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SOME PROPERTIES OF GROUPS OF TYPE III SOLAR RADIO BURSTS

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The structural properties of type III events recorded as isolated bursts, transient groups (duration $\tau < 1$ min), or persistent groups ($\tau > 1$ min) are investigated, using observations made in 1967-1969 with the radio spectrograph of the Institute of Terrestrial Magnetism at 45-90 MHz. Type III events develop a more complex structure as the importance classification of the associated flare increases. The structure also depends on the magnetic-field configuration in the corresponding sunspot group. Type III events generated above unipolar spot groups and above spot groups having a complex field configuration show an enhanced representation of persistent groups of bursts, while events associated with bipolar spot groups have the greatest representation of isolated bursts.

1. INTRODUCTION

Type III bursts are observed at meter and decameter wavelengths and their radiation shows a characteristic fast drift from high to low frequencies (see, for example, [1, 2]).

The evidence of extensive observational material indicates that type III bursts may be interpreted as the radiation of particle streams, most likely electrons, ejected from the neighborhood of a flare and penetrating the coronal plasma at a velocity amounting to an appreciable fraction of the velocity of light. This velocity lies in the range 0.2-0.8 c, corresponding to electron energies of 40-100 keV. Thus by investigating type III bursts one is able to study the manner in which particles are ejected from a flare region.

Even early observations [3] demonstrated that type III bursts are most often observed in the form of groups, suggesting a complicated behavior for the ejection of particles from a flare.

Our purpose in this paper is to examine the basic morphological properties of groups of type III bursts, and we shall endeavor to find definite characteristics of active regions and flares that will lead in some cases to the generation of isolated bursts, and in other cases to the generation of groups of type III bursts.

The discussion to follow is based on material obtained through regular observations carried out with the radio spectrograph of the Institute of Terrestrial Magnetism in the 45-90 MHz frequency range [4]. About 300 groups recorded during 1967-1969 will be considered. A group will be regarded as comprising a set of type III bursts, at least three in number, and satisfying the condition that the maximum time interval between two successive bursts shall not exceed 5 min.

2. MORPHOLOGICAL PROPERTIES OF GROUPS OF BURSTS

In analyzing the characteristics of groups, special attention has been given to their duration and structure. The duration embraces the entire phenomenon of particle ejection taken as a whole, while the structure involves the sequence of individual ejections making up that phenomenon.

It is apparent from an inspection of the histogram of group durations shown in Fig. 1 that

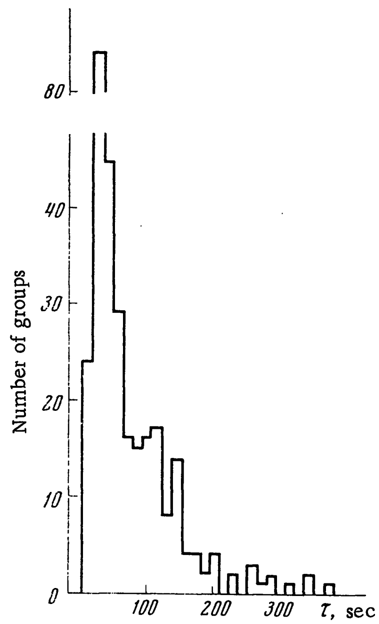

Fig. 1. Distribution of groups of type III bursts with respect to the duration of the group.

groups with a duration τ = 15-45 sec are most often recorded. Toward longer durations the number of groups diminishes for $\tau > 60$ sec. But this decrease is rather gradual; the "tail" in the distribution of groups with respect to duration extends to 3 min or more.

On the basis of this distribution, and in view of the structural peculiarities of the groups, they may arbitrarily be divided into transient groups of duration $\tau < 1$ min and persistent groups of duration $\tau > 1$ min.

Transient groups are the most characteristic form of type III phenomena. About 200 such groups were recorded altogether. As a rule transient groups show a relatively simple structure and consist of more or less regular sequences of bursts (Figs. 2a, b). The groups comprise 3-15 bursts. The number of groups containing more than 10 bursts is comparatively large. The most typical time interval between successive bursts is 6-9 sec, but groups with intervals up to 15-20 sec are encountered. In some cases adjacent bursts merge on the dynamic spectrum, forming a single complex burst lasting 4-20 sec. In that event the interval between successive bursts is evidently shorter than the duration of an individual burst. Whenever the individual bursts are resolved, their duration is 1-3 sec.

The bursts comprising a given group have approximately the same rate of frequency drift.

For most of the events the individual bursts in a group have nearly the same intensity (as measured by their brightness in the spectrum); there is no well-defined principal burst.

Among the transient groups we may include those which, in addition to a main group of bursts

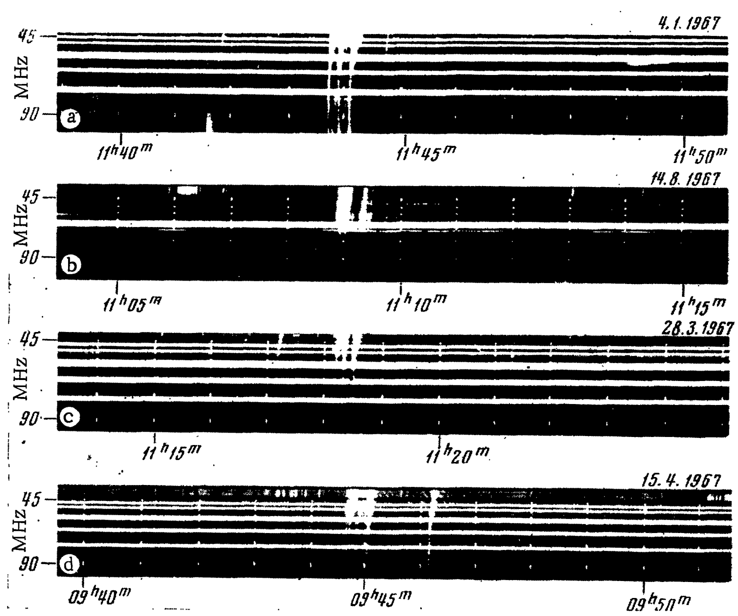

Fig. 2. Dynamic spectra of transient groups.

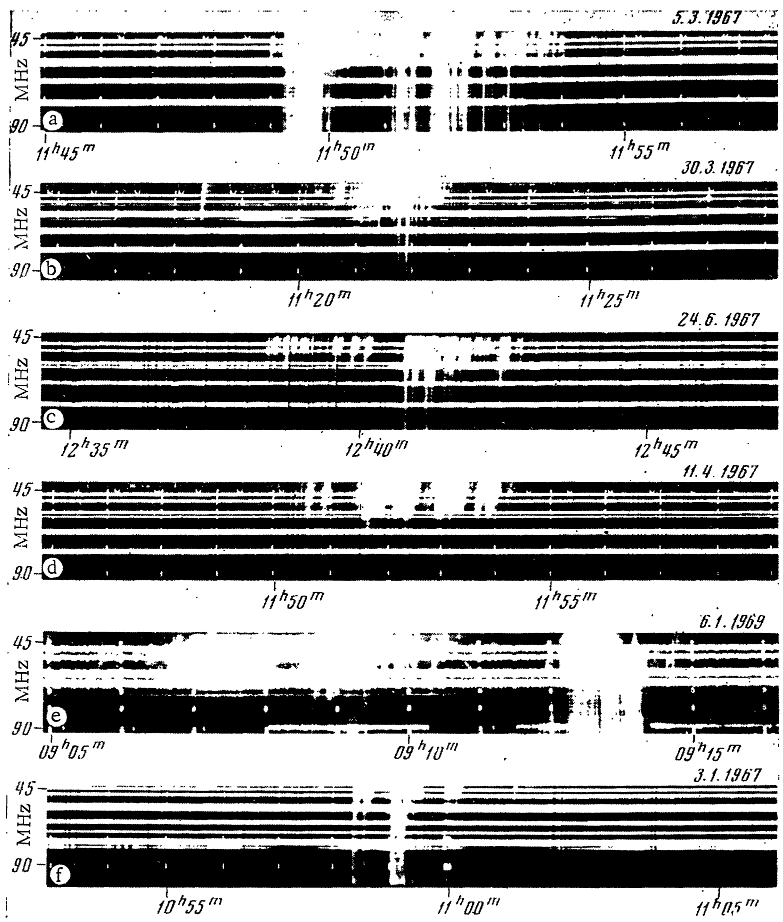

Fig. 3. Dynamic spectra of persistent groups.

of duration $\tau < 1$ min, also contain an isolated burst, in some cases leading the group (Fig. 2c) and sometimes trailing the group (Fig. 2d). The time interval between the isolated burst and the main group ranges from 15 to 60 sec, and usually exceeds the duration of the main group. The isolated bursts generally have the same intensity as the bursts comprising the group itself, although they may sometimes have a lower intensity.

P e r s i s t e n t g r o u p s with $\tau > 1$ min are recorded about half as often as the transient groups. Usually the persistent groups contain a large number of elements covering the entire frequency range investigated (Fig. 3a). There are hardly any groups covering just the low-frequency part of this range. The number of bursts in a group is greater than for the transient groups and may reach several dozen. Groups with merging bursts are often recorded. In cases where the time interval between successive bursts can be measured, it is most often 3-6 sec. In some groups the bursts follow one another at approximately equal intervals, forming a quasiregular structure similar to that described by Wild et al. [3].

The frequency range of the individual bursts belonging to persistent groups can vary in a diversified manner. In particular, groups are encountered in which the leading bursts cover the low-frequency part of the spectrograph band, but for subsequent bursts the initial frequency gradually rises (Fig. 3b). In other groups the opposite behavior is observed (Fig. 3c). However, groups exist showing no regular variation in the initial frequencies. In such groups bursts in the low-frequency part of the range may alternate with bursts covering the whole range. Within any one group the bursts covering the whole range are usually more intense than the bursts whose initial frequency falls in the low-frequency region.

The persistent groups often break down into well-defined subgroups (Figs. 3d-f). The number of subgroups comprising a group ranges from two to five. Groups consisting of two to three subgroups are encountered most often.

The duration of the subgroups is 10-60 sec. Most typical subgroups last no longer than 30 sec. The time interval between subgroups is of the same order, on the average, as the duration of a subgroup. However, groups occur having subgroups separated in time by an interval that is several times as long as the duration of a subgroup. Each subgroup comprises a sequence of two to eight bursts. The subgroups often consist of overlapping bursts.

In some groups the initial (highest) frequency of the component subgroups diminishes successively. On the other hand, within the subgroups themselves the initial frequency of the individual bursts sometimes tends to increase. But groups have also been recorded whose subgroups have successively increasing initial frequencies. As in the case of individual bursts, subgroups with a low initial frequency are less intense than subgroups with a higher initial frequency. It also appears that subgroups with a relatively high initial frequency and high intensity have a longer duration and consist of a greater number of bursts than the less intense subgroups located in the low-frequency region of the spectrum. An analysis reveals no differences in the rate of frequency drift for the individual subgroups comprising a group.

3. DEPENDENCE OF THE STRUCTURE OF TYPE III PHENOMENA ON THE IMPORTANCE OF FLARES AND THE MAGNETIC CLASS OF SPOT GROUPS

The morphological properties of groups of bursts that we have described indicate that the process whereby electron streams are ejected from a flare region is extremely complicated.

It would naturally be of great interest to ascertain the factors responsible for the generation of type III bursts in the form of events differing so rapidly in structure as isolated bursts and transient and persistent groups.

Presumably the "importance" of a flare and the magnetic-field configuration in an active region would play an important role in the generation of type III events.

In the analysis to follow we shall attempt to establish the percentage representation of isolated bursts, transient groups, and persistent groups, out of all type III events together, that are associated with flares of a definite importance, or with active regions having spot groups of a given magnetic class.

The investigation has been based on the same material regarding groups of type III bursts as used above. Furthermore, some data on isolated type III bursts have been included in the analysis. Events have been considered isolated bursts if they consist of a single burst within an interval of ±5 min during which no other phenomena have been recorded.

In this analysis the isolated bursts and groups of the type III bursts have first been identified with flares. For this purpose we have used the flare reports published in "Solar-Geophysical Data" and "Solnechnye Dannye" [5, 6]. Type III events and flares were considered to be associated with each other if they coincided in time. Only uniquely identifiable bursts have been taken into consideration, that is, events during which only a single flare was present on the solar disk. Phenomena that coincided in time with several concurrent flares were excluded from the analysis.

As a result we have obtained unique identifications with flares and active regions for 63 isolated bursts, 54 persistent groups, and 84 transient groups.

In the classification that is presently in use [5], the importance of a flare takes into account the brightness and area of the flare in the Hα line in a rather complicated way. There is a large number of importance classes (15), and it is difficult to arrange the flares in order of increasing importance. We have therefore combined the flares according to brightness and area separately. Thus in one version we have subdivided the flares by brightness (ignoring their area), as faint (F), normal (N), and bright (B). In another version we have subdivided them (ignoring their brightness) into flares of small area (S), intermediate area (1 unit), and large area (≥2 units).

Figure 4 presents histograms showing that percentage or the total number of type III events associated with flares of definite brightness (Fig. 4a) or definite area (Fig. 4b) occur as isolated bursts or transient or persistent groups. From the histograms it is apparent that: a) all flares independently of their brightness, as well as flares of small or intermediate area (S and 1), most often result in the generation of transient groups; b) as either the brightness or the area of a flare increases, the percentage representation of isolated bursts correspondingly decreases and the percentage of persistent groups increases.

Accordingly, we have the general conclusion that with transition from flares of low importance to flares of high importance, the relative contribution from type III events with simple structure (iso-

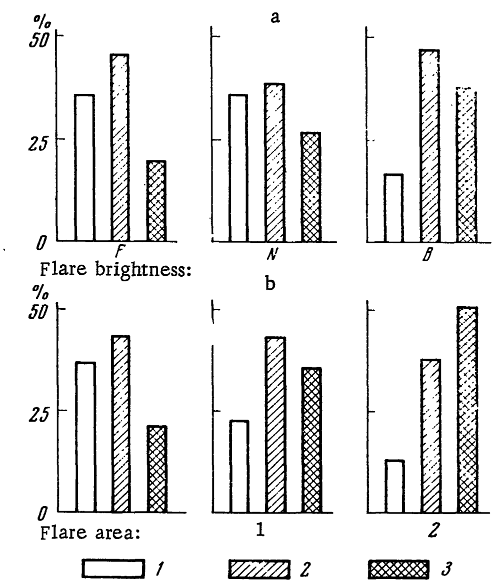

Fig. 4. Percentage representation of isolated bursts, transient groups, and persistent groups, out of all type III events together, that are associated with flares of: a) different brightnesses; b) different areas. 1) Isolated bursts; 2) transient groups; 3) persistent groups.

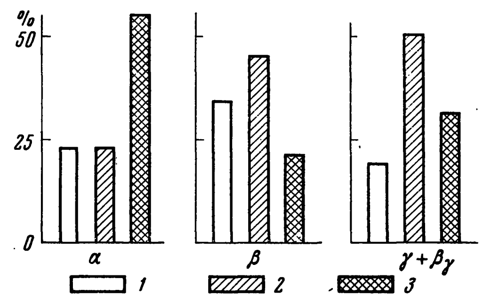

Fig. 5. Percentage representation of isolated bursts, transient groups, and persistent groups, out of all type III events together, that are generated above sunspot groups belonging to different magnetic classes. 1) Isolated bursts; 2) transient groups; 3) persistent groups.

lated bursts) diminishes, while the contribution of events with complex structure (persistent groups) increases. Thus the process of particle ejection has a more complicated character during strong than during weak flares.

In addition to the importance classification of a flare, the magnetic-field configuration in the solar atmosphere may have an essential influence on the manner in which electron streams are ejected from the flare region. Unfortunately, it is very difficult to obtain direct information on the field configuration at comparatively low heights above the photosphere. But since the magnetic field at such levels is determined by the field configuration at the photospheric level, the influence of the field on the particle-ejection process can be investigated by comparing type III phenomena with the magnetic class of sunspot groups in the corresponding active regions.

Spots are classified [5] as unipolar (α), bipolar (β), and complex ($\gamma + \beta_\gamma$). Figure 5 displays histograms showing what percentage of the total number of type III events generated above active regions of each magnetic class are isolated bursts, transient groups, and persistent groups. The following conclusions may be drawn from the histograms: a) Above active regions of magnetic class α, persistent groups are most often generated, while isolated bursts and weak groups of type III bursts occur to approximately the same extent. b) Active regions of class β most often yield transient groups, and isolated bursts are generated more frequently above such regions than persistent groups. c) Active regions of class $\gamma + \beta_\gamma$, like those of class β, most often generate transient groups, but unlike the β regions they yield persistent groups more frequently than isolated bursts.

It follows that the relative occurrence of persistent groups of type III bursts is comparatively high for active regions of magnetic class α, as well as for regions of class $\gamma + \beta_\gamma$. On the other hand, the representation of isolated bursts is greatest for regions of class β.

4. DISCUSSION OF THE RESULTS

The properties of groups of type III bursts as described in Sec. 2 suggest that the ejection of electron streams is a discrete process,[1] and that the discreteness of the ejection may take two forms. In some cases it involves a quasiregular sequence of ejections; in others there is a clustering of several successive ejections into the "subgroups" that are observed. During intervals between such subgroups, the ejection of particles responsible for type III bursts evidently is suspended. The time span during which the ejection of streams is stopped

[1]Evidence for a sequential injection of streams into the corona has been secured from recent observations with the Culgoora radio heliograph [7].

often is comparable to, or even longer than, the duration of the subgroups themselves.[2]

One should keep in mind that investigations of meter-wavelength type III bursts provide information on electron streams only in a particular energy range, 40-100 keV, corresponding to velocities of 0.2-0.5 c (where c is the velocity of light). Hence the absence of a continuous sequence of type III bursts in groups might testify to a complicated variation of the energy spectrum for the electron streams ejected from the flare region. The time interval during which a "window" appears between the bursts or subgroups comprising a group would correspond if not to a complete suspension of electron-stream ejection, then at any rate to a drop in the energy of the ejected partles, or a decline in the number of sufficiently energetic electrons.

Particles whose velocity $V < 0.2$ c are not capable of attaining heights where the local plasma frequency falls within the range we have investigated; hence they cannot generate type III bursts [9].

Such a cutoff in the velocities of particles escaping from a flare region would be caused by collisions of the stream particles with the particles of the coronal plasma.

A high-energy cutoff for the electron streams of the corona would also explain the observed constancy of the rate of frequency drift for the different components comprising a group of type III bursts.

As for the dependence of the structure of type III events on the magnetic class of sunspot groups, one should recognize that class α regions correspond to magnetic fields of "open" configuration in the corona, that is, the lines of force of such a spot group have a significant radial component. The configurations of the β and $\gamma + \beta_\gamma$ regions correspond to magnetic fields of "closed" type. However, the greater complexity of the field configuration for the $\gamma + \beta_\gamma$ regions would lead to the formation of "null" lines or planes along which particle motion would be possible.

The ejection of particles from a flare region into the corona is facilitated both for regions with an open field configuration and for regions with a complex configuration characterized by the presence of null lines and planes [10]. In this way it becomes understandable why the persistent groups of type III bursts are associated with regions of classes α and $\gamma + \beta_\gamma$.

With regard to the class β regions, we note that the closed field configuration in such regions would impede the escape of particles. On the other hand, the relatively simple configuration would not lead to the formation of null lines and planes promoting the escape of particles. This situation probably explains why the percentage representation of persistent groups of type III bursts above such regions is comparatively low.

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[2]Certain groups of type III bursts, exhibiting a quasiperiodic structure that resembles a "rain" effect, could in principle be associated with a pulsating regime of beam instability [8] in the event of an ionic stream.