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FLARE-ASSOCIATED BURSTS AT 18 MC/S

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The occurrence of increased radio noise at the onset of short-wave fadeouts (SWF's) was noted by Appleton [1], who attributed the enhancements to solar emission. Payne-Scott [2], observing at about 19 Mc/s, measured burst intensities and times of occurrence to compare these high-frequency phenomena with radio events in the VHF range from 50 to 100 Mc/s.

In connection with the IGY flare program at High Altitude Observatory, R. H. Lee [3] recently constructed an interference-rejecting receiver for observation of flare-associated sudden cosmic noise absorptions (SCNA's) at 18 Mc/s [4]. Although the beam of the antenna is vertical, solar noise bursts often appear on the records, both without and with accompanying SCNA's.

To be certain of the bursts' solar origin, we limited our study to those closely associated with an SCNA, and with a reported flare or SWF. Burst intensities, expressed in watts $m^{-2}(c/s)^{-1}$, contain correction factors for antenna pattern and ionospheric absorption. For thermal radiation, in the absence of a magnetic field, the critical frequency reaches 18 Mc/s at a height in the solar atmosphere of about one solar radius. Because of this high level, these bursts offer a powerful means of measuring frequency drifts and the corresponding velocities of radio sources. Since they refer to the highest levels of the sun, subject to routine observation, they may provide valuable data with respect to the solar source of corpuscular radiation associated with geomagnetic and ionospheric disturbance.

1. RELATION TO BURSTS AT OTHER FREQUENCIES

To find the time relations between bursts at 18 Mc/s and other frequencies, we counted all bursts within specified time intervals before and after the 18-Mc/s burst [4]. This procedure eliminates assumptions on the value of the time lag. Fig. 1 shows that the number of bursts reaches a maximum in the interval 0 to 5 minutes before the 18-Mc/s burst, for bursts at 2800, 450, and 167 Mc/s, and for type II and type III bursts. Type I bursts, and the beginning of intense continuum [5] also show a less distinct maximum in the same interval. The most intense type III bursts maximize, misleadingly, in the 5-minute interval *after* the 18-Mc/s burst. The expected time lag of the 18-Mc/s burst after the type III burst is of the order of 10 seconds. This is smaller than our time resolution, about one minute. Also, we considered the

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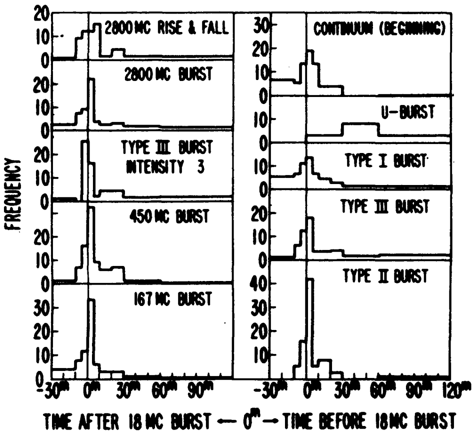

FIG. 1. Frequency of time lag between bursts on other frequencies and burst at 18 Mc/s.

time interval between maxima of the two bursts, rather than between beginning times. We believe that the 18-Mc/s burst follows the higher frequency burst within seconds and that a poor time resolution distorts the relation. Cases of gradual rise and fall [6] at 2800 Mc/s show a broader distribution than the bursts, its maximum, surprisingly, coming earlier than the maximum of the 2800-Mc/s bursts. The frequency of occurrence of inverted U-bursts that reach frequencies no lower than 100 Mc/s properly shows no relation to the occurrence of 18-Mc/s bursts.

Both type II and type III bursts occur most frequently within 5 minutes before the 18-Mc/s burst. From frequency drifts of these bursts [7], we would expect the 18-Mc/s burst to lag by some 10 minutes and 10 seconds respectively. There are 10 cases of 18-Mc/s bursts that occur within 15 minutes of a type II burst; all of these are associated with type III bursts, most of them intense. Seven of the ten bursts are the low-frequency end of type III bursts. They begin within 4 minutes after the type III burst, and before or simultaneously with the type II burst. Two begin 6 and 14 minutes after the type II bursts, and presumably are their low-frequency continuations. One burst began one minute after the type II, and 21 minutes after the type III. Fig. 2 shows an example of each type of association. We conclude that both type II and type III bursts occasionally reach 18 Mc/s. Despite the fact that most of our bursts match type III bursts, the relative occurrence of 18-Mc/s bursts as part of type II bursts is unexpectedly high.

TABLE I

Type of Burst	Relative Frequency of Occurrence	Fraction of 18-Mc/s Bursts Associated with this Type
Major, 167 and/or 450 Mc/s (within 5^m)	1.0	0.38
2800 Mc/s, single or single-complex (within 5^m)	3.4	0.44
Type III (within 5^m)	17.4	0.66
Type II (5^m to 15^m before)	0.3	0.05

Although 18-Mc/s bursts are associated most often with type III bursts, consideration of the relative frequencies of occurrence shows that the closest association is with major bursts at meter wavelengths. The frequency of association with bursts at 2800 Mc/s of flares with 18-Mc/s bursts is higher than for flares in general, but about the same as for flares with SWF [6].

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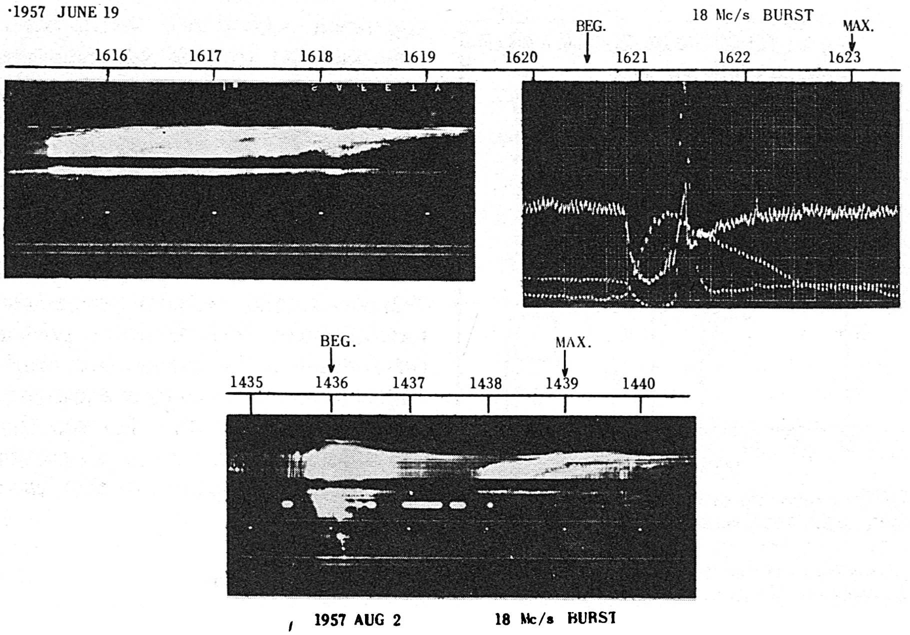

FIG. 2. *Upper left*: Type II burst (courtesy Harvard Radio Astronomy Project, Ft. Davis, Texas). The interval during which the 18 Mc/s burst occurred is indicated on the time scale at the top. *Upper right*: 18-Mc/s record of this type II burst. Three separate traces are shown on Sanborn chart; the dashed record is the 18-Mc/s flux from the Galaxy, with the superposed burst; the double dots represent an average of communication signal levels through about 40 kc/s of radio spectrum in the 18-Mc/s band; single dots represent the level of 27 kc/s atmospherics observed during this flare, and show the SEA effect beginning simultaneously. *Lower left*: Type III and type II burst (Harvard Radio Astronomy Project, Ft. Davis, Texas). The 18-Mc/s burst, indicated on the time scale at the top, is associated with the type III, rather than the type II burst.

Intensities of 18-Mc/s bursts show a small positive correlation with the intensities of bursts at other frequencies, with the highest correlation, as one might expect, at 167 Mc/s.

Only about half the flares with 18-Mc/s bursts occur in regions that are radio noisy, according to interferometer observations at 169 and/or 255 Mc/s. This fraction remains about the same for central flares. Only for regions that produced three or more flares with bursts does the fraction in noisy regions increase slightly.

2. RELATION TO ASSOCIATED FLARE

Because we have selected bursts with SCNA's we assume that all of our bursts occur with flares. However, preliminary comparison of 18-Mc/s records, taken with equipment at several locations in the United States, shows the reality that many more solar bursts do not qualify for inclusion in this analysis.

Large bursts tend to occur with important flares, but the relation is not

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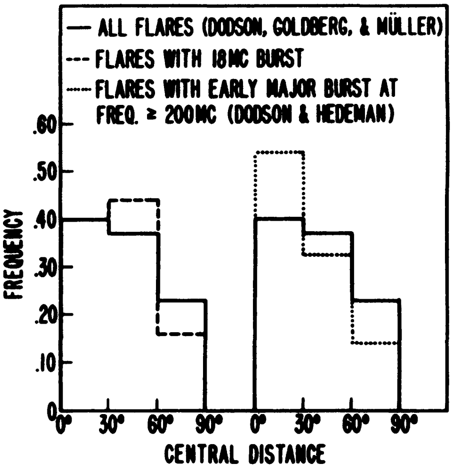

FIG. 3. Frequency of flares as a function of central meridian distance.

significant. Only one of 15 bursts that occurred after SCNA maximum was associated with a subflare (importance 1), although about one-third of the early bursts were associated with subflares.

In Fig. 3, we compare the relative frequencies of flares with 18-Mc/s bursts as a function of central meridian distance, to the relative frequencies for all flares [8]. We also present the frequencies of flares with early major bursts at frequency equal to or less than 200 Mc/s [9]. We see that the 18-Mc/s bursts show a suggestion of limb-darkening, but less than early major bursts.

3. RELATION TO GEOMAGNETIC DISTURBANCE

The time relation of 18-Mc/s bursts to bursts at higher frequencies fits Wild's [7] picture of a disturbance that travels upward through the solar atmosphere. The level at or above which the 18-Mc/s radiation escapes the solar corona lies almost one solar radius above the photosphere. On the basis of the association of 18-Mc/s bursts with major bursts at higher frequencies, and the demonstration that major bursts are exceptionally good indicators of geomagnetic disturbance [9] we may expect that bursts at 18 Mc/s should also be related to geomagnetic disturbance. Records of 18-Mc/s noise form a convenient basis for selecting such events, because the time of the burst with respect to the flare follows from the accompanying SCNA.

We have carried out superposed epoch analysis of the geomagnetic character figure A_p about the day of occurrence of our 18-Mc/s bursts. We confirm that bursts that occur early in the life of the flare, measured in our study by the SCNA, are more likely than late bursts to be followed by geomagnetic disturbance. Furthermore, the more intense bursts are more likely than less intense bursts to be followed by a storm. However, we find no clear indication that flare importance is a significant factor in the geomagnetic relation; but our sample is very small compared to that of Dodson and Hedeman.

In Fig. 4 we present the results of the superposed epoch analysis of A_p, and of the frequency of values of $A_p \geq 30$. Bursts of intensity $\geq 10^{-20}$ watts $m^{-2}(c/s)^{-1}$ that occurred before maximum of the associated SCNA define zero days. The frequency of occurrence of these events is comparable to that of the early major bursts studied by Dodson and Hedeman. We see that 18-Mc/s bursts are followed, one day later, by a peak in geomagnetic activity which, although not particularly impressive in view of the existence of peaks almost as large at -13 or -14 days and at $+10$ days, is of the same magni-

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tude as that associated with early major bursts. The Dodson-Hedeman effect is, of course, considerably more significant because of its larger sample size.

We conclude that, while flares or SCNA's with associated 18-Mc/s bursts provide a promising means of forecasting geomagnetic disturbance, they appear to offer no essential improvement over forecasts made on the basis of optical flare characteristics and radio noise bursts at higher frequencies. Despite the higher level in the solar atmosphere at which the 18 Mc/s disturbance occurs, the relation to geomagnetism does not sharpen.

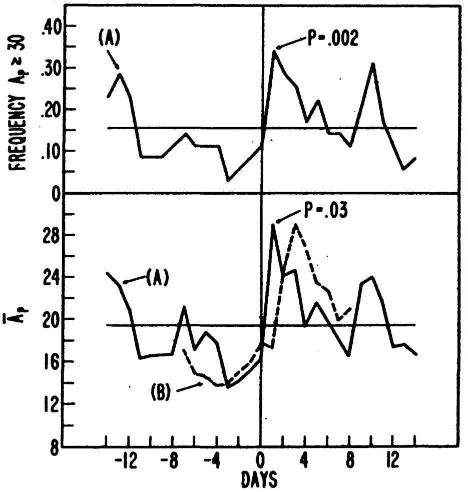

FIG. 4. Geomagnetic effect of (*a*) 18-Mc/s bursts of intensity $\geqq 100 \times 10^{-22}$ watts m^{-2} $(c/s)^{-1}$ preceding *SCNA* maximum (35 cases, 1956–57); (*b*) early major bursts at frequency $\leqq 200$ Mc/s (115 cases, 1949–56; Dodson & Hedeman).

Information on bursts at other frequencies came from the following sources: 2800 Mc/s, Ottawa, National Research Council and C. R. P. L. F-series; 167 and 450 Mc/s, Boulder, National Bureau of Standards, C. R. P. L. F-series; sweep-frequency observations, Fort Davis; reports from Solar Department, Harvard College Observatory. Radio-interferometer data on 255 Mc/s came from the NERA Observatory (Netherlands Postal and Telecommunications Service, Section on Ionosphere and Radioastronomy) and from the Paris Observatory, 169 Mc/s (unpublished). Flare data came from the *Quarterly Bulletin on Solar Activity* and from the C.R.P.L. F-series.

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