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TEMPORAL EVOLUTION OF THE PLASMA DENSITY CAVITY CAUSED BY INHOMOGENEOUS STOCHASTIC ELECTRIC FIELDS

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The time evolution of the formation of a plasma density cavity caused by inhomogeneous stochastic electric fields is investigated. The Fokker-Planck equation, which governs the temporal evolution of the plasma electron density due to localized stochastic inhomogeneous electric fields in the frequency range of lower hybrid oscillations, is solved numerically. The spatial dependence of the plasma electron density for various times is obtained.

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INTRODUCTION

In the plasma of the Earth's ionosphere and magnetosphere near the auroral zone, satellites and sounding rockets have detected regions with a depleted density of plasma and an increased level of oscillations in the lower hybrid frequency range which are called lower hybrid cavities (LHC) [1 - 8]. The measurements showed that the LHC are cylindrical regions elongated along the geomagnetic field. Their perpendicular size is 10…100 m which is equal to a few ion gyroradii, while along the geomagnetic field LHC extends for several kilometers, and possibly for tens or hundreds of kilometers. As an explanation for this phenomenon, it was suggested in [9 - 12] that LHCs appear as a result of modulation instability and lower hybrid collapse. However, it was shown in [13] that this model does not correspond to the properties of most of the observed cavities. In [14], another mechanism for the occurrence of LHC was proposed, which assumes the appearance of an ion density cavity due to their expulsion from a certain volume by inhomogeneous stochastic oscillations with a frequency of the order of the lower hybrid frequency. A similar effect of electron expulsion due to an inhomogeneous harmonic electric field was considered in [15].

In [16], the diffusion and drift motion of both ions and electrons across the magnetic field due to the action of inhomogeneous stochastic electric fields was studied. It was shown that the movement of electrons is much faster than that of ions, so that the formation of an electron cavity occurs much earlier than an ionic one. In [17, 18], the influence of the thermal motion of plasma particles on the conditions for the formation of a cavity was studied. In particular, it was shown that an electron density cavity can form if, during the formation of the cavity, the electrons do not leave the region with an increased level of oscillations along the magnetic field. Based on the Fokker-Planck equation, the steady state plasma density distribution was obtained [16 - 18], assuming that the evolution of the distribution function has ended.

In this paper, we study the temporal evolution of the formation of an electron cavity. Solving the Fokker-Planck equation, we obtain the electron density distribution at various points in time.

1. DIFFUSION AND DRIFT OF ELECTRONS

We consider collisionless and initially homogeneous plasma in a constant magnetic field H directed along the z axis, in which at some time a region with a stochastic electric field appears, which is inhomogeneous along the x axis and homogeneous in other directions. It is assumed that the frequency range of stochastic oscillations is near the lower hybrid frequency ω_{lh}, which is much lower than the electron cyclotron frequency ω_{ce}.

To study changes in time of the spatial distribution of the electron density $n(x,t)$ due to inhomogeneous stochastic electrostatic oscillations, we use the one-dimensional Fokker-Planck equation

$$\frac{\partial n(x,t)}{\partial t} = -\frac{\partial}{\partial x}\left(A(x)n(x,t)\right) + \frac{\partial^2}{\partial x^2}\left(\frac{B(x)}{2}n(x,t)\right), \quad (1)$$

where $A(x)$ is the drift velocity and $B(x)/2$ is the diffusion coefficient of electrons. These values are defined from the particle motion equation as the quasi-linear drift velocity averaged over a long time and the displacement velocity of the squared rms electron displacement.

The equation of motion of an electron in constant magnetic and stochastic electric fields is

$$\frac{d\vec{v}}{dt} = \frac{e}{m_e}F(x)\vec{E}(\vec{r},t) + \frac{e}{m_e}\left[\vec{v},\vec{H}\right], \quad (2)$$

where $\vec{E}(\vec{r},t)$ is the electric field strength of stochastic oscillations far from the region with a high level of turbulence, $F(x)$ is the envelope of stochastic oscillations, which has a maximum at $x = 0$ and $F(\infty) = 1$.

Neglecting in the zero approximation the influence of the stochastic electric field, we obtain the solution of equation (2) in the form of integrals of motion

$$X = x + \frac{v_y}{\omega_{ce}}, \quad Y = y - \frac{v_x}{\omega_{ce}}, \quad p_z = m_e v_z, \quad (3)$$

where X and Y are the coordinates of the guiding center of electron and p_z is the electron momentum along the magnetic field. The first two integrals mean the invariability in time of the coordinates of the guiding center of an electron rotating in a magnetic field.

The next approximation in (2) takes into account the effect of stochastic electric fields, which leads to small changes in the integrals of motion (3). In this case, the solution of equation (2) is represented as $\vec{v}=\vec{v}_{0e}+\vec{v}_{1e}$, where $\vec{v}_{0e}$ is the electron velocity vector at the initial moment of time the components of which are random variables distributed according to the normal law, that is, $|\vec{v}_{0e}|=v_{Te}$ is the thermal velocity of electrons, $\vec{v}_{1e}$ is the fluctuation of the velocity, caused by stochastic electric fields and which is defined by the equation

$$\frac{d\vec{v}_1}{dt}=\frac{e}{m_e}F(x)\vec{E}(\vec{r},t)+\frac{e}{m_e}\left[\vec{v}_1,\vec{B}\right]. \quad (4)$$

The solutions of (4) for the components of velocity are

$$v_{1x}=\frac{eF(x)}{m_e\omega_{ce}^2}\frac{dE_x(\vec{r},t)}{dt}+\frac{eF(x)}{m_e\omega_{ce}}E_y(\vec{r},t), \quad (5)$$

$$v_{1y}=\frac{eF(x)}{m_e\omega_{ce}^2}\frac{dE_y(\vec{r},t)}{dt}-\frac{eF(x)}{m_e\omega_{ce}}E_x(\vec{r},t), \quad (6)$$

$$v_{1z}=\frac{e}{m_e}F(x)\int_{t_0}^{t}E_z(\vec{r},t')dt'. \quad (7)$$

Since it is assumed that the stochastic electric field is inhomogeneous along the *x* axis, the electron density changes only along this axis, while in other directions the density gradient is zero. Therefore, across the magnetic field, the influence of the stochastic field is considered only on the change in the *X*-component of the coordinate of the guiding center. To define the change in *X* due to stochastic electric fields, the *X* coordinate is written as

$$X=X_0+X_1, \quad (8)$$

where X_1 is the random displacement of the coordinate of the guiding center due to stochastic electric fields. Using (3) we write

$$X_1=x_1+\frac{1}{\omega_{ce}}v_{1y}. \quad (9)$$

In equation (9), the value of x_1 is defined by integrating v_{1x} (5) over time

$$x_1=\int_0^t v_{1x}(t')dt'=$$

$$=\frac{eF(x)}{m_e\omega_{ce}^2}\left(E_x(\vec{r},t)+\omega_{ce}\int_0^t E_y(\vec{r},t')\right). \quad (10)$$

Substituting (6) and (10) into (9) yields

$$X_1=\frac{eF(x)}{m_e\omega_{ce}}\int_0^t E_y(\vec{r},t')dt'+\frac{eF(x)}{m_e\omega_{ce}^3}\frac{dE_y(\vec{r},t)}{dt}. \quad (11)$$

Differentiating (9) with respect to time and using (5) and (6), we find the rate of change of X_1

$$\frac{dX_1}{dt}=v_{1x}+\frac{1}{\omega_{ce}}\frac{dv_{1y}}{dt}=\frac{e}{m_e}\frac{1}{\omega_{ce}}F(x)E_y(\vec{r},t). \quad (12)$$

Then multiplying (11) by (12) and averaging over a large time interval, we obtain the rate of change of the root-mean-square displacement

$$\left\langle X_1\frac{dX_1}{dt}\right\rangle=\frac{1}{2}\frac{d\left\langle X_1^2\right\rangle}{dt}=\frac{e^2}{m_e^2}\frac{F^2(x)}{\omega_{ce}^2}$$

$$\times\left(\int_0^t\left\langle E_y(\vec{r},t')E_y(\vec{r},t)\right\rangle dt'+\frac{1}{\omega_{ce}^2}\frac{1}{2}\frac{d\left\langle E_y(\vec{r},t)\right\rangle}{dt}\right). \quad (13)$$

Neglecting the second term in (13) which is much smaller than the first one, we obtain

$$\frac{1}{2}\frac{d\left\langle X_1^2\right\rangle}{dt}=\frac{e^2}{m_e^2}\frac{F^2(x)}{\omega_{ce}^2}\int_0^t\left\langle E_y(\vec{r},t')E_y(\vec{r},t)\right\rangle dt'. \quad (14)$$

We assume that the strength of stochastic electric fields satisfies the conditions

$$\left\langle\vec{E}(\vec{r},t)\right\rangle=0,$$

$$\left\langle\vec{E}(\vec{r},t)\vec{E}(\vec{r},t''')\right\rangle=\left|\vec{E}^2(\vec{r},t)\right|=\left|\vec{E}^2(\vec{r})\right|, \quad (15)$$

where $\left|\vec{E}^2(\vec{r})\right|$ is the square of the amplitude of stochastic oscillations which does not depend on time. Taking into account the condition (15) we obtain from (14)

$$\frac{1}{2}\frac{d\left\langle X_1^2\right\rangle}{dt}=\frac{B(x)}{2}=\frac{e^2}{m_e^2\omega_{ce}^2}F^2(x)\left|E_y^2(\vec{r})\right|t. \quad (16)$$

Equation (16) can also be written as

$$\frac{B(x)}{2}=F^2(x)\left|v_{dx}^2(\vec{r},t)\right|t, \quad (17)$$

where

$$v_{dx}=\frac{cE_y}{H}, \quad (18)$$

is the velocity of the drift motion of electrons in crossed electric and magnetic fields along the *x*-axis. Thus, the rate of the root-mean-square displacement of the coordinate of the guiding center along the *x*-axis is defined by the mean value of the square of *y*-component of the stochastic electric field, or, otherwise, by the mean value of the square of the electron drift stochastic velocity in crossed fields.

The formation of the electron density cavity is influenced by their motion along the magnetic field. In order for the cavity to form, it is necessary that during the time of the formation of the cavity, the electrons along the magnetic field would not leave the region with an increased level of oscillations. For this estimate, we need to define the electron diffusion coefficient along the magnetic field. From (3) and (7) we get

$$\frac{1}{2}\frac{d\left\langle z(t)^2\right\rangle}{dt}\approx\frac{e^2}{2m_e^2\Delta\omega^2}F^2(x)\left|E_z^2(\vec{r})\right|t+v_{Te}^2t,$$

where $\Delta\omega$ is the width of the spectrum of stochastic oscillations which is the order of ω_{lh} [16, 17]. However, the effect of the stochastic electric field on diffusion along the magnetic field can be neglected in comparison with thermal motion, so

$$\frac{1}{2}\frac{d\left\langle z(t)^2\right\rangle}{dt}\approx v_{0e}^2t. \quad (19)$$

Comparison of (17) and (19) shows that the diffusion coefficient along the magnetic field is much greater than across the magnetic field.

In order to find the speed of the drift motion of electrons along the *x* axis *A*(*x*) due to the ponderomotive force, which caused by the inhomogeneity of stochastic oscillations, we represent the random displacement of the coordinate of the guiding center as the sum of the oscillating and quasilinear components

$$X_1=\tilde{X}+\bar{X}, \quad (20)$$

where $\langle X_1 \rangle = \bar{X}$ and $\langle \tilde{X} \rangle = 0$. Substituting (20) into (12), yields

$$\frac{dX_1}{dt} = \frac{d\tilde{X}}{dt} + \frac{d\bar{X}}{dt} = \frac{e}{m_e}\frac{1}{\omega_{ce}} F(x) E_y(\vec{r},t). \quad (21)$$

Expand envelop function $F(x)$ in a Taylor series about the initial value of the position of the coordinate of the guiding center

$$F(x) = F(X_0) + \nabla F(X_0) \cdot x_1 \quad (22)$$

and substitute (22) into (21)

$$\frac{dX_1}{dt} = \frac{e}{m_e}\frac{1}{\omega_{ce}}\left(F(X_0) + x_1 \nabla F(X_0)\right) E_y(\vec{r},t). \quad (23)$$

Then averaging over a large time interval we obtain the rate of quasi-linear change in the coordinate of the guiding center

$$\frac{d\langle X_1 \rangle}{dt} = \frac{d\bar{X}}{dt} = \frac{e}{m_e}\frac{1}{\omega_{ce}} \nabla F(X_0) \langle x_1 E_y(\vec{r},t) \rangle. \quad (24)$$

Find in (24) $\langle x_1 E_y(\vec{r},t) \rangle$ substituting the value x_1 (10):

$$\langle x_1 E_y(\vec{r},t) \rangle =$$

$$= \frac{eF(X_0)}{m_e \omega_{ce}^2} \left\langle \left(\vec{E}_x(\vec{r},t) + \omega_{ce} \int_0^t \vec{E}_y(\vec{r},t') dt' \right) E_y(\vec{r},t) \right\rangle.$$

Since $\langle \vec{E}_x(\vec{r},t) E_y(\vec{r},t) \rangle = 0$ we obtain

$$\frac{d\bar{X}}{dt} = \frac{e_e^2}{m_e^2 \omega_{ce}^2} F(X_0) \nabla F(X_0) \int_0^t \langle E_y(\vec{r},t) E_y(\vec{r},t') \rangle dt'. \quad (25)$$

Integration (25) using condition (15) yields

$$\frac{d\bar{X}}{dt} = \frac{e^2}{2 m_e^2 \omega_{ce}^2} \nabla F^2(X_0) \left| E_y(\vec{r}) \right|^2 t$$

and then applying the notation (18) we write this equation as

$$\frac{d\bar{X}}{dt} = A(x) = \frac{1}{2} \nabla F^2(X_0) \left| v_{dx}^2(\vec{r},t) \right| t. \quad (26)$$

Equation (26) defines the drift velocity $A(x)$ of the guiding center of electron along the x-axis.

2. TIME EVOLUTION OF THE PLASMA ELECTRON DENCITY DISTRIBUTION

Let us study the evolution of the development of electron density cavity in time, assuming that the size of the region with an increased level of oscillations along the magnetic field is large enough, so that the electrons do not have time to leave this region before the cavity is formed. Substituting the diffusion coefficient (17) and drift velocity (26) into equation (1) yields

$$\frac{\partial n(x,t)}{\partial t} = \left| v_{dx}^2(\vec{r},t) \right| t$$

$$\times \frac{\partial}{\partial x}\left(-\frac{1}{2} \nabla F^2(x) n(x,t) + \frac{\partial F^2(x) n(x,t)}{\partial x} \right). \quad (27)$$

It is assumed that at the initial time $t = 0$ the plasma density has a uniform distribution $n(x) = n_0 = \text{const}$. It was shown [17, 18] that due to the action of localized stochastic electric fields with an envelope $F(x)$ at the end of evolution in a stationary state, i.e., at $t = \infty$ the dependence of the electron density on the x-axis is defined by the relation

$$n(x) = \frac{n_0}{F(x)}. \quad (28)$$

Now, using the equation (27), we study the evolution of the spatial distribution of the electron density, i.e. how the density distribution changes over time from uniform to (28). To solve the equation (27), we introduce a new unknown function $N(x,t)$, which is related to $n(x)$ by

$$N(x,t) = n(x,t) F(x). \quad (29)$$

The initial condition for this function is

$$N(x,0) = n(x,0) F(x) = n_0 F(x). \quad (30)$$

Substituting (29) into (27) yields

$$\frac{1}{F(x)} \frac{\partial N(x,t)}{\partial t} = \left| v_{dx}^2(\vec{r},t) \right| t$$

$$\times \frac{\partial}{\partial x}\left(-\frac{1}{2} \nabla F^2(X_0) \frac{N(x)}{F(x)} + \frac{\partial}{\partial x}\left(F^2(x) \frac{N(x)}{F(x)} \right) \right)$$

and after simplifications this equation becomes

$$\frac{\partial N(x,t)}{\partial t} = \left| v_{dx}^2(\vec{r},t) \right| t F(x)$$

$$\times \frac{\partial}{\partial x}\left(-\nabla F(X_0) N(x) + \frac{\partial}{\partial x}\left(F(x) N(x) \right) \right).$$

Writing here the derivative of the product and simplifying, we get

$$\frac{\partial N(x,t)}{\partial t} = \left| v_{dx}^2(\vec{r},t) \right| t F(x) \frac{\partial}{\partial x}\left(F(x) \frac{\partial N(x)}{\partial x} \right). \quad (31)$$

Denote

$$\left| v_{dx}^2(\vec{r},t) \right| = D, \quad (32)$$

then (31) is written as

$$\frac{\partial N(x,\tau)}{\partial t^2} = \frac{1}{2} D F(x) \frac{\partial}{\partial x}\left(F(x) \frac{\partial N(x)}{\partial x} \right). \quad (33)$$

Equation (33) is the diffusion equation, which, unlike (27), no longer has a drift term. Introducing the renormalized coordinate ξ defined as

$$d\xi = \frac{dx}{F(x)}, \quad (34)$$

or otherwise

$$\xi = f(x) = \int \frac{dx}{F(x)}, \quad (35)$$

equation (33) reduced to the classical diffusion equation

$$\frac{\partial N(\xi,t)}{\partial t^2} = \frac{1}{2} D \frac{\partial^2 N}{\partial \xi^2}. \quad (36)$$

To solve (36), we write the Fourier transform for $N(\xi,t)$

$$\nu(s,t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} N(\xi,t) e^{is\xi} d\xi, \quad (37)$$

and then perform the Fourier transform of (36) by multiplying it by $\left(1/\sqrt{2\pi}\right)\exp(is\xi)$ and integrating over ξ

$$\frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \frac{\partial N(\xi,\tau)}{\partial t^2} \exp(is\xi) d\xi =$$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \frac{1}{2} D \frac{\partial^2 N}{\partial \xi^2} \exp(is\xi) d\xi . \quad (38)$$

Integrating the right side of (38) twice by parts and using (37) we get

$$\frac{\partial \nu}{\partial t^2} = -\frac{1}{2} s^2 D \nu(t,s) . \quad (39)$$

Equation (39) has a solution

$$\nu(s,t) = Ce^{-\frac{1}{2}Ds^2t^2} .$$

The constant C is found from the initial condition (30) and relation (37)

$$C = \nu(s,0) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} n_0 F(x(\xi')) e^{is\xi'} d\xi' .$$

And thus

$$\nu(s,t) = \frac{n_0}{\sqrt{2\pi}} e^{-\frac{1}{2}Ds^2t^2} \int_{-\infty}^{\infty} F(x(\xi')) e^{is\xi'} d\xi' . \quad (40)$$

After the inverse Fourier transform in (40), we obtain

$$N(\xi,t) = \frac{n_0}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} F(x(\xi')) e^{-is\xi + is\xi' - \frac{1}{2}Ds^2t^2} ds d\xi' . \quad (41)$$

Integrating in (41) over s yields

$$N(\xi,t) = \frac{n_0}{2\pi} \sqrt{\frac{2\pi}{Dt^2}} \int_{-\infty}^{\infty} F(x(\xi')) e^{-\frac{(\xi'-\xi)^2}{2Dt^2}} d\xi' . \quad (42)$$

To obtain the dependency $N(x,t)$, it is necessary to perform in (42) the inverse substitutions of variables (34) and (35)

$$N(x,t) = \frac{n_0}{\sqrt{2\pi Dt^2}} \int_{-\infty}^{\infty} \exp\left(-\frac{(f(x') - f(x))^2}{2Dt^2} \right) dx' . \quad (43)$$

Finally, using (29), we obtain from (43) an expression for the distribution of plasma electrons density at an arbitrary moment of time

$$n(x,t) = \frac{n_0}{F(x)\sqrt{2\pi Dt^2}}$$

$$\times \int_{-\infty}^{\infty} \exp\left(-\frac{(f(x') - f(x))^2}{2Dt^2} \right) dx' . \quad (44)$$

This completes the formal part of the solution, and further, to obtain a specific dependence of the density on the coordinate, it is necessary to choose the form of the envelope function $F(x)$. At that the form of $F(x)$ is limited by the necessary requirements to have a maximum at $x = 0$ and decrease to $F=1$ at $x=\pm\infty$. We choose $F(x)$ as

$$F(x) = 1 + \frac{a}{1 + \left(\frac{x}{x_0}\right)^2} = 1 + \frac{a}{1 + r^2} , \quad (45)$$

which satisfies these requirements. Here x_0 is the size of the inhomogeneity of the region of stochastic oscillations, parameter a defines the height of the envelope above the background value of stochastic oscillations in the environment, and r is the normalized coordinate along the x-axis. At $x = 0$, the value $(1+a)$ defines how many times the oscillation amplitude exceeds the noise level in the environment. The function $f(x)$ (35) in this case which is in the exponent in (44) is equal to

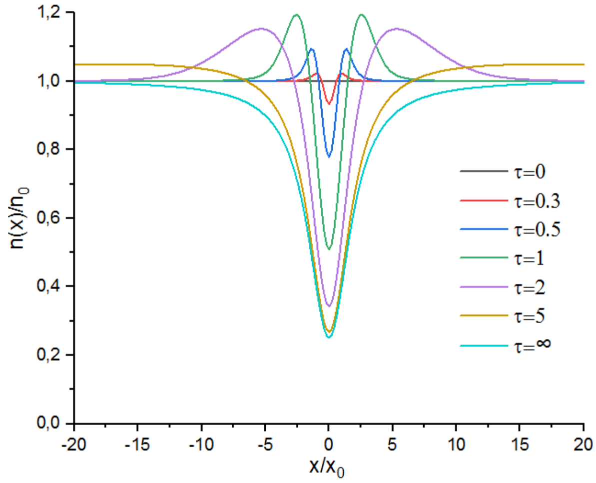
$$f(x) = x - \frac{x_0 a}{\sqrt{1+a}} \arctan \frac{x}{x_0\sqrt{1+a}} ,$$

or using denoting $r = x/x_0$ is

$$f(x) = x_0 \left(r - \frac{a}{\sqrt{1+a}} \arctan \frac{r}{\sqrt{1+a}} \right) = x_0 f(r) .$$

However, the analytical calculation of the integral (44) is associated with great difficulties, and further solution is possible only numerically.

The distributions of the plasma electron density at different times at $a = 3$, obtained from (44), by numerical integration, are shown in Figure.



The dependence of the electron density on the radius for different moments of time

Here τ is the normalized time defined as

$$\tau = \frac{t}{t_0} , \quad (46)$$

where $x_0 / \sqrt{D} = t_0$ is the average time for which an electron drifts over a distance of the size of the envelope inhomogeneity x_0. Estimate t_0 which corresponds $\tau = 1$. Observational data show that the electric field of hiss in the lower hybrid frequency range in the environment is of the order 10…40 mV/m depending on the height. The Earth's geomagnetic field is about 0.5 Oe. Then (18)

$$\sqrt{D} = \sqrt{\left| v_{dr}^2 \right|} \sim 5 \cdot 10^4 \text{cm/s} .$$

The characteristic value x_0 is usually on the order of 10 m. With these parameters, we get $t_0 \sim 0.02$ s and thus a normalized time corresponding to $\tau = 1$ is $t = 0.02$ s.

At the initial moment of time, when a burst of inhomogeneous stochastic oscillations occurs the envelope of which is defined by (45), the plasma density is uniform. Almost immediately, in the region with the maximum amplitude of oscillations, the plasma density becomes depleted, at that the depth and width of the resulting cavity increase up to a time $\tau \sim 5$, after which they practically do not change. In the area adjacent to the cavity the plasma electrons density increases due to electrons that are pushed out of the cavity by inhomogeneous stochastic electric fields. Further these electrons, moving away from the cavity, and their density decreases due to spreading in space.

Estimate the dimensions of the region along the magnetic field with an increased level of oscillations necessary for the formation of electron cavity. As already mentioned, the size of such region must exceed the distance that an electron travels along the magnetic field with a thermal velocity in the time required to form a cavity, in this case, t=0.02 s. For 0.25 eV of the thermal energy of electrons at a height of 600 km, the thermal velocity of electrons is $v_{Te} \sim 3 \cdot 10^7$ cm/s. Then the distance that an electron travels in $t = 0.02$ s is 6 km. Thus, the size of the region with an increased level of oscillations along the magnetic field should at least exceed 6 km. According to the data of the work [7], the size of LHC along the geomagnetic field is certainly a few kilometers and probably a few hundred kilometers. And it can be argued that cavities with such dimensions can be formed due to the transfer of electrons across the magnetic field due to inhomogeneous stochastic fields.

CONCLUSIONS

Inhomogeneous stochastic oscillations of the electric field with frequencies on the order of the lower hybrid frequency lead to the formation of an electron density cavity in a magnetized plasma. It has been established that the cavity formation time for the ionospheric plasma parameters is about 0.02 s. The development of the cavity proceeds as follows. Initially, the cavity depth as well as its width across to the magnetic field are small. Over time, both the depth and width of the cavity increase. The electrons displaced from the cavity form an increased density at the edge of the cavity and move away from it. The formation of an electron density cavity ends in a time of about $\tau \sim 5$ where τ is defined by (46).

A possible hindrance to the formation of a cavity is the escape of electrons along the geomagnetic field from a region with an increased level of oscillations due to thermal motion. Estimates have shown that the size of such a region along the magnetic field should be at least 6 km. At the same time, spacecraft observations have shown that the dimensions of the LHC along the geomagnetic field are tens and hundreds of kilometers. Thus, in order for the electrons to remain inside the region and form a cavity, its dimensions along the magnetic field of the order of 6 km turn out to be quite sufficient.

During the formation of the electron cavity, ions due to drift in inhomogeneous stochastic oscillations are displaced by a distance much less than electrons [16-18]. Therefore, in the region of the electron cavity a stationary electric field is formed, which, in turn, accelerates ions from this cavity and, as a result, a neutral plasma density cavity is formed.

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ЧАСОВА ЕВОЛЮЦІЯ ПЛАЗМОВОЇ ПОРОЖНИНИ, ЯКА ВИКЛИКАНА НЕОДНОРІДНИМИ СТОХАСТИЧНИМИ ЕЛЕКТРИЧНИМИ ПОЛЯМИ

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Досліджено часову еволюцію утворення плазмової порожнини, спричиненої неоднорідними стохастичними електричними полями. Рівняння Фоккера-Планка, яке визначає часову еволюцію електронної густини плазми, що викликана локалізованими стохастичними неоднорідними електричними полями в діапазоні частот нижньогібридних коливань, розв’язано чисельно. Отримано просторову залежність густини електронів плазми для різних значень часу.