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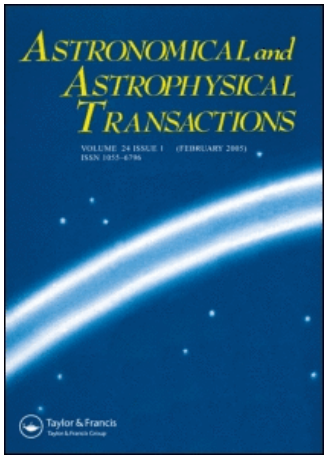

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DETECTION OF DURABLE NON-THERMAL PROCESSES IN QUIESCENT SOLAR ACTIVE REGIONS

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The problem of energy release over a wide dynamic range is key to understanding coronal heating. The detection of the smallest discrete release of energy is important for confirming the modern existing theories. Such processes are recorded on the radio telescope RATAN-600 during weak active region observations at several microwave wavelengths. The flux sensitivity of the radio telescope RATAN-600 in one-dimensional scans is about (5–10) Jy at several-decimeter wavelengths. This allowed us to discover two new types the sources in the active region: a continuum source and microbursts (MB). Here we describe the main parameters of the sources and possible interpretations of the emission.

KEY WORDS Microburst, polarization, spectrum

1 INTRODUCTION

Processes of energy release in active regions of the Sun are manifest in different ways over a wide frequency range. In the radio range an inconsistent situation frequently is observed in comparing radiation at microwave and meter wavelengths. In stable active regions, in centimeter waves, thermal radiation (bremsstrahlung) and cyclotron radiation in low harmonics of a gyrofrequency prevail. Thus, the radiation has a circular polarization with an excess of extraordinary wave. In the meter wavelength range the radio-radiation of such active regions frequently has a non-thermal character (noise storms, bursts of different types). Naturally, it is interesting to study the frequency range where there is a change of the dominant influence of these mechanisms.

High sensitivity observations on the RATAN-600 radiotelescope (Parijskij and Korol'kov, 1979) were used for the study. Two new phenomena in stable active regions were discovered: namely, the sharp increase of the polarization emission spectrum in the long part of the decimeter wavelength range (continuum source) and long-term sources of weak impulses (microbursts) with a high degree of polarized

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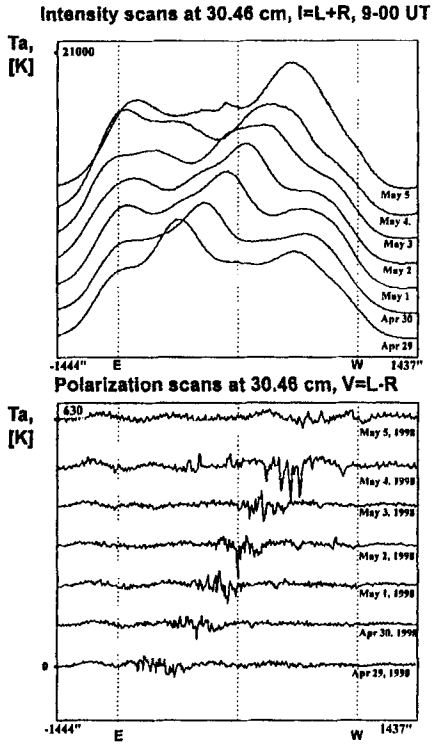

Figure 1 One-dimensional daily solar scans of the active region AR 8210 at wavelength 30.46 cm for both intensity and circular polarization over one week. The impulses in circular polarization emission are shown in each scan.

emission in the same range. The multi-wave observations allowed us to carry out plasma diagnostics of the release energy sites and to determine the mechanism of generation of radio waves.

2 OBSERVATIONS

Here we will present some examples of the observations. They were carried out in the range 0.95–16.7 GHz on 35 frequency channels with the help of the wide-range Panoramic Spectrum Analyzer (PAS) (Bogod *et al.*, 1993), which was installed on the radio telescope RATAN-600. All receivers recorded the intensity and circular polarization of the solar emission. The flux sensitivity of the reflector-type radio telescope RATAN-600 during solar observations was F = (5–10) Jy, owing to the large collecting surface (500–1000)m^2 and the wide band receivers of PAS of about f = (80–200) MHz. The time of recording was 0.2 s.

In Figure 2 the sharp growth of the active region polarized emission in the range 17.96 to 31.41cm was recorded on May 19. This emission consists of both

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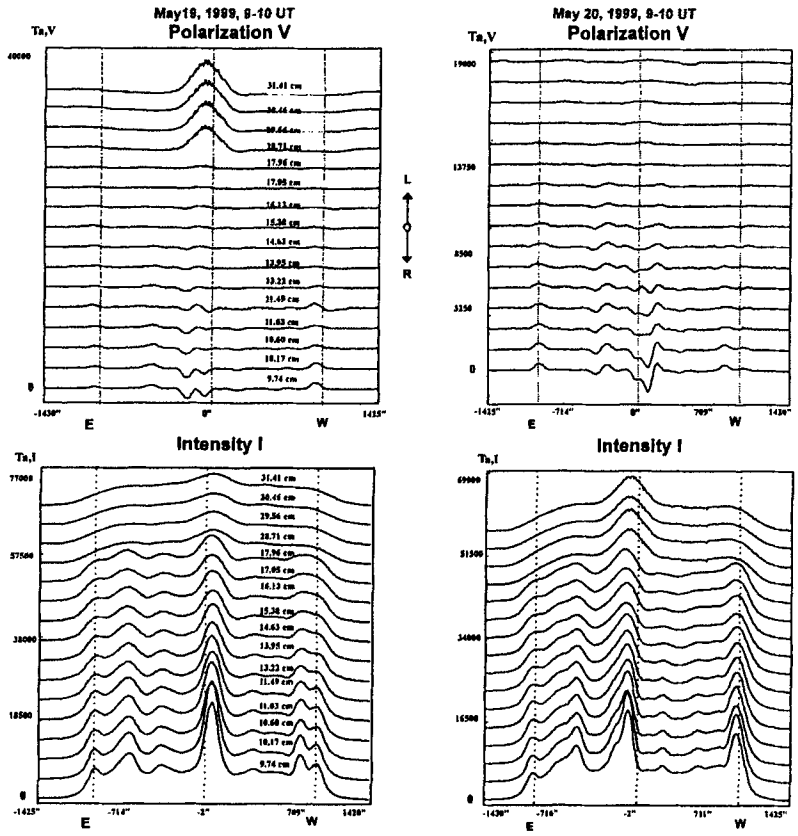

Figure 2 Example of active region AR8545 observations near solar meridian in the decimeter range (from 9.74 cm to 31.41 cm) in several wavelengths over two days May 19 and 20, 1999. Note the appearance of the left-hand polarization source at longer wavelengths during May 19, which is absent during May 20. It is in accordance with the activity of the Noise Storm recorded at meter waves by the Nancay radioheliograph recently.

a continuum emission source associated with a sunspot group with L-polarization, which, in this case, corresponds to an excess of ordinary mode emission, and a small pulsing component. Also note that at the shorter wavelengths (see Figure 2) the emission of continual emission source has R-polarization and corresponds to an excess of extraordinary mode emission. The small pulsing component represents the microbursts with very weak fluxes and a very high degree of polarization (mainly ordinary mode emission). The duration of this pulsing component (durable microbursts – DMB) lasted about 2.20 hours during all the time of observations.

Related observations at meter waves (Nancay data, France) showed an intense noise storm above this active region during 19.05.1999 detectable at both frequencies 164 MHz and 327 MHz. However for 20.05.99, the Nancay data specify an appreciable diminution of intensity of the noise storm that correlates well with the disappearance of the DMB source (see Figure 2 on the right).

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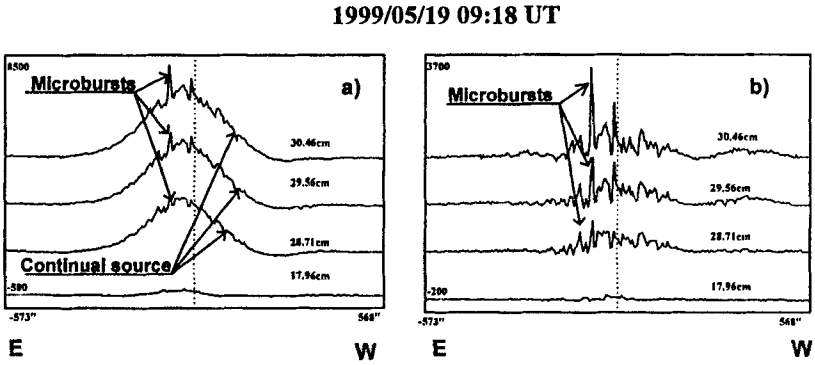

Figure 3 Detailed presentation of active region emission at several wavelengths: (a) continual emission source marked by a dotted line, (b) microburst emission after subtraction of the continual source.

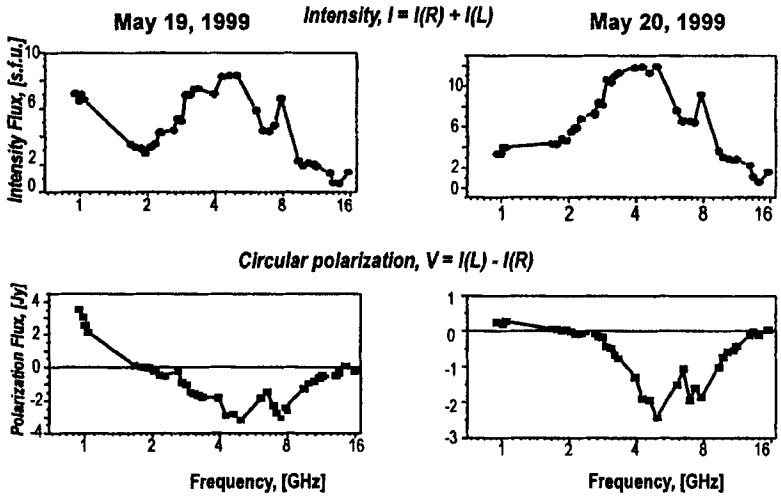

Figure 4 Wide range microwave spectra of the active region. Top row – intensity for May 19 and 20. Bottom row-circular polarization for the same days.

In Figure 4 the emission flux spectra of this active region are presented in intensity and circular polarization. The spectrum of flux intensity for the active region AR8545 has a maximum in the frequency range (5–6 GHz), which is typical for thermal emission in microwaves, however, in May 19, 1999 a new growth of intensity with wavelength begins at long wavelengths (< 2 GHz).

The spectrum of polarized emission of the AR8545 is even more complicated. In microwaves (> 2 GHz), it is similar in shape to the spectrum of intensity. The sign of polarization corresponds to an excess of x-mode emission. But in the range near 2 GHz the sign of polarization reverses, demonstrating an excess of o-mode

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Table 1.

Wavelength range	Decimeter waves
Duration of separate burst	1–2 s
Periods of appearance of separate bursts	3–5 s
Duration of microburst source	From several hours to several days
Flux magnitudes of the microbursts	From (5–10) Jy up to 300–400 Jy (for the most powerful impulses).
Brightness temperatures of DMB sources	$(3\text{–}5) \times 10^6\text{–}10^9$K
Degree of circular polarization	80–100%

emission. The polarized emission of the continuum source is fairly high with a degree of polarization of about 60–70% (see also Figure 1).

Parameters of MB measured from the observations are given in Table 1.

3 INTERPRETATION

According to solar active region observations, it is known that the generation of energetic particles occurs over short time intervals. Among the weak burst activity should be noted the quasi-periodical pulsations during the bursts at decimeter wavelengths with periods from 0.1 sec to 5 sec (Gotwols, 1972; Elgaroy and Sveen, 1973; Wiehl *et al.*, 1985; Aschwanden and Benz, 1986). Detailed information about such pulsations can be found in the work (Aschwanden *et al.*, 1993).

Analysis of the possible mechanisms of MB emission was made in the paper (Bogod *et al.*, 1999). The best acceptable mechanism is radiation at a frequency close to the plasma frequency with a plasma turbulence level of about $w = 2 \times 10^{-8}$. Apparently, the radiation of the microburst source occurs as a result of propagation of prompt electrons in an atmosphere with an open magnetic structure and with a weaker gradient of electron density of background plasma than according to the barometric formula.

To estimate the temporal characteristics of DMB sources a cross correlation analysis of the observations at different waves was applied (Bogod and Yasnov, 2000). The cross correlation function (CCF) showed that for DMB sources there is a negative frequency drift (FD) of about 100–120 MHz s^{-1}. For separate powerful impulses the FD can exceed (600–800) MHz s^{-1}. According to the temporal parameters one can conclude that the nature of DMB sources is close to type-III bursts. The results of this analysis are given in Table 2.

For further study of the MB, we compared the long-term microburst emission (RATAN-600 data) and impulse noise storm (NS) emission (Nancay radioheliograph data). In the work (Bogod *et al.*, 2000), a detailed comparison of MB emission at 1000 MHz and Noise Storm emission at 233 and 164 MHz was made. So far as many parameters of both phenomena are similar, we proposed that the plasma mechanism on the main harmonic works both at 1000 MHz and (164–233) MHz.

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Table 2.

Negative frequency drift of microbursts	(100–120) MHz s^{-1} (up to 800 MHz s^{-1})
Periods of appearance of separate bursts	3–5 s
Height of MB source	15000 km
Time delay between 1000 MHz and 233 MHz	5 ± 1.2 s
Time delay between 1000 MHz and 164 MHz	7.5 ± 1.1 s

Table 3.

Plasma turbulence level	$w = 2 \times 10^{-8}$
Velocity of non-thermal electrons	$(0.14 \pm 0.02)c$ and $(0.28 \pm 0.10)c$
Estimate of fast electron energy in all active region	5×10^{17} erg

The cross-correlation analysis of the data was applied to study the time parameters of both MB and NS. The position of the maximum on cross-correlation function was used to measure the time delay between impulses at different wavelengths. The cross correlation analysis between two ranges allowed us to find the set of physical parameters, which are given in Table 2.

Analysis of the data showed that the time delays have positive values and it can be proposed that the sites of electron generation are situated near or below the 1000 MHz emission region. Naturally, the MB have an energy level corresponding a site which is close to the fast electron generation region.

Appropriate estimates of the fast energy level are given in Table 3. Table 3.

From the observations it follows that DMB arise at frequencies where there is a change of polarization sign of the continuum emission source (Bogod *et al.*, 1999). So, this effect is stable and does not depend on the position of the active region on the disk of the Sun. The reason is probably the small gradient of magnetic field with height compared with the electron density gradient.

The realization of the condition $f_B \succ f_P$ is possible where the radio emission in the first harmonic of a gyrofrequency occurs for the very low frequencies. In this case, the active region emission mainly has an ordinary mode polarization. The determination of the frequency with prevailing o-mode polarization for the continual emission source together with the detection of DMB give a new method of magnetic field measurement at the top of the magnetic arch structure in an active region.

The change of the polarization sign of the continuum source specifies the frequency at which the condition $f_B = f_P$ is satisfied, and the presence of microbursts determines the value of the plasma frequency. This can help us to find the magnetic field in the source. For real observations one can determine that $f_B = f_P = 1.5$–2×10^8 Hz, which give the estimation of magnetic field $B_{\text{top}} = 180$–240 Gs.

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4 SUMMARY

So, the high sensitivity observations at RATAN-600 have allowed us to determine the long-term non-thermal emission in the form of durable microbursts with fluxes of about one thousandth of an s.f.u. Such processes can occur in a stable active region over a time interval from several hours to several days. The duration of one burst impulse is about 1–2 seconds, with periods of about 3 and 5 seconds and with a median frequency drift of about -120 MHz s^{-1}.

It is shown that DMB sources arise at the fundamental plasma frequency. Apparently, the radiation of a microburst source occurs as a result of propagation of prompt electrons in an atmosphere with an open magnetic structure.

A new method of magnetic field measurement in places of radio emission where the decimeter waves are generated is offered.

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