Energy Distribution of Energetic Electrons in the Source of an Especially Great Radio Microwave Burst

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Abstract

By using the data of an especially great solar radio microwave burst occurring at 1700 UT on 30 October 1992 in a "very active" active region NOAA/USAF Region 7321, on the basis of the theoretical emission mechanism of nonthermal gyro-synchrotron radiation, we have derived the energy distribution of energetic electrons in the source region of the burst and made a simple analysis.

1. Introduction

In general, solar radio microwave bursts arise from the low corona in the closed magnetic fields of active regions. An important type of microwave burst is the impulsive burst that occurs during the flash phase of flares, when the rate of energy release is highest and their profiles are remarkably similar to those of impulsive hard X-ray bursts. The radiation mechanism for the impulsive bursts is gyro-synchrotron emission from the electrons that are trapped in the loops of energy $\simeq 0.1$ to $1MeV$, spiralling in a magnetic field of $B \simeq 100$ to $500Gauss$, and emitting at harmonic numbers ≈ 10 to 50 of the gyro-frequency (Dulk,1985; Zhao, Magun and Schanda, 1990). The spectra of microwave impulsive bursts usually have a single maximum at the peak frequency ν_{peak} $(5000MHz \leq \nu_{peak} \leq 10GHz)$ and the burst sources are optically thick below ν_{peak} and optically thin above ν_{peak} (Dulk et al., 1985). But it is not clear what the energy distribution of the energetic electrons is; possibilities include a near-Maxwellian of $T_e \approx 10^8$ to 10^9K, a power law of energy spectral index $\delta \approx 3$ to 7, or a multicomponent distribution with different volumes at different effective temperature (Dulk,1985).

During the most active time of the "very active" active region NOAA/USAF Region 7321, there is an especially great radio microwave burst to be observed at 7 frequencies on October 30,1992. This burst has an impulsive and complex profile with a double-peak structure at the frequency of 2800 MHz (cf. Figure 1). There may be a considerably important significance in the researching of the burst and the active region, because its intensity is extremely high. In the present paper, therefore,we have simply and theoretically researched the energy distribution of energetic electrons in the source region of the burst.

2. Data of the Burst

The especially great burst occurred on October 30, 1992 in the "very active" active region NOAA / USAF Region 7321. The start times of the burst at 7 frequencies (1415, 2695, 2800, 4995, 8800, 9500, and 15400 MHz) are within 1656-1701 UT,the maximum times are within 1748-1751 UT, and the durations are within 116-195 minutes. The types of the burst at 7 frequencies are 49GB or 47GB. The peak flux densities of the burst are 2300 SFU at 1415 MHz,5800 or 7700 SFU at 2695 MHz,5400 SFU at 2800 MHz,7700 or 10000 SFU at 4995 MHz, 8200 or 9000 SFU at 8800 MHz,7145 SFU at 9500 MHz,and 4000 or 5600 SFU at 15400 MHz (S.-G.D.,1993).

From these values of the flux density at 7 frequencies,we can obtain the spectrum of the burst at the maximum time and determine the spectral peak frequency ,ν_{peak},by means of the method of interpolation:$\nu_{peak} \simeq 6000MHz$.

The profile of the burst at $\nu = 2800MHz$ frequency is shown in Figure 1. Its major peak at 1750 UT is about 5400 SFU and minor peak at ~ 1733 UT is about 4400 SFU (S.-G.D.,1992).

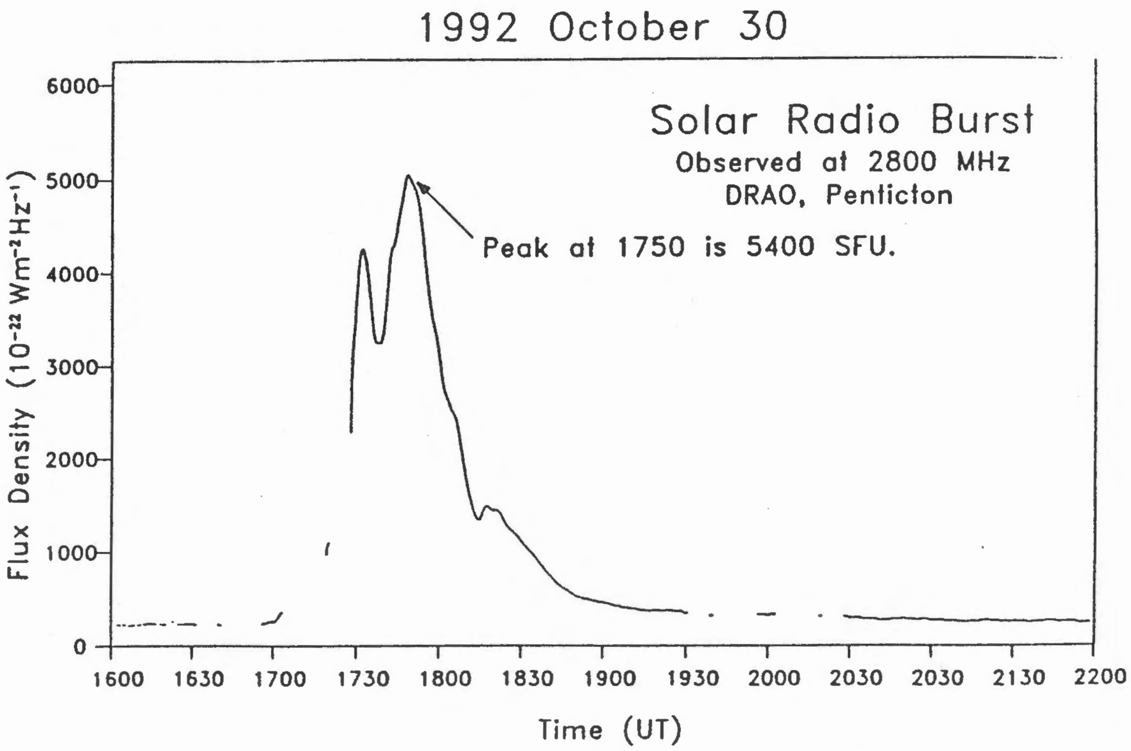

Fig.1 Solar radio burst observed at 2800 MHz, DRAO, Penticton (from S.-G.D.).

The importance and the time of start-maximum-end of the corresponding H_α are 2B and 1702-1730-2203 UT, respectively.The importance and the time of start-maximum-end of the corresponding GOES solar X-ray flare are X1.7 and 1702-1730-2203 UT, respectively (S.-G.D.,1993).

The magnetic field in NOAA/USAF Region 7321 on 30 October 1992 is very complex and strong (Ai and Zhang, 1993).

3. Theoretical Analysis

In the present paper,we try to make a simple research only for the burst at the frequency of $\nu = 2800MHz$.

In view of the profile characteristics of the burst shown in Figure 1 (for example,the extremely high intensity and the impulsive shape), it may be reasonably assumed that the burst is generated by the emission mechanism of gyro-synchrotron radiation from the nonthermal energetic electrons with a power law energy distribution (Dulk,1985; Zhao, Magun and Schanda, 1990; Zhao,1993).

The energetic electrons emitting the gyro-synchrotron radiation have an isotropic pitch angle distribution and a power-law distribution in energy (Dulk,1985):

$$n(E) = KE^{-\delta}, \tag{1}$$

where δ is the power law index of the energy distribution and K is related to N,the number of electrons per cm^3 with the energy of $E > E_0$, by the relation

$$K = (\delta - 1)E_0^{\delta-1}N. \tag{2}$$

It is assumed that the low-energy cutoff is $E_0 = 10keV = 1.6022 \times 10^{-8}ergs$, but in fact the electrons with the energy less than 50 to $100keV$ contribute very little to the radiation.

The flux density, F, of the burst source,as it is known, is related to the brightness temperature, T_b, by the relation

$$F = \frac{2k\nu^2}{c^2}\int T_b d\Omega, \tag{3}$$

where k is the Boltzmann's constant,c the speed of light,ν the radiation frequency, $d\Omega$ is a differential solid angle, and the integral is over the projected area of the source.

From the configuration of the active region,the projected dimension of the source can be taken as $L = 7 \times 10^9 cm$ corresponding to $96'' arc$. If the distribution of the brightness temperature is uniform over the source area, then the maximum radiation intensity of the major peak can be calculated by means of equation (3) from the value of flux density $F = 5400SFU$ at 1750 UT:$T_b = 1.03 \times 10^9 K$. For the sake of simplicity, the assumption of $T_b = T_{b,x} = T_{b,o}$ might be made in the present analysis, where $T_{b,x}$ and $T_{b,o}$ are the brightness temperature of the extraordinary and ordinary mode,respectively.

The burst source is optically thick for the frequency $\nu = 2800MHz$ at the maximum time of 1750 UT because $\nu < \nu_{peak}$, thus the brightness temperature approximates to the effective temperature of the emitting electrons (of course, on the supposition that T_{eff} is constant in the source region):

$$T_b \approx T_{eff}. \tag{4}$$

Through the value of T_b, therefore, the average energy of the emitting electrons can be estimated: $< E >= 88.8keV$.

For the gyro-synchrotron radiation from the electrons with the power law energy distribution,the effective temperature cab be approximately expressed by (Dulk,1985)

$$T_{eff} \approx 2.2 \times 10^9 10^{-0.31\delta}(\sin\theta)^{-0.36-0.06\delta}(\frac{\nu}{\nu_B})^{0.50+0.085\delta}, \tag{5}$$

where θ is the viewing angle(angle between the magnetic field direction and the line of sight),ν/ν_B, the harmonic number,ν_B,the electron gyro-frequency.

The magnetic field of the active region can be assumed to be a magnetic dipole field, so the field strength can be given as follows (e.g. Zhao,1991):

$$B = \frac{[r^2 + 4(h + d_0)^2]^{1/2}}{2[r^2 + (h + d_0)^2]^2} d_0^3 B_0, \tag{6}$$

where h is the height above the photosphere, r the distance from the central axis of the active region,d_0 the depth of the dipole below the photosphere, B_0 the magnetic field strength at the photosphere. The height of the burst source at the frequency $\nu = 2800MHz$ can be taken as $h = 4.2 \times 10^9 cm$ (e.g. Dulk,1985). According to the observations, the magnetic field strength at photosphere is about $B_0 = 3000Gauss$. The magnetic field in the source region, moreover, can be assumed to be homogeneous. By using equation (6) and taking $r = 0$ and $d_0 = 2.0 \times 10^9 cm$, thus, one can estimate the magnetic field strength in the source region: $B \approx 100Gauss$. That is to say, the harmonic number can be taken as $\nu/\nu_B \approx 10$. As for the viewing angle of the magnetic field θ, it may be suggested from the observations that $\theta \approx 50°$.

By means of equations (4) and (5) and substituting the values of T_b, θ, and ν/ν_B, therefore, one can obtain the power law index of the energy distribution: $\delta = 4$.

Besides,the peak frequency of the gyro-synchrotron radiation from the electrons with the power law energy distribution can be approximately written as (Dulk,1985)

$$\nu_{peak} \approx 2.72 \times 10^3 10^{0.27\delta}(\sin\theta)^{0.41+0.03\delta}(NL)^{0.32-0.03\delta} B^{0.68+0.03\delta}, \tag{7}$$

where L is the scale length of the emission (i.e. dimension of the source along the line of sight) and,B,the magnetic field strength in the source region.So, from the values of $\nu_{peak} = 6000\ MHz, \delta = 4, \theta = 50°, L = 7 \times 10^9 cm$,and $B = 100\ Gauss$,using equation (7), one can obtain the number of electrons per cm^3 with $E > E_0$: $N = 6.03 \times 10^8 cm^{-3}$.If the ratio of the fast electron density to the background electron density is about 1:10-100,then the electron density in the source region of the burst is about $N_e = 6.03 \times 10^9 - 6.03 \times 10^{10} cm^{-3}$.

Finally, inserting the δ and N into equations (1) and (2), therefore, we have derived the energy distribution of the nonthermal energetic electrons in the source region at the time of the maximum radiation (the major peak of the burst):

$$n(E) = 1.81 \times 10^{21} E^{-4}, \tag{8}$$

where energy E is in units of eV.

By using equation (8), one can calculate the number of electrons, which make predominant contributions to the gyro-synchrotron radiation, per cm^3 with the energy from $100keV$ to $2MeV$: $N(100keV < E < 2MeV) = 6.03 \times 10^5 cm^{-3}$. If the volume of the burst source is about $V \approx L^3 = 3.43 \times 10^{29} cm^3$, then the total number of these electrons in the whole burst source is about $N_{total} \approx 2.07 \times 10^{35}$.It will be seen from this that only a fraction (one thousandth) of the electrons with $E > E_0$ can play an important role in the gyro-synchrotron radiation. These electrons may be the nonthermal electrons which generate the corresponding hard X-ray burst.

As for the minor peak at ~1733 UT,if the burst source is still optically thick at this time,then the electron energy spectral index may be estimated to be $\delta = 4.4$. It follows that the electron energy spectrum at the time of the major peak is harder than the spectrum at the time of the minor peak. It may be inferred that after the minor peak there are some high-energy electrons to be injected into the source region or some low-energy electrons to be accelerated in the source region and then they generate the major peak. Those are just our tentative ideas.

4. Conclusions

The especially great radio microwave burst analysed in the present paper is an important event. On the basis of the emission mechanism of nonthermal gyro-synchrotron radiation, by using the observational data, we have derived and calculated the energy distribution of energetic electrons in the source region of the burst. The results are as follows:

1. The average energy of the emitting electrons is about: $< E > \approx 90\ keV$.
2. The energy distribution of the energetic electrons is: $n(E) = 1.8 \times 10^{21} E^{-4}$.
3. The number density of the electrons making predominant contributions to the radiation is about: $N(100keV < E < 2MeV) \approx 6.0 \times 10^5 cm^{-3}$ and the total number of these electrons in the whole burst source is about: $N_{total} \approx 2.1 \times 10^{35}$.

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