ELECTRON HEATING AND ACCELERATION WHILE MAGNETOSPHERE SUBSTORM DUE TO VARYING WHISTLER WAVE PHASE VELOCITY

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Some properties of chorus radiation while magnetosphere substorm are discussed. The influence of the hydro magnetic waves on the electron distribution function is studied by numerical simulations. A quasi-linear 2D in velocity space operator models the electron damping of plasma eigenmodes. The dynamic of process is estimated under condition of varying in time of phase velocity and hence of phase resonance on the base of chorus radiation while substorms. This allows us to explain acceleration and heating of energetic electrons that double up energy during the stage of substorm.
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1. PRELIMINARIES

The effects of particle precipitation in the Earth's aurora zone are discussed in numerous publications (for example, [1,2]). Studies have shown that the electron precipitation related to substorms can be induced by wave-particle interactions around the magnetospheric equatorial plane. Those waves can be generated in the Earth's magnetosphere due to the maser-effect [3]. A significant number of observational data on electron precipitation has been correlated to chorus [4]. In this paper we address the following problem. We consider that the turbulence is composed of hydro magnetic waves that are assumed to be propagation along the ambient magnetic field. The wave power absorption mechanism due to Landau damping is considered in the framework of the standard quasi-linear theory of wave-particle interaction. For simplicity we use the local approximation in which the velocity space is connected with the given force line of the magnetic field. Thus the magnetized plasma is assumed to be space homogeneous and that charge neutrality is provided. The hydro magnetic wave level is not too high, so the weak turbulence theory can be applied. Starting with the initial Maxwellian distribution we describe the evolution of the electron distribution function with following equation

$$\frac{df(v_\parallel, v_\perp, t)}{dt} = \frac{\partial}{\partial v_\parallel} D \frac{\partial f}{\partial v_\parallel} - \delta f,$$
$$-\infty \le v_\parallel \le \infty, v_\perp \ge 0.$$

Here D is the standard quasi-linear coefficient $D = \pi e^2 / m^2 \sum_k \left| E_{\parallel k} \right|^2 \delta(\omega - k_\parallel v_\parallel)$ which contains the information about averaged wave amplitudes. The value of the wave packet width is taken approximately of the phase velocity order $\Delta v_{ph} \sim v_{ph}$. We use the following simple approximation for D in which the diffusion coefficient is constant within the phase region and equals zero in other parts of the velocity space: $D = const$, if $\left| v_\parallel - v_{ph} \right| \le \Delta v_{ph}$, and $D = 0$, otherwise. The integrals $\int f d\breve{v}$ and $\int f v^2 d\breve{v}$ are defined normalized particle density and energy, respectively. The phase resonance region and the values of the diffusion coefficient, which are the parameters of the problem, define the electron scattering into the loss cone, i.e. energy and the particle flux, due to waves. Any external particle sources usually are not taken into account and the plasma dynamics is studied over the plasma decay. Therefore, we deal with quasi-stationary state problem. Under the wave influence the electron distribution function tends to the form of a `plateau' with respect to the parallel velocity in the resonance region. The anisotropy of the distribution function over pitch angles depends on time and after some relaxation period the electron function takes on a quasi-stationary form. The particles diffused toward high parallel velocities would enter the loss cone and would escape from the trap at once. Thus, the waves induce precipitation in two ways: due to a distortion of the electron distribution over pitch angles and due to the plasma heating.

Magnetosphere is considered being Alfvén maser and the characteristic time of the electron losses out of the magnetic trap with the mirror ratio R is chosen equal to $T_C = \sqrt{R} \approx 10$. Then in the above diffusion equation the loss term is $\delta \cdot f$, where $\delta = T_C^{-1}$ if $v_\parallel / v_\perp \ge \sqrt{R}$ and $\delta = 0$, otherwise. The dynamic of the electron precipitation process is estimated under the condition that the phase velocity of the whistler waves in not constant in time. Chorus radiation while magnetosphere substorm (see, for example, [4]) consists in successive discrete positively inclined elements, $d\omega / dt > 0$, that follow consequently with frequency 1-10 kHz. Micro precipitation of electrons with energy more than 20 keV is closely connected with chorus. From the observation data of chorus dynamic while magnetosphere substorm we take typical parameters of the process. The velocity is normalized on phase velocity and the characteristic time unit is 1 sec.

2. NUMERICAL SIMULATION RESULTS

We present the results of simulations for the following parameters. We start with the initial Maxwellian distribution and present the results of numerical simulations of the electron distribution function and rf- enhanced energy. We give two examples of simulation results: for the diffusion coefficient $D=10^{-2}$ and $D=10^{-3}$. The phase resonant region moves over parallel velocity with time following data obtained from observation. Characteristic time period of one pulsation is subdivided on two unequal periods: during time period $\Delta t_1 = 0.9$ the resonant region is maintained stable with the phase velocity equals $v_{ph} = 1.5$ and the width to $\Delta v_{ph} = 0.5$. Then during the period $\Delta t_2 = 0.1$ corresponding to chorus precipitation the resonant region it is extending until $v_{ph} = 2.5$. The wave packet does not change its phase velocity width. Such a process is successively repeated during about 0.5-1 hour. While relatively short initial stage the Maxwellian adopts the loss cone form, then the quasi-stationary state is established. In the Figs. 1 and 2 the averaged energy of precipitated electrons and of the electrons that are trapped are shown as a function of time for two values of the diffusion coefficient D. The established value of precipitated electron energy does not differ much for different diffusion coefficients. The variance can be seen in the initial stage, see Figs. 1, 2.

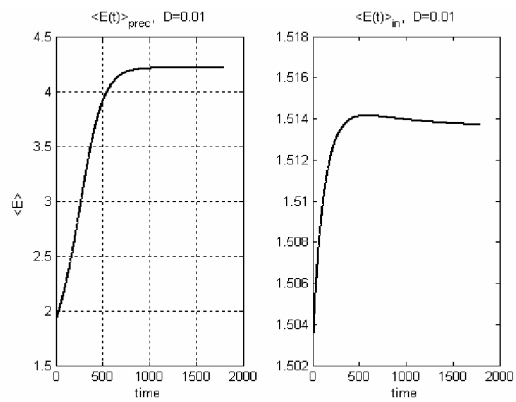

Fig. 1. Time dependence of normalized averaged energy of electrons that are precipitated into loss cone (left) and the averaged energy of the electrons in the mirror trap for D=0.01

Obviously the time relaxation of the system to quasi-state is shorter for larger diffusion coefficient. The dissipated wave power and the electron velocity can be enhanced for the wave phase velocity that increasing in time. The quasi-linear operator with moving phase resonant region rakes up electrons from the domain with higher density to the higher energetic region. That is why dissipated wave power is larger in comparison with the case when the phase velocity region is constant. The diffusion operator forms the distribution function plateau within the region of its action. Fig. 3 demonstrates the electron distribution function in the steady state for D=0.01. It should be noted that, to form plateau for relatively small diffusion coefficients D = 0.001-0.01 within "changing " in time phase resonant region there is necessary to pass over hundreds seconds.

Explanations of field-aligned particle precipitation by means of Landau damping with varying phase velocity in time is able to provide sufficient increase in electron energy of chorus while substorm. This allows us to explain acceleration and heating of energetic electrons that double up energy on the stage of substorm. In this preliminary study, the observational data could be interpreted in terms of the phenomena observed in the simulations. These simulation results can be incorporated into a more complicated model of the auroral activity.

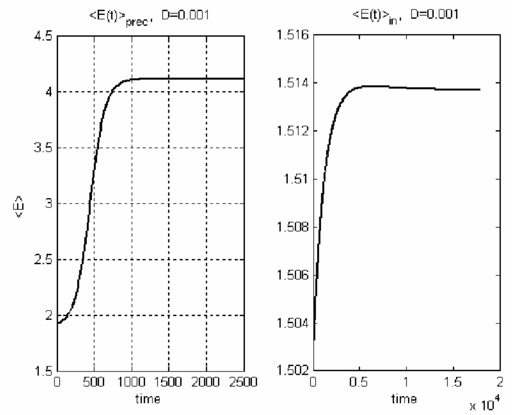

Fig. 2. Time dependence of normalized averaged energy of electrons that are precipitated into loss cone (left) and the averaged energy of the electrons in the mirror trap for D=0.001

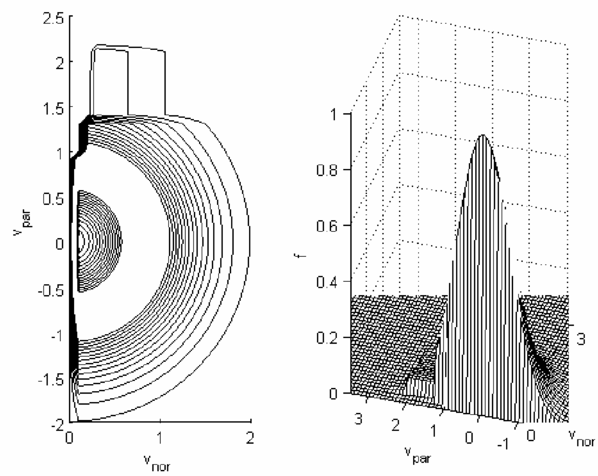

Fig. 3. The steady-state electron distribution function for D=0.01

3. SUMMARY

The established value of precipitated electron energy does not differ much for different diffusion coefficients. The variance can be seen in the initial stage, see Figs.1-3. Obviously the time relaxation of the system to quasi-state is shorter for larger diffusion coefficient. The dissipated wave power and the electron velocity can be enhanced for the wave phase velocity that increasing in time. The quasi-linear operator with moving phase resonant region rakes up electrons from the domain with higher density to the higher energetic region. That is why dissipated wave power is larger in comparison with the case when the phase velocity region is constant. The diffusion operator forms the distribution function plateau within the region of its action. Fig. 3 demonstrates the electron distribution function in the steady state for D=0.01. It should be noted that, to form plateau for relatively small diffusion coefficients D = 0.001-0.01 within "changing " in time phase resonant region there is necessary to pass over hundreds seconds.

Explanations of field-aligned particle precipitation by means of Landau damping with varying phase velocity in time is able to provide sufficient increase in electron energy of chorus while substorm. This allows us to explain acceleration and heating of energetic electrons that double up energy on the stage of substorm. In this preliminary study, the observational data could be interpreted in terms of the phenomena observed in the simulations. These simulation results can be incorporated into a more complicated model of the auroral activity.

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НАГРЕВ И УСКОРЕНИЕ ЭЛЕКТРОНОВ ПРИ ИЗМЕНЕНИИ ФАЗОВОЙ СКОРОСТИ ВИСТЛЕРОВ ПРИ МАГНИТОСФЕРНОЙ СУББУРЕ

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Обсуждаются некоторые свойства хорового излучения. Численными методами исследуется влияние магнитогидродинамических волн на функцию распределения электронов. Квазилинейный двумерный в скоростном пространстве оператор моделирует электронное затухание плазменных собственных волн. Динамика процесса описана в условиях изменяющейся со временем фазовой скорости, а, следовательно, и фазового резонанса на основе хорового излучения во время суббури. Это позволило нам объяснить ускорение и нагрев энергетичных электронов, удваивающих свою энергию во время стадии суббури.

НАГРІВ ТА ПРИСКОРЕННЯ ЕЛЕКТРОНІВ ПРИ ЗМІНІ ФАЗОВОЇ ШВИДКОСТІ ВІСТЛЕРІВ ПРИ МАГНІТОСФЕРНІЙ СУББУРІ

В.І. Карась, І.Ф. Потапенко

Обговорюються деякі властивості хорового випромінювання. Чисельними методами досліджується вплив магнітогідродинамічних хвиль на функцію розподілу електронів. Квазілінійний двовимірний у просторі швидкостей оператор моделює електронне затухання плазмових власних хвиль. Динаміка процесу описана в умовах, коли змінюється за часом фазова швидкість, а, тому, і фазовий резонанс, на основі хорового випромінювання під час суббурі. Це дозволило нам пояснити прискорення і нагрів енергетичних електронів, котрі подвоюють свою енергію під час стадії суббурі.