ON THE ORIGIN OF DECAMETRIC-WAVE CONTINUUM OF SOLAR FLARES

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Abstract

It is shown that flare-produced fast electrons with a power-law energy distribution trapped in magnetic loops are capable to produce plasma waves at the upper hybrid frequency due to a loss-cone instability. This instability has been considered as the cause of the solar decimetric continuum which exhibits a strong temporal and spatial correlation with regions of flare-energy release and sources of microwave bursts. The strong absorption of the first harmonic in the decimeter range and also the peculiarities of the conversion of the plasma waves into electromagnetic waves yield a preference of the generation of the decimetric continuum at the second harmonic of the plasma frequency. In this case the polarization of the radiation corresponds to the ordinary wave mode in a wide cone of propagation angles around the direction perpendicular to the magnetic field.

1 Introduction

Hard X-ray observations demonstrate that energetic flare-electrons frequently exhibit an energy distribution which can be approximated by a power law [Lin, 1985]. The gyrosynchrotron radiation from these electrons trapped in magnetic fields of solar active regions can be regarded as the main source of microwave bursts at frequencies > 1 GHz [Kundu and Vlahos, 1982]. Another important burst component which is intimately connected with flare electrons is formed by decimetric bursts and the decimetric continuum in the frequency range between about 200 MHz and 1 or 2 GHz [Zheleznyakov, 1970]. The presence of peculiarities in the dynamical spectrum of the decimetric continuum as zebra patterns and sudden reductions lead to the assumption that this continuum is generated by plasma waves at the upper hybrid frequency $\omega_{\rm uh} = (\omega_{\rm p}^2 + \omega_B^2)^{1/2}$, excited by fast electrons having a loss-cone anisotropy [Kuijpers, 1974; Zaitsev and Stepanov, 1975; Benz and Kuijpers, 1976].

There arises the question whether the electrons generating the microwave bursts via gyrosynchrotron emission and those electrons generating the decimetric continuum by the

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plasma-wave mechanism are belonging to one and the same population of electrons accelerated in the flare and having a power-law energy spectrum.

In the present paper we consider the instability of the power-law distribution with a loss cone anisotropy and investigate the possibility of the generation of decimetric continua and microwave bursts by one population of flare electrons.

2 Possibility of the generation of plasma waves by power-law electrons

We consider the generation of plasma waves in a system consisting of a background plasma with electron density n and a minor part of fast electrons with a density $n_1 \ll n$ and a distribution function $f(v_\parallel, v_\perp)$ where $\parallel$ and $\perp$ denote the vector components parallel and perpendicular to the direction of the magnetic field $\vec{B}$, respectively. If the plasma is sufficiently dense ($\omega_\mathrm{p}^2 \gg \omega_B^2$ where ω_p and ω_B are the plasma frequency and the electron gyrofrequency, respectively), and the plasma waves propagate nearly perpendicular to the magnetic field ($k_\perp^2 \gg k_\parallel^2$, where k is the wave number of the plasma waves at the frequency $\omega \approx \omega_\mathrm{p}$), the growth rate γ of the plasma waves is given by the following formula [Mikhailovskii, 1974]:

$$\gamma = \frac{\pi}{n}\frac{\omega_\mathrm{p}^4}{k^3}\int\limits_{-\infty}^{\infty} dv_\parallel \int\limits_{\omega^2/k^2}^{\infty} dv_\perp^2 \, \frac{\partial f/\partial v_\perp^2}{\sqrt{v_\perp^2 - \omega^2/k^2}}. \tag{1}$$

It is seen from Eq. (1) that for instability ($\gamma > 0$) it is necessary that the derivative $\partial f/\partial v_\perp^2$ is positive at least at some part of the integration path. If we take the distribution function in the form used by Benz and Kuijpers [1976]

$$f(v_\parallel, v_\perp) = \frac{A}{(v_\parallel^2 + v_\perp^2)^\delta}\,\Theta\left(v_\perp^2 - \frac{v_\parallel^2}{\sigma - 1}\right), \tag{2}$$

where

$$\Theta(x) = \begin{cases} 1 & \text{for} \quad x \geq 0 \\ 0 & \text{for} \quad x < 0 \end{cases} \tag{3}$$

is the step function and $\sigma = B_\mathrm{max}/B_\mathrm{min}$ characterizes the magnetic loop trapping the particles, we find that the derivative of the distribution function

$$\frac{\partial f}{\partial v_\perp^2} = -\frac{A\delta}{(v_\parallel^2 + v_\perp^2)^{\delta+1}}\Theta\left(v_\perp^2 - \frac{v_\parallel^2}{\sigma - 1}\right) + \frac{A}{(v_\parallel^2 + v_\perp^2)^\delta}\frac{\partial\Theta}{\partial v_\perp^2} \tag{4}$$

is always negative with exception at the border of the loss cone where it tends to infinity, since $\partial\Theta/\partial v_\perp^2 > 0$ is the delta function. In particular this part of the derivative leads to instability and must be considered at the integration of Eq. (1).

In our analysis we will apply a power-law distribution with different borders of the loss cone:

$$f_1(v_\parallel, v_\perp) = \frac{A_1}{(v_\parallel^2 + v_\perp^2)^\delta}\,[1 - \exp(-y)] \tag{5}$$

with

$$y = v_\perp^2\,(\sigma-1)/v_\parallel^2 \tag{6}$$

and the condition $v > v_0$, where v_0 is the minimal value of the velocity inside the power-law distribution. The distribution function (5) avoids the derivative $\partial f_1/\partial v_\perp^2$ to become infinity at the border of the loss cone. In the opposite case we would leave the frame of the kinetic approximation for the description of the instability and Eq. (1) for the growth rate would be no longer valid [Mikhailovskii, 1974].

The normalization coefficient A_1 in Eq. (5) correponds to the condition

$$2\pi \int_{-\infty}^{\infty} dv_\parallel \int f_1(v_\parallel, v_\perp)\, v_\perp\, dv_\perp = n_1. \tag{7}$$

In the case that the mirror ratio is sufficiently large ($\sigma \gg 1$), the value of A_1 is given by the following equation

$$A_1 = \frac{n_1}{4\pi}\frac{(4\sigma-4)}{(4\sigma-5)}(2\delta-3)\,v_0^{2\delta-3}. \tag{8}$$

In order that n_1 is finite, we must have $\delta > 3/2$, and in order to have a finite average velocity $\langle v\rangle = \int v\, f(\vec{v})\, d^3\vec{v}$ it is necessary to have $\delta > 2$.

Inserting the distribution function (5) into Eq. (1) and solving the integral, we obtain the following expression for the growth rate of the plasma waves $\omega = \sqrt{\omega_\mathrm{p}^2 + \omega_B^2} \approx \omega_\mathrm{p}$ for $\delta > 2$:

$$\gamma = \frac{2\pi^{3/2} A_1 \omega^4}{n\, k^3\, v_0^{2\delta}} \left[\frac{\delta+\sigma-1}{\sqrt{\sigma-1}}\,\mathrm{e}^{-x} - \frac{\Gamma(\delta+\frac{1}{2})}{2\Gamma(\delta)}\right] \tag{9}$$

where $\Gamma(\delta)$ is the gamma function and $x = \omega^2(\delta-1)/k^2 v_0^2$. From Eq. (9) follows that the instability is maximal for $\omega/k \le v_0/\sqrt{\sigma-1}$, i. e. for plasma waves with a sufficiently small phase velocity. For $\omega/k \gg v_0/\sqrt{\sigma-1}$ the first term in the brackets of Eq. (9) is exponentially small and the instability vanishes. The condition of instability for plasma waves with small phase velocity when $\omega/k \ll v_0/\sqrt{\sigma-1}$ can be written as follows

$$\frac{(\delta+\sigma-1)}{\sqrt{\sigma-1}}\,\frac{\Gamma(\delta)}{\Gamma(\delta+\frac{1}{2})} > \frac{1}{2}. \tag{10}$$

From Eq. (9) it can be easily seen that instability occurs for all relevant ratios σ and exponents δ of the power-law spectrum. However, the maximal growth rate

$$\gamma_{\max} = 0.36\,\frac{n_1}{n}\,\omega\,\frac{(4\sigma-4)}{(4\sigma-5)}\,\frac{(2\delta-3)}{\delta}\,\frac{(\delta+\sigma-1)}{(\sigma-1)^2} \tag{11}$$

decreases with increasing ratio σ which is related to a diminishing of the number of particles inside the loss cone contributing to the instability.

In the ambient plasma the excited plasma waves are subject to Landau damping. The damping rate γ_L for the highest instable waves with $\omega^2/k^2 = (3/2)v^2/(\sigma-1)$ is given by the formula

$$\gamma_\mathrm{L} = \sqrt{\frac{\pi}{2}}\left(\frac{3}{2}\right)^{3/2}\left(\frac{v_0}{v_T}\right)^3 \frac{\omega_\mathrm{p}}{(\sigma-1)^{3/2}} \times \exp\left[-\frac{3}{4}\left(\frac{v_0}{v_T}\right)^2 \frac{1}{(\sigma-1)}\right], \tag{12}$$

where $v_T = (\kappa T/m)^{1/2}$ is the thermal velocity of electrons of the background plasma (T – temperature, κ – Boltzmann's constant). The condition $\gamma_{\max} > \gamma_{\rm L}$ determines the values of the density of fast electrons for which the excited plasma waves are not seriously damped:

$$\frac{n_1}{n} > 6.4 \left(\frac{v_0}{v_T}\right)^3 \frac{(4\sigma - 5)}{(4\sigma - 4)} \frac{\delta}{(2\delta - 3)} \frac{\sqrt{\sigma - 1}}{(\delta + \sigma - 1)} \times \exp\left[-\frac{3}{4}\left(\frac{v_0}{v_T}\right)^2 \frac{1}{(\sigma - 1)}\right]. \tag{13}$$

It can be concluded from Eq. (13) that Landau damping impedes the generation of plasma waves only in the immediate source region of the microwave bursts, i.e the parts of the flaring loops where a sufficiently hot plasma with temperatures of the order $(0.5\text{–}1) \cdot 10^7$ K can be assumed. So, generation of plasma waves within the source region of the microwave bursts must be considered as a rather extreme event, although, apparently, this possibility cannot be fully excluded.

On the other hand, the plasma in the immediate vicinity of a flaring magnetic loop can be sufficiently cold with a temperature $T \approx 7 \cdot 10^5$ K [Benz et al., 1992]. In this case even a relatively small number of power-law electrons escaping from the flare volume can generate plasma emission. In the case of sufficiently cold plasma the threshold of instability is determined by the damping of the plasma waves due to electron-ion encounters in the plasma. Then the damping rate is given by

$$\gamma_{\rm c} = \frac{\nu_{ei}}{2}, \tag{14}$$

where

$$\nu_{ei} = \frac{5.5\, n}{T^{3/2}} \ln\left(\frac{10^4\, T^{2/3}}{n^{1/3}}\right) \qquad \text{for } T > 4 \cdot 10^5\,\text{K} \tag{15}$$

is the effective collision frequency of electron-ion encounters in the plasma.

From Eqs. (12) and (14) follows that for $n = 3 \cdot 10^9\,\text{cm}^{-3}$ and $v_0 = 3.88 \cdot 10^9\,\text{cms}^{-1}$ ($\varepsilon_0 = 10\,\text{keV}$) the collision damping of the plasma waves begins to dominate over the Landau damping if the temperature of the background plasma meets the condition

$$T < T^* = \frac{3}{\sigma - 1} \cdot 10^6\text{K}. \tag{16}$$

In this case the maximal growth rate of the instability given by Eq. (11) exceeds the collision damping if

$$\frac{n_1}{n} > 2.3 \cdot 10^{-8} \frac{(4\sigma - 5)}{(4\sigma - 4)} \frac{(\sigma - 1)^{7/2}}{(\sigma + 3)}. \tag{17}$$

We see from Eq. (17) that in the given case the threshold of the excitation of plasma waves is sufficiently small and it is $(n_1/n)_{\min} \approx 10^{-8} \div 10^{-6}$ in dependence on the mirror ratio.

3 The energy density of the plasma waves

The plasma waves generated by fast electrons lead to a diffusion of these electrons inside the loss cone and to their escape from the magnetic trap. The characteristic diffusion time T_d depends on the size of the source region of the fast particles. In the case of a sufficiently large sorce region of fast particles, which is normally realized during solar flares, the diffusion time is sufficiently small [Bespalov et al., 1991]:

$$T_\mathrm{d} < \sigma \frac{L_\parallel}{2\langle v\rangle} \qquad \text{or} \qquad T_\mathrm{d} < \frac{L_\parallel}{2\langle v\rangle}. \tag{18}$$

Here $L_\parallel$ denotes the length of the magnetic trap and $\langle v\rangle$ the average velocity of the fast particles. For characteristic values of $L_\parallel$ and $\langle v\rangle$ the diffusion time is of the order of some parts of a second to a few seconds which is much less than the flaring time of the generation of fast particles (which is about 1 minute for an impulsive flare). Thus, for an estimation of the energy density of the plasma waves we can apply the quasi-linear theory under stationary conditions.

A stationary model of the generation of plasma waves at the upper hybrid frequency $\omega = \sqrt{\omega_\mathrm{p}^2 + \omega_B^2}$ was considered by Shaposhnikov [1988]. He found that under assumption of an one-dimensional diffusion along the line

$$v_\parallel^2 = \frac{\omega - s\omega_B}{\omega_B}\, v_\perp^2 \tag{19}$$

in the velocity frame with conservation of the pitch angle of the fast electrons the energy density of plasma waves can be expressed by the formula

$$W_\mathrm{L} = \frac{Jm\langle v^2\rangle}{4\nu_\mathrm{d}} \ln\sigma, \tag{20}$$

where $J[\mathrm{cm}^{-3}\mathrm{s}^{-1}]$ is the source function, and ν_d the dissipation rate of the energy of the plasma waves which in our case either is determined by Landau damping or by electron-ion collisions:

$$\nu_\mathrm{d} = \begin{cases} 2\gamma_\mathrm{L} & \text{for} \quad T > T^* \\ \nu_{ei} & \text{for} \quad T < T^* \end{cases} \tag{21}$$

In the stationary state it is possible to calculate the energy density of the plasma waves from the density of the fast electrons n_1 and the main parameters of the magnetic flux tube:

$$W_\mathrm{L} \approx \frac{n_1\, m\langle v^2\rangle}{2} \left(\frac{\langle v\rangle}{\nu\sigma L_\parallel}\right) \ln\sigma. \tag{22}$$

The ratio of the energy density of the plasma waves to the energy density of the thermal energy of the background plasma which determines the effectivity of the conversion of the plasma waves into electromagnetic waves amounts to

$$w_\mathrm{L} = \frac{W_\mathrm{L}}{n\kappa T} \approx (6 - 16)\cdot 10^{-2}\frac{n_1}{n}. \tag{23}$$

4 Decimetric continuum

As already mentioned in the Introduction, there are several arguments which lead to the assumption that the solar decimetric continuum is generated by plasma waves at the upper hybrid frequency $\omega = \sqrt{\omega_{\rm p}^2 + \omega_B^2}$ [Kuijpers, 1974; Zaitsev and Stepanov, 1975; Benz and Kuijpers, 1976). These waves are generated by trapped energetic electrons having an anisotropic velocity distribution of loss-cone type. We will assume that the decimetric continuum originates in relatively weak closed magnetic fields directly adjoining the flare loops.

In the following the microwave-burst and decimeter-continuum source will be denoted as region I and region II, respectively, both strongly differing in their parameters. On the average, the solar microwave emission has a maximal flux density at, say, the frequency $\nu_{\rm m} \approx 5$ GHz. Inferring gyrosynchrotron radiation of energetic electrons with a power-law energy spectrum this corresponds roughly to magnetic fields in the source region of $B \approx 450$ G [Kundu and Vlahos, 1982] and a value of the gyrofrequency $\nu_B \approx 1.25$ GHz. In region I, on the average, the plasma frequency should obey the relation $\nu_{\rm p} \leq \nu_B$, because in the opposite case $\nu_{\rm p} \gg \nu_B$ a strong suppression of the gyrosynchrotron radiation occurs (Razin-Tsytovich effect). The condition $\nu_{\rm p} \leq \nu_B$ gives a restriction on the density of the background plasma in region I to $n < 2 \cdot 10^{10}{\rm cm}^{-3}$.

On the average the decimetric continuum has its spectral maximum in the frequency range $\nu \approx (0.5 \div 1)$ GHz [Isliker and Benz, 1994a]. Hence we obtain a plasma density in the source region of $n \approx (3 \div 6) \cdot 10^9{\rm cm}^{-3}$ for $\nu_m = \sqrt{\nu_{\rm p}^2 + \nu_B^2}$ or $n \approx (0.8 \div 1.5) \cdot 10^9{\rm cm}^{-3}$ for $\nu_m = 2\sqrt{\nu_{\rm p}^2 + \nu_B^2}$. Here we assume that in region II the gyrofrequency is much smaller than the plasma frequency. This condition $\nu_B^2 \ll \nu_{\rm p}^2$ is necessary in order to exclude strong gyroresonance absorption at the levels $\nu = 2\nu_B$ and $\nu = 3\nu_B$ at the escape of the radiation from region II outwards. The temperature of the plasma inside (hot) flare loops is typically $T \approx (0.5 \div 1) \cdot 10^7$K. Outside these flare loops the temperature is accordingly lower. For region II we assume $T \approx (0.7 \div 2) \cdot 10^6$K although a heating of this region during the flare cannot be excluded. Analyzing the flare-energy support of the source of the decimetric continuum, the absorption of the radiation by electron-ion collisions at the wave propagation from the source through the solar atmosphere is important. The optical depth $\tau_{\rm c}$ of the corona concerning due to electron-ion collisions for radiation propagating from the source region of the decimetric continuum to the observer is given by

$$\tau_{\rm c}(\nu) \approx \frac{74.6}{\cos\theta}\,\nu_{\rm p}^2 \left(\frac{\nu_{\rm p}}{\nu}\right)^2 \left(\frac{10^6}{T}\right)^{1/2}, \qquad (24)$$

where ν has to be given in GHz. Taking $\nu_{\rm p} = 0.5$ GHz, $T = 7\cdot 10^5$K, $\cos\theta = 0.7$, we obtain from Eq. (24) $\tau_{\rm c} \approx 32(\nu_{\rm p}/\nu)^2$. We can see that even in the most favourable case if $\nu \approx 2\nu_{\rm p}$ the optical depth becomes $\tau_{\rm c}(\nu = 2\nu_{\rm p}) = 8$ and the radiation at the second harmonic is weakened by $3\cdot 10^3$ at the transit through the source of the decimetric continuum while the radiation of the first harmonic is weakened by 10^{14} times! Our estimations show that, due to the rather strong absorption of the first harmonic, the most favourable mechanism for the decimetric continuum is the generation of the second harmonic as result of coupling of strong plasma waves excited by the loss-cone instability. Here the observed brightness temperatures $T_{\rm b}^{\rm (obs)} \approx 10^{10}$K should correspond to brightness temperatures inside the source of the decimetric continuum about three orders higher, i. e.

$$T_{\rm b}^{\rm (source)}\,(\nu \approx 2\nu_{\rm p}) \approx 10^3\,T_{\rm b}^{\rm (obs)} \approx 10^{13}{\rm K}. \tag{25}$$

The emission at the second harmonic of the plasma frequency $\omega_{\rm t} = 2\omega_{\rm p}$ is generated by non-linear coalescence of two plama waves (combination scattering) if the resonance condition

$$\omega + \omega' = \omega_{\rm t}, \qquad \vec{k} + \vec{k}' = \vec{k}_{\rm t} \tag{26}$$

is fulfilled. The transfer equation for the brightness temperature of the emission has the form

$$\frac{d\,T_{\rm b}}{d\,l} = \alpha_N - (\mu_N + \mu_{\rm c})\,T_{\rm b}. \tag{27}$$

Here α_N is the emission coefficient, μ_N is the absorption coefficient related to the decay of an electromagnetic wave of the frequency $2\omega_{\rm p}$ into two plasma waves, $\mu_{\rm c}$ is the absorption coefficient due to the absorption of electromagnetic waves by electron-ion collisions inside the source of radiation, and l is the coordinate along the ray propagation.

If the source has a steady inhomogeneous distribution of the plasma density n with a characteristic scale height $L_n = |n/(dn/dl)|$, the integration of Eq. (27) should be carried out through a thin layer $\Delta l \ll L$ in which the value of the frequency of the elctromagnetic wave is preserved as constant, i. e. $\omega(l, k(l)) + \omega'(l, k'(l)) = {\rm const}$. The depth of this layer is [Zaitsev and Stepanov, 1983]:

$$\Delta\,l \approx 3L_n\,\frac{v_T^2}{\omega_{\rm p}^2}\,(k_{\rm max}^2 - k_{\rm min}^2) \approx 6L_n\,\frac{k^2\,v_T^2}{\omega_{\rm p}^2}, \tag{28}$$

where $k_{\rm max}$ and $k_{\rm min}$ are the maximal and minimal values of the wave number in the excited wave spectrum, respectively. In the second part of Eq. (28) we took $k_{\rm max} - k_{\rm min} \approx k$ where k is the average wave number of the plasma waves. Integrating Eq. (27) in a layer Δl under the assumption $\mu_{\rm c} \ll \mu_N$, we obtain at $\nu \approx 2\,\nu_{\rm p}$

$$T_{\rm b}^{\rm (source)} \approx (2\pi)^3\left(\frac{c}{\omega_{\rm p}}\right)^3\frac{w_{\rm L} nT}{\xi}\left[1 - \exp(-\tau_N)\right], \tag{29}$$

where

$$\tau_N \approx \mu_N \Delta l \approx 10^5 w_{\rm L}, \qquad \xi = \frac{c^3}{v_0^3}\left(\frac{2(\sigma-1)}{3}\right)^{3/2}. \tag{30}$$

Eq. (29) yields for $\nu_{\rm p} = 0.5$GHz, $n = 10^9{\rm cm}^{-3}$, and $T = 7\cdot 10^5$K the required brightness temperature in the source region $T_{\rm b}^{\rm (source)}(\nu \approx 2\nu_{\rm p}) \approx 10^{13}$K if the energy density of the waves is $w_{\rm L} \approx 10^{-5}$.

As it was shown in Section 3 (cf. Eq. (23)), the generation of plasma waves by fast electrons with a power-law energy spectrum the energy density of the plasma waves in our case is $w_{\rm L} \approx 6\cdot 10^{-2} n_1/n$. Hence the required brightness temperature in the source can be explained if $n_1/n \approx 1.5\cdot 10^{-4}$. For $n = 3\cdot 10^9{\rm cm}^{-3}$ this corresponds to a density of fast electrons of $n_1 \approx 4.5 \cdot 10^5 \mathrm{cm}^{-3}$. If the source volume is $V \approx L_n^2 L_\parallel \approx 10^{28} \mathrm{cm}^3$ (by taking $L_n \approx 10^9$cm and $L_\parallel \approx 10^{10}$cm) the total number of fast electrons injected into the source region of the decimetric continuum amounts to $N_1 = n_1 V \approx 4.5 \cdot 10^{33}$.

Usually the polarization of the decimetric continuum corresponds to the extraordinary wave mode [Zheleznyakov, 1970]. We will accept that the plasma waves are generated within a certain cone of angles with a half-width ψ_0, where ψ_0 differs from the direction perpendicular to the magnetic field:

$$W_{\vec{k}} = \begin{cases} W_1 / \sin\psi_0 & \text{for} \quad \psi < \psi_0 \\ 0 & \text{for} \quad \psi > \psi_0 \end{cases} \tag{31}$$

Then, transforming the results of Zlotnik [1981] to our case, we obtain the following expression for the degree of polarization:

$$\rho(\alpha, \psi_0 \to 0) = \frac{\omega_B}{\omega_\mathrm{p}} \left[-\frac{3.96}{\cos\alpha} (\sin^4\alpha - 0.88\cos^2\alpha) - \frac{5}{16}\cos\alpha \right]. \tag{32}$$

We find that the sense of polarization corresponds to the ordinary wave ($\rho < 0$) maintained for angles $\alpha > 50°$. Here, for $\alpha = 60°$, the degree of polarization becomes $\rho = -2.75\, \omega_B/\omega_\mathrm{p}$. For angles $\alpha < 50°$ the polarization corresponds to the extraordinary mode. It must be mentioned that for sources of radio emission concentrated in magnetic traps like, as we inferred, the source of the decimetric continuum, the observation of a major part of the source under angles α near $\pi/2$ is very likely.

5 Discussion

We have shown that fast flare electrons with a power-law energy distribution trapped in magnetic loops are generating plasma waves at the upper hybrid frequency which is here considered as the source of the solar decimetric continuum. Evidently this source is seated near a flaring loop. In this source the magnetic field is sufficiently weak satisfying the condition $\omega_\mathrm{p}^2 \gg \omega_B^2$. This condition is necessary in order to prevent a strong gyroresonance absorption at the layers $2\omega_B$ and $3\omega_B$ at the escape of the radiation from the source region.

The absorption of the decimetric continuum due to free-free transitions in the corona is rather high which favours emission at the second harmonic of the plasma frequency $\omega \approx 2\omega_\mathrm{p}$. This emission turns out to be polarized in the ordinary sense within a wide cone of angles α between the (perpendicular) magnetic field and the direction to the observer.

The direct vicinity of the source of the decimetric continuum to the flare loop (or system of flare loops) allows to explain the good temporal and spatial correlation between the decimetric continuum and the microwave bursts. This circumstance allows to conclude that both components are feeded by one and the same source of fast electrons originating during the flare process.

We estimated the total number of fast electrons needed for the generation of the decimetric continuum with an observed brightness temperature $T_\mathrm{b}^{(\mathrm{obs})} \approx 10^{10}$K which amounts to

$N_L \approx 4.5 \cdot 10^{33}$. Our estimation shows that this value is about 20% of the number of the fast electrons required for generation of the related microwave burst. Hence a non-negligible part of the fast flare electrons should be injected into the source region of the decimetric continuum furnishing the observed brightness temperatures up to 10^{10}K.

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