OBSERVATIONS OF A COMPLEX SOLAR RADIO BURST WITH FINE STRUCTURE ON 3 MAY 1973

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Abstract. The simultaneous high resolution recordings of dynamic spectra in the range 93–220 MHz and polarization at 204 MHz of a complex type II–IV event which started at 08:33 UT on 3 May 1973 shown a sporadic zebra pattern. In contrast with the unpolarized type II burst, the stripes in the emission and absorption of the zebra pattern were fully polarized and most likely corresponded to the ordinary wave.

As to spectral and polarization characteristics, the fiber bursts with intermediate frequency drift did not differ from the stripes of the zebra pattern.

The microstructure of the type II burst was characterised by a lot of spikes with variable frequency drift, duration 0.1 s and instantaneous bandwidth ≈1 MHz.

1. Introduction

In the last few years there has been an intensive development in the observation of solar radio bursts with high time-frequency resolution, which make it possible to obtain new information on solar coronal processes. Spectral and polarization observations with high resolution are being continued in IZMIRAN. At the present time spectral observations cover a continuous frequency range from 45 to 230 MHz.

A compound type II–IV radio burst was observed in IZMIRAN on 3 May 1973 with a high resolution spectrograph over the range 180–220 MHz and partly with a new spectrograph from 93–186 MHz. The flux density and the polarization have been also registered at fixed frequencies 74, 204 and 3000 MHz. At the frequency 204 MHz the left- and right-hand polarized radiation components have been registered on the film at the rate 1.0 cm s^{-1} and a time constant 0.01 s. The descriptions of the spectrograph with high resolution and of the polarimeter at the frequency 204 MHz are given, respectively, in Markeev and Chernov (1970) and Amiantov *et al.* (1971). Chernov *et al.* (1972) describe the methods of observation and of data treatment where the spectrum and polarization with high time resolution are simultaneously registered. The spectrograph in the range 93–186 MHz makes it possible to register some weak events with the time resolution ≈0.05 s; for its detailed description see Korolev (1975).

In the literature there were many reports concerning the observations of fine structure, consisting of stripes in emission and absorption in the zebra patterns in continuous bursts (Elgarøy, 1961; Elgarøy, 1971) and of fiberbursts with intermediate frequency drift (Young *et al.*, 1961). It is known that in each event such stripes revealed a great variety of frequency drifts and intensity in the lines of emission and absorption. One of the most striking structures, consisting of strips with the bursts of

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type 'tadpole' was observed on 2 March 1970 by Slottje (1972). However, up to now, there is little observational data of fine structures including polarization measurements with high time resolution.

The present work gives the data on simultaneous registration of the frequency spectrum and circular polarization of stripes in emission and absorption at 204 MHz with high time resolution observed in the compound type II–IV burst on May 3, 1973.

2. General Characteristics of the Burst

2.1. The relation with the active region

The phenomenon of type II–IV on 3 May 1973 began after a solar flare of importance 3B was observed in the eastern region McMath No. 12336 with the co-ordinates S14 E51. A detailed description of the radioburst global spectrum and of all accompanying phenomena is given in Benz *et al.* (1974). In Figure 1 the radio-emission flux density at fixed frequency 204 MHz is given from IZMIRAN data. The durations of the fine structure occurrence are marked by horizontal thick lines in the middle of the figure. The oblique lines in the upper part of Figure 1 correspond to the flare duration from the maximum phase. The figure represents also a general picture of the sunspot group. (*Solar Data*, 1973). Attention may be drawn to the existence of a great number of spots in the group (more then 40) and to the multipolarity of the region.

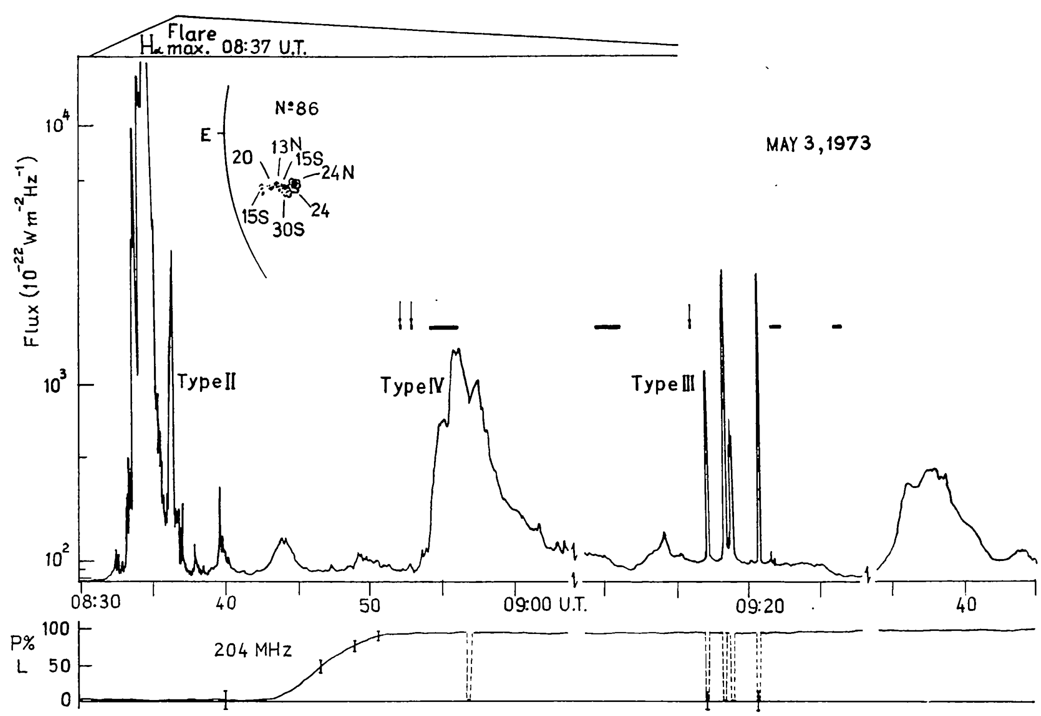


Fig. 1. The flux density and polarization of radiation at 204 MHz for the type II–IV burst on 3 May 1973. Vertical segments on the curve of polarization degree (p %) signify the interval of measurement errors. Horizontal segments and arrows in the middle of the figure indicate the moments of occurrence of microstructure. The magnetic field intensity values are given in hundreds of gauss (*Solar Data*, 1973). The oblique lines in the top of the figure correspond to the Hα flare duration from the maximum phase (*Solar-Geophysical Data*, 1973).

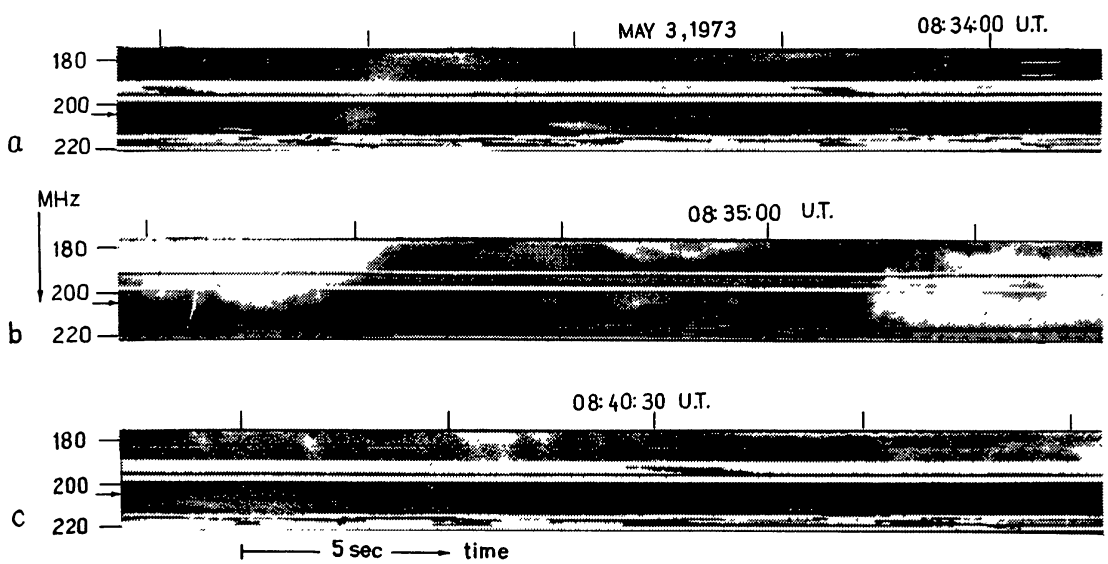
It is known that the zebra patterns were observed usually in complex continuum bursts of type IV connected with proton flares. However, near-Earth satellites of 'Explorer' type have not registered any long-lived proton bursts or corresponding geo-effects after the event of 3 May 1973; a fact pointed out in Benz *et al.* (1974). Yet about 5 hours after the starting of the flare a short-lived increase of the number of particles was registered by satellites Explorer-43 (against a decreasing background of the preceding flare) and by Pioneer-9 (*Solar-Geophysical Data*, 1973). The absence of prolonged proton fluxes may be connected with their directed motion away from a distant eastern region (E51).

The frequency spectrum of type IV burst had a shape proper to proton events (Benz *et al.*, 1974). Besides, a powerful burst of hard X-ray emission (0.5–3 Å), a spectrum characteristic of proton events was simultaneously observed.

2.2. Spectral classification

Simultaneous spectral and polarization observations at 204 MHz make it possible to distinguish in the event of 3 May 1973, beginning at 08:33 UT, an unpolarized type II burst which lasted for the first ten minutes. The following burst of type IV began with a smooth continuum increase, starting from 08:44 UT with an increasing degree of left-handed circular polarization. The same spectral classification based on the broadband spectrum was made in Benz *et al.* (1974). Figure 1 shows the variation of the degree of polarization $p\%$ at 204 MHz. The continuum radiation was almost completely polarized beginning at 08:52 UT; and it lasted till 10:08 UT, peaking several times.

Figure 2 shows the spectrum of the beginning of the event registered by a spectrograph with high resolution. One can see that the radiation is sporadic, which is



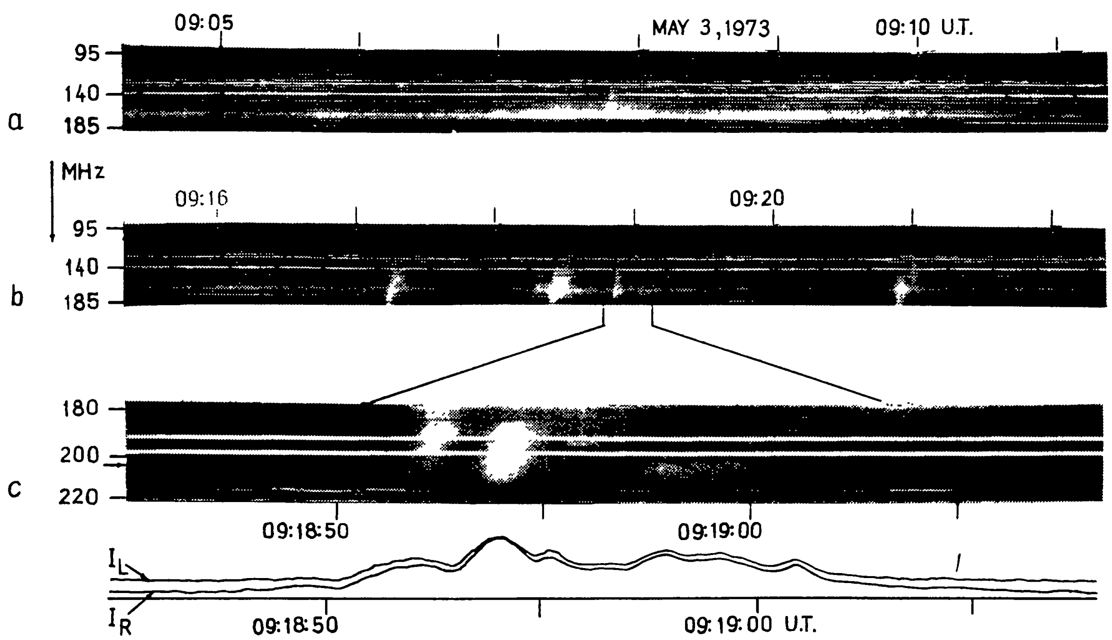
Figs. 2a–c. Development of type II burst on a spectrum with high resolution. (a) U-burst with subsequent prolonged patch-shaped spectrum. (b) Onset of a strong phase of type II burst with patched structure. (c) A part of herringbone structure on the decay of type II burst.

manifested by a patch-shaped spectrum characteristic of type II bursts. At 08:40:00–08:40:30 UT reversed drift burst with the duration ≈1 s were observed – being, probably, a part of herringbone structure in type II burst. This herringbone structure is clearly pronounced on a broadband spectrum obtained in the Weissenau observatory (BRD) (Benz *et al.*, 1974). Patch-shaped spectra could be observed throughout the whole burst of type II, during the maximum phase at 08:34–08:35 UT as well as during the radiation decrease. Besides, during type II burst decrease a fine structure could be observed consisting of a lot of short-lived fiberbursts. The whole radiation of type II burst was unpolarized.

As was mentioned above, a type IV burst began simultaneously with the polarization degree increase. The polarization has increased up to 100% at about 08:52 UT and it remained full until the end of the event. Left-handed polarization corresponds to the ordinary wave emission in the case of a northern polarity of the largest sunspot in the group. The radiation of type IV burst was characterized by separate increases of a broadband continuum with a low-frequency cut-off at about 130 MHz. Such continuum increases, which lasted several minutes, were often accompanied by pulsations of emission with the period of 10–15 s; (Figures 3a and 3b).

Having no positional measurements, but taking into account the continuum radiation spectrum character and the polarization sense corresponding to an ordinary wave, we may consider the source of the meter-wavelength type IV burst as a stationary one (Kundu, 1965).

A few groups of type III bursts with U-bursts could also be observed throughout



Figs. 3a–c. (a–b) Groups of type III bursts together with U-bursts on the background pulsating continuum emission, with a low-frequency cut-off at about 130 MHz. (c) a group of type III-U-bursts is given recorded by means of a high-resolution spectrograph at 09:19 UT. Below the spectrum the recording of left (I_L) and right-hand (I_R) polarized radiation is given at 204 MHz marked by an arrow at the frequency scale.

the whole burst of type IV. The most intensive group of such bursts was observed at 09:17–09:21 UT. Figure 3b shows that the reversal frequency for the U-burst at 09:21 UT was ≈97 MHz. Taking into account that all the bursts of type III-U were unpolarized against the fully polarized continuum (Figure 1), we may conclude that their sources were, probably, far from the type IV source with a strong magnetic field. Figure 3c shows the dynamic spectrum of a group of bursts at 09:19 UT with a high resolution and a synchronous registration of the left- (L) and right-handed (R) polarized components of radio-emission at 204 MHz. The high resolution spectrum shows that the emission of these U-bursts has a patch character.

3. The May 1973 Event Microstructure

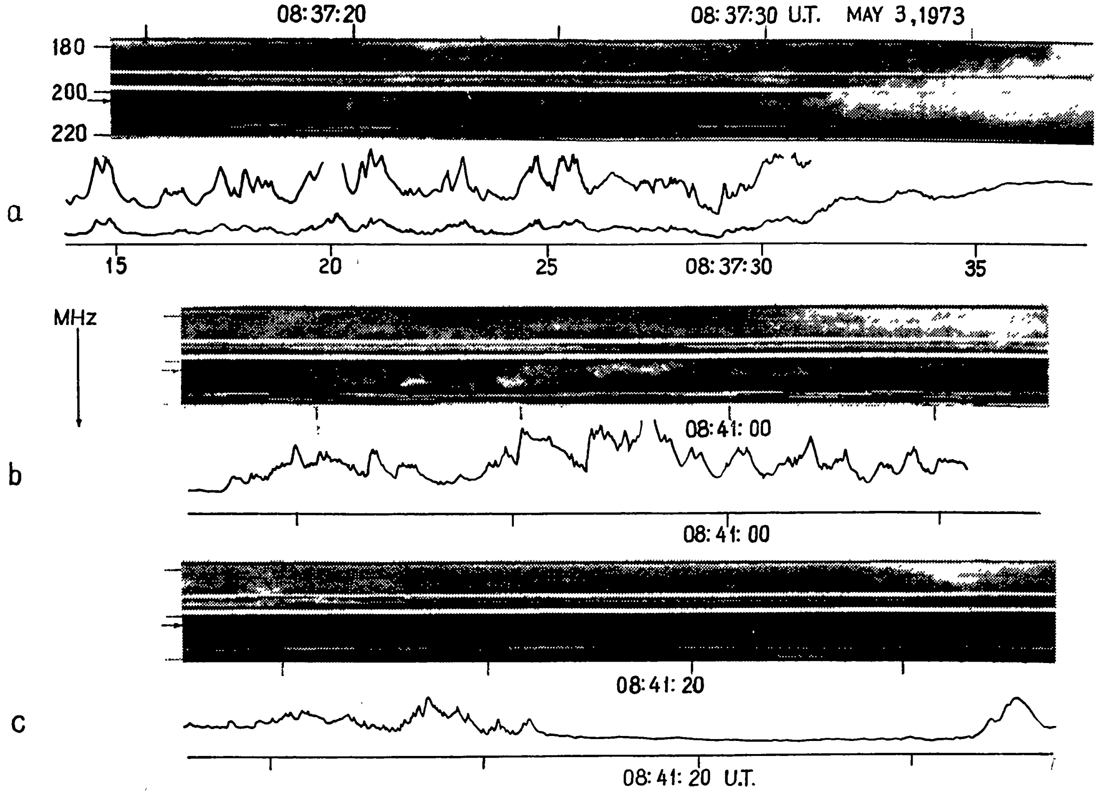
As was mentioned before, the radiation was very variable throughout the whole event – which found expression in the patch-shapes in the spectrum lasting for 0.5–3 s and with a bandwidth of 3–10 MHz in the type II burst, as well as in pulsating continuum emission of the type IV burst. A patched radiation in the type II is very much like a strongly developed noise storm. Their parameters on a high-resolution spectrum over the frequency range 180–220 MHz differ but little from the values obtained in Korolev *et al.* (1973) at 45–90 MHz. Besides, some smaller-scale elements could be observed on a spectrum with the duration of ≈0.1 s and an instantaneous bandwidth of ≈1–2 MHz; we shall classify them as microstructure.

3.1. Spikes in a type II burst

An example of microstructure observed between 08:37 and 08:42 UT at the type II burst decay is given in Figure 4. The radiation is seen to consist of separate fiberlike stripes both with positive and negative drifts and of short-lived increases of brightness with an instantaneous band 1–2 MHz.

These stripes have an inconstant drift, therfore they often have a zigzag shape (see, e.g., at 08:37:35 UT). The mentioned fiberlike stripes are tiny elements of the fine structure in the type II bursts and have not yet been described in the literature. They may be identified with the spike type bursts which are, however, unpolarized like the whole type II burst, in contrast with the full polarized spikes observed in the noise storms and in the type IV burst (De Groot, 1966; Markeev and Chernov, 1970). These spikes showed up at time profiles at 204 MHz as short-lived fluctuations with a characteristic duration of 0.1 s. Fragments of such intensity profiles are given below the spectra in Figure 4.

The given elements of microstructure differ from the well-known herringbone structure observed in type II bursts in their considerably smaller duration and emission bandwidth, narrower frequency range and inconstant drift. The spikes under discussion were usually situated in the frequency range between 5 and 10 MHz at the frequency 200 MHz. Figure 4a shows how a moderate frequency drift of the spikes towards the low frequency ($\mathrm{d}f/\mathrm{d}t \approx -30$ MHz s^{-1}) decreases smoothly almost down to zero, these spikes being similar to miniature J-bursts. In Figure 4b the spikes form



Figs. 4a–c. Spectra and profiles of intensity at 204 MHz of type II burst microstructure with high time resolution. The interval between marks of time is 5 s. The scale of intensity profiles is linear in arbitrary units. (a) Spikes with inconstant negative frequency drift of shape J. (b) Groups of reverse drifting spikes with sharp high-frequency cut-off. (c) Groups of reverse drifting spikes and a part of herringbone structure.

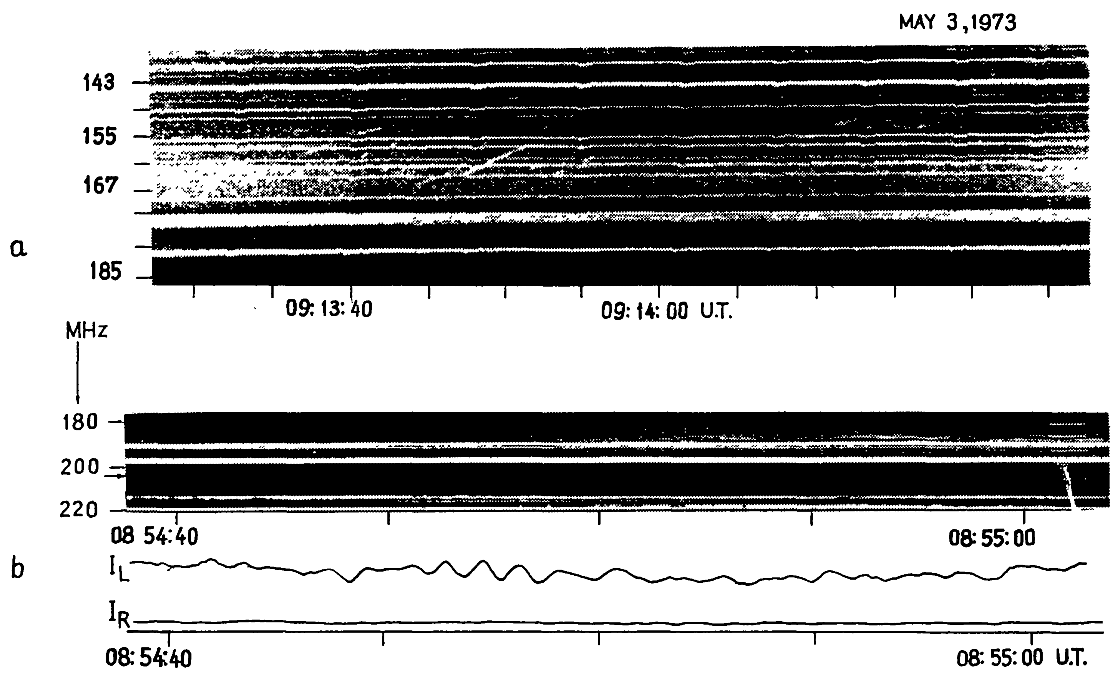
chains of reverse-drifting bursts ($df/dt \approx 30$–40 MHz s^{-1}). The sharp high-frequency cut-off of the emission is also remarkable; at first it drifts slowly towards low frequencies and then goes without drifting to the frequency ≈ 205 MHz. A sharp cut-off at the high frequency edge was observed earlier in the chains of type I bursts (Markeev and Chernov, 1970; Tarnstrom and Philip, 1971; Chernov, 1973). The present observations show that such a cut-off may be revealed also in the fine structure of type II bursts.

3.2. Zebra pattern in the type IV burst

3.2.1. *Spectrum*

The first weak stripes in emission and absorption occurred at 08:52 UT (Figure 1) when the continuum flux density was still small ($\approx 50 \times 10^{-22}$ W m^{-2} Hz^{-1}) but the emission was already fully polarized. Later on the stripes of zebra pattern were appearing until 10:04 UT in discrete pulsations lasting from a minute to a second marked in Figure 1 with segments and arrows respectively along the time axis above the flux density curve at 204 MHz. It is evident from Figure 1 that the zebra pattern has appeared on the background of the strong continuum increase up to 1500 flux units only at 08:54–08:55 UT. In other cases it could be observed against a weak continuum background of ≈40–60 flux units.

At each occurrence the stripes occupied different but rather narrow frequency ranges. On a high resolution spectrum they could not be observed at a frequency higher than 212 MHz and separate stripes were recorded over the range 93–186 MHz reaching ≈145 MHz, which is the zebra pattern low-frequency boundary. As these stripes were not occupying the whole of the mentioned range at a time, Figure 5 gives examples of spectra at different times. All horizontal white stripes on the spectra represent noises from local stations. Figure 5 demonstrates that in the narrow bandwidth of the spectrogaph, stripes with different frequency drifts may be observed at a time. In the high-frequency part the emission and aborption stripes drift slowly to high frequencies ≈4 MHz s^{-1} and in the low-frequency part they remain with small variation parallel to the time axis. The width of the stripes changes with frequency as well as with time, showing no definite regularity. It may only be noticed that at high frequencies the width of the stripes is somewhat bigger (2–3 MHz) than at low frequencies (1–2 MHz). The same observational fact is cited in Elgarøy (1973) represented by one event as well as by different events and ranges. It should be noted, however, that we characterized the zebra pattern by the instantaneous frequency bandwidth of the emission line and the absorption line taken separately (as sometimes the absorption line is considerably wider than the emission line), unlike the frequency separation between the emission bands shown by Elgarøy (1973).



Figs. 5a–b. Zebra pattern and fiberbursts in the continuum of type IV bursts. The interval between marks of time is 5 s. (a) Fiberbursts with intermediate frequency drift, which are registered at frequencies ≳ 145 MHz. (b) Stripes of zebra pattern with different frequency drift and temporal profiles of left (I_L) and right-hand (I_R) polarized emission at 204 MHz. The scales of the channels I_L and I_R are the same and linear in arbitrary units. The stripes of zebra pattern as well as the whole continuum were fully polarized in a left-hand sense.

Figure 6 represents a zebra pattern in which the width of the stripes and their frequency drift have an irregular character. The event under consideration had no regular zebra pattern stripes over a broad frequency range as were observed, for example, on 29 June 1971 (Rosenberg, 1973). On the contrary, they occurred sometimes in the form of isolated stripes (see Figure 6 at 08:55:20 UT). In such cases we distinguish clearly the absorption situated at the low-frequency edge from the stripe in emission. This already known observational fact may be followed at other moments of this event too. Isolated zebra pattern stripes do not practically differ from the fiberbursts with intermediate frequency drift, examples of which are shown in Figure 7. The stripes in emission with a bandwidth of ≈ 1 MHz are inevitable accompanied by a more wide low-frequency absorption and the drift velocity is $-(1–2)$ MHz s^{-1}. The position of the absorption line on the low-frequency edge of the emission line is mentioned in Young *et al.* (1961) for fiberbursts with positive and negative intermediate drifts. The intermediate frequency drift fibers do not differ as to their parameters from the zebra pattern with which they are concurrently observed. Therefore there is no necessity to single them out as a specific type of burst.

3.2.2. *Polarization*

The intensity curves of left- and right-hand polarized zebra pattern components are given below the high resolution spectra in Figures 5, 6 and 7. Let us notice that all these elements of zebra pattern have been appearing at a strongly polarized continuum ($p \approx 80–90\%$ of the left-hand sense). All the intensity variations at 204 MHz (marked by an arrow on the frequency scale) connected with the zebra pattern, occurred on the recording of the left-hand polarized emission components. Thus, all elements of the microstructure occurred in fully polarized radiation corresponding to the ordinary wave.

The examples of zebra pattern recorded on 2 March 1970 (Abrami, 1970), on 29 June 1971 and on 6 March 1972 with a multichannel spectro-polarimeter (Holland) given in Slottje (1973) and Rosenberg (1973) also testify to the fact that the emission in the stripes of zebra pattern was strongly polarized.

The high-speed polarization recordings of the zebra pattern on 3 May 1973 show that the polarization degree was not changing at the moment of neighbouring drifting stripes intersection. Besides, these recordings make it possible to estimate the radiation level in the zebra pattern stripes with respect to the continuum background. Figures 5 and 6 show that the intensity in radiation lines increases by one third relative to the average continuum background and that only a slight decrease of the continuum intensity (about 0.1) occurs in the absorption stripes. Some of the absorption stripes had an intensity level even higher than the average ambient continuum.

Fiberbursts with intermediate frequency drifts given in Figure 7 are distinguished due to a still more significant modulation of the continuum background. On high-speed profiles of polarized radiation the continuum was enhanced more than twice in the emission lines of the fiberbursts and it dropped approximately by one third in the absorption lines. All variations of intensity both in zebra pattern and fiberbursts

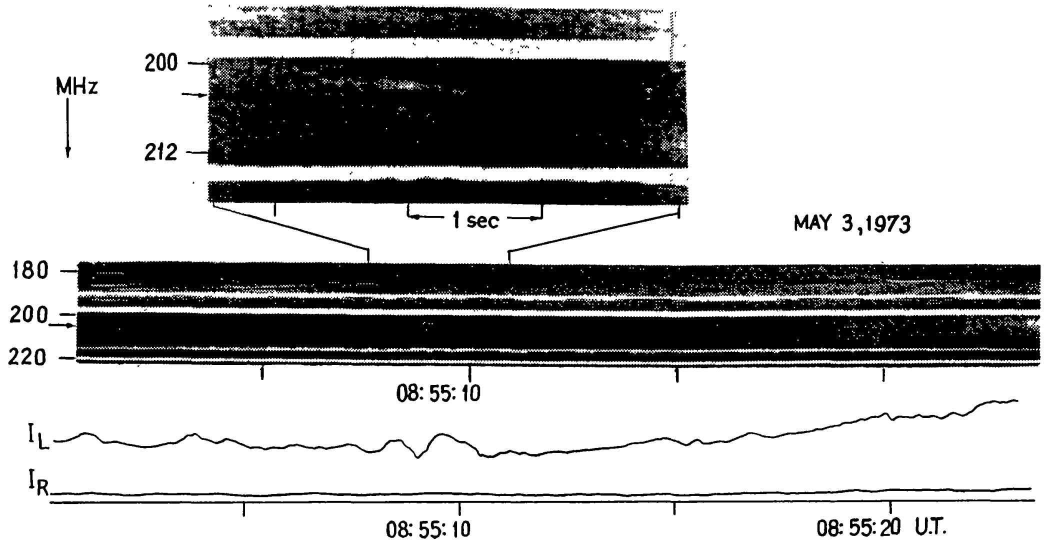


Fig. 6. Zebra pattern with variable drift of emission stripes and inconstant frequency separation between them. It is seen that in isolated stripes the absorption takes place at the low-frequency edge of emission. An enlarged fragment of the spectrum with divergent and convergent stripe in emission is given at the top. Polarization recording is analogous to that of Figure 5.

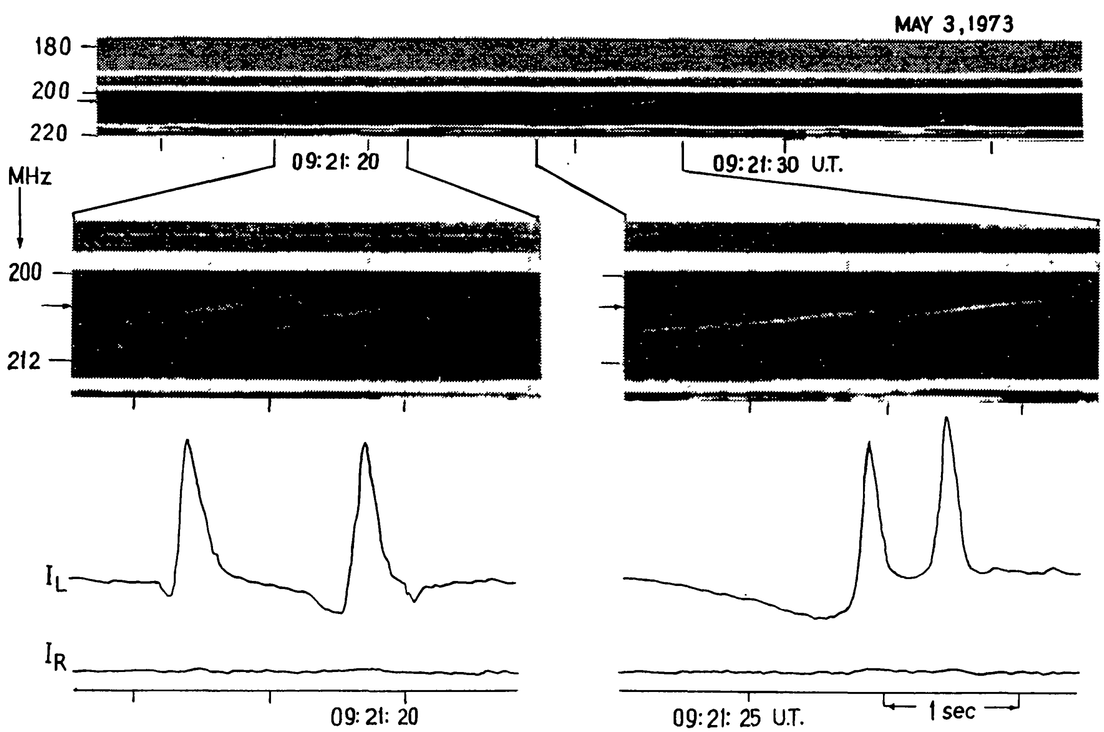


Fig. 7. The fiberbursts with constant negative frequency drift. The absorption line at the low-frequency edge is often wider than the emission line. Enlarged three-second parts of the spectrum and recordings of I_L and I_R channels of the polarimeter are given on the same time scale at the foot of the figure.

were occurring in the left-hand polarized radiation. The intensity levels in emission and absorption lines with respect to continuum is one of the fundamental observational facts which must be explained by any zebra pattern emission theory. Besides, the mechanism must explain a fully polarized emission most likely of an ordinary type.

4. Conclusion

The performed analysis has shown that a complex radio event of type II–IV with a fine structure on 3 May 1973 was connected with a flare of importance 3B accompanied by a short-lived proton burst.

Spectral and polarization high-resolution observations during this event have shown that spikes may be observed also in the type II bursts. In this case they are distinguished from spikes, which accompany other types of bursts (I, III, IV) only by zero degree of polarization. If we admit a single mechanism of generation for the spikes observed with different types of bursts, (e.g. the beams of fast electrons) then the presence of both polarized and unpolarized spikes testifies to the fact that unpolarized radiation in this case is most likely produced by the mechanism itself; and the polarization degree is determined by the escape conditions of radio emission from the corona.

Observations of a sharp cut-off on the high-frequency edge in the fine structure of the type II burst does not contradict its interpretation by the plasma mechanism of generation based on a velocity non-monotony along the electron stream taking into account the Landau damping for a high-frequency radiation (Chernov, 1973). The zebra pattern radiation has a sporadic character both in its frequency drift and in the width of emission and absorption stripes. The magnetic field determination from Δf – the frequency separation between the stripes in the emission as of a value $\approx f_{He}$ – of electron-cyclotron frequency (see Rosenberg, 1973), may give for the event under discussion very understated values $H \lesssim 1$ G for the magnetic traps (for $\Delta f \approx 2$ MHz at 190 MHz) (Takakura, 1966). This fact suggests that the frequency f_{He} is not the main determined parameter of the zebra pattern.

On the strength of the fact that the zebra pattern occurs both at a strong and at a weak continuum, the continuum radiation level at a given moment of time should not be considered as a critical parameter for the occurrence of such a structure.

A high-speed recording of the zebra pattern has shown that the intensity was but slightly below the continuum background and sometimes above it in absorption lines whereas a considerable amplification of the main continuum intensity occurred in emission lines. Each stripe in the emission is accompanied by an absorption stripe on the low-frequency edge.

The fiberbursts with intermediate frequency drift do not differ from isolated zebra pattern stripes either by their spectral parameters or by polarization degree, therefore it is not necessary to isolate them as a special burst type. In the event of 3 May 1973 the whole emission of a microstructure was fully polarized and was corresponding to an ordinary wave. Thus, the zebra pattern emission mechanism must take into account the above mentioned facts.

An emission mechanism at a sum frequency which includes an upper hybrid frequency and several electron-cyclotron harmonics (Bernstein mode) proposed by Rosenberg (1972) and Chiuderi *et al.* (1973) and developed in detail by Zheleznyakov and Zlotnik (1975) satisfactorily explains many characteristics of the zebra pattern for the model of the point source. However, Sy (1974), for example, points to some difficulties in explaining the strongly polarized emission within the above mentioned mechanism. Besides, Zheleznyakov and Zlotnik (1975) and Kuijpers (1975) consider the emission from the extended source in the regions of double plasma resonance.

It is important to trace the role of any other mechanism for the events having sporadic character. The formation of transverse plasmons, escaping from the solar corona at a frequency close to the local plasma frequency, due to a non-linear coupling of Langmuir plasmons and whistlers can be a promising mechanism of zebra pattern emission. This mechanism was suggested by Kuijpers (1973) to explain the emission of isolated fiberbursts with intermediate drift. Chernov (1975) discusses it in detail for a complex fiber structure of continuum emission of type IV bursts.

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