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VO RTEX STRUCTURES AND ELECTRON BEAM
DYNAMICS IN MAGNETIZED PLASMA

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The formation of vortex structures at reflection of electron beam from the double layer of the Jupiter ionosphere is investigated in this paper. And also the influence of these vortex structures on the formation of dense upward electron fluxes, accelerated by the double layer potential along the Io flux tube is studied. Then a phase transition to the cyclotron superradiance mode becomes possible for these electrons. The conditions of the vortex perturbations formation are considered. The nonlinear equation is found that describes the vortex dynamics of electrons and its consequences are studied.

Key words: electron beam dynamics, double electric layer, mechanism of electron reflection, Jovian ionosphere, plasma, vortices

1. Introduction

In this paper the vortex dynamics of electrons are considered and the processes that can influence on formation of upward electron fluxes in plasma double layers (DL) are studied in the framework of the cyclotron superradiance (CSR) effect. The possibility of vortex structures formation due to the interaction of electron currents with the Jupiter ionosphere plasma is discussed.

The influence of Io on Jupiter’s magnetosphere and its radio emission has been studied for a long time [1, 2]. This active satellite is constantly erupting particles into the ionosphere and is connected with the generation of strong radio emission from Jupiter, discovered in 1955. The interaction between Io and Jupiter occurs in the form of electric currents that moves from Io along the Jupiter magnetic field lines and close through the ionosphere near the planet poles, forming Io magnetic flux tube (IFT). Near the footprint of the IFT, where the particles carrying this current influence on the Jupiter atmosphere, auroras arise. They are observed in the form of bright tails of radiation stretched behind the main spot along the movement of the IFT footprint on the planet surface [3, 4]. Besides the projections of other satellites are also visible, but of much lower brightness. The radiation spot of Io at a certain point has the shape of ellipse with a size ~200-500 km, which is slightly larger than the projection size of the satellite itself onto the planet near ~200 km (due to the IFT con-
striction). It indicates that the Io-Jupiter interaction region is slightly larger than the size of Io. IFT tail is less bright in the northern hemisphere, where the magnetic field is stronger than in the southern hemisphere. And conversely, the radio emission is more intense in northern areas [5, 6]. Jupiter’s equatorial field strength is 4.3 gauss, and ranging from 10 gauss at the south pole to 14 gauss at the north pole.

Since 2016 NASA’s Juno spacecraft has been orbiting Jupiter, equipped with devices to compile detailed information about the planet. Based on these data, new effects were discovered, for example, the observations report of distinct, high-energy, discrete electron acceleration in Jupiter’s auroral polar regions and also about upward magnetic-field-aligned electric potentials of up to 400 keV, an order of magnitude larger than the largest potentials observed at Earth. Also Juno’s Energetic particle Detector Instrument (JEDI) detected intense electron beams moving away from Jupiter’s polar regions. In these beams there are often found electrons with energies above ~1 MeV, sometimes up to >10 MeV. These beams occur primarily above the swirl region of the polar cap aurora. It have found a correlation between the swirl emergence from Ultraviolet Spectrograph (UVS) and the very intense beams from JEDI [4, 5, 8]. While in literature additional mysteries still exist on the precise nature of this acceleration.

In works [10–14] the original model was proposed that describes the generation of a super-powerful Jovian radio emission, which is based on the effect of the Fomin–Dicke collective coherent CSR for a system of inverted electrons at high Landau levels in rarefied magnetized plasma. According to the model, electron beams are accelerated from Io toward Jupiter and are reflected from double electric layers that arise in the plasma of the ionosphere. Then the reflected electron beams move upward and pass into the coherent superradiance CSR mode. The criterion of the phase transition to the CSR mode depends, in particular, on such characteristics of electron beams as density and temperature.

Earth’s aurora. The electric DL are plasma regions with a violated quasineutrality and with size of several Debye radii. The formation of such layers is possible at the border between regions in plasma with different characteristics, for example, with different temperatures. The formation mechanisms of sufficiently strong DL are also possible, associated with the injection of particles into the plasma, due to the current amplification of the plasma instability. Most of the beam electrons in the ionosphere are reflected by parallel electrical layer and cause auroras, although some of the electrons are scattered.

Numerical simulation in [14] showed the possibility of a quasi-stationary DL formation during the interaction of an electron beam with a plasma in the non-relativistic case. When electron beam with a density of $10^4$ cm$^{-3}$ is injected into the plasma of the Jupiter ionosphere, a DL can form in the region where densities of the beam and plasma are approximately equal. The phase portrait of DL and the distribution of free and trapped components of the electron beam were found. It also shows the formation of cold electron beams, for which a transition to the CSR mode is possible. A characteristic potential drop is observed in the DL region. The DL potential is shown in Fig.1.

The presented distribution was obtained by averaging the values of potential and field strength over a time interval that exceeding much the period of plasma oscillations. The instantaneous values can be significantly distorted due to plasma oscillations. As seen in Fig.1 the DL has width of approximately $2r_{de}$. The potential drop in the DL is determined by the energy of the electron beam. For example, for the following parameters of plasma electrons - concentr-
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Fig. 2. The phase portrait of the double layer in plasma

tion $n_0 \approx 10^4 \text{ cm}^{-3}$ and temperature $kT \approx 1 \text{ keV}$, we get the Debye radius $r_{de} \approx 2.4 \text{ m}$, plasma frequency $\omega_p^{-1} \approx 1.8 \cdot 10^{-7} \text{ s}$ and, accordingly, the width of DL is $\approx 50 \text{ m}$, the time of formation $\approx 10^{-6} \text{ s}$. In this case the energy of the beam is $50 \text{ keV}$, which corresponds to the potential of DL $50 \text{ kV}$.

Numerical simulation of double layer was carried out in the region of $100 r_{de}$ with open boundary conditions. At the initial moment of time it was assumed that the region is filled with an equilibrium plasma with a temperature $kT$ and an electron concentration $n_0$, the ion component of the plasma is frozen and uniformly distributed. A continuous electron beam was injected into the plasma from the left at a rate equal to $10 v_T$. Within a short time, approximately equal to $30/\omega_p$, a quasistationary mode is established in the phase space of the system with DL reflecting a part of the beam back and small oscillations in the plasma. A typical view of phase portrait is shown in Fig. 2.

In [24, 25] it was shown that when an electron beam from Io enters Jupiter's ionosphere, beam-plasma instability (BPI) develops. The electron distribution function becomes wider due to the excited fields and then these electrons cause the ultraviolet aura. Since BPI develops locally in the inhomogeneous plasma, it can lead to the formation of DL at a certain height. The properties and stability of the formed intense DL, as well as the dynamics of plasma particles, are described. It is noted that the reflection of electron beams from the Jupiter atmosphere can lead to the formation of a semi-vortex. The effect of the space charge of a decelerated reflected beam and its collision with particles of partially ionized plasma lead to a gradual expansion of the beam. Thus the beam is reflected back with a large radius, which can lead to vortex formation.

2. Vortex in a plane $(r, z)$ in a collisional magnetized plasma with a reflected electron beam

Consider the feasible vortex dynamics of a reflected electron beam near Jupiter in a plane, one of the axes of which is directed along the magnetic field under the presence of electron collisions.

We assume that axis $z$ is directed towards the surface of Jupiter. Since the electric double layer has a finite longitudinal size along $z$, approximately equal to $L_{DL} \approx \sqrt{2V_b/\omega_{pe}}$ [15–17, 19]. And also, due to the finite radius of the beam, the DL has a finite transverse dimension. Then the DL has not only a longitudinal electric field $E_z$, but also a transverse electric field $E_r$.

Although electrons are magnetized, the beam expands in $E_r$ due to collisions and forms an obvious half-vortex in the process of reflection from the DL, under the condition when the radius of a half-vortex exceeds the radius of the beam, that falls on the layer. We will estimate this condition. Since the crossed configuration of the radial electric $E_r$ and longitudinal magnetic $H_o$ fields is maintained in the vicinity of the DL, then the electron beam, due to collisions of electrons with a frequency $\nu_e$, expands with a velocity

$$V_r = \frac{e \nu_e E_{or}}{m_e \omega_{He}}.$$  \hspace{1cm} (1)

where field $E_{or}$ is determined by the space charge of the DL, $\omega_{He} = eH_o/m_e c$ is the cyclotron frequency of electrons. For close longitudinal and radial dimensions of the double layer, we have approximately $E_{or} \approx E_{oz}$. Since the amplitude of the electric potential of the DL is approximately equal to the kinetic energy of the beam, and the length is approximately equal to $L_{DL} \approx \sqrt{2V_b/\omega_{pe}}$ [15–17, 19], then for the formation of a half-vortex, one can obtain the condition

$$\frac{\nu_e \omega_{pe}}{\omega_{He}^2} \approx 1.$$  \hspace{1cm} (2)
So, \( \omega_{pe} \equiv \left( 4\pi n_{oe} e^2/m_e \right)^{1/2} \) - the electron plasma frequency must be greater than \( \omega_{He} \), if \( \omega_{He} \) is greater than \( \nu_e \).

3. Vortex in the plane \((r, \theta)\) in the collisionless approximation in a magnetized plasma with a reflected electron beam

Now we consider the vortex dynamics of a reflected electron beam near Jupiter in a plane orthogonal to the magnetic field. Since in the vicinity of DL there is a crossed configuration of the radial electric \( E_{or} \) and longitudinal magnetic field \( H_o \), then vortices can also form in the plane \((r, \theta)\), because the nonequilibrium state is maintained due to the drift of electrons along the angle \( \theta \) with a velocity

\[
V_\theta = -\frac{eE_{or}}{m_e} = \left( \frac{\omega_{pe}^2}{2\omega_{He}} \right) \left( \frac{\Delta n}{n_{oe}} \right) \equiv r\omega_\theta.
\]

\( \Delta n \equiv n_{oe} - q_in_i/e \)

where \( q_i, n_i \) - ion charge and density.

Consider a vorticity \( \alpha \) - an electron vortex characteristic

\[
\alpha \equiv e_z \text{rot} \vec{V} = \frac{1}{r} \partial_r r V_\theta - \frac{1}{r} \partial_\theta V_r.
\]

The physical sense of \( \alpha \) becomes obvious if we introduce the angular velocity of electron rotation in a vortex \( \Omega \equiv V_\theta/r \), then

\[
\alpha = 2\Omega + r\partial_r \Omega - \frac{1}{r} \partial_\theta V_r.
\]

If \( \Omega \neq \Omega(r) \) in \( V_r = 0 \), then the vorticity is equal to the double angular velocity of electron rotation \( \alpha = 2\Omega \).

4. Equations describing the excitation of nonlinear vortex perturbations

Let us obtain the equation that describes the excitation and properties of vortex perturbations. In \([20]\) derivation of the equation for the vorticity begins with the momentum equation (2) for a viscous, Newtonian conducting fluid, in which there is no explicitly electric field. We use the hydrodynamic equations for electrons at times shorter than the capture with taking into account electron collisions

\[
\frac{\partial \vec{V}}{\partial t} + \nu_e \vec{V} + \left( \vec{V} \nabla \right) \vec{V} = \left( \frac{e}{m_e} \right) \nabla \varphi + \left[ \omega_{He}, \vec{V} \right] - \left( \frac{V_{th}^2}{n_e} \right) \nabla n_e, \tag{5}
\]

and the Poisson equation for the electric potential \( \varphi \)

\[
\Delta \varphi = 4\pi \left( e n_e - q_in_i \right), \tag{6}
\]

here \( \vec{V}, n_e \) - electron velocity and density, \( V_{th} \) - thermal electron velocity, \( \vec{V}_i \), \( n_i, q_i \) - ion velocity, density and charge. As we will see below the dimensions of vortex disturbances are much larger than the Debye electron radius \( r_{de} \equiv V_{th}/\omega_{pe} \), then we can neglect the last term in (5).

We obtain a unified nonlinear equation describing the vortex dynamics of electrons. For this we use rot for (5), i.e. we act vectorially by the operator \( \nabla \times \) on (5). Then we get

\[
\frac{\partial \alpha}{\partial t} + \nu_e \vec{a} + \left[ \vec{V} \times \left( \vec{V} \nabla \right) \vec{V} \right] = \left[ \vec{V} \times \left[ \omega_{He} \times \vec{V} \right] \right] \tag{7}
\]

Here \( \vec{a} = \left[ \vec{V} \times \vec{V} \right] \). To transform the last equation we use the expression

\[
\left[ \vec{V} \times \left[ \omega_{He} \times \vec{V} \right] \right] = \left( \vec{V} \nabla \right) \omega_{He} - \left( \nabla \omega_{He} \right) \vec{V} = \omega_{He} \left( \vec{V} \nabla \right) \vec{V} + \left( \vec{V} \vec{V} \right) \omega_{He} - \left( \omega_{He} \vec{V} \right) \vec{V} \tag{8}
\]

at \( \nabla \omega_{He} = 0 \) and

\[
\left[ \vec{V} \times \left[ \vec{V} \times \vec{V} \right] \right] = \left[ \vec{V} \times \alpha \right] = 1/2 \vec{V} \nabla^2 - \left( \vec{V} \nabla \right) \vec{V}. \tag{9}
\]

From (9) we get the expression

\[
\left[ \vec{V} \times \left( \vec{V} \nabla \right) \vec{V} \right] = - \left[ \vec{V} \times \left[ \vec{V} \times \alpha \right] \right] = - \left( \vec{V} \alpha \right) \vec{V} + \left( \vec{V} \nabla \right) \alpha = \left( \vec{V} \nabla \right) \alpha + \alpha \left( \vec{V} \nabla \right) - \left( \alpha \nabla \right) \vec{V} - \vec{V} \left( \alpha \nabla \right). \tag{10}
\]
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From (17), (8), (10) and \( \vec{\omega} \alpha = 0 \) we find

\[
\partial_t \alpha + \nu_e \alpha + \left( \vec{V} \vec{\nabla} \right) \alpha + \alpha \left( \vec{\nabla} \vec{V} \right) - \left( \alpha \vec{V} \right)_t \vec{V} =
\]

\[
= \omega_{He} \left( \vec{\nabla} \vec{V} \right) + \left( \vec{V} \vec{\nabla} \right) \omega_{He} - \left( \omega_{He} \vec{V} \right)_t \vec{V}
\]

Hence we have

\[
d_t \left( \alpha - \omega_{He} \right) + \nu_e \alpha + \left( \alpha - \omega_{He} \right) \left( \vec{\nabla} \vec{V} \right) =
\]

\[
= \left( \left( \alpha - \omega_{He} \right) \vec{\nabla} \right) \vec{V}
\]

where \( \vec{W} \equiv \frac{\alpha - \omega_{He}}{n_e} \).

We transform the third term of the left side of (12) as follows

\[
\left( \alpha - \omega_{He} \right) \left( \vec{\nabla} \vec{V} \right) = - \left( \frac{\alpha - \omega_{He}}{n_e} \right) \cdot \left[ \partial_t + \left( \vec{V} \vec{\nabla} \right) \right] n_e = - \left( \frac{\alpha - \omega_{He}}{n_e} \right) d_t n_e
\]

From (12), (13) we find

\[
d_t \vec{W} + \nu_e \frac{\alpha}{n_e} \left( \vec{W} \vec{\nabla} \right) \vec{V},
\]

where \( \vec{W} \equiv \frac{\alpha - \omega_{He}}{n_e} \).

From (17), (18) we obtain the expression for the vorticity

\[
\alpha \approx \left( \frac{\omega_{pe}}{\omega_{He}} \right) \left( \frac{\Delta n}{n_{oe}} \right) + \frac{e}{m_e} \partial \vec{V} \left( \vec{\nabla} \left( \frac{1}{\omega_{He}^2} \right) \vec{\nabla} \phi \right).
\]

The expression (17) is convenient for physical interpretation of connection between the electron density perturbation \( \delta n_e \) and the vortical motion. To see this, we consider the limiting case and neglect the ion motion. In this case from (17) it approximately follows

\[
\alpha \approx \left( \frac{\omega_{pe}}{\omega_{He}} \right) \left( \frac{\Delta n}{n_{oe}} \right) + \frac{\omega_{pe}^2}{m_e \omega_{He}^2} \frac{\Delta n}{n_{oe}}.
\]

The first member in (19) specifies electron movement on the closed trajectories in the crossed fields. The second member in (19) shows, that the vortical motion begins as soon as there appears a perturbation of the electron density \( \delta n_e \). From (19) it also follows, that vorticity has one sign in all beam area in the case of vortical perturbations of the small amplitudes. The opposite sign of the vorticity occurs in some regions of the beam, where the vortex amplitude exceeds a certain value.
5. Conclusions

The Juno measurements of the aurora reveal valuable information about the precipitating particle population, which interact with the Jovian ionosphere plasma at varying altitudes. More detailed measurements of auroral structures from satellite trails in the infrared and ultraviolet ranges have been obtained. Fine structure is observed on scale of approximately tens of kilometers. It reveals that in the case of the IFT trail, the emission has an alternating series of spots, reminiscent of vortices, at small distances from each other, and sometimes split into two arcs. The research of vortex structure formation mechanism can give an understanding of the reasons for these morphologies and of Jovian auroral processes.

In this paper the vortex dynamics of electron beams is considered in the framework of Io - Jupiter interaction. Currents flow from Io along the magnetic IFT and closed near the poles. These particles impact the ionosphere plasma and in the area of IFT footprint the auroras are generated.

The conditions of vortex perturbations formation, its properties and dynamics in the crossed configuration of the radial electric and longitudinal magnetic fields are described. The velocity of radial expansion of the electron beam due to electron collisions is taken into account. The nonlinear vector equation is obtained that describes the vortex dynamics of electrons. It is also analyzed how the vortex motion depends on the occurrence of electron density perturbations.

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1. T.D. Carr, M.D. Desch, and J.K. Alexander. Phenomenology of magnetospheric radio emissions. Physics of the Jovian Magnetosphere, Ch. 7, p. 226 (ed. A.J. Dessler, Cambridge. Univ. Press, MA, 1983).
2. N. Krupp, et al. Dynamics of the Jovian Magnetosphere, in Jupiter: Planet, satellites, magnetosphere (ed. F. Bagenal, Cambridge. Univ. Press, U.K., 2004).
3. J.T. Clarke et.al. Ultraviolet emissions from the magnetic footprints of Io, Ganymede and Europa on Jupiter. Nature 415 (6875), 997 (2002).
4. J.E.P. Connerney et al. Jupiters magnetosphere and aurorae observed by the Juno spacecraft during its first polar orbits. Science 356, 826 (2017).
5. B.H. Mauk, D.K. Haggerty, et al. Discrete and broadband electron acceleration in Jupiter’s powerful aurora. Nature 549, 66 (2017).
6. W.R. Dunn, G. Branduardi-Raymont, et al. The independent pulsations of Jupiter’s northern and southern X-ray auroras. Nature. Astronomy 1, 758 (2017).
7. D.J. McComas, N. Allegreni, et al. The Jovian auroral distributions experiment (JADE) on the Juno mission to Jupiter. Space Sci. Rev. 213, 547 (2017).
8. B.H. Mauk et al. Juno observation of energetic charged particles over Jupiter’s polar regions: Analysis of monodirectional and bidirectional electron beams. Geophys Research Lett. 44, 4410 (2017).
9. W.S. Kurth, M. Imai, et al. A new view of Jupiter’s auroral radio spectrum. Geophys Research Lett. 44, 7114 (2017).
10. P.I. Fomin, A.P. Fomina. Dicke superradiance on Landau levels. Probl. of atomic sci. and techn. 1, 45 (2001).
11. V.M. Mal’nev, A.P. Fomina, P.I. Fomin. Polarization phase transition to the superradiance regime of the inverted system of electrons on high Landau levels. Ukr. J. Phys. 47, 1001 (2002).
12. P.I. Fomin, A.P. Fomina, V.N. Mal’nev. Superradiation of magnetized electrons and the power of decameter radiation of the Jupiter-Io system. Ukr. J. Phys. 49, 3 (2004).
13. O.P. Novak, A.P. Fomina, R.I. Kholodov. Account of the longitudinal temperature in cyclotron superradiance. Probl. of atomic sci. and techn. 85, 69 (2013).
14. O. Novak, R. Kholodov, A. Fomina. Role of double layers in the formation of conditions for a polarization phase transition to the superradiance state in the Io flux tube. Ukr. J. Phys. 63, 740 (2018).
15. V.I. Maslov. The double layer formed by a nonrelativistic electron beam in the one-dimensional plasma. Ukr. J. Phys. 33, 1342 (1988).
16. V.I. Maslov. Electron beam reflection from the plasma due to double layer formation. Proc. of 4th Int. Workshop on Nonlinear and Turbulent Processes in Physics (Singapore, 1990), p.898.
17. V.I. Maslov. Properties and evolution of nonstationary double layers in nonequilibrium plasma. Proc. of 4th Symposium on Double Layers and Other Nonlinear Structures in Plasma (Innsbruck, 1992), p.82.
18. V.I. Maslov. Double layer formed by a relativistic electron beam. Sov. J. of Plasma Phys. 18, 676 (1992).
19. V.I. Maslov, V.V. Oraevsky, Yu.Ya. Ruzhin. Ion acceleration in collective fields at electron beam injection from spacecraft in experiment "APEX". Physica
Vortex structures and electron beam dynamics in magnetized plasma

Scripta 57, 453 (1998).

20. V. Lapshin, V. Maslov, V. Stomin. Analytical description of T.Sato’s mechanism of transformation of ion-acoustic double layer into strong bunemann’s one in cosmic and laboratory nonequilibrium plasmas. J. Plasma Fusion Res. Series 4, 564 (2001).

21. Ie.V. Borgun, N.A. Azarenkov, A. Hassanein, A.F. Tselbyko, V.I. Maslov, D.L. Ryabchikov. Double layer influence on dynamic of the EUV radiation from plasma of the high-current pulse diode in the tin vapour. Physics Letters A 377(3-4), 307 (2013).

22. M.A. Raadu. The physics of double layers and their role in astrophysics. Physics Reports 178, 25 (1989).

23. R.E. Ergun, Y.J. Su, L. Andersson, et al. Direct observation of localized parallel electric fields in a space plasma. Phys. Rev. Lett. 87, 045003 (2001).

24. V.I. Maslov, I.P. Levchuk, S. Nikonova, I.N. Onishchenko. Occurrence of accelerating field, formation and dynamics of relativistic electron beam near Jupiter. East Eur. J. Phys. 5, 78 (2018).

25. V.I. Maslov, A.P. Fomina, R.I. Kholodov, I.P. Levchuk, S. Nikonova, O.P. Novak, I.N. Onishchenko. Accelerating field excitation, occurrence and evolution of electron beam near Jupiter. Probl. of Atomic Sci. and Techn. 4, 106 (2018).

26. P.J. Hendricks. Vorticity transport by electromagnetic forces. NUWC-NPT Techn. Report 10, 712 (1998).

27. H. Helmholtz. Uber integrale der hydrodynamischen Gleichungen, welche den Wirbewegungen entsprechen. Crelle J. 55, 25 (1858).

28. W. Thomson. On vortex motion. Trans. Roy. Soc. Edinburgh 25, 217, (1869).

29. C. Paranicas, B. Mauk, et.al. Intervals of intense energetic electron beams over Jupiter’s poles. J. of Geophys. R.: Space Physics 123(A10), 1998 (2018).

30. A. Mura, A. Adriani, J.E.P. Connerney, et al. Juno observations of spot structures and a split tail in Io-induced aurorae on Jupiter. Science 361 (6404), 774 (2018).

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Вихрові структури і динаміка електронного пучка в замагніченні плазмі

Р е з ю м е

В даній роботі ми досліджуємо задачу про формування вихрових структур при відбитті пучка електронів від подвійного шару іоносфері Іоаніза та вплив цих структур на виникнення цільних висхідних електронних пучків, прискорених потенціалом подвійного шару вздовж токової трубки Іо, для яких стає можливим фазовий переход в режим циклотронного сверхізлучення. Розглянуто умови формування вихрових збурень. Знайдено нелінійне рівняння, яке описує вихрову динаміку електронів та винені його наслідки.

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