleration and propagation mechanism of solar cosmic rays.

As is clearly seen in Fig. 3, S type events are associated with the development of SSC geomagnetic storms. This suggests that the particles for these events are transported by corpuscular clouds which produce these geomagnetic storms (e.g., Obayashi and Hakura, 1960;

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Sinno, 1961; Obayashi,1962, 1964; Sakurai, 1965a).

3) Geomagnetic Storms

A few days or more after the onset of solar flares, geomagnetic storms are sometimes observed at the earth. These storms start with the sharp increase of the horizontal intensity of the geomagnetic field, which is defined as the SSC (Storm sudden commencement). A typical example is shown in Fig. 4. In this figure, the three components of the geomagnetic field are described; they are the horizontal, vertical intensities and the declination. By analyzing these components and their time variation, we are able to investigate the development and structure of geomagnetic storms. As is seen in this figure, several hours after the SSC, the horizontal component starts to sharply decrease in its intensity. After reached minimum, this component is recovered within a week or two to the state before the onset of storms.

The Forbush decrease of cosmic rays, aurora and the auroral zone absorption (AZA) usually occur in association with geomagnetic storm. These phenomena are, therefore, triggered by some mechanism connected with the cause of geomagnetic storm (e.g., Obayashi, 1967). This suggests that it is most important to know the mechanism of

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geomagnetic storm, because we may find out the physical

relationships of this storm with the Forbush decrease,

auroral and other phenomena if we can understand this

mechanism. It is explained that SSC occurs as a result

of the interaction of the geomagnetic field with inter-

planetary shock waves or disturbances generated by solar

flares (e.g., Burlaga and Ogilvie, 1969; Chao and Lepping,

1972). In association with geomagnetic storm as shown

in Fig. 4, substorms develop at first over the polar cap

regions, and then extend to the lower latitude regions.

The expansion of the auroal zone to lower latitudes is also

seen during the main phase of storms.

At present, satellite observations show that inter-

planetary shock waves passing through the earth's magneto-

sphere are responsible for SSC of geomagnetic storms (e.g.,

Ness and Taylor, 1969; Lazarus and Binsack, 1969). These

waves seem to have been sometimes produced as blast waves

in solar flares. As shown by Chao et al. (1973), the

shock waves producing type II radio bursts are not always

able to reach the earth's orbit without heavy dissipation.

Therefore, the shock waves observed at the earth's orbit

by satellites may have been originated somewhere between

the sun and the earth by the action of flare-ejecta, while

they are sweeping through interplanetary space after

ejection by flares.

When we investigate the time differences between flares

and associated SSC's as a function of the longitudinal

position of these flares, we are able to find a statistical

pattern of the propagation of interplanetary disturbances

generated by flares (e.g., Akasofu and Yoshida, 1967;

Sakurai, 1973b). Fig. 5 indicates that these time differences

are dependent on the position of parent flares and that the

minimum is reached when flares occur about 30 degrees west

of the central meridian of the solar disk. The average

of these data shown in this figure also shows that the

minimum mean time difference is observed when a flare

occurs 20-30 degrees west of the central meridian plane

of the solar disk (Sakurai, 1973b). This result suggests

that flare-generated interplanetary disturbances tend to

propagate eastward from the flare region. This pattern

of their propagation has recently been obtained by Ness

and his colleagues (e.g., Ness and Taylor, 1969; Bavassano

et al., 1970; Lepping and Chao, 1972); their results suggest

that the formation of this pattern is closely related to
the mechanism of their generation in the flare region,
because it is known that the shock waves indirectly ob-
served as the moving source of type II radio bursts tend
to propagate along the magnetic fields near and above the
flare region (Smerd and Dulk, 1971; Dulk, Altschuler and
Smerd, 1971; Wild and Smerd, 1972).

While propagating through interplanetary space, these
disturbances may deform the configuration of the inter-
planetary magnetic field between the sun and the earth.
This variation of the field seems to be examined by
analyzing the field strength and direction in the region
behind the propagating front of these disturbances (Schatten
and Schatten, 1972). Furthermore, this variation would
affect the Forbush decrease of galactic cosmic rays during
geomagnetic storms. Sinno (1962) found that this decrease
is highly dependent on the longitudinal position of parent
flares on the solar disk. As shown in Fig. 6, the per-
centage of this decrease tends to increase as the flare
position moves eastward over the solar disk (Sakurai, 1965a,
1973b). This result, furthermore, indicates that some

flare-ejecta tend to change the configuration of the inter-

planetary magnetic field; in this case, the western portion

of these ejecta must produce high field intensity region

just behind the propagating front of those disturbances as

mentioned above. This situation is shown in Fig. 7,

which suggests that the cut-off efficiency of galactic

cosmic rays from reaching the earth is dependent on the

location of the earth within these bottle-like flare-ejecta.

In this section, we have given a review on geophysical

disturbances associated with solar flares. These disturbances

are detected through the two distinct media; the one is

related to the ionospheric variation, while the other is

communicated through the magnetospheric medium. The relation-

ships between solar and geophysical phenomena are summarized

in Table 1. This table shows what sorts of solar emissions

are responsible for various geophysical disturbances.

3.   Nature of Solar Flares and Associated Emissions

It is known that, as shown in Figs. 1 and 2, solar

flares produce various geophysical disturbances. In order

to understand these disturbances in greater detail, therefore,

it is necessary to investigate the nature of solar flares

and associated wave and particle emissions. In this section,
we shall, therefore,give a review on the observed character-
istics of solar flares and associated phenomena, and then
describe the relationships between the development of flares
and various emissions associated with flares. Finally,
the emissions responsible for geophysical disturbances as
mentioned in section 2 will be considered.

Solar flares are the phenomena which some areas on
the solar disk suddenly become brighter with respect to
the hydrogen Balmer alpha line intensity in the relative
meaning. These areas are sometimes located in or near
the sunspot groups, while some flares occur in the plage or
prominence regions. They are respectively called 1)
sunspot, 2) plage and 3) prominence flares (Tandberg-Hanssen,
1973). Sunspot flares are most important for the generation
of various wave and particle emissions which produce
geophysical disturbances. In general, spectral lines
like the Hα one are observed as the Fraunhofer lines for
the quiet sun. When flares occur, the absorption for
these lines are reduced and hence the intensity of the Hα
emission, for example, relatively increases in comparison

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with that for the quiet condition. At first, this increase

rapidly goes on and then the Hα brightness reaches maximum

during a few minutes. Later on, this brightness gradually

decreases exponentially to be recovered to the state before

the occurrence of flares. The time-profile of the Hα

brightness is shown in Fig. 8. While the brightness is

rapidly increasing, the area of the Hα brightening expands

rapidly in or above the sunspot group, and later covers a

large area over this group, as shown in Fig. 9. Filamentary

structure of the brightening area suggests that the Hα

brightening tends to occur along or across the magnetic

lines of force rooted from the sunspot group. By studying

the relation between sunspots and Hα brightening areas,

Kiepenheuer (1964) has obtained the result as shown in

Fig. 10. This figure indicates that the formation of these

Hα brightening areas is strongly controlled by the locations

of sunspots. Since the generation of sunspots is closely

related to the behavior of magnetic fields in the solar

photosphere, the location of the Hα brightening areas also

seems to be connected with the magnetic configuration in

and near the sunspot group. As indicated by chain lines

in Fig. 10, magnetic field lines tend to be across these

brightening areas. Since flares are observed in the

chromosphere or the lower corona, these field lines seem

to extend into these atmospheric regions and then control

the formation of the Hα brightening regions near the photo-

spheric surface.

It seems that solar flares are triggered in the region

where magnetic fields along the line of sight are null, i.e.,

the magnetically neutral layers or points (e.g., Severny,

1964, 1969; Sturrock, 1968). These regions are sometimes

generated in sunspot magnetic fields. Although there exist

serious theoretical problems to explain magnetic dissipation

in the neutral layer or point, it is thought that solar

flares occur as a result of this dissipasion due to sunspot

field annihilation (e.g., Parker, 1963; Sweet, 1964, 1969;

Priest, 1972a,b; Tandberg-Hanssen, 1973; Sakurai, 1973a).

At present, it is known that the sunspot groups of δ-type

are very active in producing solar flares (Sawyer, 1966;

Sakurai, 1967a, 1970a). These sunspot groups generally show

unusual magnetic configuration such that north and south

polarity regions appear together in the same main penumbral

regions (Kunzel, 1960; Sawyer, 1966; Sakurai, 1967a, 1972a).
Furthermore, the distribution of these two magnetic polarities
is unusual for sunspot groups which produce proton flares
(Sakurai, 1967a; Sawyer and Smith, 1970; McIntosh, 1970,
1972). The origin of this distribution seems to be related
to the rotating motion of sunspot axis (see Sakurai, 1972a).
By taking into account the twisting motion produced by
this rotating motion, the mechanism of solar flares is
investigated (e.g., Sakurai, 1967a; Barnes and Sturrock,
1972). Thus it is very important to study the detailed
structure and variation of sunspot groups in reference to
magnetic configuration.

Solar flares are generally associated with various
wave and particle emissions; gamma-ray, X-ray and EUV
bursts, radio bursts of spectral types II, III, IV and V,
the Moreton waves, shock waves, microwave radio bursts, solar
cosmic rays, magnetic bottles or clouds and flare ejecta.
Not all flares are accompanied by these emissions, but a
flare of importance 4B, for instance, produces the most
emissions described above. These emissions are not produced
simultaneously with the start of flare. It is now known
that a typical flare develops through three distinct

phases defined as the explosive, main and late phases

(e.g., Ellison and Reid, 1964; Sakurai, 1973a). During

each phase, several proper emissions are generated as

indicated in Table II. It is known that, within a few

days before the occurrence of a flare, some active

phenomena are observed in the sunspot group where this flare

is triggered; they are filament activation, plage brighten-

ing, the flux increase of microwave and X-ray emissions

(Sakurai, 1973a). These phenomena are important as a

precursor foregoing the onset of flares. When the Proton

Flare Project was planned to study the prediction and

development of proton flares in the IQSY committee, the

observation of those phenomena as mentioned above was

extensively done to find out what was going on before

the occurrence of proton flares (see, Stickland, 1969).

Analyzing the phenomena associated with flares, it

seems possible to classify flares into three different

types, as shown in Fig. 11; they may be called 1) SWF

type, 2) geomagnetic storm type and 3) solar proton type.

These classifications were first done by Sinno and Hakura

(1958a,b). This result indicates that the time-profile of

radio bursts for several discrete frequencies is a measure

for geophysical phenomena observed at the earth; for

example, SWF type of flare does not produce geomagnetic

storm nor high energy solar cosmic rays. As shown in

this figure, this flare only accompanies SID phenomena

as SWF. A flare of geomagnetic storm type (Fig. 11-2)

is associated with geomagnetic storm, but does not produce

solar cosmic ray event other than S type event. It is

noted that an associated SWF does not show a sudden onset.

The third solar proton type of flare is accompanied by

Mev-Bev solar cosmic rays, geomagnetic storm and sudden-

onset type SWF. Therefore, we may say that the develop-

mental pattern of radio burst is very useful to estimate

what disturbances are produced on the earth after the onset

of flares.

Although the characteristics of solar flares and

associated radio and SWF phenomena are shown to indicate

the developmental pattern of radio bursts and SWF's, these

flares are also associated with X-ray bursts, as expected

from the observations of SWF's. In fact, microwave bursts

are usually accompanied by X-ray bursts (Fig. 12) (Kundu,

1961; de Jager and Kundu, 1963; Cline, Holt and Hones, 1968). Association of these bursts with type III radio bursts at metric frequencies is well known, as shown in this figure (Anderson and Winckler, 1962; Kundu, 1963; Kane, 1972). Fig. 11 also indicates that the time-profiles of microwave emissions is similar to those for SWF's pattern. This fact suggests that the mechanism of X-ray emissions by flares is closely connected with that of microwave emissions (de Jager and Kundu, 1963; Kundu, 1963; Takakura and Kai, 1966; Takakura, 1967, 1969a). Since it is known that these two emissions are, respectively, generated by bremsstrahlung and gyro-synchroton mechanisms from high energy electrons accelerated in flares, we are able to interpret systematically these emissions by considering the energy spectra and number of these electrons in the flare regions (Takakaura and Kai, 1966; Takakura, 1969a,b; Holt and Ramaty, 1969; Holt and Cline, 1968). In order to understand SID phenomena in greater detail, therefore, we have to know physical mechanism which under-goes in the flare region during each phase as summarized in Table II. As shown in Fig. 11, SWF's always start simultaneously with the start of microwave radio bursts.

Furthermore, the developmental patterns of SWF's are similar to those of microwave bursts at 9400 MHz, for instance (Hakura, 1966).

We shall consider the developmental pattern of a major solar flare and associated wave emissions. This consideration seems to be important for the understanding of the relationships between flare phenomena and geophysical disturbances.

1) <u>Wave emissions and the developmental pattern of solar flares</u>.

The development of a typical flare consists of three different phases as described in Table II. As shown in Fig. 8, the Hα line brightness rapidly increases for a first few minutes. During these times, various wave emissions begin to be radiated from the flare region. The period for this brightness to increase sharply is now defined as the explosive or flash phases (e.g., Ellison, 1949, 1963). Because various wave emissions from gamma-rays to radio waves are observed almost simultaneously during this phase, it seems that the release of flare-energy to these emissions occurs very rapidly with the start of this phase by means of some mechanism though

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still not known very well. The transfer of this energy

to various modes of energy consecutively occurs to make

the main and late phases develop. Thus, the most important

phase is the explosive phase; however, we do not know yet

the mechanism of the storage and release of flare-energy

in sunspot groups in spite of our effort to find out the

cause of flares (e.g., Bruzek, 1967; Sweet, 1969; de Jager,

1969; Sakurai, 1973a). A current review on the origin of

solar flares is described in Tandberg-Hanssen (1973).

While the Hα line brightness is rapidly increasing

during the explosive phase, microwave (M-W) and hard X-

ray bursts begin to be emitted. Thermal component of

X-ray bursts follows hard X-ray emissions. During this

phase, type III radio bursts are often observed at metric

and lower frequencies. The emission of microwave type IV

bursts (IVμ) also starts almost simultaneously with micro-

wave bursts (M-W). When we plot the onset times for these

radio bursts as a function of observed frequencies, the

result as shown in Fig. 13 is obtained. This figure shows

that, at first, microwave burst starts to be emitted at

frequencies higher than ~500 MHz. Type III bursts at

metric frequencies are associated with this microwave burst

during the explosive phase. It is very difficult to find

out the onset time of type IV radio bursts because forruning

microwave and type II bursts, in general, overlap type IV

burst. In Fig. 13, by arrows, we only show the times for

the maximum flux intensities by type IV burst at frequencies

higher than 500 MHz. By schematically reproducing the

dynamic spectrum of radio bursts of spectral types II, III

and IV, we obtain the result as shown in Fig. 14 for the

frequency range from 10 to 10^4 MHz. This figure indicates

that type IV radio burst consists of several different

components as IVμ, IVm, IV$_s$A and IV$_s$B. Since the classifica-

tion of these components is very different from one author

to another, the result shown here must be considered as one

of these classifications (see, Wild, 1962; Fokker, 1963;

Kundu and Smerd, 1962; Takakura and Kai, 1961; Kundu, 1965).

As shown in this figure, microwave type IV burst (IVμ) starts

before the emission of microwave burst (M-W) ceases.

Moreton (1960) observed the surface waves propagating

away from the flare region, being mainly along the photo-

spheric surface. These waves are now known as the Moreton

waves. In association with the solar flare of 20 September

1963 described in Fig. 14, a beautiful picture was taken

for this wave as shown in Fig. 15 (see, Ramsey and Smith,

1966; Martin and Harvey, 1971). This result shows that

this wave propagated into some limited direction within

~90 degrees. When we compare this observation with the

sunspot configuration and other data, we can see that this

wave propagated out of the flare region along the magnetic

axis which was almost coincident with the magnetically

neutral line shown by a chain line in Fig. 16. A wave

front is indicated in this figure, which has been deduced

from the picture shown in Fig. 15. These Moreton waves are

also generated during the explosive phase. Hence the origin

of these waves seems to be related to the process for

flare-energy to be released, but the reason why these waves

don't propagate in every direction from the flare region has

not been found yet. Recently, Uchida et al. (1973) have

theoretically calculated the motion of shock wave fronts

generated by flares in order to explain the relation between

the Moreton waves and the shock waves responsible for type

II radio bursts at metric frequencies. As considered by

Sakurai (1971b,c), these shock waves are also generated

during the explosive phase of flares.

The time variation of hard X-ray emission intensity is

similar to that of microwave emission (see, Fig. 11). Fig.

17 indicates that solar X-rays > 80 Kev observed by the

IMP-3 satellite is almost the same as the intensity-time

profile of microwave burst at 17,000 MHz (Cline et al.,

1968). This suggests that the source for these two emissions

must be the same (Takakura and Kai, 1966; Takakura, 1969a,b;

Holt and Cline, 1968; Holt and Ramaty, 1969). Because it

is known that these X-ray emissions (< 1Å) are responsible

for the production of SID's, these solar X-rays associated

with the flare of 7 July 1966, as shown in Fig. 17, must have

produced SID's. Hakura (1969) found that the time variation

of SCNA observed at Penticton, Canada, is almost the same

as that of soft X-ray burst (< 14Å), which was reported by

Van Allen and Ness (1967). The intensity-time profile of

this soft component is not fully equal to that shown in

Fig. 17, but the starting time of both emissions is almost

equal to each other. However, the time for intensity

decrease is usually longer for soft component than for

hard component because the former is generated in

association with the thermalization of flare plasma (e.g., Friedman, 1964, 1969). These two components have been directly found by using the observation of several channels for energy by the OGO-5 satellite (Fig. 18) (Kane, 1969). The first peak in this figure are generated by non-thermal emissions, while the second peak around 1900 UT are due to thermal emissions, which are mainly responsible for the production of SID phenomena. In general, the first peak intensity is very low in comparison with the second peak intensity, and the duration is much shorter for the first component than for the second component (Frost, 1972; Simnett, 1973). This tendency is also seen in microwave radio burst (see, Fig. 17).

Chupp et al. (1973) first observed gamma-ray bursts from the solar flares occurred in August 1972. Since several characteristic gamma-ray line emissions were observed for these flares, a number of high energy Mev protons must have been produced to make nuclear interactions possible with ambient nuclei in the flare region. This means that these high-energy nuclear particles are accelerated during the explosive phase of flares. Since the

mechanisms of X-ray and radio bursts as mentioned earlier are explained by taking into account the interaction of high energy electrons (Kev-Mev) with ambient plasmas and sunspot magnetic fields, respectively, these electrons must also be generated during the explosive phase. Therefore, we may say that the acceleration of high energy protons, heavier nuclei and electrons is very important to produce various wave emissions as mentioned earlier. We have now evidence that these high energy particles are generated during the explosive phase of flares (Svestka, 1970; Sakurai, 1971b).

The expansion of shock waves from the region where a flare triggered, is a good measure for the start of the main phase of flares (Sakurai, 1966). This phase seems to be initiated by the outward movement of type IV radio sources from the flare region. This movement usually follows the expansion of shock waves in the solar atmosphere, but the speeds of these sources and waves are generally not equal to each other (Smerd and Dulk, 1971; Sakurai and Chao, 1973a). The sources of type IV radio bursts at metric frequencies (IVm in Fig. 14) generally move outward

with speed of several hundred Km sec^{-1}, which is always lower than that of foregoing shock waves. Because the source for type IVμ burst does not move out of the flare region, this source seems to be independent of the source for type IVμ burst (e.g., Kundu, 1965; Takakura, 1967; Sakurai, 1971d).

The generation of the shock waves mentioned above may be related to the mechanism which triggers the onset of flares due to the sudden release of flare-energy stored in sunspot magnetic fields. This energy is transfered to particle energy through the acceleration processes of protons, heavier nuclei and electrons during the explosive phase. Particles thus accelerated are first trapped by sunspot magnetic fields in or near the flare region, and then these particles transport these fields whenever the kinetic pressure of the former finally becomes higher than the tension of these fields. Thus magnetic bottles or bottle-like structures are formed by high energy particles accelerated in flares; they move outward through the solar atmosphere while emitting radio bursts identified as type IVm bursts.

It is known that the magnetic bottles as the moving
metric type IV sources are preceded by the moving sources
for type II bursts identified as shock waves (see, Fig. 14).
Sakurai (1973c,d) has found that the direction of motion
of these bottles is not in the meridian plane across the
flare region, but 10-30 degrees east of this plane, as
shown in Fig. 19. As the radioheliograph observations show
that the shock waves generally propagate along the magnetic
field lines in the coronal region (Dulk, et al., 1971), the
moving pattern of the bottles is somewhat different from
that of these waves after ejection from the flare region;
the bottle tends to transport field lines with energetic
electron cloud, which is the source of type IVμ bursts.
These electrons emit radio waves identified as these bursts
by gyro-synchrotron mechanism due to their interaction with
the field lines constituting the bottle.

Shock waves expand farther into the envelope of the
sun and then often into interplanetary space. These waves
are thought to sometimes become the interplanetary shock
waves, which produce SSC's on the geomagnetic field.

During the initial stage of this main phase, the heated

plasmas in the flare region would be thermalized to be

10^6 - 10^7 degrees in temperature. These plasmas are capable

of producing soft X-ray and microwave radio G-R-F emissions

(e.g., Kawabata, 1960, 1963). SID phenomena are associated

with this X-ray emission. It is interesting to note that

there seem to exist two types of this thermalization process

as shown in Fig. 20 (Hakura, 1966); the one is sudden-onset

type, whereas the other is gradual-onset type.

Later on, stationary radio sources are formed in the

solar atmosphere, as shown in Fig. 14. When they are produced

above the flare region, it is said that the late phase of a

flare starts, because all violently disturbed phenomena are

not observed in this phase. Metric continuum radio source

(IV_sB) is often identified as type I noise source. The

emission mechanism for these two sources seems to be the

same (e.g., Kai, 1970); they are generated by some plasma

processes related to electron plasma oscillation. Sometimes,

stationary loop prominences are formed (Bruzek, 1964a,b).

These prominences seem to be produced as a result of storage

of high energy particles in the flux tubes of sunspot

magnetic fields in or near the flare region (Jefferies and

Orrall, 1965a,b).

These particles are gradually emitted into outer space

for the period from several hours to a few days (Simnett and

Holt, 1971; Simnett, 1972; Sakurai, 1973e). The duration

of this period seems to be related to the magnetic configura-

tion of the flare region. Therefore, the duration of continuum

emissions $IV_S A$ and $IV_S B$ is also dependent on this configura-

tion because these emissions are produced by energetic electrons

trapped by sunspot magnetic fields.

2) Particle emissions

High energy particles are mainly accelerated during

the explosive phase. Initially, Kev electrons are accelera-

ted suddenly during 1-10 seconds immediately after the onset

of this phase. However, the main part of high energy particles,

Mev-Bev protons and other nuclei and relativistic electrons

are accelerated during the explosive phase which continues

for a few minutes (e.g., Ellison et al., 1971; Sakurai, 1965b,

1971b; Svestka, 1970). The acceleration mechanism has not

been fully understood for these particles, but Sakurai (1965c,

1971a) has shown that the Fermi acceleration works efficiently

to produce high energy particles. General theory of particle acceleration is discussed in several references as follows: Hayakawa et al (1964), Wentzel (1965), Sakurai (1965d,e), Schatzman (1967) and Hayakawa (1970).

The ejection of the main part of these particles into outer space is associated with the expansion of magnetic bottles (Sakurai, 1969b). Therefore, it seems that these particles are emitted into interplanetary space before the end of the explosive phase (Ellison et al., 1961; Mathews et al., 1973). In August 1972, Bev solar cosmic ray events were observed three times, which were produced by flares which occurred in the active region McMath No. 11976. These Bev events are, however, not so often produced during the solar activity cycle. It is estimated that these events occur about 20 times for one cycle (Hayakawa, 1970; Sakurai, 1973a). Since these events do not produce any geophysical disturbance, we shall not consider them hereafter. The readers who are interested in this subject may refer to the references; Carmichael (1962), Ellison (1963, 1964), McCracken (1962, 1969), McCracken and Rao (1970) and Sakurai (1973a).

Mev solar cosmic ray events were discovered by Bailey (1957, 1959) from the analysis of the HF forward scatter propagation in the high latitude regions of the earth. He found that the wave intensity decreased while Mev solar protons and other nuclei were bombarding these regions. This indicated that the wave energy is heavily absorbed in the region where the electron density is increased by the excess ionization of the lower ionosphere due to their bombardment (e.g., Bailey, 1957; Webber, 1962; Reid, 1963, 1967). It is now known that these Mev events occur more frequently than the Bev events mentioned above; their occurrence frequency is well related to the phase of the solar activity cycle, as shown in Fig. 21 (Collins et al., 1961; Svestka and Olmr, 1966; Sakurai, 1967b). It seems likely that Bev events do not occur during the maximum phase of this cycle (Takakura and Ono, 1961, 1962).

Hakura and Goh (1959) first attempted to study the relation of these Mev events with solar phenomena; they found these events were always associated with the flares accompanying type IV radio bursts of wide frequency band. This result indicates that the generation of Mev solar

cosmic rays is closely connected with that of relativistic electrons.

Since these Mev particles ionize the region of the upper atmosphere 50-100 Km high above the polar caps, the ionosondes and the riometers on the polar regions are able to indirectly detect the bombardment of these particles as the ionospheric absorption of transmitted waves and cosmic background noises. These absorption phenomena are now called the polar cap absorptions (PCA). We have shown in Fig. 3 that there exist several types of these absorption (PCA) events. When we compare these types with the peak flux spectra of type IV radio bursts, we obtain the result that the spectra indicated with A in Fig. 22 are always associated with the PCA events of F or F* type, whereas the spectra shown by B are accompanied by S type events (Sakurai, 1963). The importance of A type spectra for the generation of solar cosmic rays has been pointed out by Castelli et al. (1967, 1968), who called them the U-shape spectra.

Analyzing the IMP-3 satellite data, Cline and McDonald (1968) have shown that Mev electrons are also ejected by flares which produce Mev solar cosmic rays. The first observation of these electrons was done by Meyer et al. (1962)

by means of the detectors on-board balloons. Fig. 23

shows the time variation of Mev electron flux from the

sun with Mev protons as observed by the IMP-3 satellite.

These electrons seem to be emitted from the flare region,

although the main part of these electrons seem to be trapped

by sunspot magnetic fields as emitting type IV radio bursts.

The direct observation of these electrons has proven that

the source of type IV radio bursts is identified as the

Mev electrons produced in flares. This idea was first put

forward by Boischot and Denisse (1957), but, for many years,

no direct evidence had not been obtained. As Sakurai (1972b)

has shown, all of Mev electron events detected by satellites

near the earth are associated with Mev solar cosmic ray

events. This result indicates that protons and heavier

nuclei are accelerated together with electrons to Mev energy

in flares. It seems that these electrons sometimes invade

the polar cap regions and ionize atmospheric constituents

over there (Hakura, 1967a).

Van Allen and Krimigis (1965) first reported that solar

flares of minor importance produced $>$ 45 Kev electrons.

Since the most these flares do not produce distinguished

SID phenomena at the earth, the acceleration of these

electrons is not related to the large-scale disturbances

associated with solar flares. However, we know that these

flares are usually accompanied by impulsive X-ray and micro-

wave bursts of short duration for a few minutes at most and

type III radio bursts (e.g., Lin, 1970; Lin and Anderson,

1967; Kane, 1972). These X-ray emissions often produce

small SID phenomena characteristically different from

those as shown in Figs. 11 and 21.

Magnetic bottles are often ejected into the envelope

of the sun. While expanding there, these bottles push solar

plasmas located above the flare region out to the outer space.

These plasmas seem to be identified as the flare-ejecta

which propagate into interplanetary space. It is thought

that the helium enriched shells are formed at the front

of these ejecta (Hirshberg et al., 1972; Hirsberg, 1973).

Since the thickness of these shells observed at the earth's

orbit is dependent on the longitudinal position of parent

flares (Fig. 24), the expansion of these shells also seems

to occur anisotropically in the space between the sun and

the earth (Sakurai et al., 1973b). However, we do not know

yet the mechanism of such expansion of these shells in interplanetary space. It seems that this expanding mode is causally related to the propagation pattern of inter-planetary disturbances generated by flares.

3) Flare development related to the emissions described in 1) and 2).

So far we have considered both wave and particle emissions by using observed results. As shown in 1), the development of a major solar flare consists of three distinct phases; the explosive, main and late phases. Various emissions are generated during the development of flares, but it seems that they are properly associated with one of these three phases. We summarize these associations in Table III in reference to the nature of these emissions which is related to high energy particles accelerated in flares. Since the cause of all wave emissions is explained by taking into account the action of these high energy particles in the flare region, it is important to know what type of particles is responsible for those wave emissions. These informations, furthermore, are very useful to study SID phenomena by considering the characteristics of solar wave emissions. They may make it possible to predict the occurrence of SID's

and geomagentic storms. It is, therefore, important to investigate the mechanism of particle generation in solar flares.

The number and other characteristics of energetic particles responsible for wave emissions from flares are summarized in Table IV (Takakura, 1967; Bruzek, 1967). The energy expensed by these particles must be supplied in the region where solar flares occur. It is known that the most flare-energy is transfered to optical emissions and flare-ejecta, the energy of which amounts to about 10^{32} ergs, respectively. When we consider the total amount of flare-energy released in a major flare to be several times of 10^{32} ergs (e.g., Bruzek, 1967, 1969; Sakurai, 1973a), the energy that flare-ejecta shares and its transport mechanism must be understood in order for the mechanism of flares to be understood. At present, it is thought that the flare-energy is supplied by the annihilation of sunspot magnetic fields, but we have not succeeded in explaining the mechanism of flares (see, Sweet, 1969; de Jager, 1969; Sakurai, 1973a).

It seems better to summarize the relationship between flare-associated emissions and geophysical phenomena (Table

V). They seem to give an important information on the cause of these phenomena.

4. Interpretation of Flare-Associated Geophysical Disturbances

We shall consider geophysical disturbances by taking into account the observed results on flare-associated emissions. As summarized in Table V, it is known what type of solar emissions produces proper disturbances at the earth; wave emissions are mainly responsible for SID phenomena, whereas particle emissions produce disturbed phenomena as PCA and geomagnetic storms. By considering the results described in section 3, we shall explain geophysical phenomena in the following.

1) SID's

Fig. 20 shows that there exist two distinct patterns for SWF's. The time-profile of these SWF's is very similar to that of microwave radio bursts. This means that the emission of soft X-rays is closely related to that of these radio bursts (e.g., Kawabata, 1960; Hakura, 1966). Therefore, these SWF's are explained by considering these X-ray emissions from flares.

The developmental pattern of SEA's is dependent on the characteristics of solar flares. When we use several frequencies to observe SEA's, we are able to find out such dependence (Sakurai, 1968, 1969c). Two examples are shown in Fig. 25, which are associated with proton flares. The SEA's shown in Fig. 25(a) and (b) are accompanied by Bev and Mev proton flares, respectively. It is evident that the rise time is shorter for the former than for the latter. The behavior of 10 kHz field intensity is also significantly different between them. By studying these characteristics of SEA's, therefore, we can estimate what is going on the sun. Since the duration of these rise times is correlated with that of the Hα brightness increases, it is clear that the fastness of the thermalization of the flare plasmas plays a main role for the X-ray emission from the flare region (Sakurai, 1970b). It has been statistically shown that the rise time of solar X-ray emission is proportional to that of the Hα brightness (Thomas and Teske, 1970). These results suggest that SID phenomena are completely dependent on the developmental pattern of flare X-ray emissions.

The developmental pattern of SCNA's is almost the same as that of SWF's, because they are generated by the absorption of the cosmic noise due to the enhanced ionization of the ionosphere by flare-associated soft X-ray emissions. This ionization mainly takes place in the lower region of the ionosphere and so the electric current in the ionosphere of the sunlit side is sometimes enhanced by this additional ionization. This phenomenon appears as the enhancement of the Sq electric current in the ionosphere and is called "sfe" (e.g., Akasofu and Chapman, 1971).

These SID phenomena mentioned above are generated by the enhanced ionization in the lower ionosphere, mainly, the D and E regions. However, we also know that some phenomena as SFD and the increase of foF2 are produced by the ionization increase in the lower part of the ionosphere F regions (Kanellakos et al., 1962a,b; Donnelly, 1966, 1967). The ionization of this part is produced by the EUV emissions from flares. The satellite observation of the He II 304Å resonance line intensity, for instance, shows that this intensity rapidly increases with the onset of the explosive phase of flares (Neupert, 1964). The continuum EUV emissions

show a similar increase as does the He II 304Å intensity (Donnelly, 1968).

When Knecht and McDuffie (1962) discovered the first evidence of the foF2 increase, they found that this increase is only associated with big flares which produce solar cosmic rays. Their analysis, furthermore, showed that the height where the peak frequency foF2 is observed, must be lower than 300 km above the ground. This suggested that the increase of the ionization occurs in the lower region of the ionosphere F2 region. Recent SFD observations indicate that the ionization enhancement occurs in the lower portion of the ionosphere F2 region. The study of these disturbances like SFD was also opened up by the investigation of the relation between the foF2 increase and solar proton flares.

These phenomena called SID's are all generated by the enhanced ionization of the earth's upper atmosphere by solar X-ray and EUV emissions associated with solar flares.

2) PCA

Solar flares often produce Mev protons and other nuclei. These particles are later emitted from the flare region and some of them arrive at the earth and its vicinity.

When they begin to interact with the geomagnetic field, their

orbits start to be deflected by the influence of this field

(e.g., Störmer, 1955; Gall et al., 1968). As Schlüter

(1958) has shown, we can calculate these motions under the

guiding-center approximation because the gyro-radii of these

particles are much smaller than the characteristic scale

length of the geomagnetic field (see, Alfvén, 1950; Northrop,

1963; Sakurai, 1961). The result for these orbital motions

shows that these particles can only approach the polar

latitude regions, although depending on their rigidities.

Obayashi and Hakura (1960) studied the developmental

pattern of the polar cap absorption (PCA) produced by the

invasion of Mev solar cosmic rays over the polar cap

ionosphere. They found that the cut-off latitude for their

invasion is usually seen around 75 degrees N and S, but

this latitude is lowered down to ~65 degrees when the main

phase of geomagnetic storms starts. This variation is related

to the geomagnetic variation during storms. Hakura (1967a)

found that the development of PCA consists of three distinct

phases, as schematically shown in Fig. 26. At first, the

invasion of Mev electrons produces weak PCA near the magnetic

pole, higher than 85 degrees N and S, which is identified as the first phase. The second and third phases are generated by the invasion of Mev protons and helium nuclei, respectively. Because of the difference of rigidities between proton and helium, the starting times and cut-off latitude for invasion are different between these two particles, as shown in Fig. 26.

Several different developmental patterns of PCA events are known (Fig. 3). It seems that the cause of these patterns is closely related to the physical condition of interplanetary space (Sakurai, 1965a); that is, this cause is made clear when we consider the duration from forgoing geomagnetic storms to the onset of PCA events (see, Fig. 27). This result indicates that, within several days after the passage of the flare-ejecta producing these storms, the distribution of the interplanetary field is so smooth that Mev solar cosmic rays can propagate almost freely without serious scattering in the space between the sun and the earth.

The access of these cosmic rays to the polar regions has been investigaged by many authors (e.g., Reid, 1963, 1966, 1970; Reid and Sauer, 1967; Dessler, 1964; Michel and

Dessler, 1965; Hakura, 1967b; Gall et al., 1968). However, we do not know yet any theory capable of explaining all the observed phenomena for solar cosmic ray invasion into the polar cap regions.

3) Flare-generated interplanetary disturbances

About 90 percent of solar flares associated with both type II and type IV radio bursts are followed by SSC geomagnetic storms (Chao, 1973, private communication). This shows that shock waves propagating in interplanetary space are produced by these flares.

We have known that type II radio bursts are generated by shock waves propagating through the solar coronal region (e.g., Stewart et al., 1970; Dulk, 1971; Dulk et al., 1971). Although we do not know yet whether or not these waves are able to arrive at the earth's orbit, it is certain that some disturbances are sent out of the flare region, which can propagate through interplanetary space. It seems that these disturbances sometimes generate shock waves at the front of themselves while propagating in this space (Chao, et al., 1973). Because of the almost spherical expansion, the shock waves which produce type II bursts, would be

dissipated very quickly while propagating in the envelope

of the sun. However, flare-ejecta following these waves

seem to generate newly shock waves somewhere between the

sun and the earth. Such process seems to be repeated

several times before these ejecta arrive at the earth's

orbit. For this reason, we do not observe one-to-one

correspondence between SSC storms and interplanetary

shock waves near the earth observed by satellites (Sakurai,

1973f).

In case of solar proton flares, however, we generally

observe interplanetary shock waves near the earth. In

association with the proton flare of 4 November 1968, type

II bursts were observed and their characteristics showed

that the radio source moved outward with the speed of

about 2600 Km sec^{-1} in the solar corona (Sakurai and

Chao, 1973a). Three days later, we observed the inter-

planetary shock wave at the earth's orbit by the Explorer

33 satellite. The mean speed of this wave was about 650

Km sec^{-1} (see, Fig. 28). Although we do not know whether

the shock wave near the sun continued to propagate until

it arrives at the earth's orbit as the shock wave mentioned

above, this flare was associated with these two shock waves,

one near the sun and the other at the earth's orbit. If

the shock wave observed near the sun is identified with

that at the earth's orbit, our result suggests that, while

propagating in interplanetary space, shock waves must be

decelerated highly in this space (see, Pinter, 1973; Sakurai

and Chao, 1973a).

It is known that flare-generated interplanetary disturbances

do not propagate spherically symmetric with respect to the

flare position after ejection into outer space. Figs. 5

and 24 indicate that the propagations of these disturbances

and of accompanied helium enriched shells are highly dependent

on the longitudinal positions of parent flares. Sakurai

(1973f) has analyzed a series of flare-generated inter-

planetary disturbances for the period from 23 October to 4

November 1968. During this period, more than 10 times of

these disturbances were observed. By analyzing the time

intervals between flares and SSC storms, he has obtained

the result shown in Fig. 29. This result shows that the

minimum interval was observed when the flare occurred about

35 degrees west of the central meridian of the solar

disk. Using this result, the mean propagation pattern of

the interplanetary disturbance at 1 AU has been estimated as shown in Fig. 30. This result is consistent with that shown in Fig. 7 with respect to the shape of the disturbance. During the period mentioned above, three cases for these disturbances were identified as interplanetary shock waves (Sakurai and Chao, 1973a).

Anisotropic propagation of interplanetary disturbances has been first suggested by Ness and Taylor (1969) on the basis of their analysis of satellite magnetic data for the 8 July 1966 storm event. At present, we have further supporting evidence for the anisotropic propagation (e.g., Bavassano et al., 1970; Lepping et al., 1972). Although it is very difficult to theoretically explain such anisotropic propagation pattern as shown in Fig. 30, these observations must be explained by investigating the inter-action of shock waves with the interplanetary magnetic field and plasma. Observationally, we have known that the shock waves responsible for type II bursts propagate along the magnetic lines of force in the coronal region (Dulk et al., 1971; Wild and Smerd, 1972). Kopp (1972) has tried to theoretically explain this observed result. In case of

interplanetary shock waves, it seems necessary to explain

the observations, as shown in Fig. 30 on theoretical basis.

It is thought that SSC's occur when those interplanetary

disturbances encounter the geomagnetic field (or the earth's

magnetosphere). The cause of the main phase of geomagnetic

storms seems to be triggered when flare-ejecta arrive at

the earth (e.g., Obayashi, 1967). However, we do not know

what factor is most important to trigger geomagnetic storms

(see, Akasofu and Chapman, 1971). It is now known that the

main phase of a geomagnetic storm is triggered when the

direction of magnetic field transported by flare-ejecta

becomes southward. Simultaneously with the start of this

phase, auroral flare is broken up. Kev electrons responsible

for this flare are supplied from the neutral tail region

of the earth's magnetosphere. It seems likely that this

flare is characteristically similar to solar flare.

5. Forecasting of Solar Flares

Solar flares are classified into three distinct types;

"plage", "prominence" and "sunspot" flares. Among them,

the last ones are most important in studying solar terrestrial

relations. The occurrence of these flares is highly dependent

on the age of associated sunspot groups (Fig. 31). This figure shows that the maximum of the mean daily occurrence frequency of flares is reached when the sunspot group area becomes maximum about 10 days after the birth of sunspot group. At the bottom of this figure, the type of sunspot group proposed by Waldmeier (1957) is indicated. The type of sunspot group is often useful to infer how much sunspot group is active during its growth. Four examples for this classification are shown in Fig. 32. In general, solar flares of great importance are generated in the sunspot groups of type E and F. It is shown that most proton flares occur in these sunspot groups (Anderson, 1961, 1964).

These proton flares are always associated with type II and type IV radio bursts. Furthermore, these flares are initiated by the break-up of microwave impulsive and hard X-ray bursts, and the time-profiles of these bursts are very similar to each other (see, Fig. 17). Associated X-ray bursts produce SID phenomena on the earth. Recently, Sakurai (1967a) has found that the sunspot groups which produce proton flares tend to rotate counterclockwise (clockwise) in the northern (southern) hemisphere. This

rotating motion produces unusual distribution of magnetic polarities in sunspot group. Thus it seems important to observe the distribution of magnetic fields in sunspot group in order to predict successfully a possibility of proton flare occurrence.

Microwave and soft X-ray observations are also very important in predicting the onset of proton flares (Tanaka and Kakinuma, 1964; Friedman and Kreplin, 1969). In case of the 7 July 1966 event, Tanaka et al. (1969) predicted the occurrence of proton flares based on their observation for microwave S-components (3750 and 9400 MHz): when the ratio of 9400 to 3750 MHz fluxes became greater than unity, this occurrence was predicted by them before the onset of the 7 July 1966 proton flare. In order to predict proton flares, therefore, it is important to observe microwave S-component continuously. However, it is difficult to predict the occurrence of minor flares. At present, much effort to find out method for predicting solar flare onset is being made by studying the characteristics of solar flares and their precursors (see, Simon, 1969; McIntosh and Simon, 1972).

6. Summary and Future Problems

In this paper, we have considered solar flare emissions, both waves and particles and their relation to geophysical disturbed phenomena. In particular, we have reviewed the developmental pattern of solar flares since it seems that the understanding of flare phenomena is most important to find out the cause of geophysical disturbances as described in section 2. Although many problems have still remained for the study of solar flares, we have known the characteristics of various flare-associated emissions properly responsible for geophysical disturbances. In order to study the flare mechanism, we also need to consider the results deduced from the study of these disturbances. By referring to both solar and terrestrial phenomena, it seems possible to construct a unified view for solar terrestrial relations. This would help us to build up the model of solar flare development, too.

At present, we are too busy in pursuing our own problems, but sometimes we had better think about various fields other than our owns. This would give us some important insight to lead breakthrough for the opening of new fields of

science. Although, in this paper, I have been mainly

concerned with solar flare emissions, any information

for these emissions would be very important to understand

the origin of geophysical disturbances. We have not known

the true mechanism of "sunspot" flares as yet, but we have

a lot of observational results about flare-associated

emissions. We believe these results will become soon

important for the study of the mechanism of solar flares.

Geophysical data would be important for this study.

It is still very difficult to predict the occurrence

of solar flares. However, the prediction would be relatively

easier if we could find out the true mechanism of solar

flares. By observing forrunning phenomena for flares,

it would become possible to predict the onset of flares,

although, at present, we have not known what these phenomena

are.

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Content of Tables

Table I Flare-associated emissions and related
geophysical phenomena

Flare-associated emissions	Geophysical pheonomena	
X-ray burst	SID	
$(\lesssim 5 \ \text{Å})$		SWF
		SEA
		SPA
		SCNA
		sfe
EUV burst	SFD	
		ΔfoF2 increase
Solar cosmic rays		
(Mev-energy)	PCA	
Flare-ejecta	Geomagnetic storm	

67

Table IV Flare energy and flare-associated particles

	Number	Mass	Energy(ergs)
Hα			10^{31}
Total line emission			5×10^{31}
Continuum emission			8×10^{31}
Total optical emission			10^{32}
Optical flare region	10^{41}	2×10^{17}	
Soft X-rays (1-20Å)			2×10^{30}
Hard X-rays (50 Kev electrons)	10^{39}		5×10^{31}
Type IV burst (3 Mev electrons)	10^{33}		5×10^{27}
Type III burst ($\lesssim$100 Kev electrons)	10^{35}		10^{28}
Visible ejection	10^{40}	2×10^{16}	10^{31}
Energetic protons (E > 10 Mev)	10^{35}		2×10^{31}
Cosmic rays (1-30 Bev)			3×10^{31}
Interplanetary blast wave	10^{37}	2×10^{15}	2×10^{32}
Moreton wave			$>10^{30}$

Table V   Geophysical phenomena produced by solar flares

Waves
$\Big\{$
X-rays (Hard), $< 1\overset{\circ}{A}$

(soft), $1 - 100\overset{\circ}{A}$ SID

EUV (including He II $304\overset{\circ}{A}$)   SFD

ΔfoF2 increase

Particles
$\Big\{$
Mev protons and electrons   PCA

Plasma clouds
  (flare-ejecta)   Geomagnetic storm

aurorae

polar substorm

Shock waves   SSC

Table III   Particles accelerated in solar flares and
related solar and geophysical phenomena

Solar particles	Solar phenomena	Geophysical effects
Kev electrons	Type III bursts Hard X-ray bursts	
Mev electrons	Microwave bursts Type IV bursts	PCA
Mev-Bev protons and heavier nuclei	Solar cosmic rays Gamma-rays White light emissions	PCA
Heated flare plasmas	Thermal X-rays Microwave bursts	SID

Table II Developmental pattern of solar flares and associated emissions

Preflare state

- $H\alpha$ plage bright spots
- Birth of satellite sunspots
- Peculiar distribution of sunspot magnetic configuration
- Activation of dark filaments
- Enhancement of soft x-rays and microwave Emissions

Explosive phase

- Sudden expansion of the $H\alpha$ bright area
- Sharp increase of $H\alpha$ brightness
- Microwave bursts (often associated with type III bursts)
- Hard X-ray bursts
- Moreton waves
- Acceleration of high-energy particles (Solar cosmic rays, relativistic electrons)

Main Phase

- Blast waves and the ejection of magnetic clouds (or flare-ejecta)
- Radio bursts of spectral type II and IV
- Soft X-rays
- Ejection of accelerated high-energy particles

Late Phase

- Stationary continuum storm
- Flare nimbus
- Loop prominence system

Fig. 11   Three types of the development of solar radio
           bursts and SWF's associated with solar flares.
           1) SWF type, 2) geomagnetic storm type and 3)
           solar proton type. (Hakura , 1961)

Fig. 12   The time profiles of both microwave and X-ray bursts
           and associated type III radio bursts (Anderson and
           Winckler, 1962).

Fig. 13   Time sequence on the beginning of solar radio
           bursts as a function of radio frequency.

Fig. 14   A model of the development of solar radio emission
           associated with a major flare. Intensity is high
           in the dark shaded areas.

Fig. 15   Picture of the Moreton wave associated with the
           solar flare of 20 September 1963 (Martin and
           Harvey, 1971). White part is the Hα brightening
           area of flare.

Fig. 16   Relation of the sunspot structure with the propaga-
           tion direction of the Moreton wave in the case of
           the 20 Sept. 1963 flare. A chain line indicates
           the magnetically neutral line.

Fig. 17   The intensity-time profiles of microwave and
           hard X-ray bursts associated with the flare of
           7 July 1966 (Cline et al., 1968).

Fig. 18   The developmental patterns of X-ray bursts as
           observed by different energy channels (Kane, 1969).

Fig. 19   Motion of magnetic bottle and forerunning shock
           wave above the flare region (Sakurai, 1973d).
           Trapped electrons are identified as the source
           of metric type IV burst (IV_M).

Fig. 20   Two distinct developmental patterns of SWF's.
           They are very similar to those for microwave
           radio bursts (Hakura, 1966).

Fig. 21   Long-term variation of the occurrence number
           of solar proton flares, Bev and Mev, for the solar
           cycle No. 19 (Sakurai, 1967b).

Fig. 22   Two reprentative peak flux spectra of type IV
           radio bursts. The spectra A are associated
           with flares which produce F and F* types of
           solar proton events, whereas the spectra B are
           related to those for S type events (Sakurai, 1969b).

Fig. 23   Satellite observation of Mev electrons associated
           with the solar flare of 7 July 1966. Proton
           data are also shown. (Cline and McDonald, 1968).

Fig. 24   Dependence of the thickness of helium-enriched
           shells observed at the earth's orbit on the
           longitudinal position of associated flares.

Fig. 25   Two distinct patterns of SEA's associated with
           solar proton flares (Sakurai, 1968). (a) SEA
           associated with Bev proton flare, (b) SEA associated
           with Mev proton flare.

Fig. 26   Schematic representation of three phases of the
           development of polar cape absorption event.

Fig. 27   Durations between foregoing geomagnetic storms
           and solar proton events. These durations are
           important in forming the developmental pattern
           of these proton events as shown in Fig. 3 (Sakurai,
           1965a).

Fig. 28   Shock wave and magnetic bottle near the sun and
           interplanetary shock wave as produced by the solar
           proton flare of 4 November 1968. Their speeds
           are different from each other (Sakurai and Chao,
           1973a).

Fig. 29   Time intervals from solar flares and SSC
           geomagnetic storms during 23 October to 4 November
           1968. These flares occurred in the active region
           McMath No. 9740 (Sakurai, 1973f).

Fig. 30   An example of the propagation pattern of inter-
           planetary disturbances associated with solar
           flare. This is derived from the data shown in
           Fig. 29.

Fig. 31   Relation between flare occurrence and the development
           of sunspot group (Waldmeier, 1957).

Fig. 32   Development of sunspot groups. Zürich classifica-
           tions are given on the sunspot types (Waldmeier,
           1957).

FLARE (3+)

RADIO BURST (200 MHz)
HIRAISO

GEOMAGNETIC FIELD
H—COMPONENT (sfe)

SEA (28 KHz)

SWF (20MHz)

SCNA (50 MHz)

04   05   06   07

UT
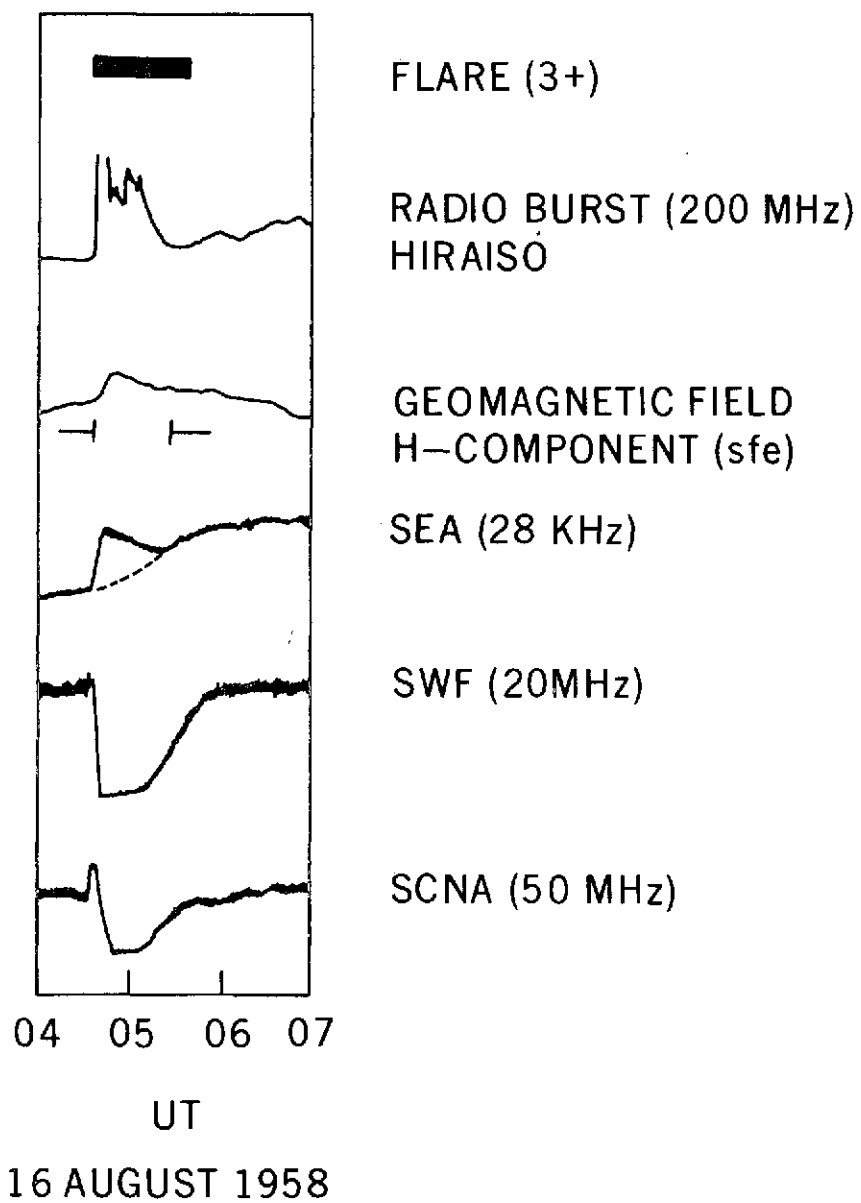
16 AUGUST 1958

Fig. 1

76

SOLAR-TERRESTRIAL EVENTS ON AUGUST 16-18, 1958.
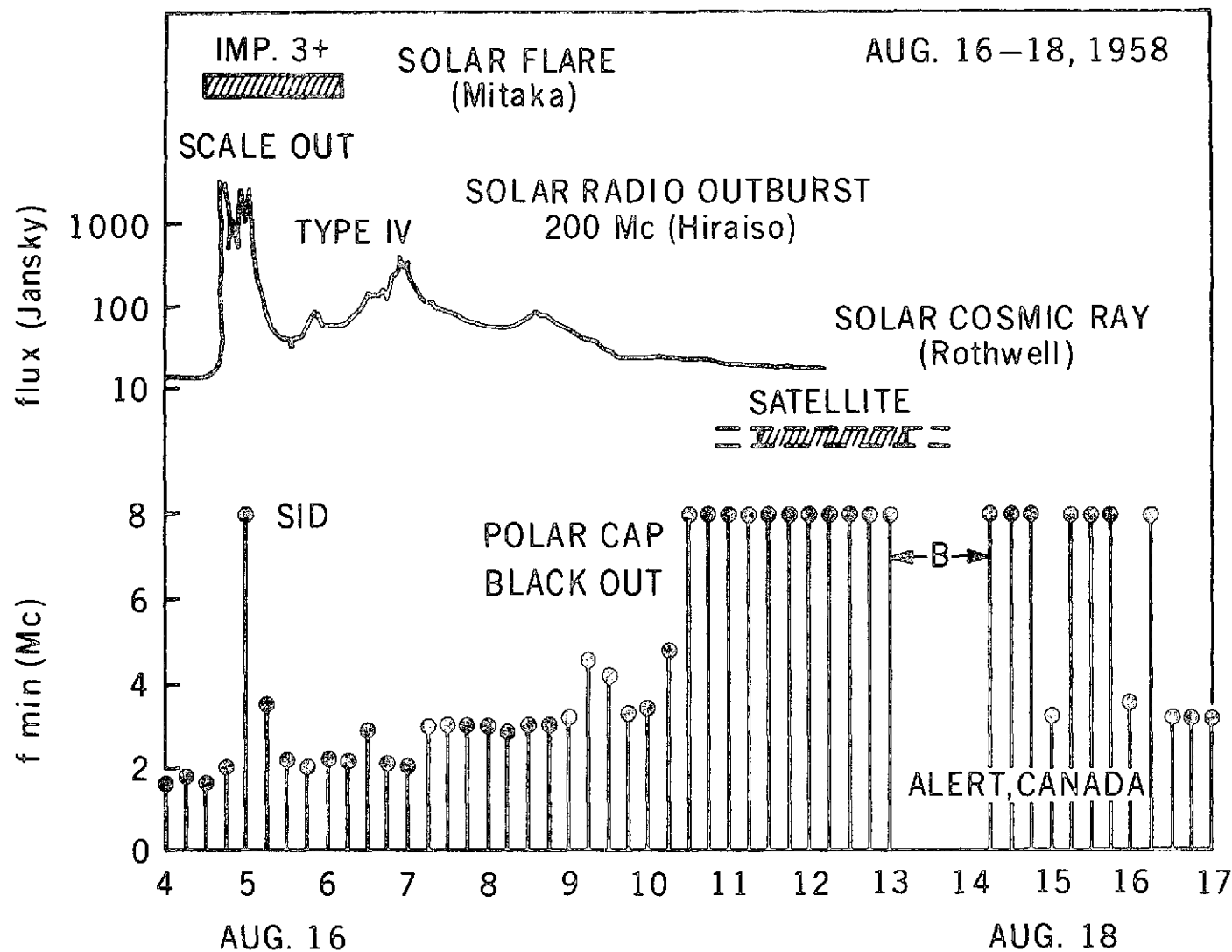
Fig. 2
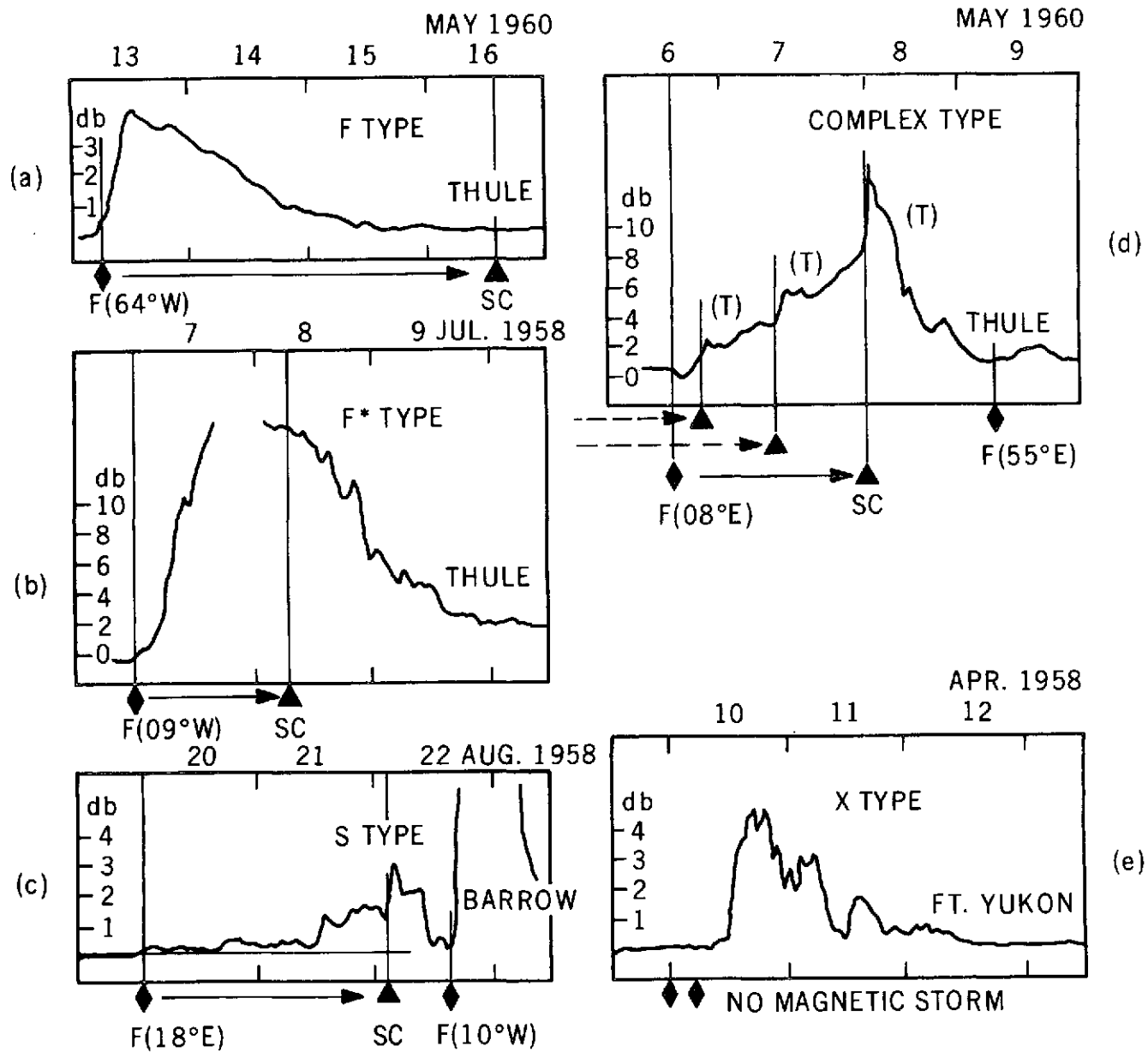
Fig. 3

RANGE H 280 γ
Z 80 γ
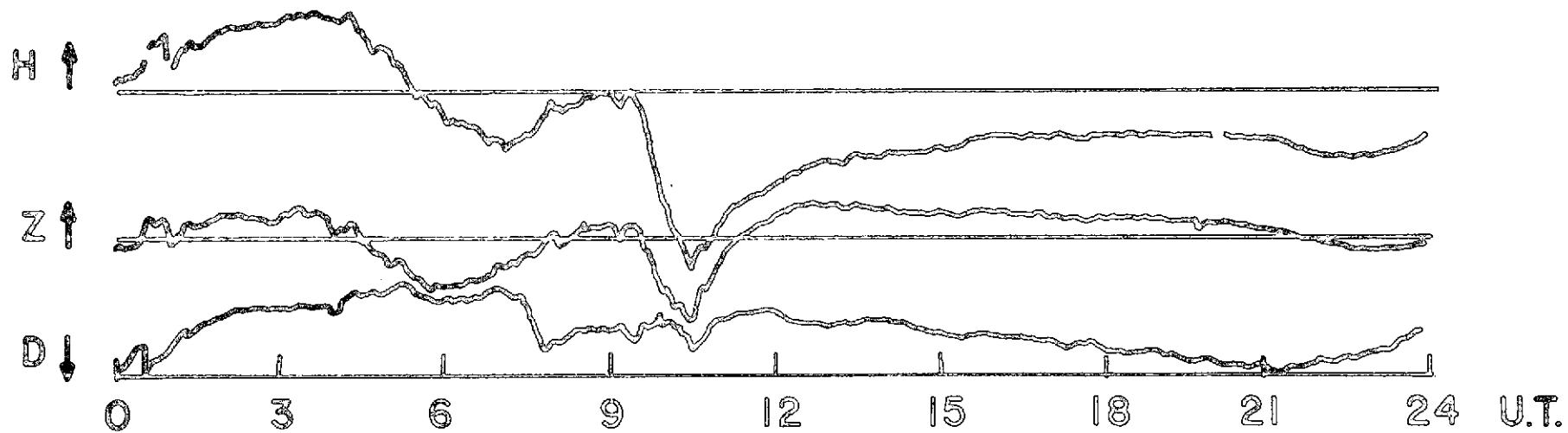
9 AUGUST 1972

SSC 0036 U.T. KAKIOKA, JAPAN

fig. 4

Fig. 5

18

Fig. 6

Fig. 7

Hα INTENSITY
McMATH HULBERT OBS.

NOV. 12, 1960

Fig. 8

Solar flare on 17 July, 1959.   Fig. 9

a)

b)

c)

Hα FLARE AREA

MAGNETIC LINES
OF FORCE

SUNSPOT

d)

Fig. 10

1

OCT. 16th 1957 U.T.

m	h m	m
50	02:00	10
h m	m	m
01:45	55	05

OUTBURST INTENSITY (WM^{-2}(c/s)$^{-1}$)

200 Mc
(Hiraiso)

10

1000 Mc
(Toyokawa)

200
150

2000 Mc
(Toyokawa)

300
200

3750 Mc
(Toyokawa)

400
300

9400 Mc
(Toyokawa)

500
400

FLARE

S25, E 21 imp.3

S-SWF imp.3

FIELD INTENSITY (db)

40
30
20
10
0
-10
-20

SAN
FRANSISCO
17 Mc (Hiraiso)

ZAN

NO DISTURBANCE

2

SEPT. 11th 1957 U.T.

h m	m	m	h m
03:00	40	20	05:00
h m	m	h	m
02:40	20	04:00	40

DYNAMIC SPECTRUM 40~140^{MC}

TYPE II   TYPE IV

1000

200

200 Mc
(Hiraiso)

1000

100

1000 Mc
(Toyokawa)

1000

200

2000 Mc
(Toyokawa)

1000

200

3750 Mc
(Toyokawa)

1000

200

9400 Mc
(Toyokawa)

FLARE

N 17. E05 imp. 3 (Sydney)

SLOW S-SWF imp. 2

50
40
30
20
-10

SAN FRANCISCO
17 Mc (Hiraiso)

POLAR CAP BLACKOUT
AND SC-TYPE MAGNETIC
STORM

3

FEB. 23rd 1956

m	m	h m	m	
40	20	05:00	40	U.T.
h m	m	h	m	h m
03:20	04:00	40	20	06:00

TYPE II   TYPE IV

200 Mc
(Hiraiso)

1000, 2000 Mc
NO OBSERVATION

10000

3750 Mc
(Toyokawa)

1000

200

9400 Mc
(Toyokawa)

10000

1000

200

FLARE

N 25, W 85 imp.3+(Mitaka)

S-SWF imp. 3+

40
20
0
-20

ZAN

SAN FRANCISCO
13 Mc (Hiraiso)

POLAR CAP BLACKOUT AND
SC-TYPE MAGNETIC STORM

Fig. 11

III   TYPE III BURSTS

9500 MHz IV$_\mu$
(Tokyo)

X RAYS

INTENSITY

2210   2220   2230   2240

UT   28 SEPTEMBER, 1961

Fig. 12

Fig. 13

Fig. 14

$\vdash$ $\vdash$ 3×10^5 KM

2359:25   2400:25   2401:25

2402:25   2403:55   2404:55

Fig. 15

N

DIRECTION OF THE MORETON
WAVE PROPAGATION

Hα BRIGHTENING AREA

E

N

W

S

NEUTRAL LINE
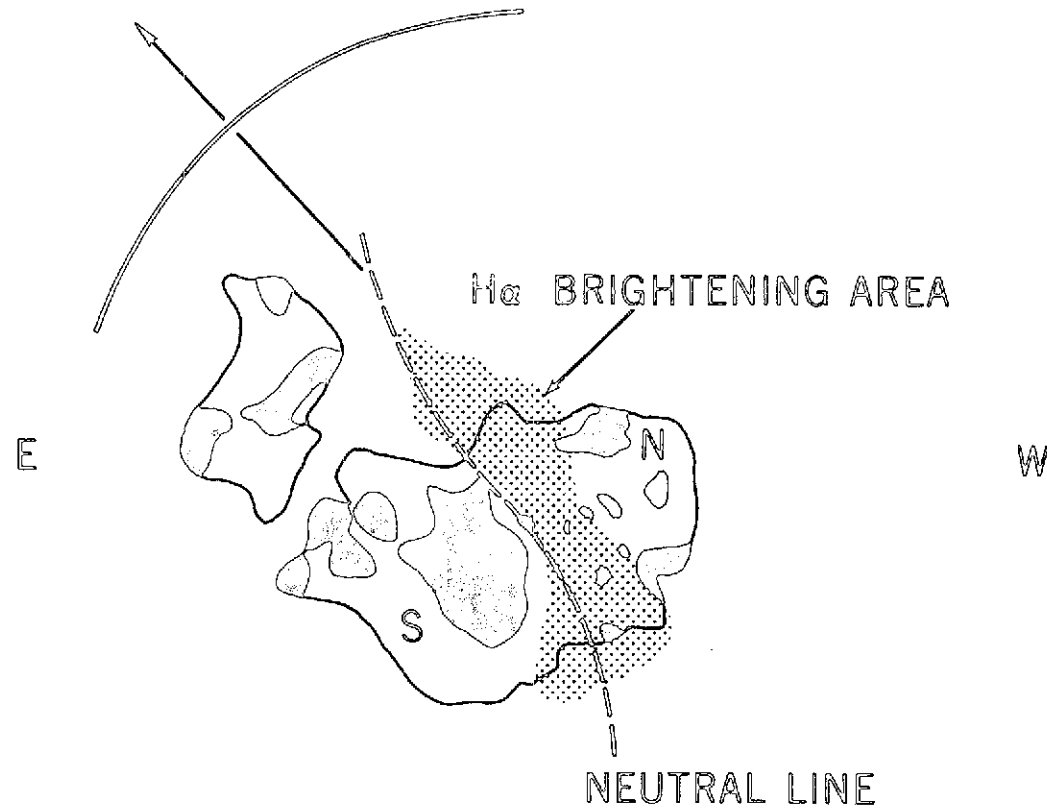
SOLAR FLARE IMP. 2B
2347 UT 20 SEPTEMBER, 1963
N10° W09°

Fig. 16

S

JULY 7, 1966

MICROWAVES
17, 000 MHz

SOLAR X-RAYS
> 80 KeV

DETECTOR BACKGROUND

U.T.

92

Fig. 17

Fig. 18

EXPANDING SHOCK WAVE

ENERGETIC ELECTRON CLOUD

P   F

SUNSPOT GROUP

WEST   EAST

♦ FLARE SITE

VIEWED FROM NORTH

Fig. 19

(a)

(b)

FLARE (3+)

FLARE (3)

3750 MHz
(Toyokawa)

3750 MHz
(Toyokawa)

RADIO INTENSITY ($\times 10^{-22}$ Wm^{-2} Hz^{-1})

10000

1000

200

S-SWF (3+)
SAN FRANCISCO 13 MHz
(Hiraiso)

SLOW S-SWF (2)
SAN FRANCISCO 17 MHz
(Hiraiso)

FIELD INTENSITY (db)

200

20

0

−20

60

40

20

0

−20

0320 0400 0440 0520

0300 0340 0420 0500

U.T.

U.T.

23 FEBRUARY 1956

11 SEPTEMBER 1957

Fig. 20

Fig. 21

Fig. 22

Fig. 23

PROTONS

ELECTRONS

U.T., 7 JULY 1966

PARTICLES/CM^2–SEC–STER

10^3

10^2

10^1

10^0

10^{-1}

10^{-2}

0000   0200   0400   0600   0800   1000   1200

Fig. 24

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Fig. 25

fig. 26

Fig. 27

PIONEER 6
2.292 GHz

4 NOV. 1968

WEST

FLARE 2B   A
B
SUN
$V_{II} \approx 2600$ KM SEC^{-1}
EAST
$V_B \approx$
200 KM SEC^{-1}

TYPE II RADIO BURSTS

A: SHOCK WAVE EXCITING
TYPE II BURSTS

B: MAGNETIC BOTTLE (SOURCE
OF TYPE IV BURSTS)

V_{II} : SPEED OF TYPE II ASSOCIATED SHOCK
V_B : SPEED OF MAGNETIC BOTTLE
V_I : SHOCK SPEED IN INTERPLANETARY SPACE

INTERPLANETARY SHOCK WAVE (6 NOV. 1968)
$V_I \approx 650$ KM SEC^{-1}

EARTH

Fig. 28

PERIOD: OCTOBER 23 – NOVEMBER 4, 1968

Fig. 29

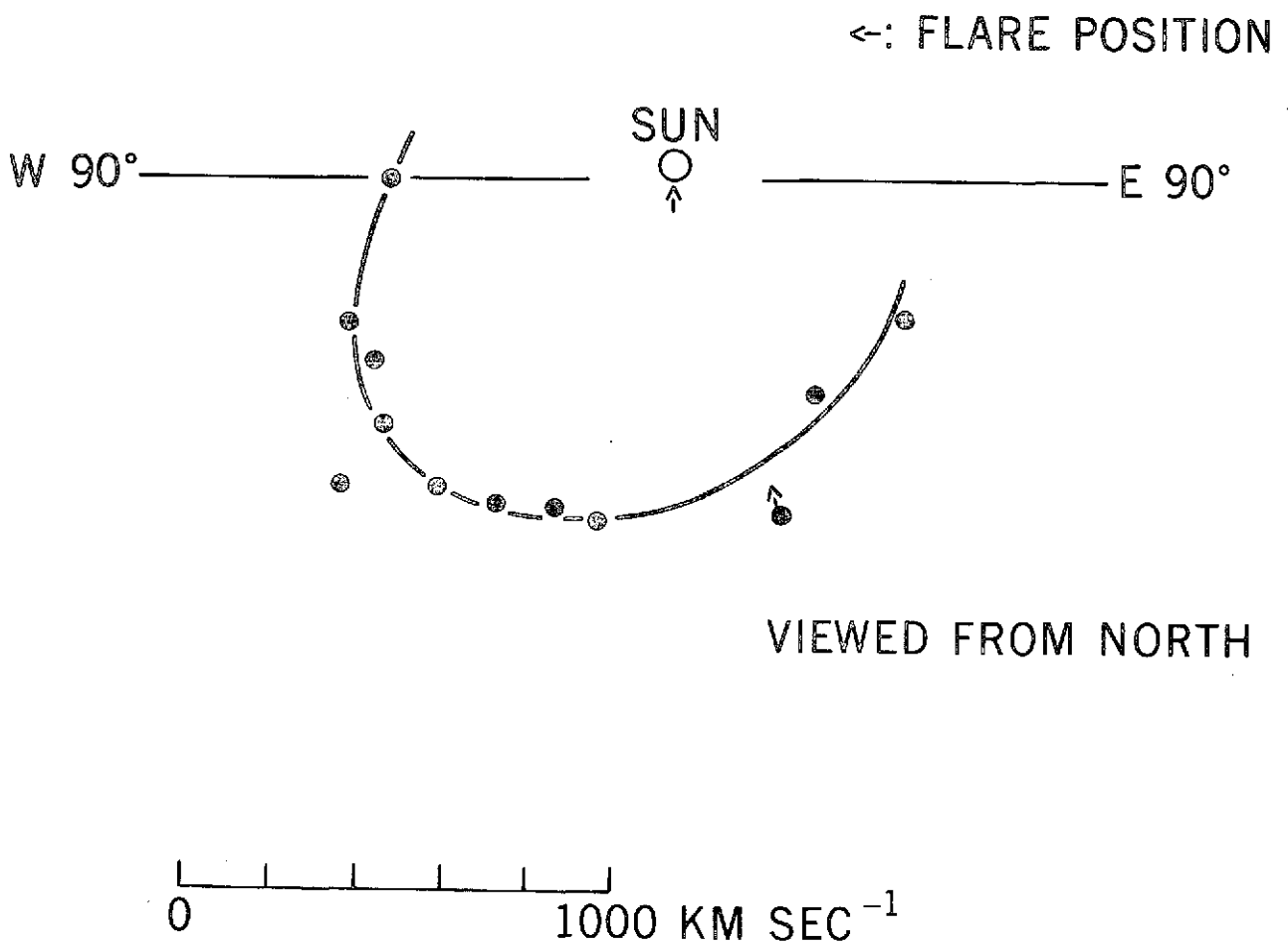# PROPAGATION PATTERN OF FLARE–ASSOCIATED INTERPLANETARY DISTURBANCES NEAR THE EARTH

←: FLARE POSITION

W 90° ——————————— SUN ——————————— E 90°
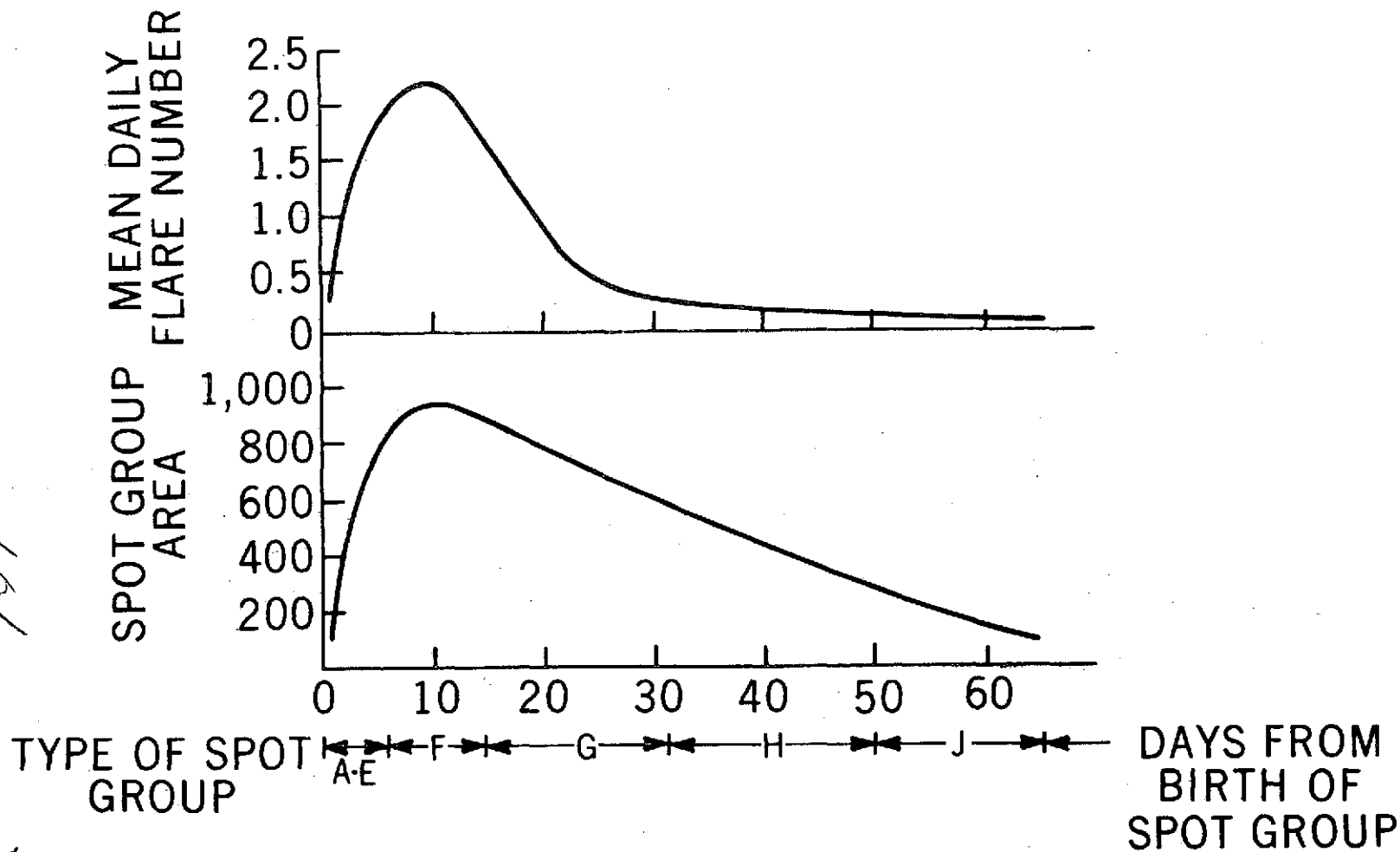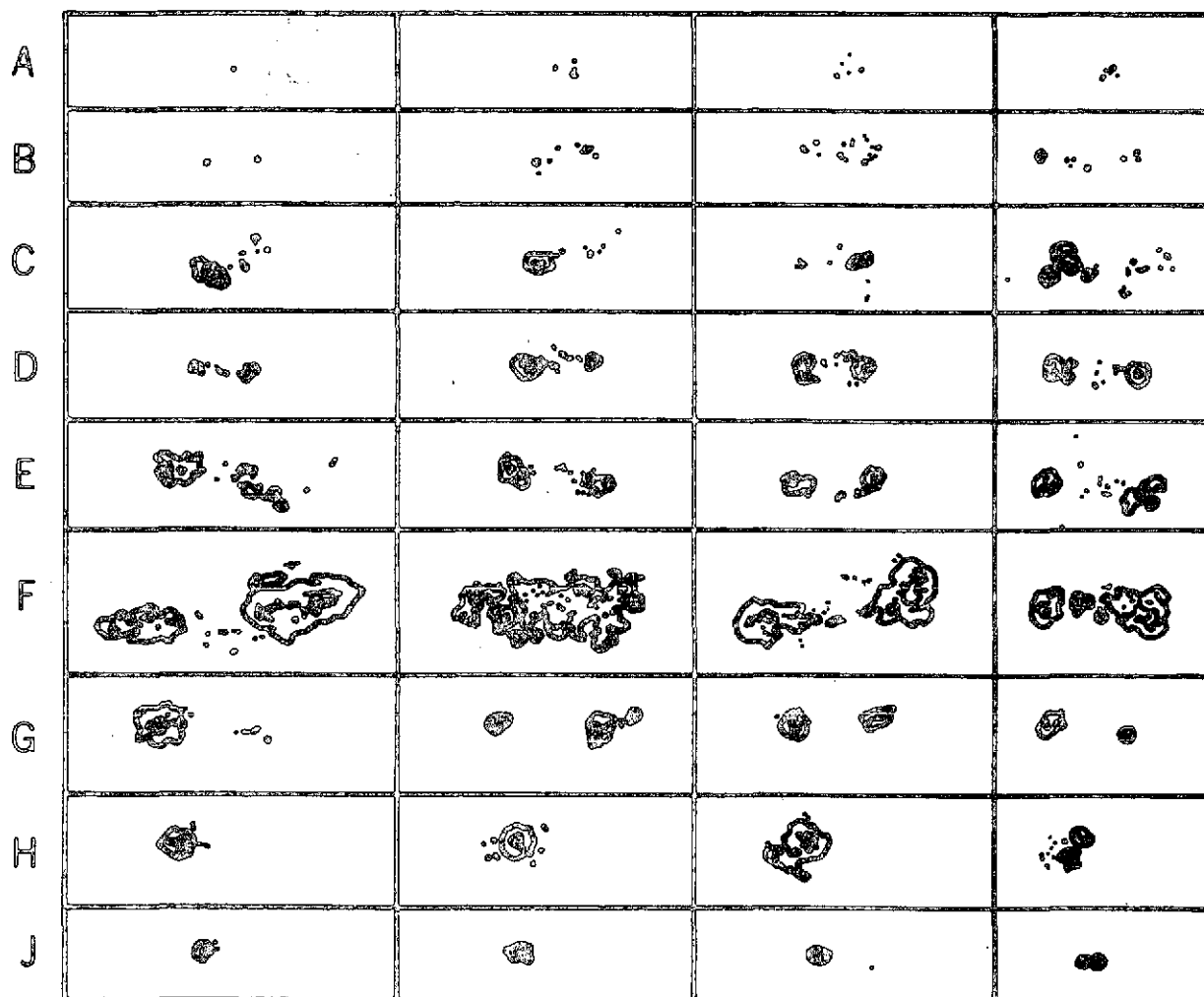
VIEWED FROM NORTH

0   1000 KM SEC^{-1}

Fig. 30

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Fig. 31

THE ZURICH CLASSIFICATION OF SUNSPOT GROUPS. FOUR
EXAMPLES OF EACH CLASS ARE SHOWN. THE SCALE AT THE
BOTTOM INDICATES DEGREE OF HELIOGRAPHIC LONGITUDE.

Fig. 32

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