DYNAMICS OF DUST CLOUDS IN PLASMAS

O.Yu. Kravchenko, M.M. Yurchuk, O.M. Radchenko

Taras Shevchenko National Kyiv University, Faculty of Radio Physics, Kyiv, Ukraine, e-mail: kay@univ.kiev.ua

We study a dynamics of dust clouds embedded in the infinite uniform initially plasma using computer simulation. In the one dimension, the movement of dust particles and ions is governed by cold hydrodynamics equations, electrons are assumed to be in thermal equilibrium. It is assumed that the forces on the dust consist of electrostatic force and ion drag forces. The spatial distributions of parameters were obtained at various initial densities of dust grains at different times. Results show the expansion of dust clouds at low initial dust grain density, which is evidence of exceeding the electrostatic force over the ion drag force. At the increasing of dust density oscillations of the central part of dust cloud are observed.

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1. INTRODUCTION

Ionized gases with dispersed dust grains occur in a wide variety of cosmic and terrestrial environment, as well as in laboratory experiments [1, 2]. Dust grains often form clouds and there is interest to study their interaction with plasmas. In particular, the expansion of dust clouds is a fundamental process which is important in many practical situations. For example, in laboratory devices dust particles produced in source region can subsequently expand into the central plasma region [3].

Earlier it was studied the interaction of dust clouds with plasmas at conditions immobile dust particles [4]. Results show an initiation of soliton-like structures in distributions of the electrostatic potential and the ion density. Because of this the interest was appeared to the investigation of the influence these structures on the dust grains expansion.

In this paper we study a dynamics of dust clouds embedded in the infinite uniform initially plasma.

2. MODEL

We consider one-dimensional layer of dust particles immersed into uniform initially plasma.

In our model dust grains acquire a charge and influence the potential of the electric field φ, which is described by Poisson equation

$$\frac{\partial^2\varphi}{\partial x^2} = -\frac{e}{\varepsilon_0}\left[n_i - n_e + q_d n_d\right],$$

where n_i, n_e, n_d are the ion, electron and dust densities, q_d is a dust particle charge.

The change of the dust charge is described by equation

$$\frac{\partial q_d}{\partial t} + v_d\frac{\partial q_d}{\partial x} = I_e + I_i,$$

where electron and ion currents I_e and I_i flowing into dust particle are defined by OML theory [5]:

$$I_e = -\pi r_d^2 e\left(\frac{8kT_e}{\pi m_e}\right)^{1/2} n_e \exp\left(\frac{eq_d}{akT_e}\right),$$

$$I_i = \pi r_d^2 e n_i\left(\frac{8kT_i}{\pi m_i} + v_i^2\right)^{1/2}\left(1 - \frac{eq_d}{a(kT_i + m_i v_i^2/2)}\right).$$

Here T_e and T_i are electron and ion temperatures, r_d is the radius of dust particle.

The electrons are assumed to be in thermal equilibrium; therefore the density n_e satisfies the Boltzmann relation

$$n_e = n_{e0}\exp\left(\frac{e\varphi}{kT_e}\right),$$

where n_{e0} is the electron concentration at the unperturbed plasma.

The ions and dust particles are described by the fluid equations:

$$\frac{\partial v_i}{\partial t} + v_i\frac{\partial v_i}{\partial x} = -\frac{e}{m_i}\frac{\partial\varphi}{\partial x} - \frac{1}{n_i m_i}\frac{\partial T_i n_i}{\partial x} + F_{id},$$

$$\frac{\partial n_i}{\partial t} + \frac{\partial(v_i n_i)}{\partial x} = -I_i n_d,$$

$$\frac{\partial v_d}{\partial t} + v_d\frac{\partial v_d}{\partial x} = -\frac{q_d}{m_d}\frac{\partial\varphi}{\partial x} + F_{di},$$

$$\frac{\partial n_d}{\partial t} + \frac{\partial(v_d n_d)}{\partial x} = 0,$$

where v_i, e, m_i are a drift ion velocity, ion charge and ion mass, M_d, v_d are a dust mass and a drift dust velocity. The member in the right part of the continuity equation expresses an ion deposition on dust particles.

The ion drag force F_{di} is determined according to [5], where

$\sigma_{coul} = 2\pi b_0^2 \ln\Lambda$ is a section of ion-dust Coulomb collisions, $b_0 = \dfrac{eq_d}{4\pi\varepsilon_0 m_i v_i^2}$, $\sigma_{coll} = \pi r_d^2\left(1 - \dfrac{2eq_d}{r_d m_i v_i^2}\right)$ is a section of an ion deposition on dust particle.

3. RESULTS AND DISCUSSION

We have modeled the time evolution of the one-dimensional dust layer located in electron-ion plasma. It is considered the case when an ion and electron densities in the unperturbed plasma are $n_0 = 10^{18}\,m^{-3}$, an electron temperature $T_e = 2\,eV$, an ion temperature is $T_i = 0.03\,eV$, and a dust particle radius is $r_d = 2\,\mu m$. The ratio of the ion mass to the dust mass is $m_{id} = 0.001$. Note, that the dust particle mass is chosen smaller in our simulations in comparison with experimental data in order to reduce the time of computations. As a result of numerical calculations we have obtained spatial distributions of plasma parameters at different initial dust densities $N_{d0} = n_{d0} / n_0$.

Results have revealed that the dust cloud dynamics have essential distinctions at different N_{d0}. It is occurred monotonous expansion of the dust cloud at low values N_{d0} and oscillations of dust particles at large values N_{d0}. It is have seen from Fig. 1a and Fig. 2 where spatial distributions of dust density at different times are depictured. Here the dust density is normalized on the ion density in the unperturbed plasma; the spatial coordinate is normalized on Debye radius, time is normalized on the inverse ion-plasma frequency.

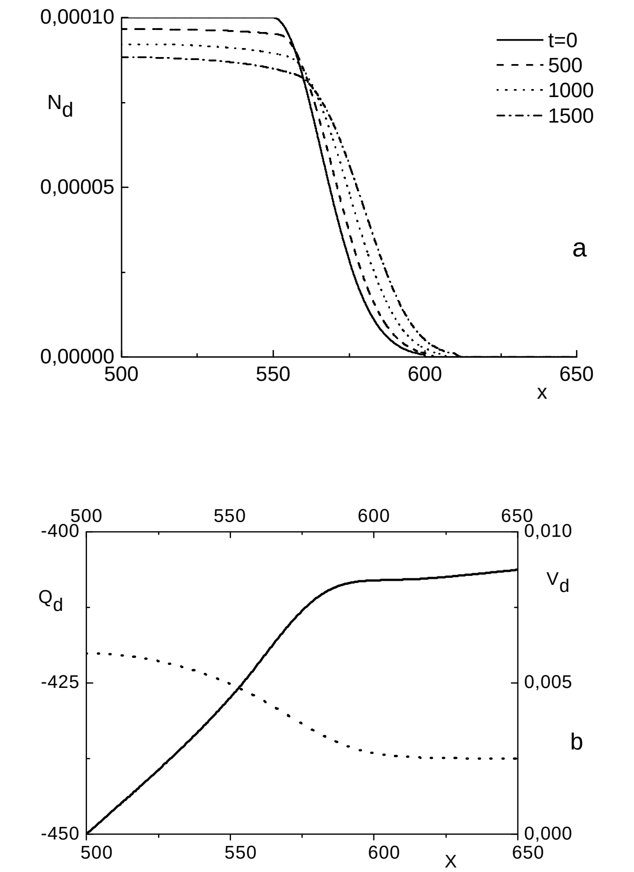

Fig.1. The spatial distributions of dust density at different times and spatial distributions of the dust particle charge (solid curve) and the dust drift velocity (dotted curve) at time $t = 1500$ for case $N_{d0} = 0.0001$

One can see that the dust density is decreased and the drift velocity of dust particles is increased monotonically at the increasing of the spatial coordinate x from the centre toward the periphery of the dust cloud. The normalized dust particle charge $Q_d = q_d / |e|$ is increased at the decreasing of the dust density (Fig.1b). The sharp boundary of dust cloud is not forming in this case.

The Fig. 2 shows the spatial distributions of dust density at different times for case with $N_{d0} = 0.003$. We can see that dust particles perform the oscillations. Therefore the central part of dust cloud is compressed at first and the pick of the dust density is formed in this location. At the same time peripheral dust particles are expanded forming a sharp front of dust cloud. Then, the front is stopped at time $t\omega_{pi} = 700$ and starts to move back while the central region of the cloud starts to expand.

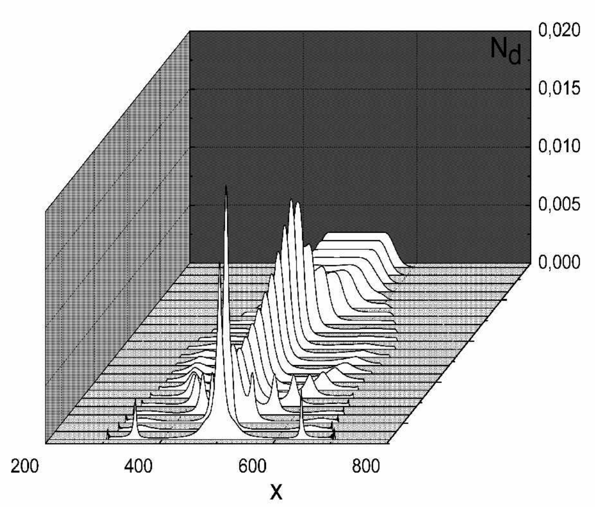

Fig.2. The spatial distributions of dust density at different times for $N_{d0} = 0.003$

So, counter propagating flows of dust particles occur. As a consequence they are generated two peaks of dust density which are moved toward the centre of the dust cloud and embodied together. This process is accompanied by the increasing of a dust density peak in the centre of the cloud. In some time peaks of dust density are formed at the periphery again.

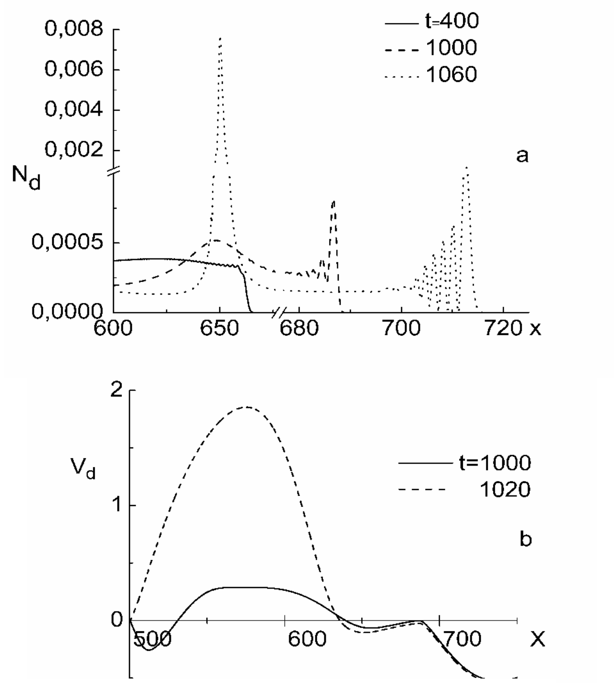

Fig.3. Profiles of the dust density near the dust cloud front (a) and profiles of dust drift velocity (b) for the case with $N_{d0} = 0.003$

Profiles of the dust density in the region of the dust cloud periphery are pictured in Fig. 3a for the case with $N_{d0} = 0.003$. We can see the forming of the dust cloud front where the dust density is decreased abruptly. After the dust front oscillations of dust density are appeared and at $x \approx 650$ the peak of the dust density is formed. Profiles of the dust drift velocity are shown in Fig. 3b. They are evidence of dust particles oscillations. It is seen alternate regions with the positive and negative dust drift velocity. Note, that the dust drift velocity is zero at the dust cloud front and the peak location.

REFERENCES

1. M. Mikikian, L. Boufendi, H.M. Thomas, G.E.Morfill, A.P. Nefedov, V.E. Fortov et al. // *New Journal of Physics*. 2003, p.19.1-19.12.
2. D. Wang, D. Liu, J. Liu // *Journal of Applied Physics*. 2000, v. 88, p.1276-1280.
3 G.E. Morfill, H.M. Thomas, U. Konopka, H. Rothermel, M. Zuzic, A. Ivlev, J. Goree // *Phys. Rev. Letters*. 1999, v.83, p.1598-1601.
4. A.Yu. Kravchenko, M.M. Yurchuk // *Proceedings of International Conference on Physics of Low Temperature Plasma*, Kyiv, 2004, p. 9.14.113.
5. P.K. Shukla, A.A. Mamun. *Introduction to Dusty Plasma Physics*. Bristol and Philadelphia: "IoP Publishing Ltd.", 2001, p.36-49.

ДИНАМИКА ПЫЛЕВЫХ СГУСТКОВ В ПЛАЗМЕ

А.Ю. Кравченко, Н.Н. Юрчук, А.Н. Радченко

При помощи компьютерного моделирования исследуется динамика пылевых сгустков в неограниченной плазме. Движение пылевых частиц и ионов описывается одномерными уравнениями холодной гидродинамики, электроны предполагаются равновесными. В модели предполагается, что на пылевые частицы действуют электростатическая сила и сила ионного трения. Получены пространственные распределения параметров в различные моменты времени при различных значениях начальной концентрации пылинок. Показано, что пылевые сгустки расширяются при малых концентрациях пылевых частиц, поскольку в этом случае электростатическая сила превышает силу ионного трения. При увеличении концентрации пылевых частиц наблюдаются осцилляции центральной части пылевых сгустков.

ДИНАМІКА ПИЛОВИХ ЗГУСТКІВ У ПЛАЗМІ

О.Ю. Кравченко, М.М. Юрчук, О.М. Радченко

За допомогою комп'ютерного моделювання досліджується динаміка пилових згустків в необмеженій плазмі. Рух пилових частинок та іонів описується одновимірними рівняннями холодної гідродинаміки, електрони вважаються рівноважними. В моделі припускається, що на пилові частинки діють електростатична сила та сила іонного тертя. Одержані просторові розподіли параметрів в різні моменти часу при різних значеннях початкової концентрації пилинок. Показано, що пилові згустки розширюються при малих концентраціях пилових частинок, оскільки в цьому випадку електростатична сила переважає силу іонного тертя. При збільшенні концентрації пилових частинок спостерігаються осциляції центральної частини пилових згустків.