The Reversion of Polarization Sense of Spikes observed on May 16,1991

Sheng-zhen JIN, Ren-yang ZHAO, Xiao-cong LI and Qi-rang QI

Beijing Observatory, Academia Sinica, Beijing 100080, China

Abstract

In this paper, the polarization reversions of the radio spikes and fine structures, superimposed on the microwave burst on May,16 1991, were introduced briefly. It may be caused by the fluctuations of plasma density and magnetic field in the source region in corona, and the fluctuation leads to the growth of the electron-cyclotron maser to control the radiation of X-mode or O-mode wave and to reverse the sense of the polarization of radio emission.

1. Introduction

It is well known that the spike emission of solar microwave radio burst often have the characteristics of high polarization and rapid sense variation of polarization. This may be explained as that spike emission is of the coherent nonthermal one and it relates closely to the magnetic field strength of the radio burst source region and the plasma density.

Since 1970s, the problem on the polarization of spike emission draws attentions of many solar radio physicists. The 100% LHCP spike emission has been observed at the frequency of 2600MHz by Slottje (1978)[1]. And Gary has also observed that the degree of polarization of spike emission changes from 26% RHCP to 83% LHCP in 370ms period at the frequency of 2840 MHz, he then gives a preliminary explanation in terms of the relation between the cutoff frequency of the second harmonic O-.X-modes and the ratio of the plasma density of background to the magnetic field strength[2].

2. Observation

On May 16, 1991, a 47GB microwave radio burst, which was associated with a optic flares on solar surface, had been observed at the frequencies of 2545 and 2645 MHz with high time resolution at Beijing Astronomical Observatory. During the peak phase of the bursts, a group of spikes had been obtained. From the observation, spike emission has been dominated by LHCP within the time scale in the main burst phase, but during $0645 - 0648UT$, the burst changes from LHCP to RHCP, the observation with a high time resolution shows complicated variations in the sense of spike polarization,especially within the 1500ms period after 0647 UT, the sense of polarization of spike emission gives six reversions continuously. In general, the LHCP value of spike emission is about 80% to 90%, and the RHCP value is about 40% to 50%, the mean time interval of reversion is about 100ms, and the shortest one is about 60ms[3].

Figure 1 shows the time profile of the May 16, 1991 radio burst at the frequencies of 2545 and 2645 MHz, and from 0645 to 0648 UT.

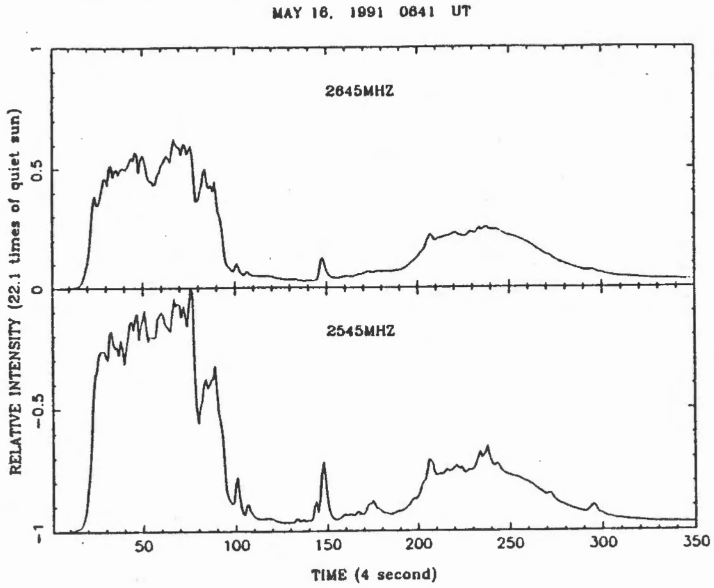

Fig. 1 The profile of the microwave burst occurred on May 16,1991.

Figure 2 is the morphological figure that shows the rapid reversions of the sense of spike polarization within the 0647 UT period. From Figure 2 we can see, during about 1000s period, the sense of spike polarization alternates between LHCP and RHCP rapidly.

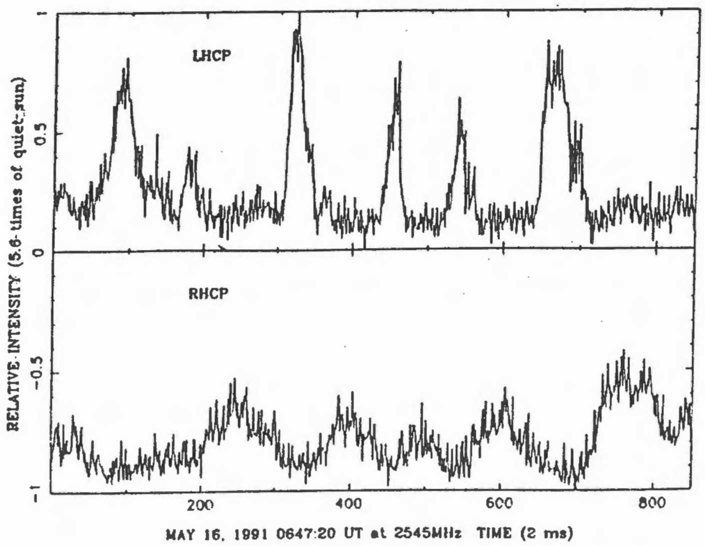

Fig. 2 The reversion of the spike polarization senses.

3. Discussion

The frequency and the waves mode of spike emission are determined by the physical background of the coronal source region. Melrose has already given their general expression in *detail*[4]. In this paper, we only discuss the electron-magnetic wave in a approximate way. Under the condition that the propagating direction get perpendicular to the magnetic field, the dispersion equations of O- and X-modes may be written as follows [5]

$$1-(\frac{ck}{\omega})^2+(\frac{\omega_p}{\omega})^2\int dv^3(\Omega\frac{\partial f}{\partial v_\perp}+k_\parallel v_\perp\frac{\partial f}{\partial v_\parallel})\frac{v_\perp J_1'^2(b)}{(\omega-\Omega/r-k_\parallel v_\parallel)}=0 \tag{1}$$

$$1-(\frac{ck}{\omega})^2+(\frac{\omega_p}{\omega})^2\int dv^3(\Omega\frac{\partial f}{\partial v_\perp}+k_\parallel v_\perp\frac{\partial f}{\partial v_\parallel})\frac{v_\parallel^2}{v_\perp}\frac{J_1^2(b)}{(\omega-\Omega/r-k_\parallel v_\parallel)}=0 \tag{2}$$

where ω_p, Ω and ω are the plasma frequency, the electron cyclotron frequency and the emitting frequency respectively; $v_\perp$ and $v_\parallel$ denote the velocity components of the nonthermal electron beams perpendicular and parallel to the magnetic field; n is the density of the nonthermal electron beams; $k_\parallel$ is the component of the electron-magnetic wavevector parallel to the magnetic field; f is the electrons distribution function in the plasma momentum space;γ is the Lorentz factor; $J_1(b).J_1'(b)$ denote the regular Bessel function and its derivative, respectively, and its variate is $b=k_\perp v_\perp/\Omega$.

From the dispersion equation, we could derive the emitting frequency of spike $\omega=\omega_r+i\Gamma, \omega_r$ is the real part, Γ is the unreal part. In fact, Γ describes the damping or growth rate of the modes against time. When $\omega_r \gg \Gamma$, we can derive the growth rates Γ_x, Γ_o of the X- and O-modes as

$$\Gamma_x=\frac{\pi^2\omega_p^2}{\omega^2}\frac{n_b}{n}\int_0^\infty dv_\parallel\int_0^\infty d^2v_\perp v_\perp^2(\Omega\frac{\partial f}{\partial v_\perp}+k_\parallel v_\perp\frac{\partial f}{\partial v_\parallel})/(\omega-\frac{\Omega}{r}-k_\parallel v_\parallel) \tag{3}$$

$$\Gamma_x=\frac{\pi^2\omega_p^2}{\omega^2}\frac{n_b}{n}\int_0^\infty dv_\parallel\int_0^\infty dv_\perp(\frac{v_\perp}{c})^2v_\parallel^2(\Omega\frac{\partial f}{\partial v_\perp}+k_\parallel v_\perp\frac{\partial f}{\partial v_\parallel})/(\omega-\frac{\Omega}{r}-k_\parallel v_\parallel) \tag{4}$$

Under the wave-particle resonant condition,

$$\omega-S\frac{\Omega}{\gamma}-k_\parallel v_\parallel=0 \tag{5}$$

We can see that Γ_x and Γ_o will reach the maximum values. Taking the distribution function of plasma into the above equation and integrating it along the momentum space coordinate, then we will get the growth rates of Γ_x and Γ_o.

The mode, frequency and growth rate of the electron-magnetic wave of spike emission are completely determined by the physical conditions of source region (ω_p, Ω), the density. velocity of the nonthermal beams and the angle between the incidence beam velocity and the magnetic field. If we select the factor (ω_p/Ω) as the parameter, taking Γ as the function of (ω_p/Ω), and in the meantime taking account of the cutoff condition that the electron-magnetic waves propagate in the coronal region, we could get that the generation and propagation of the X-, O-modes and their harmonics of spike emission are seriously confined by the factor ω_p/Ω

$$\omega_p/\Omega<\sqrt{S(S-1)} \tag{6}$$

the condition for X-mode to propagate

$$\omega_p/\Omega < S \tag{7}$$

the condition for O-mode to propagate
where S is the harmonic number.

The source region of spike emission at the frequencies of $2.5 - 2.6GHz$ is located at the lower coronal atmosphere. The first harmonic X- and O-mode can not escape from the corona due to heavy absorption by the second and higher cyclotron resonance layers. Only the second X- and O-mode harmonics may be possible to escape from the corona and reach the earth.

When $\omega_p/\Omega \leq 1$, the emission is dominated by the first harmonic O-mode; when $1 \leq \omega_p/\Omega \leq \sqrt{2}$, the second harmonic X-mode will replace the first harmonic O-mode and govern the emission; and when $\omega_p/\Omega \geq \sqrt{2}$, the second harmonic X-mode will be quenched and the second harmonic O-mode will take the place of it. If the value of ω_p/Ω changes close to $\sqrt{2}$, the second harmonic X- and O-modes will dominate the emission alternately and then give rise to changes in the sense of polarization alternately.

At the observed frequency of 2.6 GHz and we assume that spike emission is the second harmonic radiation, then

$$\nu_p = \frac{1}{2\pi}\omega_p = (\frac{e^2 N_e}{\pi m_e})^{1/2} \doteq 9 \times 10^3 \sqrt{N_e} \;\; Hz \tag{8}$$

$$\nu_\Omega = \frac{1}{2\pi}\Omega = \frac{eB}{2\pi m_e c} \doteq 2.8 \; B \;\; MHz \tag{9}$$

where m_e is the mass of electron, e is the quantity of electron, the unit of B is Gauss. From above, we can derive the magnetic field strength ($\sim$ 500 Gauss) of the source region of the May 16, 1991 spike emission and the plasma density ($10^{10}/cm^3$).

It is well known that the disturbances will cause MHD waves ("sausage" mode), then they would create the resilient shrink of magnetic loop and the undulation of plasma density which will make the value ω_p/Ω rise and fall around $\sqrt{2}$. Furthermore, this would cause the second harmonic X- and O-modes to rule spike emission by turns, and eventually lead to the reversion of polarization of spike emission.

Acknowledgements: This work was financially supported by the National Science Foundation of China and the Chinese Academy of Sciences.

References

Slottje, C. 1978, *Nature*, **275**, 520.
Gary. 1990, *Bull. Am. Astron. Soc.*, **22**, 823.
Jin Shengzhen et. 1991, *ACTA Astrophysics Sinica*, **11**, 394.
Melrose, D.B. 1980, *Plasma Astrophysics*, Gordon and Breach, New York.
Loukas Vlahos. 1987, *Solar Physics*, **111**, 155.