SOLAR RADIO EMISSION OF SPECTRAL TYPE IV AND ITS ASSOCIATION WITH GEOMAGNETIC STORMS

By D. J. McLean*

[*Manuscript received August 5, 1959*]

Summary

A new type of solar radio event, the type IV storm, first described by Boischot, has been identified on Dapto radio-spectrographic records. It has been shown to be distinguishable from type I storms by (i) its smooth spectrum, (ii) its close association with type II bursts, and (iii) its remarkably close association with geomagnetic storms. In common with some type I storms, all type IV storms are found to be associated with very large solar flares.

It appears possible to explain the production of type IV emission and the occurrence of the related phenomena in terms of a single cloud of gas which moves through the Sun's corona.

I. Introduction

It has long been known that large outbursts of solar radio emission from the Sun are sometimes followed by periods of prolonged radio " storms " (e.g. Hatanaka and Moriyama 1950 ; Payne-Scott and Little 1952). Until recently these outburst-associated storms were presumed to be particular cases of " noise storms " which dominate the metre-wavelength radio records of the Sun over certain active periods and which are now called type I storms. The spectral records of type I storms show that they consist of many narrow-band, short-lived bursts, superposed on a background of continuum radiation.

More recently, Boischot (1958), observing the Sun with a multi-element interferometer at 169 Mc/s, has made a distinction between the ordinary noise storm (type I) and storms to which he gives the new classification of type IV. What Boischot has described is a long-duration ($\sim\frac{1}{2}$–6 hr), very smooth increase in intensity of solar radio emission extending through metre and decimetre wavelengths. These events are preceded by high intensity, short-duration outbursts which Boischot identifies as type II bursts (the characteristics of a type II burst are briefly described near the beginning of Section II), and are closely associated with very big flares (importance 2 or greater). The type IV sources are generally of larger diameter than those of type I noise storms (7–12 min of arc for a type IV, a little less for a type I source). They show rapid motion, generally away from the centre of the disk, at speeds of $\sim$1000 km/s, during the first few minutes of their existence. After this they remain steady until the storm fades, or possibly drift back slightly before fading. Boischot also presents some evidence that the flares associated with big cosmic ray increases are often, perhaps always, associated with type IV storms.

* Division of Radiophysics, C.S.I.R.O., University Grounds, Chippendale N.S.W., and School of Physics, University of Sydney.

Observing with a radio-spectrograph, Haddock (1958) has reported that, while type IV storms occur mainly after type II bursts, similar events are occasionally observed without any type II burst.

Recently Wild, Sheridan, and Trent (1959), working with a two-element, swept-frequency interferometer, have observed the motions of type IV sources over a range of frequencies, and they report that, at any one time, all frequencies arrive from the same direction (with a little scatter). This observation is taken as evidence that the mechanism of emission is not plasma oscillations, since radiation emitted from plasma oscillations will be restricted to frequencies near the fundamental (and second harmonic) of the plasma frequency in the region of the source and so a wide range of frequencies cannot be emitted from the same point. (In the case of type II and type III bursts, which are believed to be radiation from plasma oscillations, Wild, Sheridan, and Trent do observe different frequencies arriving from different directions.) However, Wild's observations are consistent with a suggestion by Boischot and Denisse (Boischot 1958) that the type IV radiation could be produced by synchrotron emission from high energy electrons spiralling in a magnetic field.

In the present paper it is proposed (1) to present the results of a recent study of spectral records of those solar radio storms which last only a few hours (" discrete storms "), with emphasis on the distinction between type I and type IV storms, (2) to describe the association of type IV storms with other solar and terrestrial events, and (3) to suggest, in the light of the evidence presented, a theory of the evolution of the type IV event.

II. Observations

Since 1952, solar radio-spectrograph records have been made at Dapto, N.S.W., on equipment described briefly by Wild, Murray, and Rowe (1954). These records were examined, mainly but not exclusively at times immediately after flares of importance 2 or greater and after outbursts which appeared on the spectral records as type II bursts, and all periods of greater than 10 min and less than about 5 hr duration, during which the observed intensity was appreciably greater than the quiet-Sun level over part or all of the observed frequency range, noted as discrete storms. The record of October 21/22, 1958, at the bottom of Plate 1, shows the start of a typical storm at 2341 U.T., preceded by an example of a type II burst from 2328 to 2342 U.T. It can be seen in the latter that there is a narrow band of high intensity activity at a frequency which drifts from $\sim$100 Mc/s to 40 Mc/s in about 10 min and that all the details are reproduced at a frequency which is approximately twice the fundamental frequency. This pair of bands is generally considered to be the fundamental and second harmonic of the frequency of plasma oscillations at the source region in the solar corona, the frequency drift being due to the motion of the source. For a fuller discussion of type II observations and theory see Roberts (1959).

The period studied was from 1952 to 1958. Only 22 discrete storms were found, of which perhaps 12 could be classified as type IV, the other 10 as type I. Possibly other such events have been obscured by what appear to be continuous periods of several days of type I noise storms. It appears probable from Boischot's work, which is supported by the present, non-exhaustive, examination of the Dapto records, that all type IV events may be associated with flares.

(a) *The Distinction between Type I and Type IV Storms*

In order to examine the possible distinction between type I and type IV storms the set of 22 storms was divided into two groups by two different classifications, one dependent on the prevalence or absence of bursts, and the other on

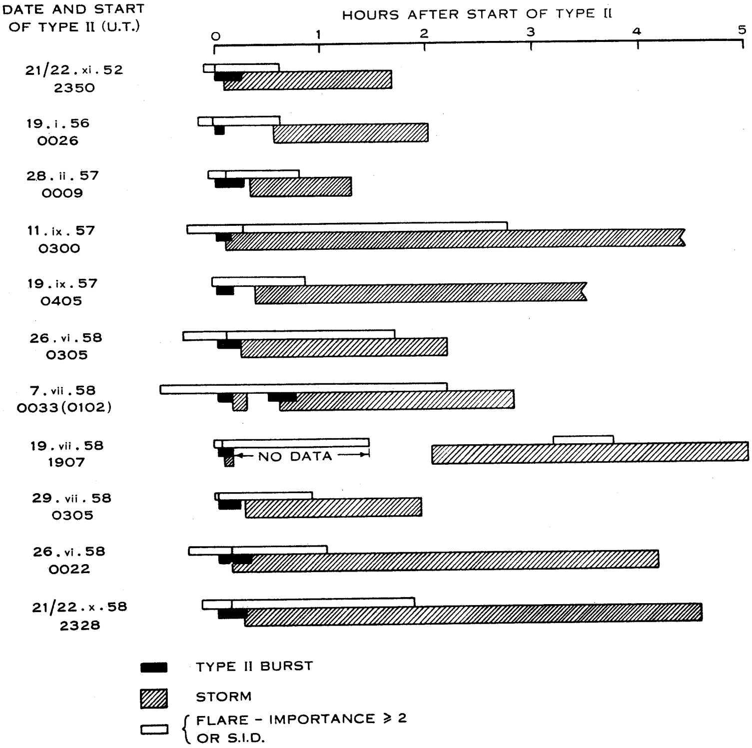

Fig. 1 (*a*).—Schematic diagram showing durations of radio storms which follow type II bursts and their relations in time to the type II and big flare event. These storms are shown later to be all the type IV storms observed.

whether or not the event was associated with a type II burst. Both these depend on characteristics capable of recognition from spectra alone. The two pairs of groups were then compared to see whether or not the classifications could be shown to be nearly equivalent.

In the first classification we divide the storms into groups of those showing many bursts which we term " bursty " and those showing few which we term " smooth ". Storms of the former type satisfy the definition of type I storms given in the introduction, i.e. a long series of very short, narrow-band bursts, superposed on a broad-band continuum—the bursts being the dominant feature.

The latter (smooth) type consist almost entirely of a smooth, very broad-band, sometimes intense, increase in radio emission, which in many cases rises quickly to a maximum and then decays slowly. In other cases multiple maxima, about half an hour apart, are observed, as in the event of August 26, 1958, in Plate 1. Total durations are of the order of a few hours.

The start of these smooth storms often shows more detailed structure. Frequently the continuum exhibits a low frequency cut-off, drifting towards lower frequencies at a rate typical of type II bursts. Sometimes the event

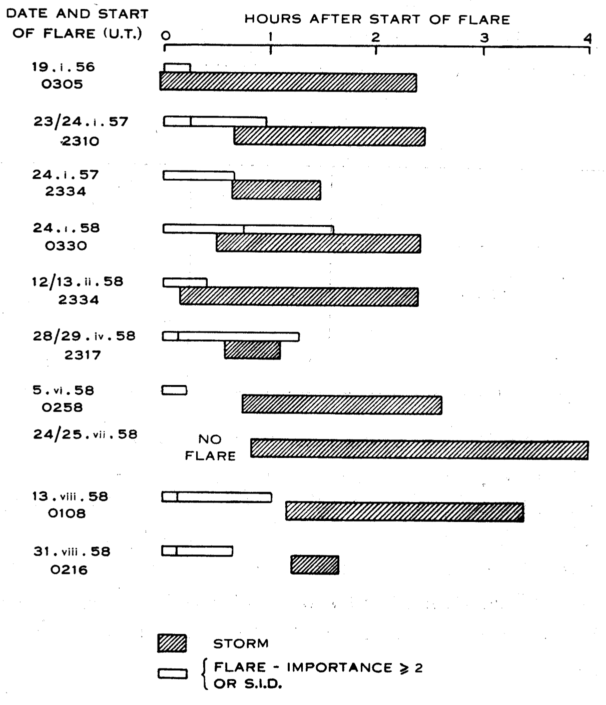

Fig. 1 (*b*).—Similar to Figure 1 (*a*), showing the durations and flare relationships of radio storms not associated with type II bursts. These are all type I storms.

starts as two broad bands, about 20 Mc/s wide, which merge within a few minutes into even broader continuum. Also, sometimes the storm starts with a few bursts (which do not resemble a type II burst) then blurs out after a few minutes and the storm continues as a smooth continuum.

Plate 1 shows examples of the " spectral appearance " of this smooth type of storm. It will be shown that this type is distinctive in other respects, justifying Boischot's extension of the spectral classification to distinguish it from type I.

The second classification is by the presence or absence of an associated type II burst. This could be decided from the available records in most cases but in two cases Harvard spectral data in CRPL " Solar Geophysical Data " were consulted.

Figure 1 (*a*) shows the time relationships of events which have been interpreted as being associated ; the differently shaded rectangles represent the times and durations of type II bursts, type II associated storms, and big flares (or S.I.D.'s which are indicative of big flares.) The events involved are sufficiently rare to make precise criterion for association unnecessary. The association can be judged from inspection of Figure 1 (*a*).

Figure 1 (*b*) shows the times of flares and related storms not associated with type II bursts and has been included here for comparison with Figure 1 (*a*) in a later discussion of flare associations.

The two classifications are compared in Table 1 which shows the correlation between type II–associated and smooth storms.

TABLE 1

CORRELATION BETWEEN TYPE II BURSTS AND SMOOTH STORMS

	Smooth	Bursty	Total
Type II–associated	12	0	12
Non-type II–associated	1	9	10
Total	13	9	22

Clearly the correlation is good and hence the distinction between type I (or bursty) and type IV (or smooth) storms emphasized. In fact, from this table it appears that the simplest definition of a type IV storm, and the easiest to apply from a spectral point of view, is " a storm which closely follows a type II burst ". Some care is needed, however, since in one case, which occurred since the data for this paper were collected, a type IV was observed at frequencies above 40 Mc/s, associated with a type II burst which was observed only at frequencies below 40 Mc/s. Hence Haddock's observation on equipment which had a low frequency limit of 100 Mc/s, of smooth storms without an associated type II burst is not contrary to the above conclusion. For the purposes of the rest of this paper, therefore, an event has been classed as a type IV storm if it closely followed a type II burst. This implies, as Table 2 shows, that the storm also fitted the original description of a smooth storm.

III. The Association of Type IV Storms with Flares and Geomagnetic Storms

(*a*) *Flares*

As Figures 1 (*a*) and 1 (*b*) show, most of the events examined, whether type IV or type I storms, are associated with the occurrence of large solar flares. In only one case is there no evidence of flare association, and at that time there appears to have been no flare patrol. Four cases are consistent with flare association but the evidence is either confused (due to the occurrence of more than one suitable flare or in one case due to the occurrence of two storms during the one flare) or indirect (i.e. inferred from ionospheric effects). The remaining

17 all occur between ½ and 2 hr after the start of a big flare. Hence in almost every case there is evidence of close flare association.

Clearly, due to the mode of selection, this is not very significant for type I events, since the records were only examined systematically after big flares and type II bursts, and those events following type II bursts are type IV storms. However, as Roberts (1959) pointed out, approximately half the total number of type II bursts are associated with flares of importance 1, and it is therefore significant that all type IV events were associated with flares of importance 2 or greater. The probability of this occurring by chance is about 1/5000.

TABLE 2

DISTRIBUTION OF TYPE IV AND TYPE I STORMS WITH IMPORTANCE OF FLARE

	Uncertain or None	Imp. 2	Imp. 3	Imp. 3+	Total
Type IV	2	2	6	2	12
Type I	3	5	2	0	10
Total . .	5	7	8	2	22

When cases are split amongst the flare importance classes as in Table 2, there seems to be a strong tendency for type IV storms to associate with big flares, bigger than do type I storms; two-thirds of the observed cases are associated with flares of importance 3 or 3+.

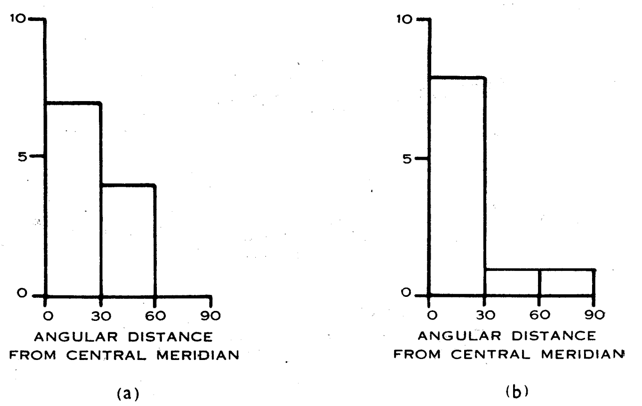

Fig. 2.—Distribution with central meridian distance (*a*) of flares associated with an observed type IV storm and (*b*) of importance 3 flares known to be not associated with a type II storm.

Another aspect of the type IV–flare relationship is the distribution with central meridian distance of type IV–associated flares. The observed distribution, in Figure 2 (*a*), shows no cases more than 60° from the central meridian. This may be due to (1) angle discrimination or (2) biased sampling.

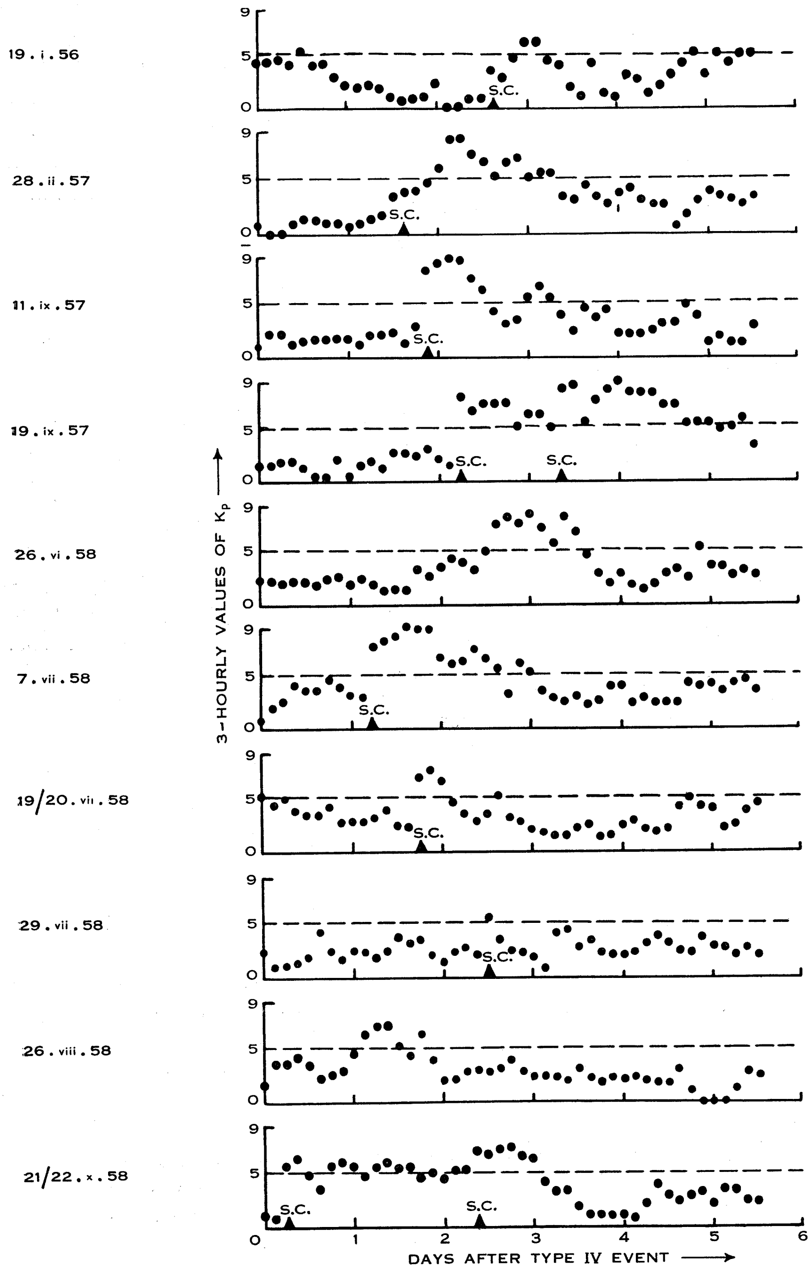

Fig. 3.—Values of K_p (geomagnetic index) plotted at 3-hourly intervals for a period from 0 to $5\frac{1}{2}$ days after each of the ten most recent type IV storms observed.

Since no type IV storm has been observed without an associated flare, seeing difficulties involved in flare observations near the limb cannot cause this effect. However, if a type II burst were less likely to be observed if its associated flare were near the limb than near the centre of the disk, the observed effect might be produced. Again, it is not believed that any of the storms observed without type II bursts, can be identified as a type IV, contrary to what would be expected if the distribution of Figure 2 (*a*) were due to angular discrimination in the observability of type II bursts rather than type IV storms. Also, Roberts (1959) has shown that there does not appear to be any significant discrimination against observations of type II bursts associated with flares near the limb.

Since these arguments appear to el minate the possibility of biased sampling, Figure 2 (*a*) is interpreted as an angular discrimination in the observability of type IV storms.

It might be argued that the observed effect is due to absorption. If this were the case the same effect should be observed for type II bursts, since these are believed to originate from the lowest level in the corona from which the radiation can escape without being completely absorbed. However, type II bursts are observed even associated with flares on the limb (Roberts 1959). The explanation therefore appears to be that the emission is confined to a cone whose axis is in or near the plane of the solar meridian through the associated flare.

For comparison, Figure 2 (*b*) shows the spatial distribution of ten flares of importance 3, occurring during the radio observing periods, but not associated with any observable type IV storm. If all importance 3 flares were associated with type IV storms, the flares in Figure 2 (*b*) should all lie outside the range associated with observable type IV's. Figure 2 (*b*) therefore shows that not all importance 3 flares are associated with type IV storms. This is as expected from Roberts' observation that not all importance 3 flares are associated with type II bursts.

(*b*) *Geomagnetic Storms*

Figure 3 shows plots of K_p, an index of geomagnetic variability, at 3-hourly intervals, for several days after each of the ten most recent type IV events. In all cases, except perhaps one, there is seen to be evidence of a magnetic storm commencing between 1 and 3 days after the type IV, and in most cases there is an associated sudden commencement.

To compare this apparent effect with that produced by other types of events, especially those intimately associated with type IV storms, the superposed epoch method was used. In Figure 4 is plotted the mean K_p index, before and after each of the following:

(*a*) The ten type IV storms used above.
(*b*) The ten type I storms, associated with flares, used earlier in this paper.
(*c*) The ten importance 3 flares occurring in radio observing periods, but not associated with any type IV, also used earlier.
(*d*) Thirty-six type II bursts, none of which occurred within four days of a known type IV storm observed from Sydney.

As can be seen, the correlation of geomagnetic storms with type IV storms is outstanding and is probably the only significant one; certainly type II bursts, without type IV storms following them, do not appear to be associated in any but a small percentage of cases. This is in direct agreement with Sinno and Hakura (1958), but the conclusion is different from that of Dodson (1958), who associates geomagnetic storms with "major early bursts". (Figure 1 (*a*) shows that type IV storms generally occur after the maximum of a flare.)

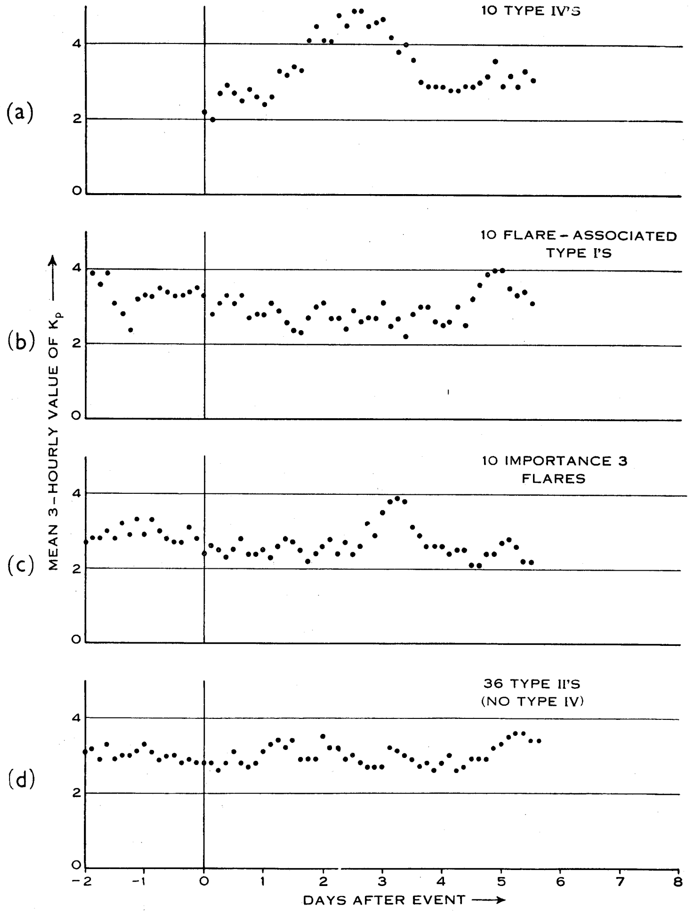

Fig. 4.—The mean value of K_p for each 3-hourly period before and after (*a*) type IV storms (10 events); (*b*) type I storm (10 events); (*c*) importance 3 flares, not associated with type IV storms (10 events); and (*d*) type II bursts, not associated with type IV storms (36 events).

It is interesting to note that the previously mentioned restriction of the type IV–associated flares to within 60° of the central meridian, is similar to the restriction to within ~45° of the central meridian of flares associated with magnetic storms (Kiepenheuer 1953).

Apparently type IV radiation and magnetic-storm clouds are confined to roughly the same cone of emission. Hence, if a magnetic storm followed a type IV storm occurring anywhere on the Sun, it would be reasonable, from the direction of the Earth, to expect to see both or neither. This is relevant to a consideration of the percentage of geomagnetic storms associated with type IV's (which has not been investigated yet).

It appears from Figure 3 that occurrence of a type IV storm will become a reliable guide for the prediction of terrestrial disturbances 1–3 days later.

IV. A Hypothesis of Origin

Boischot and Denisse (Boischot 1958) have already proposed synchrotron radiation, from relativistic electrons spiralling in a magnetic field, as the mechanism for type IV emission.

Since type II bursts, geomagnetic storms, and flares have been shown above to be closely associated with type IV storms, the following results and ideas arising from previous work are relevant.

(i) Type II bursts are believed to be produced by plasma oscillations in the solar corona (Wild, Murray, and Rowe 1954 ; Wild, Sheridan, and Trent 1959) ; such oscillations could be excited by the passage of a shock front ahead of a fast moving column of gas (Westfold 1957 ; Roberts 1959).

(ii) Geomagnetic storms are thought to be due to the arrival at the Earth of a cloud of plasma ejected from the solar corona, and carrying trapped magnetic fields and high energy protons (Kiepenheuer 1953 ; Gold 1959).

(iii) Type IV sources are observed with velocities of 500–3000 km/sec ; type II sources and magnetic storm clouds are believed to have velocities of the same order (Boischot 1958 ; Wild, Sheridan, and Trent 1959).

(iv) Boischot (1958) has observed type IV sources to have diameters of $\sim$7–12 min of arc.

In addition it has been shown in this paper that :

(v) Although not unique, a fairly typical description of the start of a type IV is as follows : a type II burst occurs, then, after a short delay of minutes, a smooth increase of intensity commences at high frequencies and rises gradually to a maximum in a period of about 10 min. Lower frequencies appear at later times, the effect being that of a low frequency cut-off drifting to lower frequencies at roughly the same rate as the type II. This can be observed fairly easily for the event of August 26, 1958, in Plate 1.

(vi) The spectrum is essentially smooth and changes slowly with time.

(vii) As stated above, a type II burst, geomagnetic storm, and large flare are all closely associated with the occurrence of a type IV.

In the rest of this paper, the outline of a hypothesis is presented which appears capable of combining these facts and ideas and of explaining the spectral observations. This is done by considering the sequence of events in 4 phases, illustrated diagrammatically in Figures 5 (*a*) to 5 (*d*).

First phase (Fig. 5 (*a*)).—A flare occurs low in the solar atmosphere, in the region of high magnetic field associated with a sunspot group. It has been

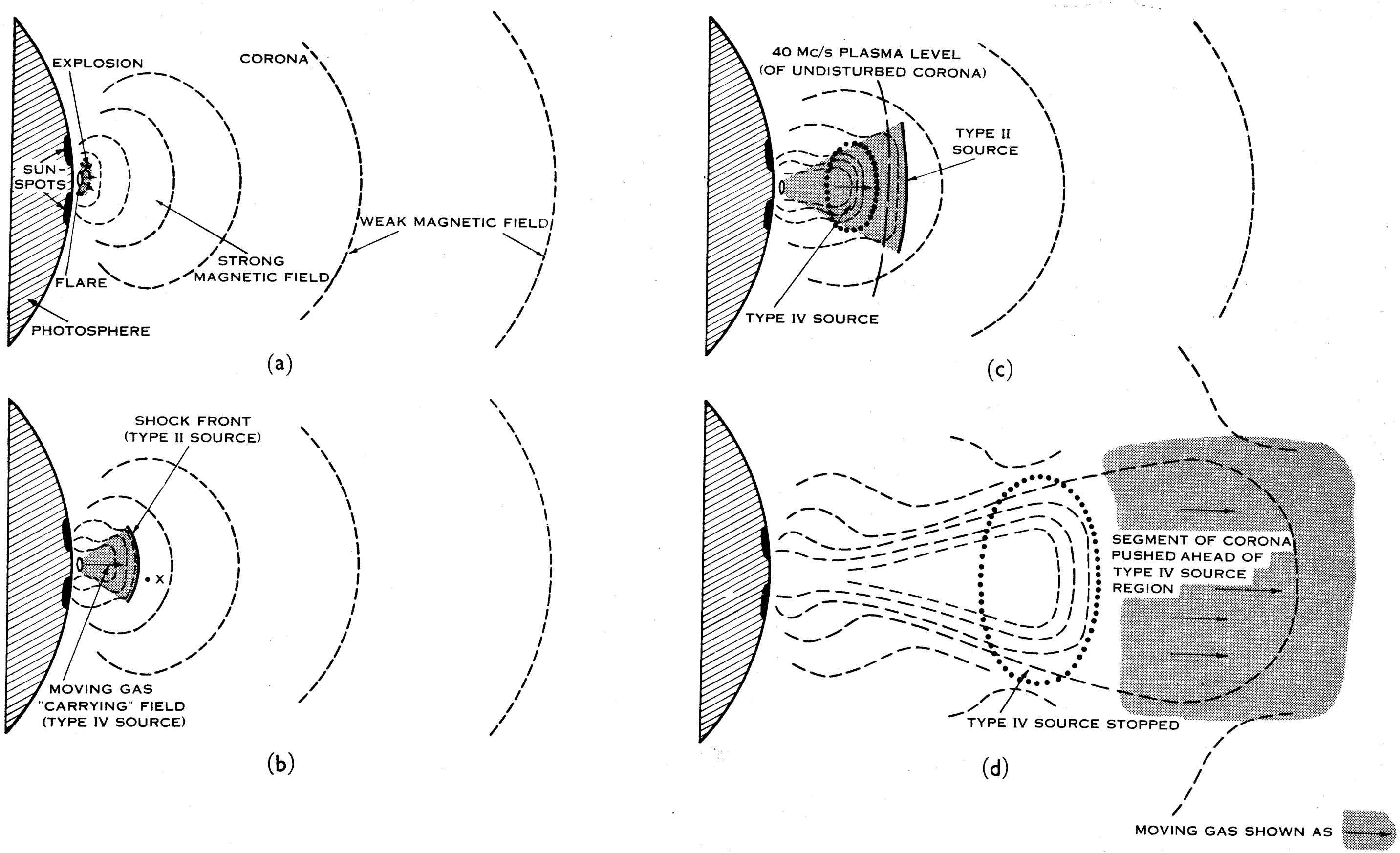

Fig. 5.—A simple representation showing a possible mode of development of a type IV storm and its relation to flares, type II bursts, and geomagnetic storms (see text).

postulated that an explosion of some sort occurs near the start of the flare and ejects a column of gas, which travels radially outwards from the region of the flare.

Second phase (Fig. 5 (*b*)).—The column travels with a velocity of about 1000 km/sec. For such a high velocity the front of the column will be bounded by a shock front. This is a sharp discontinuity between the stationary corona, as yet unaffected by the explosion, and the moving gas constituting the column which is at a higher temperature and pressure. As the shock front reaches a point such as X in Figure 5 (*b*) the gas near X is compressed and accelerated to the velocity of the column, thus becoming a homogeneous part of the column. In this way the boundary of the column moves forward relative to the gas in the column, i.e. the shock front moves faster than the gas comprising the column.

As mentioned earlier, the shock front is assumed to excite plasma oscillations in the corona, which in turn produce the type II radiation. This has already been shown to fit the observations in most respects (Roberts 1959). Also, it is well known (e.g. Westfold 1957) that magnetic fields which are in the coronal gas before it is accelerated by the explosion are " frozen in " and carried by the gas.

It is not unreasonable to expect that a small percentage of particles in the column will have been accelerated to high energies (1 MeV would be sufficient to explain the observed effect) either by the explosion, or by the rapidly changing fields in the shock front, or by both. Under suitable conditions these will be trapped within the column by the frozen-in magnetic fields and the electrons will radiate continuously over a wide frequency range (Schwinger 1952). This is taken to be the type IV emission.

Boischot's cosmic ray evidence suggests that during the first or second phase extremely high energy protons might be generated, which under favourable conditions (not necessarily immediately) might be liberated from the magnetic fields to give rise to terrestrial cosmic ray increases (see Piddington 1958).

Third phase (Fig. 5 (*c*)).—When the disturbance reaches greater heights in the corona, the gas in the forward part of the column, which has been accelerated by the shock front, does not contain such strong, frozen-in magnetic fields and so the conditions are unfavourable for the generation of synchrotron emission in this region. The type II source (near the shock front) and the type IV source (in the region of the high magnetic fields and moving with the velocity of the gas in the column) therefore tend to become separated. Hence, at the time shown in Figure 5 (*c*), a single-frequency record of solar emission at 40 Mc/s would show the type II burst to be already over and the type IV storm not yet started. (Following other workers, we have here assumed that the type II radiation comes from just in front of the shock front; its frequency is then determined by the undisturbed coronal density.) Owing to the nature of the shock front, the gas in the column will be maintained at a higher density than the gas in the surrounding corona and so the plasma frequency (which is the low frequency cut-off for transmission of radiation) will be higher here than in the adjacent corona. Hence, the type IV source will not be observed at, say, 40 Mc/s till the gas in and ahead of the source has expanded to the density at the 40 Mc/s plasma level in the undisturbed corona, which is unlikely to occur until after the type IV source crosses the original position of this level. This is the explanation of the observed delay between a type II burst and the associated type IV storm and the drifting cut-off frequency. An exactly similar discussion can of course be applied to, say, 30 Mc/s observations, which should not show the type IV radiation till after the source passes through the 30 Mc/s level, which is above the 40 Mc/s level—hence the drifting cut-off.

The rise time may be explained by postulating a long extent of the type IV source in the direction of motion. It is clear from the above discussion that, while the leading edge of the source is " visible " at 40 Mc/s, the tail of the source may still lie in denser gas which absorbs 40 Mc/s radiation. Hence, as each part of the storm becomes visible, the observed intensity rises.

The observed value of rise time seems to agree with that estimated by assuming that all the type IV emission at a given frequency becomes visible at the same height in the corona. Boischot (1958) observes type IV sources $\sim$10 min of arc across, which is roughly 4×10^5 km. A source 4×10^5 km long with a velocity of 10^3 km/sec should take about 7 min to cross a particular level in the corona. This is the order of the observed time for a type IV storm to rise from zero to maximum intensity at a given frequency.

Fourth phase (Fig. 5 (*d*)).—The type IV source is observed to stop moving high in the corona. No attempt is made here to postulate a stopping mechanism. It is postulated, however, that the stopping mechanism is such that the segment of the corona, which has been pushed out ahead of the type IV source region and which has already been considered not to emit type IV radiation owing to the insufficient magnetic field, is not stopped. In that case, this moving cloud of gas, carrying weak magnetic fields and possibly high energy protons, becomes the magnetic storm cloud, travelling with the velocity the type IV source had initially.

This completes the suggested outline for the explanation of type IV emission. Two points, predicted by the hypothesis, which it should be possible to test from interferometric measurements, are :

(i) that the type IV source should follow the type II source along the same path,

(ii) that the type II source should travel appreciably faster than the type IV source.

V. Conclusion

There are at least two distinct types of solar radio storm observable at metre wavelengths. One is the type I, which has long been recognized ; the other is the type IV, only recently distinguished from type I by Boischot.

The type IV storm is a smooth, long-duration, enhancement of radio emission from the Sun, which is closely associated with very big flares and nearly always follows a type II burst. However, it appears necessary to allow the possible existence of a small amount of burst structure in the definition of a type IV storm, especially early in the storm. On the other hand, the type I storm is distinguished by its extremely bursty nature and its non-association with type II bursts. Further, type I storms of less than, say, 10 hr duration may be associated with flares, but the tendency appears to be towards less important flares than those associated with type IV storms.

Evidence has been produced that the occurrence of a type IV storm is a very significant event in the prediction of a geomagnetic storm commencing 1–3 days later. Large flares and type II bursts, both of which are commonly associated with type IV storms, do not appear to be followed by geomagnetic storms if they are not associated with type IV storms. Further, type I storms do not appear to be associated with geomagnetic storms, which is also a useful point of distinction between type I and type IV storms. The type IV storm appears therefore to be a valuable prediction guide.

A hypothesis has been proposed in which type II bursts, type IV storms, and magnetic storms are all observable effects of the one cloud of gas ejected from near the photosphere by an explosion.

VI. Acknowledgments

This work was done while the author, who is a student at the University of Sydney, was attached to the Radiophysics Laboratory. The author especially wishes to thank Mr. J. P. Wild for considerable direction, discussion, and assistance during this study; also Dr. J. L. Pawsey for acting as a supervisor. Further, the author wishes to thank all those people whose work has made this study possible, by producing, processing, and analysing the records.

VII. References

Boischot, A. (1958).—*Ann. Astrophys.* **21**: 273.

Dodson, H. W. (1958).—*Proc. Inst. Radio Engrs., N.Y.* **46**: 149.

Gold, T. (1959).—*Nature* **183**: 355.

Haddock, F. T. (1958).—*Proc. Inst. Radio Engrs., N.Y.* **46**: 3.

Hatanaka, T., and Moriyama, F. (1950).—*Rep. Ionosphere Res. Japan* **4**: 173.

Kiepenheuer, K. O. (1953).—" The Sun." (Ed. G. P. Kuiper.) (Univ. Chicago Press.)

Payne-Scott, Ruby, and Little, A. G. (1952).—*Aust. J. Sci. Res.* A **5**: 32.

Piddington, J. H. (1958).—*Phys. Rev.* **112**: 589.

Roberts, J. A. (1959).—*Aust. J. Phys.* **12**: 327.

Schwinger, J. (1952).—*Phys. Rev.* **75**: 1912.

Sinno, K., and Hakura, Y. (1958).—*Rep. Ionosphere Res. Japan* **12**: 296.

Westfold, K. C. (1957).—*Phil. Mag.* **2**: 1287.

Wild, J. P., Murray, J. D., and Rowe, W. C. (1954).—*Aust. J. Phys.* **7**: 439.

Wild, J. P., Sheridan, K. V., and Trent, G. H. (1959).—I.A.U.-U.R.S.I. Symposium on Radio Astronomy, Paris 1958. p. 176. (Stanford Univ. Press.)

Explanation of Plate 1

" Spectral appearance " of type IV storms. The first three examples are reproductions of spectral records in which the time scale has been considerably compressed by a special photomechanical process. The fourth shows the start of the third event on a more normal time scale.

In all cases, frequency and time scales are as marked and intensity is shown by the whiteness of the record.

Horizontal white lines are due to interference from radio transmitters and horizontal black lines mark the limits of the individual frequency bands in the equipment.