HELIOGRAPHIC LONGITUDE DISTRIBUTION OF THE FLARES ASSOCIATED WITH TYPE III BURSTS OBSERVED AT KILOMETRIC WAVELENGTHS

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Abstract. We have grouped observed type III solar bursts according to the discrete frequencies of observation in the kilometric wavelength range. For each group we have obtained the bursts' frequency of occurrence as a function of the heliographic longitude of the associated optical flares. We found that flares occurring east of a certain cutoff longitude do not produce bursts observable near the earth below a given frequency. The cutoff on the west is determined by observational limitation for flares beyond the limb. The mean longitude and the extreme eastern end of the longitude distribution both shift to the west as the radio frequency decreases. We interpret these findings in terms of radio wave propagation effects and curved trajectories of the bursts' exciter particles.

1. Introduction

The purpose of this work was to study qualitatively the propagation of radio waves and particles associated with type III solar radio bursts observed at kilometric wavelengths. We have used the data obtained by the radio astronomy experiments of the University of Michigan Radio Astronomy Observatory aboard OGO-5 and IMP-6 satellites.

The solar corona is an inhomogeneous plasma with a negative electron density gradient in the radial direction. Consequently radio waves propagating through it experience refractive, scattering and absorptive effects.

The first observational studies of coronal scattering of radio waves used the occultation by the corona of galactic or extragalactic radio sources. The observation of type III bursts at very low frequencies from Earth satellites provides a method to study the effects of the corona on the propagation of radio waves originating far out in the corona itself.

The theory for coronal scattering of radiation from solar radio sources has been studied recently by several authors (Fokker, 1965; Steinberg, 1972; Riddle, 1972).

The scattering of solar radio sources depends on the frequency of observation, on the average electron density distribution of the corona, on the size, shape and orientation of the electron density inhomogeneties and on the distance of the emitting region from the observer.

For burst sources at a given frequency and on the ecliptic plane, the scattering effects could be expected to be symmetrical with respect to the Sun's central meridian provided that possible directionality effects at emission have only radial symmetry.

Although the observations of IMP-6 have the capability to give the burst direction of arrival with respect to the Sun-spacecraft line, the complete data analysis are not yet available. In this preliminary study, we have used the heliographic longitude of the optical flare associated with a burst. The relationship between the heliographic longitude of the radio emitting region at a given frequency and that of the associated flare is given by the trajectory of the burst exciter particles. This relationship is not known, but the results of this study should help to determine it.

We found that bursts at a given frequency are observed in association only with flares located west of a limiting heliographic longitude. This limiting longitude, λ_c, increases (from east to west) as the frequency decreases. We interpret this eastern radio cutoff as being due to propagation effects, mainly wave scattering. At the very low frequencies we do not observe a western radio cutoff. The observed western cutoff seems to be determined by the observational cutoff for flares beyond the limb. These results are further evidence that the trajectories of type III bursts are curves similar to the interplanetary magnetic field lines.

2. Data

The observing frequencies of OGO-5 are: 3.5, 1.8 MHz, 900, 600, 350, 200, 100 and 50 kHz. The observing frequencies of IMP-6 are: 3.5 MHz, 900, 600, 350, 230, 130, 80 and 50 kHz.

The lowest four frequency channels in OGO-5 had low sensitivity due to spacecraft radio interference; only the strongest bursts could be detected. The consequences of the intensity selection effects will be discussed later. The IMP-6 radiometer is at least one order of magnitude more sensitive than OGO-5's.

3. Discussion of the Results

We selected the type III bursts detected by OGO-5 at 350, 200, 100 and 50 kHz between March 1968 and March 1971, and at 600 kHz between March 1968 and November 1969. We selected the bursts detected by IMP-6 at 130, 80 and 50 kHz between April 1971 and May 1972. From these bursts we chose only those associated with an Hα flare. The criterion for association was that the burst at 3.5 MHz should start within 5 min of the Hα onset. All observed bursts associated with flares beyond the limb were thus excluded. The criterion was based on the following results of the analysis of type III bursts observed by OGO-5 between March 1968 and November 1969: (1) By using a similar criterion, a high degree of correlation was found between the 64 km-wavelength bursts observed associated with flares west of the central meridian and energetic solar electron events detected near the Earth (Alvarez *et al.*, 1972). (2) During approximately 18 months covered by the analyzed OGO-5 data there occurred about 4600 reported Hα flares. Since the mean time between these flares is 169 min, which is 16.9 times longer than the adopted 10 min interval, the probability of a chance association is only 0.06; and (3) five of the 64 radio events were associated with active regions behind the limb. 70% of the 59 remaining bursts occurred within 5 min of the average onset time of the flare (Alvarez, 1971).

For each of the selected frequencies we made a histogram of the distribution in heliographic longitude of the associated flare. The results for IMP-6 and OGO-5 data are shown in Figures 1 and 2, respectively. The cross-hatched area represents confirmed flares, and the blank area represents unconfirmed ones. The longitudes correspond to the group average as given by N.O.A.A. reports in *Solar-Geophysical Data.* Whenever a longitude was equal to an integer multiple of 10, the burst was split in two halves. The parameters of these distributions are presented in Tables I and II; σ is the

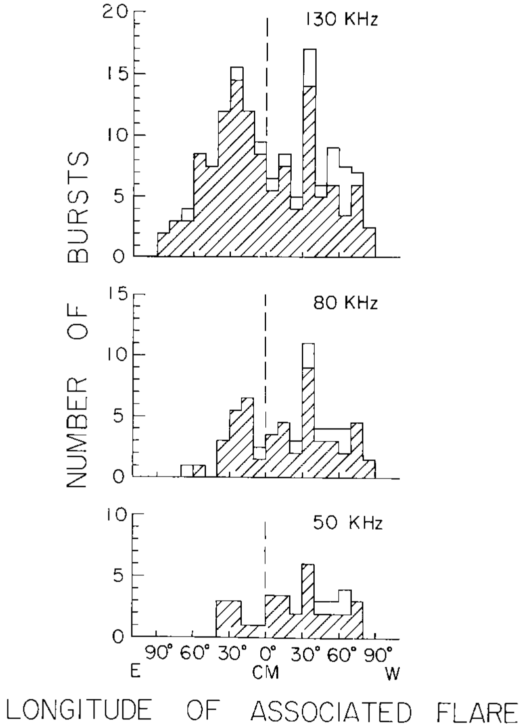

Fig. 1. Distribution of bursts observed by IMP-6 starting within five minutes of a confirmed optical flare onset. In the absence of a confirmed flare an unconfirmed flare was used; these cases are indicated by blank units. Data cover from April 1971 through May 1972.

TABLE I

Parameters of the distribution in heliographic longitude of burst associated flares. Bursts observed by OGO-5

f	n	σ	$\bar{\lambda}$	λ_c
(kHz)		(deg)	(deg)	(deg)
600	147	41.7	4.7 ± 3.4	-70
350	76	43.9	13.5 ± 5.0	-72
200	36	40.5	25.4 ± 6.7	-55
100	13	39.8	34.8 ± 11.0	-29
50	1		90	

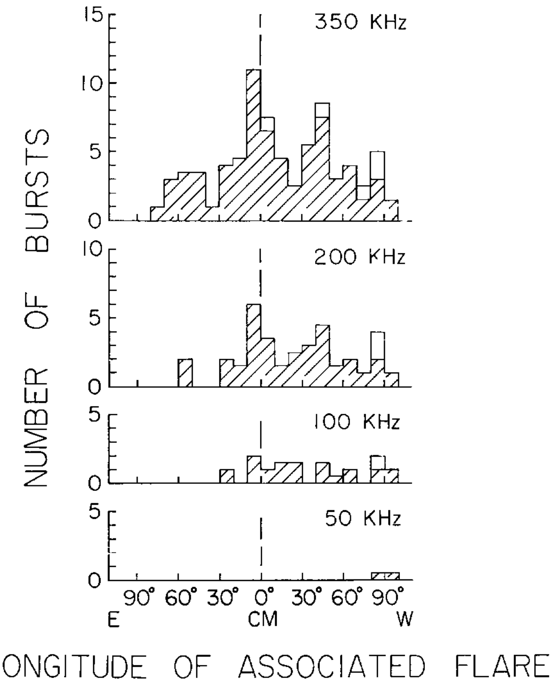

Fig. 2. Same as Figure 1 except for bursts observed by OGO-5 from March 1968 through March 1971. The number of bursts detected by IMP-6 is larger than that detected by OGO-5 because of IMP-6's higher sensitivity.

TABLE II

Parameters of the distribution in heliographic longitude of burst associated flares. Bursts observed by IMP-6

f	n	σ	$\bar{\lambda}$	λ_e
(kHz)		(deg)	(deg)	(deg)
130	144	42.9	1.8 ± 3.6	−85
80	59	36.2	18.6 ± 5.2	−68
50	36	33.8	24.9 ± 5.6	−35

standard deviation, $\bar{\lambda}$ is the mean with its standard error, n is the number of cases and λ_e is the longitude of the easternmost flare.

In Figures 1, 2 and Tables I and II, it is seen that the eastern end of the distributions, λ_e, and the mean longitude both shift westward as the frequency decreases.

The actual shape of these distributions are affected by the distribution of the parent population of all Hα flares during this period. During the time covered by the IMP-6 observations reported, there were 3784 confirmed optical flares both with and without type III bursts. They have a distribution with $\bar{\lambda} = -3.2° \pm 0.8°$ and $\sigma = 45.9°$. This distribution tapers down more or less symmetrically about $\bar{\lambda}$. This tapering is most probably due to an observational effect, and it could be expected to introduce a selection against burst association with flares near the east or west limb.

The fact that with increasing radio frequency the distribution shifts to the east is consistent with a known but unexplained fact obtained from ground-based observations: that type III bursts tend to be associated with flares occurring on the east half of the disk (see Kundu, 1965, p. 305).

The western end of the distributions shown in Figures 1 and 2 could be determined either by a west radio cutoff or by the optical cutoff at the limb, whichever occurs first. From the figures it seems that the observed cutoff is optical. This must affect the mean of the distributions. In fact, if we had optical observations beyond the west limb, the east and west ends of the distribution would be determined only by radio cutoff, and the mean of these distributions would be more to the west than the values given in Tables I and II. The values of the mean in these tables should be considered then, as eastern lower bounds.

The mean of the distributions of Figures 1 and 2 are plotted versus frequency in Figure 3. The trend of increase in $\bar{\lambda}$ with decreasing frequency is obvious. The fact that

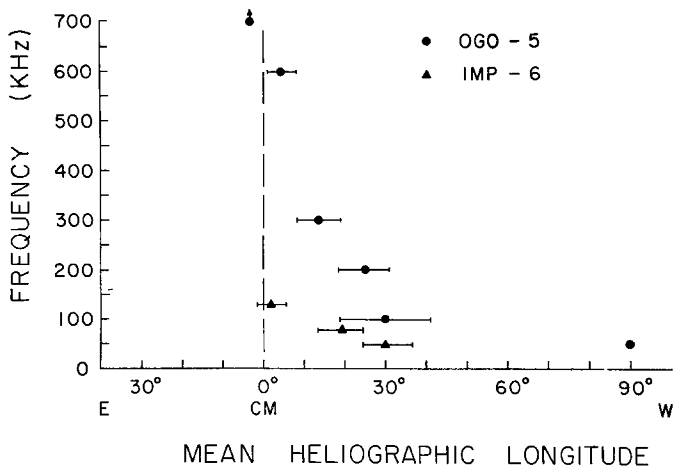

Fig. 3. Mean of the distributions shown in Figures 1 and 2 plotted as a function of frequency. Error bars correspond to the standard error of the mean. The point at 600 kHz, not shown in Figure 2, includes 72 bursts that drifted down to 600 kHz and were observed between March 1968 and November 1969. The arrow indicates the mean of all flares reported from April 1971 through May 1972; the diameter of the dot covers the error. The point at 90° corresponds to only one observation.

OGO-5 points are higher than IMP-6's is due to the higher detection thresholds of the OGO-5 radiometer. With more sensitivity in the OGO-5 radiometer the bursts would have been detected down to lower frequencies, thus shifting downward the OGO-5 points in Figure 3. The difference in slope suggested by the two sets of data may also be due to a radiometer sensitivity effect. In fact, by increasing the sensitivity indefinitely the points would fall on a limiting curve determined only by propagation effects. This curve would be below the IMP-6 points. Possible effects of burst intensity and flare importance were not considered in this study.

The fact that the average of these distributions, modified by the optical limitations beyond the west limb, shifts to the west as the frequency decreases can be understood qualitatively with the help of Figure 4. We have assumed in a simplified picture that the radiation at a given frequency from a certain plasma level is observed at the Earth only if it is emitted within a range of positions that is centered with respect to the Sun-Earth line. Also we have assumed the local plasma hypothesis and that the trajectories are curves resembling Archimedes spirals. For example, the bursts at frequency f_1 should be emitted in the range from C' to D', which corresponds to a certain range C to D in longitude of the associate flare. At a lower frequency, such as f_2, the range of associate flare longitude has moved westward to AB.

We believe that the data on Figure 3 is strong evidence for a curvature of the burst exciters' trajectories as suggested in Figure 4. Trajectories along a curve with opposite curvature or along a radius would not produce the observed effects. Other evidence for the kind of curve suggested comes from the observation of the interplanetary magnetic field, from the observation of the direction of arrival of type III bursts at very low frequencies (Alvarez *et al.*, 1973; Fainberg *et al.*, 1972; Potter *et al.*, 1971) and from the association of type III bursts with solar electron events (Alvarez *et al.*, 1972).

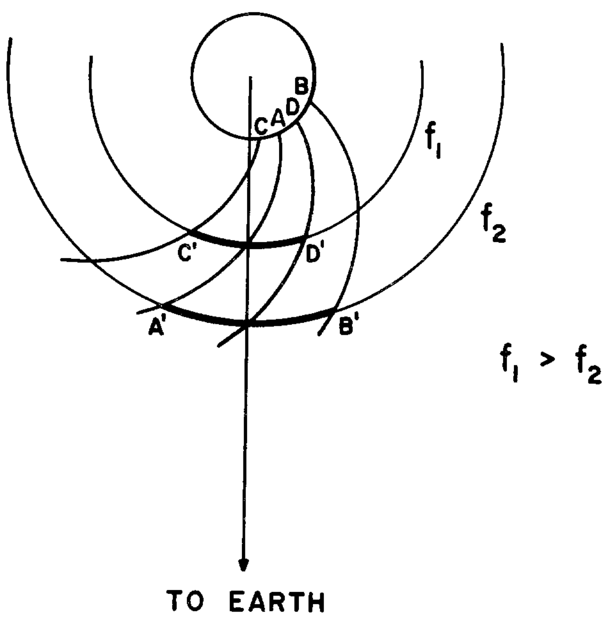

Fig. 4. Simplified geometry of the exciter particle trajectories used to explain qualitatively the distributions shown in Figures 1 and 2. Assuming that the sources of the bursts observed at a given frequency occur symmetrically with respect to the solar central meridian then, as the frequency decreases, the range of the associated flare longitudes is expected to shift to the west.

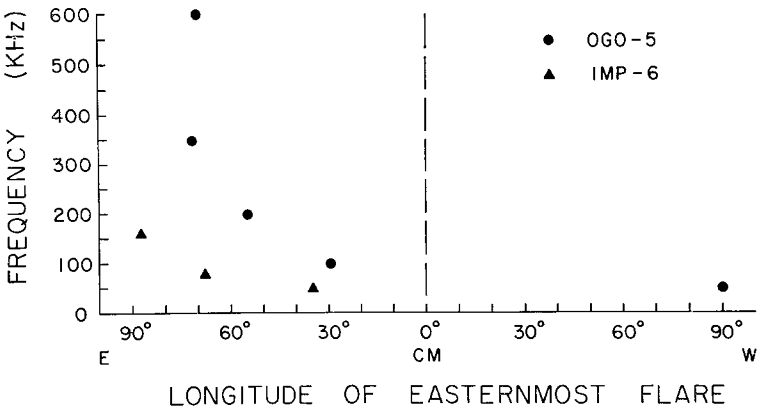

Fig. 5. Heliographic longitude of the easternmost flare associated with type III bursts plotted against observing frequency. The observed cutoff is attributed to radio wave propagation effects. The same comments as in Figure 3 apply to the OGO-5 points at 600 and 50 kHz.

Figure 5 shows the plot of eastern cutoff longitude versus frequency for the distributions discussed earlier. In general the trend is similar for the two sets of observations. Here again the fact that OGO-5 points are above the IMP-6's is due to the intensity selection effect built into the OGO-5 data.

Fainberg and Stone (1970) observing at 2.8 MHz detected type III bursts associated with active regions at the east limb.

The distributions in Figures 1 and 2 should also be affected by the mode of emission of the observed radiation: whether as fundamental from a plasma level with electron density N or as second harmonic from a plasma level with density 0.25 N. After having this information and the heliographic longitude of the sources it would be fruitful to compare the observations with the theory.

4. Conclusions

Our analysis of the type III solar bursts observed in the kilometric wavelength range has shown that the distribution of bursts' occurrence as a function of heliographic longitude of the associated flare varies with the observing frequency. At each frequency no bursts are observed whose flare occurred east of a certain eastern cutoff longitude. We have interpreted this as a radio cutoff due to propagation effects. No similar radio cutoff is observed towards the west; the observed cutoff seems to be determined rather by visual limitations beyond the west limb. We found that the eastern cutoff and the mean longitudes of the distributions shift westwards as the observing frequency decreases. The amount of shift per frequency interval depends on radiometer and burst characteristics. Qualitatively we have interpreted the shift trend and its asymmetry as evidence that the trajectories of the burst exciters have a curvature similar to that of the interplanetary magnetic field lines.

At the present time it is not possible to compare theories on scattering mechanisms with our observations because we need to express our results in terms of the *source* heliographic longitude rather than the associated flare longitude. The relationship between these two angular parameters is determined by the curvature of the exciter particle packet trajectory. When data on the direction of arrival of the bursts become available it will be possible to compare observation with theory.

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