SESSION VIII

CREATION OF HIGH-ENERGY ELECTRON TAILS BY THE LOWER-HYBRID WAVES AND ITS RELEVANCE TO TYPE II AND III BURSTS

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It is commonly anticipated that high-energy electrons play an important role for the wave emission in flare bursts. For instance, electrons with >100 KeV are considered to create microwave emissions through gyrosynchrotron process and hard x-rays may be due to bremstrahlung with >25 KeV electrons. However, electron acceleration mechanism itself is still in speculations.

Recently, Holman(this symposium) proposed the runaway acceleration of electrons by existing dc electric field parallel to the magnetic field. According to his theory, the number of the accelerated electrons is determined by scattering rates of electrons into the runaway regime. He gave the acceleration time of 0.1 sec which is shorter than the observed acceleration time of 1 sec. However, the origin of the dc electric field must be explained for his mechanism to work.

Another candidate for the electron acceleration involves plasma waves which are self-consistently generated by drift current in the plasma. The drift current is associated with gradients of plasma condition (such as density) and exists at the shock front, the edge of the plasma and the magnetic neutral sheet. This drift excites the plasma instability, especially at low plasma beta condition. Most plausible among various plasma instability is the lower-hybrid or modified two-stream instability whose frequency is close to the lower-hybrid frequency and it propagates nearly perpendicular to the ambient magnetic field.

According to the closed or open geometry of the magnetic field lines, two different processes involving the waves are possible for the electron acceleration. First, when the magnetic field lines are partly open such as in Type III bursts, the waves excited in the closed magnetic loop must propagate in space into the open field line region. Otherwise, the accelerated electrons never escape into the free space. This may be called indirect process. Secondly, when the acceleration takes place only in the closed magnetic field, the acceleration can be direct and more efficient. In the latter case, the excited waves act as catalyst

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and accelerate electrons in the source region (for example, Type II bursts). In this case, it is possible that the final electron energy is comparable to the drift current energy, which could be by orders of magnitude larger than the wave energy itself.

Recent simulation study by Tanaka and Papadopoulos (1983) discovered selective acceleration of electrons via plasma instability even at low drift speed condition. Their mechanism is physically quite self-consistent and does not need to assume "external" electric field. Figure 1 shows formation of high-energy electron tails in the (x,v) phase space. This process occurs in the time scale of $50\omega_{LH}^{-1}$. Final shape of the electron distribution function vs. $v_{\parallel}$ is shown in Figure 2. For the case shown in Figure 1 and 2, the simulation was done in 1-D. In 2-D run, the high-energy electron tails appear on the both side of v =0. The number of electrons being accelerated is approximately 10% and their energy is 50 to 100 times of the background electron temperature.

Formation of the energetic electron tails is possible when the following conditions are satisfied: (1) Plasma instability (so called modified two-stream instability - McBride et al.(1972)) must occur. This gives the lower threshold to the drift speed v_d as $v_d>c_s$ where c_s is the sound speed, (2) Ions must be trapped first and saturate the instability so that "heavy" electrons may not be confined in the wave potential field. This is possible when $v_d \lesssim 3v_i$ where $v_i=(2T_i/m_i)^{1/2}$ is the ion thermal speed, (3) Plasma beta must not be high, say $\beta \lesssim 0.1$. This is because the saturation level of the instability (hence the wave amplitude) is a rapidly decreasing function of the plasma beta around $\beta \sim 1$, and also because the most unstable wave propagates almost perpendicular to the magnetic field at low beta condition. The latter yields $v_{ph,\parallel}=\omega/k_{\parallel} \sim (T_i/T_e)^{1/2} v_e$ $(k_{\parallel}/k \sim (m_e/m_i)^{1/2}$ for $\beta \ll 1)$. Combining (2) and (3) yields the condition for the selective acceleration of electrons as $c_s \lesssim v_d \lesssim 3v_i$. This criterion is new and different from the previous study by McBride et al. (1972) which showed bulk heating of electrons at high drift speed conditions.

Theoretically, the high-energy electron tails are the result of the wave-particle interaction where the wave mode changes from the slower one to the faster one with $v_{ph,\parallel}=5 \sim 7v_e$. Rowland et al.(1983) tried to explain this process in terms of the eigenmode shift due to ion heating. However, what is happening in the simulation is not ion heating but clealy ion trapping (cf. right column of Figure 1). The eigenmode shift is then explained in terms of ion trapping (cf. Tanaka and Papadopoulos(1983)). The dispersion equation for the ion trapping state is given by

$$D = 1 + \frac{2\omega_e^2}{k^2 v_e^2}\left[\ 1 + \zeta_0 Z(\zeta_0) e^{-\lambda}\ \right] - \frac{\omega_i^2}{(\omega - k_{\perp} v_d)^2 - k_{\perp}^2 u_0^2} = 0, \qquad (1)$$

where ω_e, ω_i are the electron and ion plasma frequency, respectively,

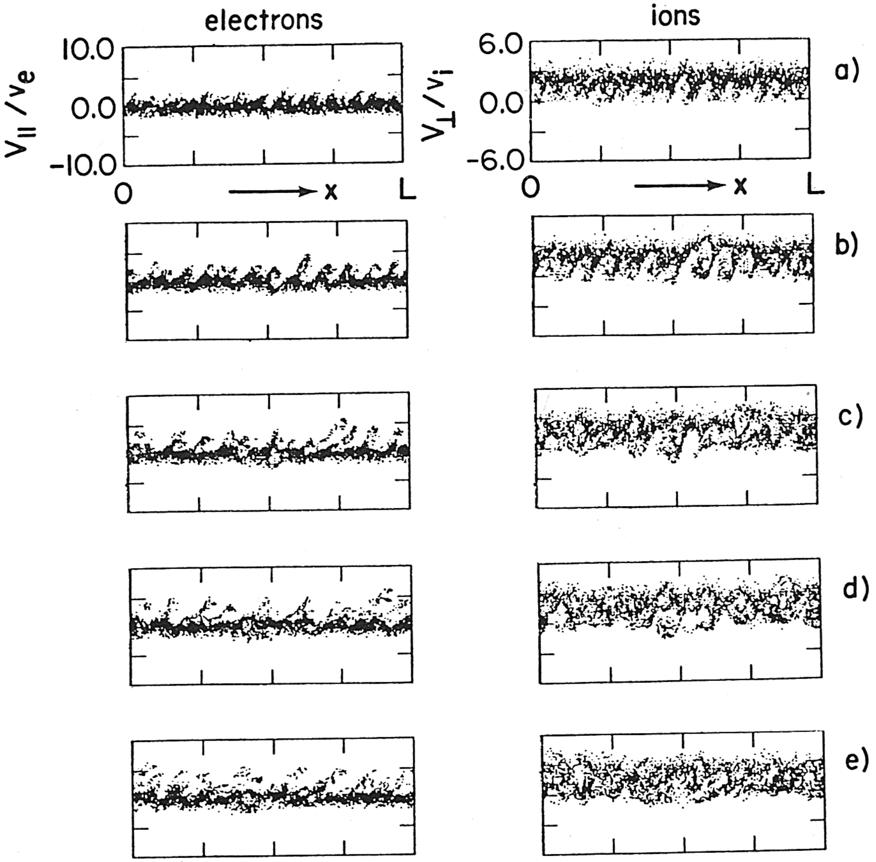

Fig.1 Phase space plots of electron and ion distributions. a)-e) correspond to time 20,30,40,50,60ω_{LH}^{-1}.

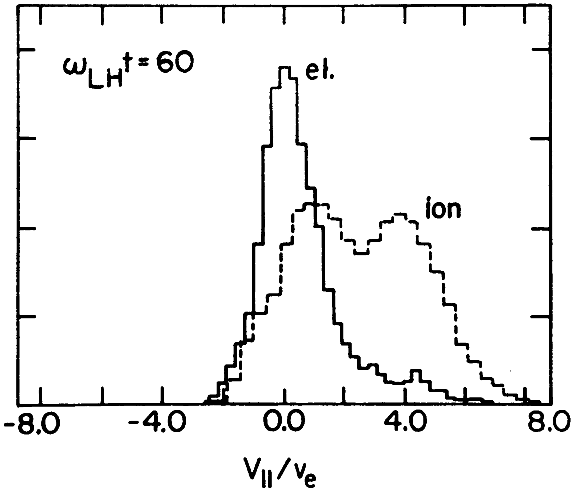

Fig.2 Distribution functions corresponding to Fig.1e).

v_e is the electron thermal speed, $\zeta_e=\omega/k_\parallel v_e$, $\lambda=k_\perp^2 v_e^2/2\Omega_e^2$, v_d is the cross-field drift and u_0 is the "effective" temperature of the trapped (square) ion distribution function. Equation (1) gives the frequency of the faster mode as

$$\omega \gtrsim [\ 1+(k_\parallel^2/k^2)(m_i/m_e)\ ]^{1/2},$$

and $v_{ph,\parallel}\sim 6v_e$. This very well explains the simulation results.

Finally, some applications are shown here. One attempt was made by Smith(this symposium) to explain hard x-ray bursts. Another possible application is to the Type II bursts (closed field line case). If we assume a travelling spherical shock with the radial speed of V and the diamter L, the number of electrons picked up per unit time is estimated by $\pi(L/2)^2Vn$ where n is the electron density at the shock front. This yields 10^{35} electrons/sec which appears to be large enough to explain x-rays and microwaves ($L=10^4$ Km, $V=10^3$ Km/sec, $n=10^9$ cm^{-3} are used. To get the number of energetic electrons we have to multiply some factor to 10^{35}. However, this factor is order of 0.1). The energy of these electrons can be 50 to several hundred KeV, and this acceleration is achieved in the time of $50\omega_{LH}^{-1}\sim 10^{-6}$ sec (B=100G). This is of course short enough to explain the observed flare and emission growth.

References

McBride, J.B., Ott, E., Boris, J.P., Orens, J.H.: 1972, Phys. Fluids 15, 2367.

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DISCUSSION

D. Smith: For your model of type II bursts, even though you have a couple of orders of magnitude to spare, the condition for the angle between the ion flow and magnetic field is fairly critical and is probably only satisfied in small regions of the total shock. Shouldn't you include some factor for this in your estimates?

Tanaka: The plasma drift v_d, which is a free energy source for the instability, is actually dependent on the angle between the shock normal and the magnetic field. The drift may be largest for the perpendicular shock. However, once $v_d \gtrsim c_s$ is satisfied, the instability and high-energy electrons are resulted.

Steinolfson: How do you envision that the electric fields needed for this instability could be produced?

Tanaka: My mechanism proposed is physically self-consistent and does not need a priori assumption on the electric field.