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"Oblique" Bernstein modes in solar preflare plasma: Generation of second harmonics

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Abstract

Process of second harmonics generation due to development of corresponding instability has been investigated for pure electron weakly oblique Bernstein mode. This mode was supposed to be modified by taking into account the influence of pair Coulomb collisions and weak large-scale electric field in flare loop. Investigated area was located near the loop foot-point in the "lower–middle" chromosphere of active region. It has been shown, that for the Fontenla–Avrett–Loeser model of solar atmosphere the investigated process of second harmonics generation starts at the extremely low threshold values of subdreicer electric field, well before the beginning of "pre-heating" phase of flare process.

Keywords: Sun: magnetic field; Sun: activity; Sun: flare loop; Sun: plasma instabilities

1. Introduction

Microwave emission in santimetre–millimetre range has been regularly fixed during last two decades and it is continually fixed now in the atmosphere of solar active regions (Aschwanden, 2001; Bogod et al., 2000; Gel'freikh et al., 2004). Most frequently this phenomenon has been detected at gradual phase of flare process (Foukal and Hinata, 1991; Gopasyuk, 1987), but there is enough number of observational data, when it had been detected before the "flash" phase, actually, before the flare (Schmahl et al., 1986; Farnik and Savy, 1988; Antonov et al., 2007). The situation becomes the most interesting, when such data are obtained during the systematic observation of concrete active region (Charikov, 2007; Harra et al., 2001; Aurass, 1993). In Fig. 1 from paper (Antonov et al., 2008) the recording of the flare's M8.2 intensity of emission is presented. This flare had been registered by radiotelescope RT-2 (Kharkov, Ukraine) during the observations of active region NOAA 9893 at 3.4 mm wavelength on April 10, 2002.

The flare had started at 12:27:30 UT, and recording had been started at 12:23:00 UT. So, during the first four minutes and a half the preflare phase had been registered. The intensity values at this stage are relatively low in comparison with average values on the recession background. The analogous picture was observed in case of flare M6.1 in active region NOAA 808 on September 12, 2005 (Antonov et al., 2007). In both these cases recording of flare emission (actually, preflare one) had been obtained at frequency 84 GHz. The corresponding values of electron cyclotron frequency can lead to the idea about the existence of "kilogauss" magnetic fields in the parts of NOAA 9893 and NOAA 808 under investigation.

2. Some possible mechanisms of microwave emission formation

Theoretical analysis, which has been made by number of authors (Podgorny, 2001; Bogod et al., 2000; Gel'freikh et al., 2004) show the possibility of registration of the sepa-

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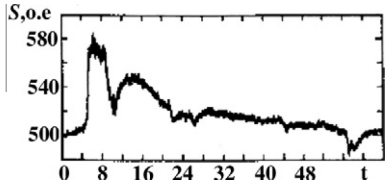

Fig. 1. Intensity of emission of the flare M82, expressed in relative units. Start of recording – at 12:23 UT.

rate cyclotron lines at the electron gyrofrequency harmonics in the atmosphere of solar active region. This fact has been confirmed later by the observations (Farnik and Savy, 1988; Antonov et al., 2008). The main reasons of this phenomenon can differ greatly one from another, namely: (a) it may be a beam of high energy electrons, which propagates in a loop and excites cyclotron instability at the Bernstein harmonics and generates Bernstein modes (Brinca and Dysthe, 1983; Bogod et al., 2000); (b) great number of authors suppose that registrated emission is the gyrosynchrotron radiation of nonthermal electrons, which is very sensitive to the changes of magnetic field values in radio source (Aurass, 1993; Aschwanden, 2001; Schmahl et al., 1986); (c) oscillations of magnetic field values, which modulate the efficiency of gyrosynchrotron radiation, when whole process of acceleration of electrons can result in the appearance of the pulsations (or spikes) of microwave emission; (d) the reason of observed pulsations (or spikes) of microwave emission may be the fast radial magnetoacoustic oscillations of magnetic tube with plasma density, which is more high then density of surrounding plasma (Podgorny, 2001; Gel'freikh et al., 2004). This list, of course, is not complete. In spite of variety of all these mechanisms and models, the close connection exists always between specific dynamics of the flare process and specific mechanism of generation of microwave emission. Most frequently dynamics of a flare process is based on the Heyvaerts–Priest–Rust model of a flare (Heyvaerts et al., 1977). The authors of "HPR"-model divide process into three parts: (1) "preheating" phase, when stream velocity $\vec{u}$ of electrons in "preflare" plasma exceeds their thermal velocity. Thus Buneman instability appears, develops and transforms into Buneman turbulence, which heats plasma; (2) flash ("impulsive") phase; (3) "gradual" phase (phase of recession). Microwave emission is fixed as a rule at last two phases, and very rarely-at the first. This connection of emission with second and third phases as well as "obligatory" existence of the beams of high-energy particles in a loop together with existence of compact source of radiation with "hot" (T $\approx$ 1 MK) and dense plasma at the apex of loop structure and, finally, location of the region of the first energy ejection at the same place, to insert a dash there is typical set of "requirements" practically for all the models of a flare and mechanisms of microwave emission (Aschwanden, 2001; Fontenla et al., 1993; Gel'freikh et al., 2004). In present paper we demonstrate that necessary conditions for generation of second Bernstein harmonics (more exactly, oblique Bernstein one) at the frequency near the corresponding electron cyclotron frequency are satisfied in "cold" and dense plasma near the foot-point of a loop, well before the "preheating" phase, when the beams of high-energy particles are practically absent there, i.e. without any element from "obligatory" typical set of "requirements" mentioned above. It becomes possible only owing to the fact that weak large-scale electric field, which was named the "subdreicer" field, exists in a loop. As a rule it exists at the part of its current circuit, which corresponds to the "lower–middle" chromosphere i.e. in the area of "kilogauss" magnetic fields (Solanki, 1993). For such electric field the ratio of its amplitude E_0 to the amplitude of local Dreicer field E_D (Alexandrov et al., 1988; Krall and Trivelpiece, 1973) is small:

$$\varepsilon_R \equiv \frac{E_0}{E_D} = \frac{u}{v_{Te}} = \frac{eE_0}{m_e v_{Te} \nu_{ei}} << 1, \tag{1}$$

and percentage of "runaway electrons", which are continually accelerated by quasi-static electric field E_0, is extremely low. In the expression (1) e и m_e are the charge and mass of electron correspondingly; ν_{ei} is the frequency of ion–electron collisions, v_{Te} is the electron thermal velocity. Thus, to simplify the picture, we can say that subdreicer field E_0 "swings" the instability of second oblique Bernstein harmonics. At the same time Landau damping and pair Coulomb collisions (Chen, 1984) "try" to damp it. Namely due to very fine balance of these three reasons the given harmonics can appear and be generated during the linear stage of perturbation development at least (Kryshtal, 1998). For the wave with high quality, i.e. with very small ratio of the growth rate value to the value of main frequency, the time of instability development can be enough large. We name the wave under consideration the "oblique" Bernstein mode because of the existence of small, but nonzero component of wave vector $k_z \neq 0$, which is longitudinal with respect to the external magnetic field B_0 of a loop. This component $k_z \neq 0$, makes this wave similar to the well known neutralized ion Bernstein mode (Chen, 1984), which was obtained in laboratory conditions. Obviously, study of "oblique" Bernstein mode's instability and conditions of its generation can give us only the necessary conditions for generation of microwave emission in preflare plasma. Electromagnetic wave, which can reach a remote observer, can appear in the area of generation and probably escape from it through the process of three-wave interaction

$$B_1 + B_2 \Rightarrow \text{EHW}. \tag{2}$$

It was first considered by Willes and Robinson (1996) at qualitative level. Here B_1 and B_2 are Bernstein modes, EHW is electromagnetic wave. For oblique Bernstein modes such process may be more complicated. The same complexities can rise in the problem of instability's transformation into a turbulence. But anyway this first step, investigation of instability, seems to be the most important. Results of such investigation can be useful for the solution of the problems of short-time forecast of solar flare and location of the area of the first energy ejection of a flare in the "lower–middle" chromosphere of active region.