DELAY BETWEEN THE CIRCULARLY POLARIZED COMPONENTS IN FINE STRUCTURES DURING SOLAR TYPE IV EVENTS *

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Abstract. We analyzed intermediately polarized (20–80%) fine structures (pulsations, sudden reductions, fiber bursts and zebras) that were recorded in type IV events. The mean polarization degree was practically the same for all the fine structures recorded in an interval lasting a few minutes and it was similar to the polarization of the continuum. A detailed analysis during the evolution of single structures reveals changes in polarization (in particular an 'undulation' at flux density minima) even stronger than 20%. They were caused by a delay, up to 0.1 s, between the two circularly polarized components. The weaker polarimetric component was delayed in 2 sets and the stronger one in 1 set. In the event of April 24, 1985 different types of fine structures were sporadically detected in more than one hour long time interval. Short delays of the stronger or of the weaker component were sometimes observed.

The events characterized by fine structures are generally totally polarized in the ordinary mode. We assume that this holds also for the phenomena studied here. The observed intermediate polarization therefore requires a depolarization due to propagation effects. We discuss the mode coupling and the reflection of the original radio signal that could also generate the delay of the weaker and the stronger component respectively. The possibility of polarization variation due to the change of the angle between the direction of the propagation and the magnetic field in a quasi-transversal region and in a low intensity magnetic field in a current sheet is also given.

1. Introduction

Fine structures (pulsations, sudden reductions, fibers, zebras) are sometimes present in type IV solar radio bursts at meter wavelengths (Kuijpers, 1980; Bernold, 1980; Slottje, 1981). They can be used as important diagnostic indicators of the phenomena going on in the active coronal plasma. In the majority of cases (Zlobec *et al.*, 1987) they are totally polarized, as well as the underlying continuum. Chernov's (1976) theory explains the generation of these structures in ordinary mode.

In the IZMIRAN and Trieste Astronomical Observatory records we found four contemporaneous observations of fine structures that were intermediately (20–80%) polarized. Examples of the spectra and polarimetric data are shown in Chernov and Zlobec (1994) where the basic properties of the intermediately polarized fine structures are given:

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(a) the mean polarization in a group of structures is essentially the same;

(b) there is no remarkable difference in polarization for different types of fine structures which appear almost simultaneously;

(c) the polarization of fine structures has nearly the same value as the continuum.

Here we report new interesting results from a more detailed analysis of fine structures, a general discussion and a possible explanation of the observed phenomena.

We used polarimetric data that were recorded at the Trieste Astronomical Observatory at 237 MHz; the rate of digital measurements was 29.3 Hz prior to 1983 and 50 Hz afterwards. A simultaneous signal at both (left-handed (L) and right-handed (R)) inputs reveals in laboratory tests a delay smaller than 1 ms between the outputs of the two channels (Comari, 1994). IZMIRAN spectral data in the range 180–270 MHz were recorded on film with a 50 Hz sweep rate and 0.2 MHz frequency resolution.

The problem of the evaluation of the polarization degree during the lifetime of a fine structure (in emission or in absorption) can be heavily influenced by the subtraction of the background in the two channels. To avoid this problem, it is necessary to use a method that is unbiased by the background subtraction (Kattenberg and Van der Burg, 1982; Wentzel, Zlobec, and Messerotti, 1986). This can be derived from plots where $L - R$ versus $L + R$ (or R versus L) data are reported, however the trend of the polarization can be identified directly only on polarization degree versus time plots. Due to the presence of the background noise, which is rather strong in type IV events, we normally used the running averaging technique on 3, 5, or even 7 adjacent measurements in order to obtain smoother signal profiles. Such a mathematical tool introduces the same time delay in the two channels.

Let us remark that in order to avoid the negative sign in polarization data we always considered its absolute value characterized by the symbol 'L' (left-handed) or 'R' (right-handed).

2. Characteristics of the Fine Structures Studied

In Table I the characteristics of fine structures that were analyzed during the four type IV events considered are given. For each group of samples studied the order is the following: date, starting time, type of the selected fine structures, number of the samples considered, maximum modulation depth in respect to the continuum, mean polarization of the samples, their standard deviation, minimum of the estimated absolute error, background polarization, polarization of the signal of the delayed channel and amount of the delay (uncertain data are marked by '?').

TABLE I

Selected fine structures during type IV events with intermediate polarization

Date	Time UT	Type	No.	Modulation depth	Polarization				Delayed signal	Delay (s)
					Fine struct. (%)	σ (%)	Δp (%)	Cont. (%)		
May 18, 1981	08:31	fibers	11	0.30	79.5 *R*	1.9	2	75 *R*	*L*	0.02
Dec. 16, 1982	10:15	pulsations	20	0.32	79.5 *L*	5.3	6	65 *L*	*R*	0.10
Apr. 26, 1984	07:00	sudd. red.	17	0.26	76 *R*	5.5	4	80 *R*	*R*	0.08
Apr. 24, 1985	10:24	zebras	26	0.14	66.5 *R*	4.9	12	49 *R*	?	0.01 ?
	10:34	fast puls.	34	0.34	68 *R*	7.0	5	43 *R*	*L* ?	0.01 ?
	10:49	fibers	12	0.31	24 *R*	2.8	4	29 *R*	*R* ?	0.01 ?
	10:51	fibers	16	0.36	22 *R*	2.2	1	29 *R*	*R* ?	0.01 ?
		zeb. rope	5	0.29	22 *R*	2.2	2	29 *R*	?	0.01 ?
	10:57	fast puls.	56	0.30	25 *R*	2.2	2	45 *R*	*R* ?	0.01 ?
	11:18	sudd. red.	8	0.21	59.5 *R*	5.3	5	54 *R*	?	0.01 ?
	11:19	sudd. red.	26	0.32	64.5 *R*	2.1	3	59 *R*	*L* ?	0.01 ?

σ = standard deviation.

Δp = minimum absolute error according to the formula by Markeev *et al.* (1976).

2.1. May 18, 1981

During the time interval $8^h31^m-8^h35^m$ UT we selected the *fibers* with an amplitude in flux density larger than 200 s.f.u.; the strongest sample had an intensity of about 1100 s.f.u. The part in absorption was generally stronger than the one in emission. The only exception was the last event (at $8^h34^m29^s$). The background level was high (about 1700 s.f.u.) and its polarization value was about 75% R. The absorption phase was generally the preceeding one, however also few examples of opposite behaviour occurred. The mean polarization of the fibers was 79.5% in the R-handed circular sense and the standard deviation was 1.9%. The application of the Markeev *et al.* (1976) formula

$$\Delta p = \pm \frac{2\Delta}{I}(1+p)\ ,$$

where I is the flux density intensity, Δ the absolute calibration error, and p the polarization, determines the absolute error of the polarization (in Table I its minimum is reported). The values range from 2 to 14% for the strongest and the weakest event, respectively.

The experimental data allow us to say that the mean polarization, measured in $R-L$ versus $L+R$ plots, for the whole set of fibers was the same (in the limits of uncertainty). That is in agreement with the more general result reported in Zlobec *et al.* (1987) . After reasonably subtracting the background we found a common trend of the polarization function at the time near the flux density minimum: first a lowering and afterwards an enhancement (Figure 1(a)). This particularity means that the 'undulation' is not due to a real change in polarization but to a small delay of the signal of the weaker polarimetric channel, the L-handed one, in respect to the stronger one (R-handed) (Figure 1(b)). We found such a type of delay for all the fibers considered independent of their emission-absorption ratio and of the sequence absorption-emission phase. The amount of the delay was not the same in different samples nor during a single fiber. A delay shows up in R versus L plots the form of a loop (Wentzel, Zlobec, and Messerotti, 1986); a larger area delimited by the loop means a bigger delay. Instead of R versus L plots we used $L-R$ versus $L+R$ plots which allow more direct measurements of the polarization, meanwhile the other characteristics remain similar, in particular the loop.

The average delay of the L-handed channel was about 0.02 s. Such a value cannot be derived by direct measurements as it is smaller than the time resolution of measurements. However we are confident about it as the typical duration of a single fiber was of about one second and during that time in normalized L- and R-plots we considered the number of single measurements when the L-data were delayed in respect to the R-data. Using the theory of probability, the reliability of the existence of the delay was established.

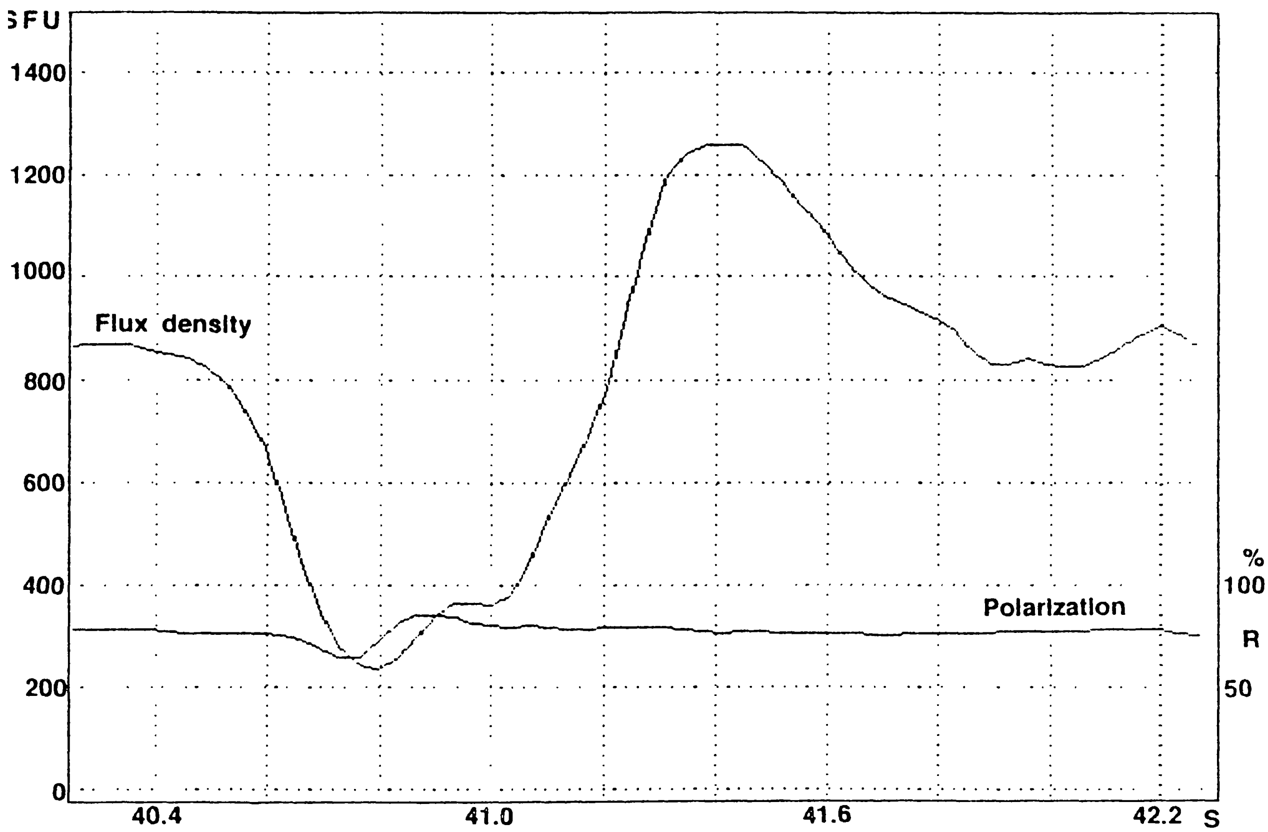

Fig. 1(a). Flux density profile of a fiber at 237 MHz recorded on May 18, 1981, starting time $8^h31^m40.3^s$ UT. Running average on 3 points. On the left-hand side the flux density scale is given after the subtraction of 1000 s.f.u. On the right-hand side the polarization scale is provided (the subtracted background was 1020 s.f.u. for the R channel and 170 s.f.u. for the L channel). Notice the 'undulation' in the polarization plot.

2.2. December 16, 1982

Starting at 10^h15^m UT *pulsations* in emission were visible for about 5 min. We selected the most intense ones (25–200 s.f.u.). The background level was about 150 s.f.u. and its polarization about 65% L-handed. During the evolution of single pulsations we realized a particular behaviour of the polarization trend: it was systematically higher near the beginning and lower near the end (Figure 2(a)) where the flux density amounts were smaller. Even in this case the polarization variation was caused by the delay: typically the emission of the L channel preceded the R-channel by 0.1 s (Figure 2(b)). The mean polarization was 79.5% (L-handed); the standard deviation was 5.3%. The absolute polarization was the same as in the previous case; the higher standard deviation is due to the lower intensity of the phenomena considered (see Table I). Application of the formula by Markeev *et al.* (1976) gives higher uncertainties: from 6 to 44%.

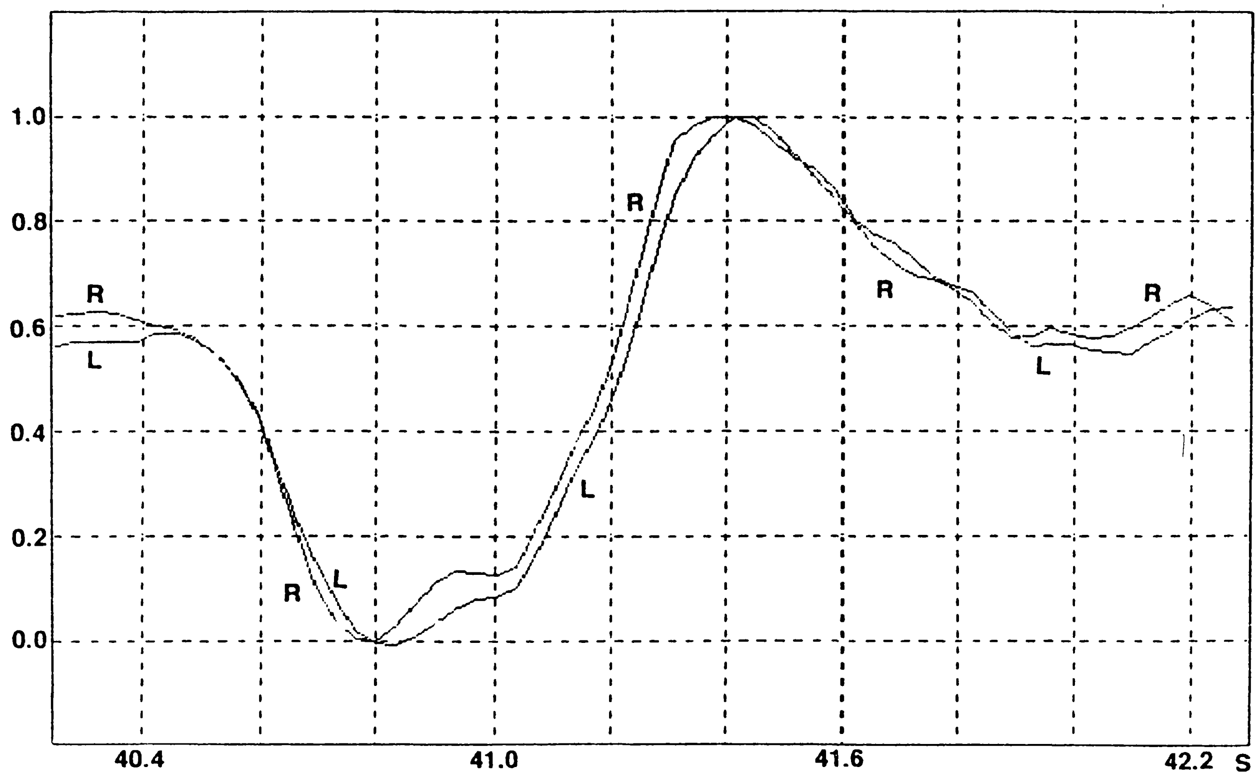

Fig. 1(b). Normalized profiles (separately L and R component) of the same fiber. A delay of the L-channel data (the weaker ones) is present during practically the whole evolution of the fine structure.

2.3. April 26, 1984

During a time interval of 1 min, at about 7^h00^m UT, a series of *sudden absorptions* was observed. The background consisted of a slowly evolving 'rise and fall' large burst with a maximum intensity of about 2500 s.f.u. and polarization 80% R-handed (Nonino *et al.*, 1987). We selected the strongest sudden reductions with a flux density in the range of 160–700 s.f.u. The average value of the polarization was 76% in the R-handed sense and the standard deviation 5.5%. The Markeev formula gives the limits 4–9% for the absolute error of polarization values. We noticed once more an undulation in the polarization at the absorption minima: first an enhancement and afterwards a decrease. That trend is similar to the one detected in the May 18, 1981 fibers but in the opposite sense. That comes out that the R-handed component, the stronger, was systematically delayed by about 0.08 s (Figure 3).

2.4. April 24, 1985

The type IV burst lasted several hours (Aurass *et al.*, 1987). A coronal mass ejection was observed from the SMM, its starting time was 9^h36^m UT (Cyr and Burkepile, 1990). In the first part of the event, at least in the frequency range 230–610 MHz, the emission was polarized in the L sense. At 10^h04^m an enhancement of the

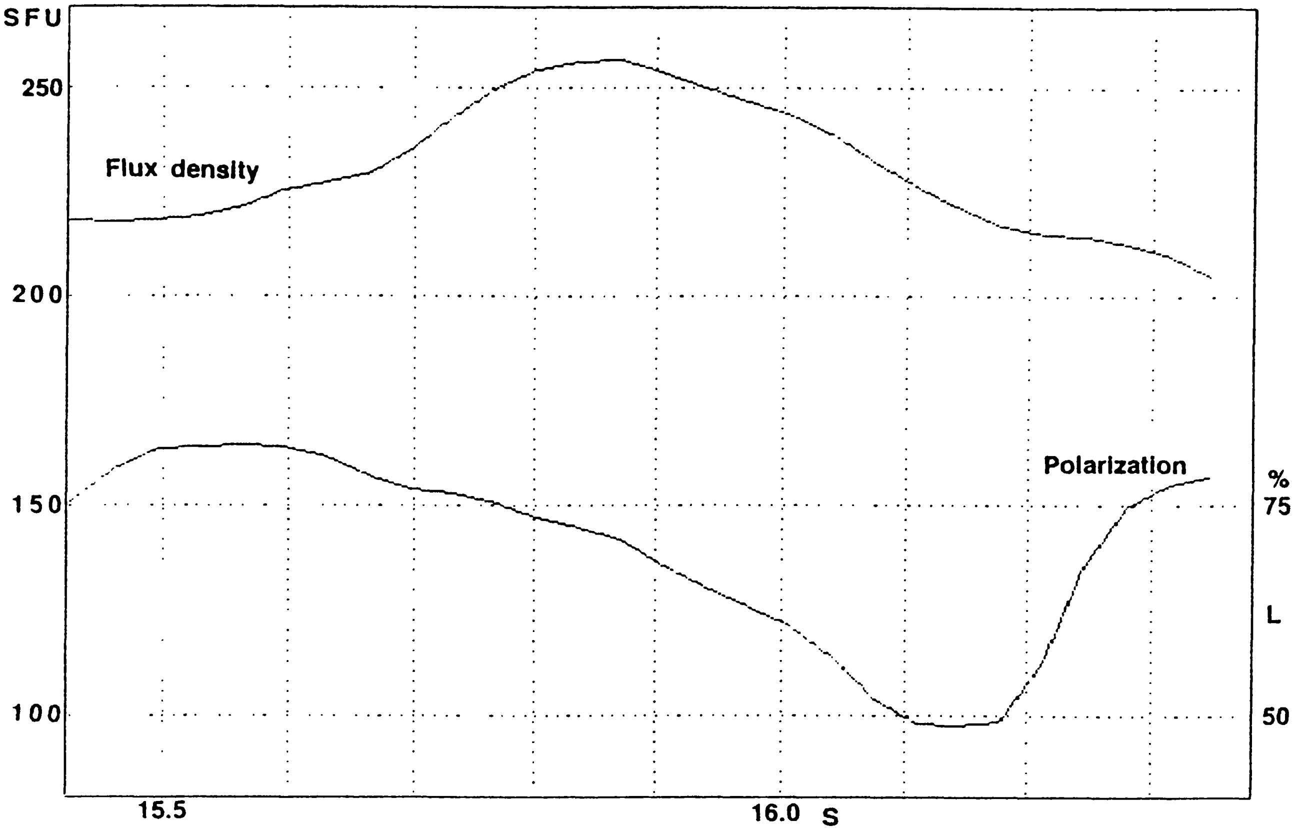

Fig. 2(a). Plot of the pulsation in emission recorded on December 16, 1982, start at $10^h16^m15.5^s$. Running average: 5 points. Flux density (no background subtraction) and polarization (background subtraction 160 s.f.u. in the L data and 35 s.f.u. in the R data) are given similarly as in Figure 1(a). Note that the polarization is higher near the beginning than near the end of the pulsation.

activity in the R channel started. That indicates the presence of at least two sources polarized in opposite senses. Afterwards the background level (R-handed) was sometimes stronger than 2000 s.f.u. and generally above 400 s.f.u., the polarization was variable in the range between 20 and 75% with no evident regularity. During more than one hour, groups of zebras, fibers, sudden reductions and fast pulsations were observed.

The most prominent *zebra patterns* recorded at 237 MHz were detected at 10^h24^m UT. The noise in the data was strong as the background level was at about 2500 s.f.u. We considered the most evident fast structures for detailed study. The most prominent example of delay was visible at $10^h24^m42.8^s$ for about 0. 7 s: the R channel was delayed by about 0.01 s (max. 0.03 s) in respect to the L channel (Figure 4(a)). There were other shorter intervals of different behaviour in both senses. We considered separately the zebras lasting more than 1 s (which were the most numerous) but it was not possible to recognize the predominance of the delay of the signal in one channel with respect to the other. The same was the case also for the structures shorter than 1 s. Even after performing running averages on 5 adjacent measurements and the normalization, a random crossing

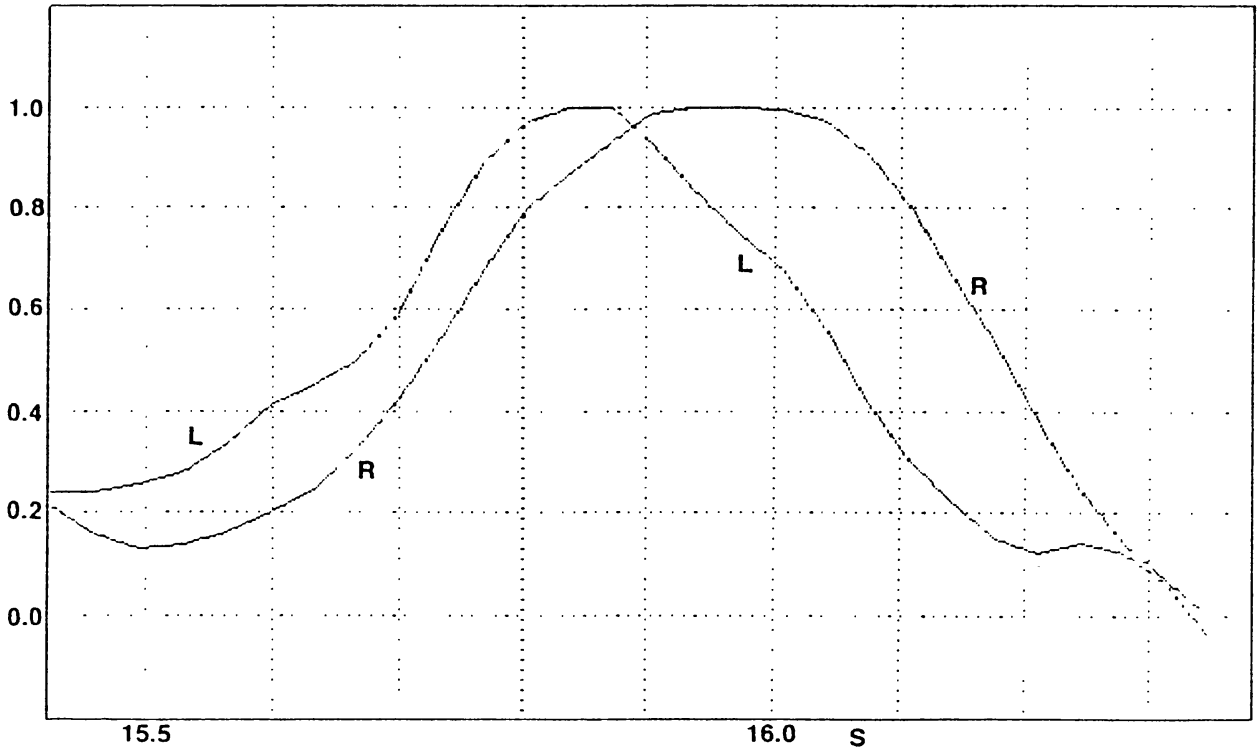

Fig. 2(b). Normalized R and L components of the same event. The delay of the R channel is very evident.

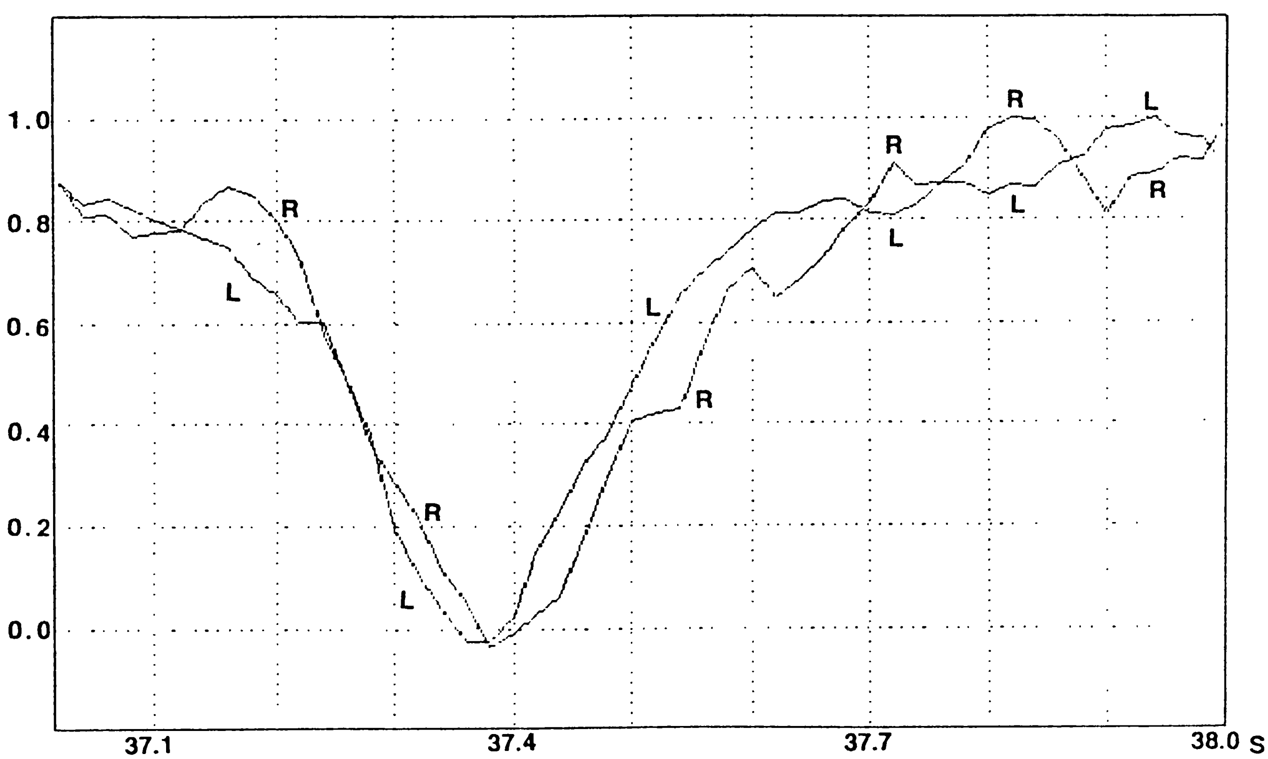

Fig. 3. Normalized R and L components of the sudden absorption recorded on April 26, 1984, start at $7^h00^m37.1^s$. Running average 3 points. Notice the delay of the R data (the stronger ones).

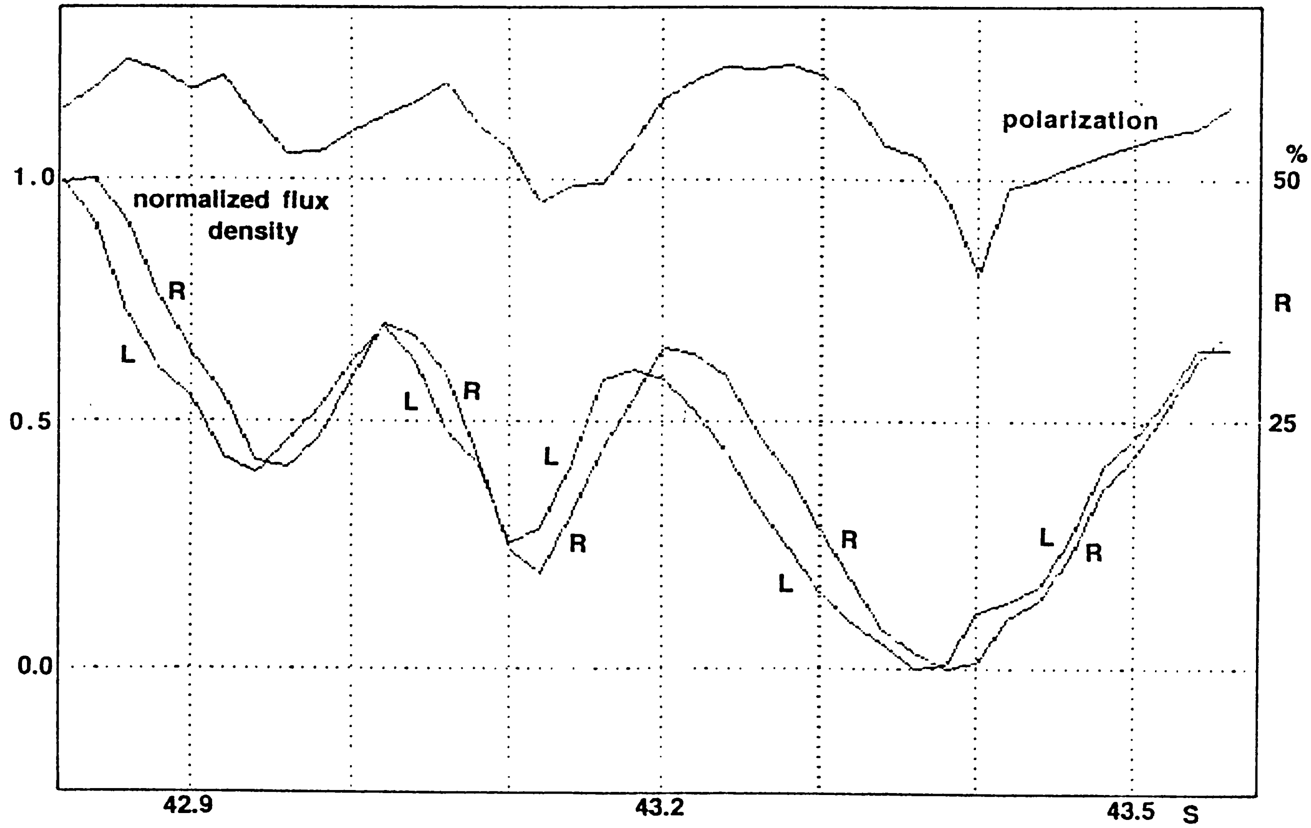

Fig. 4(a). Normalized L and R components of fast pulsations recorded on April 24, 1985, starting time $10^h24^m42.8^s$. Running average 5 points. In the same box also the polarization trend is given after the background subtraction (2000 s.f.u. in the R channel and 640 s.f.u. in the L channel). Notice that the delayed profile is in the R channel.

between L-handed and R-handed plots generally appears. Correspondingly in $R-L$ versus $L+R$ plots evident loop shapes were rare and their evolution in time was sometimes clockwise and sometimes anti-clockwise, which characterizes one or the other sense of the delay. The mean polarization was 66.5% (standard deviation 4.9%) and no difference in polarization could be found when the signal in one or in the other channel was delayed. The formula by Markeev *et al.* (1976) gives an uncertainty of the polarization between 12 and 30%.

At about 10^h34^m *zebra patterns* were also visible in the spectrum, but the *pulsations* were still more evident. During a 10 s lasting interval we selected 27 pulsations trying to find out the delays: this happened 12 times for the L channel, 5 times for the R channel and no evident delay in the remaining 10 cases. Figures 4(b) and 4(c) show an example where the L channel was delayed.

At 10^h49^m in a time interval of 10 s 12 *fibers* were detected. Their intensities were in the range 700–1800 s.f.u. and their polarization was 24%. The R channel looks generally delayed during 9 fibers, the L channel in 1 case, and in the remaining samples there was no clear trend during the evolution of the phenomena.

Two minutes later, 16 strong *fibers* (400–1600 s.f.u.) and 5 *zebras* (700–1200 s.f.u.) in a rope structure (Aurass *et al.*, 1987) appeared. The typical para-

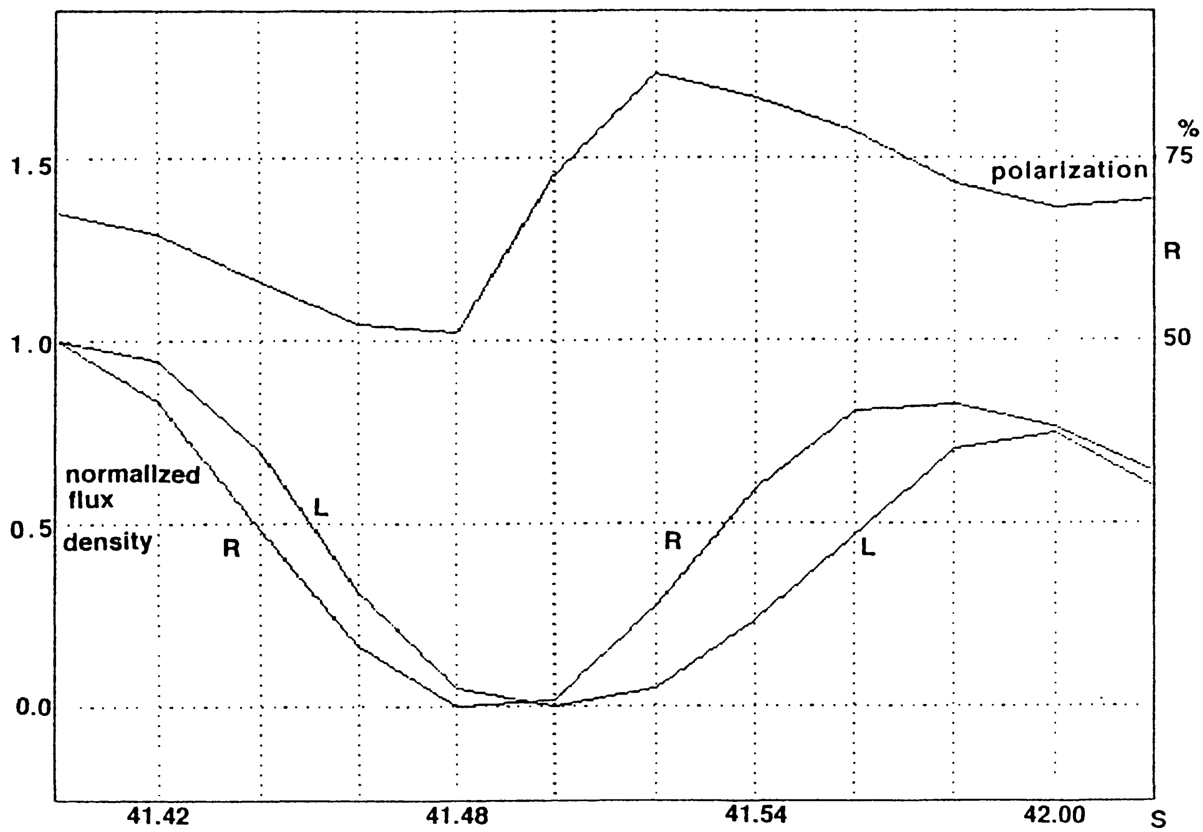

Fig. 4(b). Normalized flux density in the R and L channel and polarization of a fast pulsation (after subtraction of 175 s.f.u. in the R data and 78 s.f.u. in the L data) recorded about 10 min later, start at $10^h34^m41.4^s$. Running average 3 points. The L channel signal appears delayed.

meters were similar to those in the previous time interval. There was no difference in the polarization value for zebra structures with respect to fibers in the limits given by the uncertainty. In the majority of the events studied the normalized plots show small delays of the R channel during short time intervals. For the zebra rope it was not possible to indicate the predominance of the delay, nor to find out the way they alternate.

Some characteristics of other selected samples of fine structures are given in Table I. The symbol 'L?' (or 'R?') means the preponderance of the delayed L data in respect to the R data (or the opposite). In the last column we put '0.001?'; this should indicate the order of magnitude of the delay, when present.

Due to the presence of noise in the data, it is difficult to be sure if the delay, due to its very small amplitude (with respect to the digitization rate) and its short duration in the different sets of the considered cases, corresponds to a real phenomenon; however, we realize that during some time intervals the presence of one particular sense was preponderant. In particular we are confident that at least the examples reported in Figures 4(a–c) represent a real delay between the signals of the two channels.

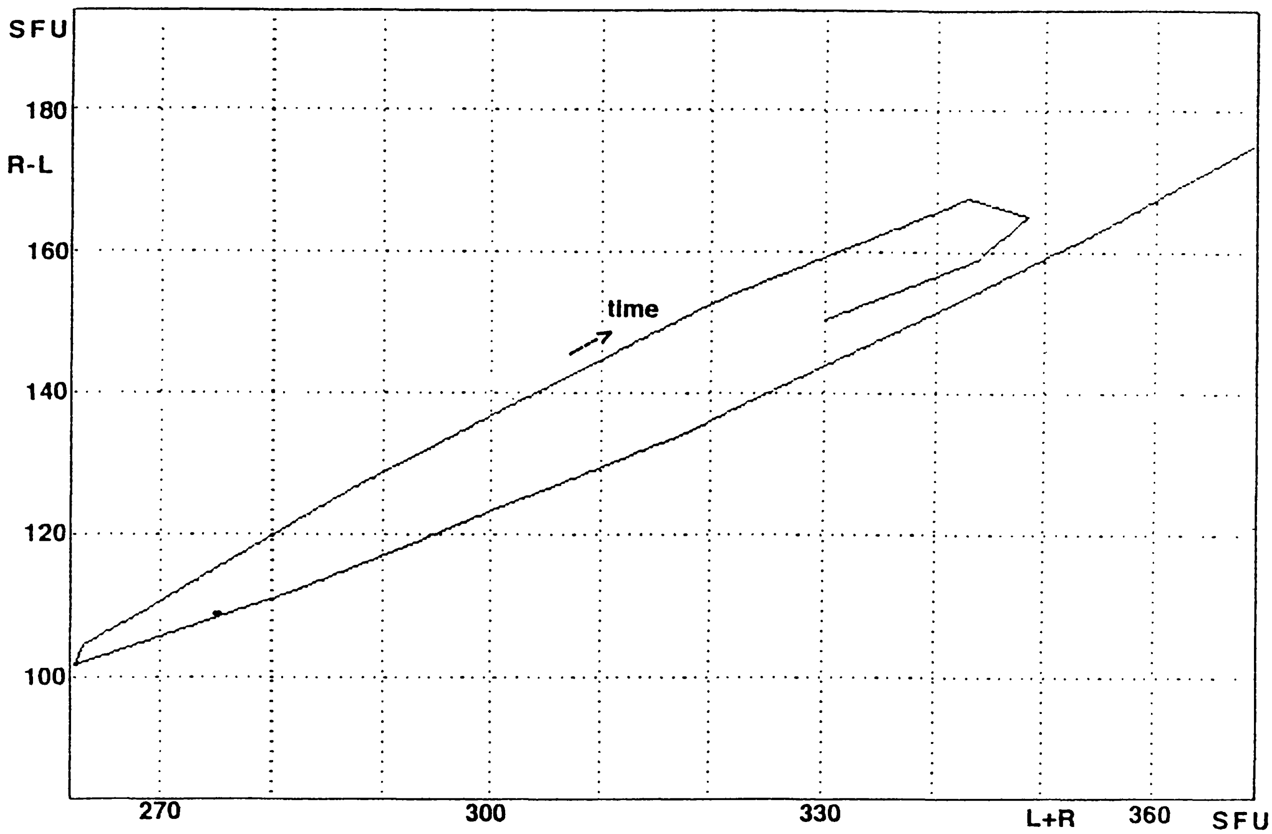

Fig. 4(c). Evolution in time (see the arrow) of the same fast pulsation shown as $R - L$ versus $L + R$. The resulting loop looks rather wide, the enclosed area is proportional to the delay.

3. Discussion

Polarization profiles during the lifetimes of different fine structures showed different trends:

(1) On May 18, 1981 the fibers during their absorption phase were characterized by an 'undulation' with first a minimum and afterwards a maximum (see Figure 1(a)). That happened as the consequence of the delay of the weaker (L-channel) data. The polarization and the delay are not related to the emission-absorption ratio and to the sequence absorption-emission phase, therefore polarization and delay should not depend upon the source itself.

(2) Pulsations in emission on December 16, 1982 showed at the beginning an enhancement in polarization (Figure 2(a)), then a decrease which is related to the delay of the weaker (R) component.

(3) At the time near the sudden reduction minima observed on April 26, 1984 the R-handed polarization 'undulation' showed first a maximum and then a minimum which is the consequence of the delay of the stronger signal (which is just the opposite to the above cases). The time difference between polarization maximum and flux density minimum was smaller than 0.1 s.

(4) The fine structures observed on April 24, 1985 were also R-polarized and during the time interval of more than one hour the percentage was changing considerably. Intervals of certain time shift between the two polarimetric signals were rare, although we analysed many more fine structures (of different types) than in previous cases. Different types indicate the presence of various sources (at different places), however at a given time all were characterized by nearly the same polarization. This confirms our suggestion that the observed polarization did not have its origin in the source itself.

From the usual expression for the polarization,

$$p = \frac{I_L - I_R}{I_L + I_R} \,,$$

where I_L and I_R are the flux density measured in the L and R channel respectively, it follows that a constant degree of polarization means also a constant ratio between I_L and I_R. A time variation of the polarization as a function of the delay, d, between the signals in respective channels results:

$$\frac{\mathrm{d}p}{\mathrm{d}t} = \frac{2I_L I_R}{(I_L + I_R)^2} \left(\frac{1}{t} - \frac{1}{t-d} \right) .$$

It follows that there is no change in the polarization trend when the delay is absent, otherwise near the flux density minimum an undulation appears. The time interval between the maximum and minimum of that undulation can be considerably longer than d, and this depends also on the way the flux density varies in time. The existence of a single source for a definite type of structure follows from the observed analogous trend in both polarimetric channels.

The change of the polarization can vary by more than 25%, which happens both in absorption (Figures 1(a) and 4(b)) and in emission (Figure 2(a)).

We realize, even when the delays are very evident, that their amount is slightly different for various features belonging to the same group and also during the evolution of a single fine structure, which can be caused by changing propagation conditions (see Section 3.3).

We have no position measurements of the radio sources for the phenomena considered, so we have no direct way to find out if the emission was in the ordinary (o) or extraordinary (x) mode. To overcome, at least partly, this disadvantage let us consider the information at our disposal for other similar fine structures. For the phenomenon observed on March 12, 1989 the Nançay radioheliograph determined that the source position was rather far from the flare site and was emitting in the ordinary mode (Klein, 1995). The same instrument determined the source position of fast pulsations and zebra patterns on June 5, 1990, which implied ordinary emission (Chernov *et al.*, 1994). The same holds for the May 3, 1973 event (Chernov *et al.*, 1975). In a statistical study, considering pulsating and similar structures, prepared by Zlobec *et al.* (1987), the emission in the ordinary mode looks to be the most probable one. In the same paper it was suggested that the original emission should be totally polarized (supported also by theoretical considerations (Chernov, 1976)), therefore the observed intermediate and low polarization degree has to be attributed to propagation effects. For the above reasons it is reasonable to suppose that also for the data considered here the sources were originally totally polarized in the ordinary mode. Intermediately polarized fine structures therefore require a depolarization mechanism which could generate also a time delay.

3.1. Depolarization

The problem of depolarization is an old, classical question considered in many papers. Usually it is explained due to propagation effects when e.m. waves cross perpendicular magnetic field lines high in the corona (Cohen, 1960; Zheleznyakov, 1970, 1977; Melrose, 1980; Benz, 1993) or pass through a weak magnetic field in a current sheet (Zheleznyakov, 1977). In the first hypothesis the important parameter is the critical frequency, f_t (Cohen, 1960), which represents the limit when the change of the polarization sign takes place.

According to Zheleznyakov (1970) the linear mode coupling is not probable at the source.

The most detailed theoretical calculations of depolarization due to reflection (from overdense inhomogeneities with magnetic field lines almost perpendicular to the incident wave vector) and transmission of waves were published by Hayes (1985). She developed a method for calculating the relative magnitudes for the magnetoionic modes produced when a mode strikes a density discontinuity within a plasma. Her plotted results show the energies of the reflected and the transmitted modes as functions of plasma and wave parameters.

Wentzel, Zlobec, and Messerotti (1986) explained the moderate and low polarization of type I bursts as due to a large-angle scattering by lower-hybrid waves high in the corona. Melrose (1989) proposed a common depolarization mechanism for all metric bursts due to scattering by ion-sound waves and whistlers. Benz (1993) considers also ducting and anisotropic scattering from overdense flux tubes as possibilities that generate depolarization.

In a recent paper Melrose and Robinson (1994) suggest propagation through numerous quasitransverse magnetic field lines and they derive the pertinent Stokes parameters.

Zebra patterns were explained, applying the theory of Bernstein modes (at double plasma resonance: Zlotnik, 1977). According to that theory a moderate polarization results:

$$p = \frac{2\cos\alpha}{1+\cos^2\alpha}\,,$$

where α is the angle between the wave propagation direction and the magnetic field. According to that there should be a relationship between the polarization degree and the position on the disk of the associated flare region, but this is not observed (Chernov, Korolev, and Markeev, 1975).

As several depolarizing mechanisms are known, we will try to find that one which is most adequate to explain our observations.

3.2. Delay

Considering that the source is emitting in the o-mode, the delay, according to the theory, can be created only during the propagation through regions where the transformation between o- and x-mode takes place.

The group velocity of the x-mode is generally slower in respect to the o-mode. Such a question was evaluated in the papers by Wentzel *et al.* (1986) and Chernov (1990). In Chernov's paper, detailed calculations were presented for the metric range. Near the plasma level where the refractive index is $\ll 1$ the greatest delay between the waves of opposite circular polarization appears at about 200 MHz: it attains a value of about 0.1 s when the magnetic field intensity is 3 G; a smaller delay (0.01 s) is the consequence of a weaker magnetic field (0.5 G) higher in the corona.

The detectable delay that we observed is a direct indication that the transformation between the modes should occur not very far from the source. This happens very rarely, and the data we present here are therefore unique.

The delay of the strongest component (i.e., the o-mode) could be more peculiar. It can be created only by reflection (Hayes, 1985). The o-mode propagates deeper, up to the layer $X = 1$ (where $X = f_p^2/f^2$ and f_p is the plasma frequency) where it is reflected, than the x-mode, being the reflection layer defined by $X = 1 - Y$ (where $Y = f_B/f$ and f_B is the cyclotron frequency). The path of the o-mode is therefore longer than that for the x-mode, and their difference is responsible for the delay of the strongest (i.e., o-) component. Hanasz *et al.* (1980) reported low-frequency radio observations performed on board the satellite *Copernicus 500*, where in one case (of the four described) the x-emission was detected first.

We can roughly evaluate the delay between the o- and x-wave after a reflection. The distance between the escape levels of the o- and x-modes is

$$\Delta h = \frac{f_B}{2\,\mathrm{grad} f_p} \,.$$

Using the values grad $f_p = 1\,\mathrm{MHz}\times 10^{-8}\,\mathrm{cm}^{-1}$, $B = 2$ G (which are similar to the ones in Chernov (1990)) and the group velocity of the o-mode $v_{gr_0} = n_0 c$ (where n_0 represents the refractive index of the o-wave, and its value is assumed equal to 0.2), the resulting delay is about 0.1 s (as observed in the April 26, 1984 event). A smaller delay should be related to a reflection at a larger distance from the source, i.e., higher in the corona.

We can summarize our ideas, stating that when waves cross a quasi-transverse magnetic field (Cohen, 1960) this should also affect the propagation time of the

o- and x-wave in a different way, in particular the weakest wave should be more delayed (May 18, 1981 and December 16, 1982 events). Meanwhile for the April 26, 1984 data the probable explanation is related to the reflection of waves. For the April 24, 1985 fine structures, nice examples of delay (in both senses) are rare and it is also not clear how much the noise was affecting these measurements. The proposed explanation for such a case considers a combination of both: propagation of waves through transverse magnetic field (or through low magnetic field in a current sheet) and reflection. In the following paragraph we try to explain another type of polarization variability, which is due to the variation in time of the propagation angle α.

3.3. Change of Polarizaton due to the Propagation Angle

As our observing frequency is 237 MHz, in order to have $X < 1$ let us consider the plasma frequency at 230 MHz in the quasi-transverse magnetic field. We deduce the magnetic field for the April 24, 1985 event using the typical frequency difference in fiber bursts between the neighbouring maxima (in emission) and minima (in absorption) which is equal to the whistler frequency in the source (Chernov, 1976) and typically amounts to about $0.1 f_B$. The result is $B = 3.6$ G. For the upper-lying quasi-transverse magnetic field it is reasonable to assume a lower value, $B = 3$ G. So we consider the typical parameters, $X = 0.94$ and $Y = 1.236 \times 10^{-3}$, and derive the critical frequency and the polarization using the formulae from Zheleznyakov (1970) for Cohen's (1960) theory:

$$f_t = \left(2.9 \times 10^{17} \frac{N_0 B^3}{|\mathrm{d}\alpha/\mathrm{d}z|} \right)^{1/4} ,$$

$$p = 2e^{-\delta_0} - 1 ,$$

where

$$2\delta \simeq 1.45 \times 10^{17} \frac{N_0 B^3}{f^4 \, |\mathrm{d}\alpha/\mathrm{d}z|} ,$$

and using the expression (24.18) in Zheleznyakov (1970):

$$\frac{\mathrm{d}\alpha}{\mathrm{d}z} = \frac{2\pi f}{4c} X (4 \cos^2 \alpha + Y^2)^{3/2} .$$

The variability of the polarization degree is very critical, as can be seen in Table II.

The polarization data are mirror-symmetric with regard to 90°, i.e., $p(90° - \beta) = p(90° + \beta)$, where β is a very small angle.

The polarization changes the sign for $f_t = 237$ MHz. At higher levels in the corona with $X \ll 1$ a change of polarization is not possible.

TABLE II

Parameter variations with changing α

α	89.2	89.3	89.4	89.5	89.6	89.7	89.8	89.9°
$\mathrm{d}\alpha/\mathrm{d}z$	10.7	9.31	8.14	7.19	6.45	5.89	5.50	5.27×10^7
f_t	242.8	251.5	260.1	268.2	275.7	282.0	286.9	289.9 MHz
$2\delta_0$	0.76	0.88	1.01	1.14	1.27	1.39	1.49	1.55
p	6.85	17.0	26.9	35.9	43.8	50.2	54.9	57.7%

TABLE III

Change of polarization sign for $G_0 > 3.7$

α	89.4	89.75	89.8°
G_0	16	4	2.6
Q	0.2	0.45	0.65
p (%)	−60	−10	30

The time scale when the polarization maintains its maximum value depends on the velocity of the agent which produces the fine structure within the source. If such an agent is a beam of fast particles, then the maximum polarization should last for about 0.1 s. If the agent is a whistler wave packet, then it can last for about 1 s, as was observed in the case of slow variations of the polarization during April 24, 1985.

Let us consider the depolarization introduced by propagation through a weak magnetic field in a current sheet. The parameter G_0 (Zheleznyakov, 1977) is a function of the propagation angle:

$$G_0 = 4\sqrt{2}\frac{2\pi f}{c} X \cos^2\alpha \left|\frac{Y}{\mathrm{d}Y/\mathrm{d}z}\right| .$$

The polarization is defined by the transformation coefficient Q: $p = 2Q - 1$.

For $G_0 > 3.7$ a change of the polarization sign is possible. For typical parameters one gets the results shown in Table III.

We did not observe such large changes in the polarization trend, however a partial transformation of modes in the quasi-transverse magnetic field and in the weak magnetic field in a current sheet is possible for α very near 90° for the usual plasma parameters. That yields an additional variation in the time profiles of the polarization.

Lower variations of the polarization during the emission phase of fibers and zebras in comparison with stronger changes in polarization during their absorption phase are in accordance with the theory (Chernov, 1976) of coupling of Langmuir waves (l) with whistlers (w) for the generation of radio waves (t) at the frequency $f_t = f_l + f_w$. In this case the agent (whistler) is located at the plasma level $f_p \approx f_l$ and the polarization variation of the continuum corresponds to the frequency in absorption $f_t = f_l$.

4. Conclusions

It is reasonable to suppose that originally the fine structures considered were totally polarized and emitted in the ordinary mode. As we observed intermediately polarized phenomena, some depolarization must occur due to propagation effects. In each analysed set (lasting one or a few minutes) the mean polarization of single structures was practically the same. Only during April 24, 1985 were the different structures spread over a quite long interval (more than one hour) and during that time the percentages of polarization were different. However, even in that case groups of fine structures (sometimes of different types) lasting a few minutes were characterized by no relevant changes in polarization.

Different fine structures showing measurable time delays between the two circularly polarized channels are reported probably for the first time. It is reasonable to consider that the delays should also be related to the same propagation effect. It results that for each selected set of data the delay was similar (but not strictly constant in time) and in the same sense during three type IV events: May 18, 1981, December 16, 1982 and April 26, 1984. Only during the long-lasting type IV burst of April 24, 1985 were definite delays during the evolution of fine structures hardly discernible. It is interesting to note that the most regular and strong delays were observed when the polarization was rather strong (76–80%).

At the flux density minima the time delay between the two channels generates an 'undulation' in the polarization function. This consists of a minimum and a maximum, the order in time depends in which channel the signal is delayed. The weaker component was delayed on May 18, 1981 and December 16, 1982, meanwhile the stronger was delayed on April 26, 1984. This different behaviour suggests a different type of depolarization: the less intense (x) mode is delayed when the waves cross perpendicular magnetic field lines or weak magnetic field in a current sheet, while the strongest (o) mode shows up delayed after a reflection on a density discontinuity. The numerous and different fine structures recorded on April 24, 1984 with very few samples of definite delay might suffer a combination of both processes. Finally we mention also the possibility of an additional polarization variation (which overlaps the undulation due to the delay) according to small changes of the propagation angle with respect to the magnetic field.

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