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A Boundary Structure of Dusty Cloud.

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Self-organization and self-structuring properties of complex plasmas led to various shapes of dusty clouds observed in experiments. To describe a form and parameters of a dusty cloud a self consisted model of the discharge with dusty particles is necessary. A simple model of the discharge with a constant ionization coefficient and zero electron density at the walls is applicable for typical experimental conditions (when the size of a discharge chamber is much grater than the ion mean free path length, but much less than the electron energy relaxation length). In the case of a large cloud, the task can be separated on the description of the quasi uniform regions (inside cloud and outside cloud) and description of the cloud's boundary. In quasiuniform regions following equations should be satisfied.

$$\frac{\nabla n_e}{n_e} = -\frac{eE}{T_e} \tag{1}$$

$$Zn_d = n_i - n_e \tag{2}$$

$$j = \frac{\mu_i E n_i}{(1 + \mu_i \langle \sigma_{id} v_{ti} \rangle m_i n_d / e)} \tag{3}$$

$$\nabla j = \alpha n_e - \beta n_e n_d \tag{4}$$

$$EeZ = j \langle \sigma_{id} v_{ti} \rangle m_i + F \tag{5}$$

Here j is the ion flux (equal to electron flux), μ_i is the ion mobility, E is the electric field, n_i, n_e, n_d are the ion, electron and dusty densities, Z is the dusty particle charge in electron units, e is the absolute value of the electron charge, σ_{id} is the cross section of ion-dust collisions, v_{ti} is the ion thermal velocity, m_i is the ion mass, α is the ionization coefficient, β is the recombination on dusty grains coefficient, F is the thermophoretic force which acting on dusty grains (here we will consider microgravity conditions).

In the boundary regions the electron density and ion flux can be assumed as constants. The ion diffusion term should be taken into account:

$$j = \frac{\mu_i (E n_i - \frac{T_i}{e} \nabla n_i)}{(1 + \mu_i \langle \sigma_{id} v_{ti} \rangle m_i n_d / e)} \tag{6}$$

and quasineutrality equation (2) should be exchanged on Poisson equation

$$\nabla E = \lambda_{De}^{-2} T_e \frac{n_i - Z n_d - n_e}{e n_e}. \qquad (7)$$

Here λ_{De} is the electron Debye length.

Since the ion density changes from n_e to n_e+Zn_d across the boundary layer, a short variation of the electric field should present in the vicinity of dusty cloud edge. But the ion drag and thermophoretic forces can't rapidly change its values due to a continuity of the ion and thermal fluxes. So, the system of equations (5), (6), and (7) can't describe a sharp edge of the cloud as has been shown by *Tsytovich 2004*. Indeed, equations (5) and (7) corresponded to Vlasov approximation which neglects correlation effects. But the correlations in complex plasma usually are essential. A correlation correction above Vlasov approach (as applied to the dusty plasmas) has been considered by *Murillio 1998*. This correction can be fulfilled through an additional force, which in a simplest approximation has the form of 'negative pressure'.

$F_{corr} = -\nabla n_d \, 4\pi e^2 Z^2 a^2 f(a/\lambda_D)$ Here $a = \left(\frac{3}{4\pi n_d}\right)^{1/3}$ is the Wigner-Seitz radius, λ_D – Debye length, and $f \approx -0.08$ for $a/\lambda_D < 2$ (following to *Kalman, 2000*). So, the force balance equation becomes

$$eeZ = j\langle \sigma_{id} v_{ti} \rangle m_i + F - (36\pi)^{1/3} e^2 Z^2 f n_d^{-2/3} \nabla n_d \ . \qquad (8)$$

This modification of the force balance equation permits one to join solutions inside and outside of the cloud and ascribe a boundary structure. As an illustration, the results of calculations for the one-dimensional flat geometry discharge with dusty cloud model are presented in figures 1-3. At figures 1 and 2 the structures of the centered dusty clouds are shown when the thermophoretic force is negligible (fig.1) and considerable (fig.2). The structure of cloud in presence of void is shown in fig.3. The inner edge of cloud corresponds to position where the ion drag force on a probe particle is equal to the electric force. Following parameters were assumed: the electron temperature is 3 eV, the gas is argon at pressure of 0.4 mbar, the grain radius is 1.7μm, the charge Z is constant and equal to 2000, ion temperature is 300 K, thermoforetic forces correspond to parabolic temperature profiles with ΔT_g at center of chamber of 0.1 K in fig.1, 1 K in fig.2, and 0.75 K in fig.3, the ion-dust collision cross section was calculated using the model of *Barnes, 1992.*

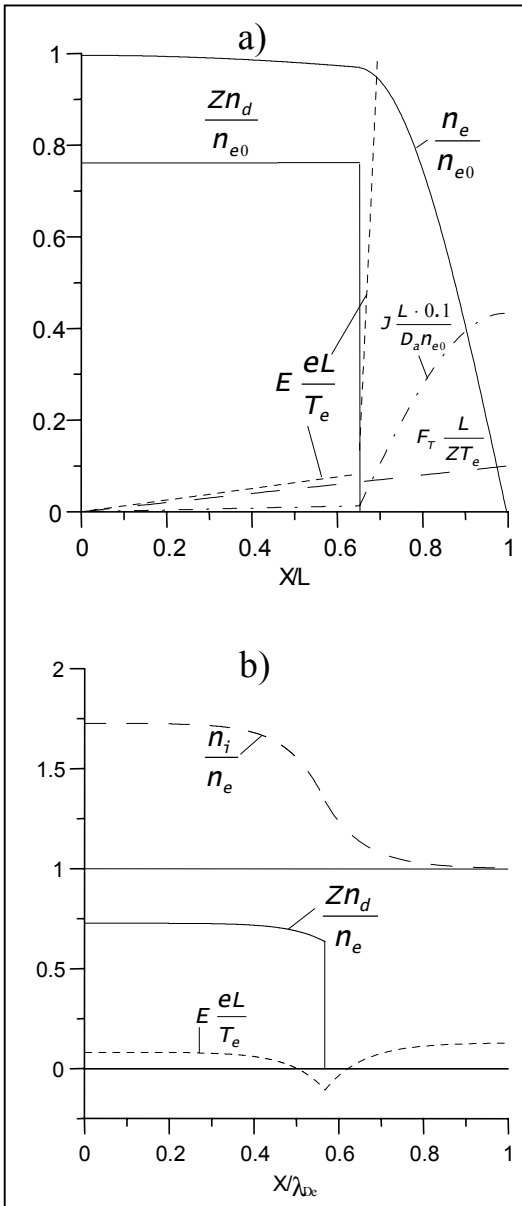

Fig.1 The centered cloud.

$n_{e0} = 10^8\,\mathrm{cm}^{-3}$, $\frac{\alpha L^2}{D_a} = 20$,

$\frac{\beta L^2 n_{e0}}{D_a Z} = 26$, $\frac{F_T L}{ZT_e} = 0.1\frac{X}{L}$

L is a half of the chamber width.

a) Distributions in the chamber.

b) The edge of the cloud.

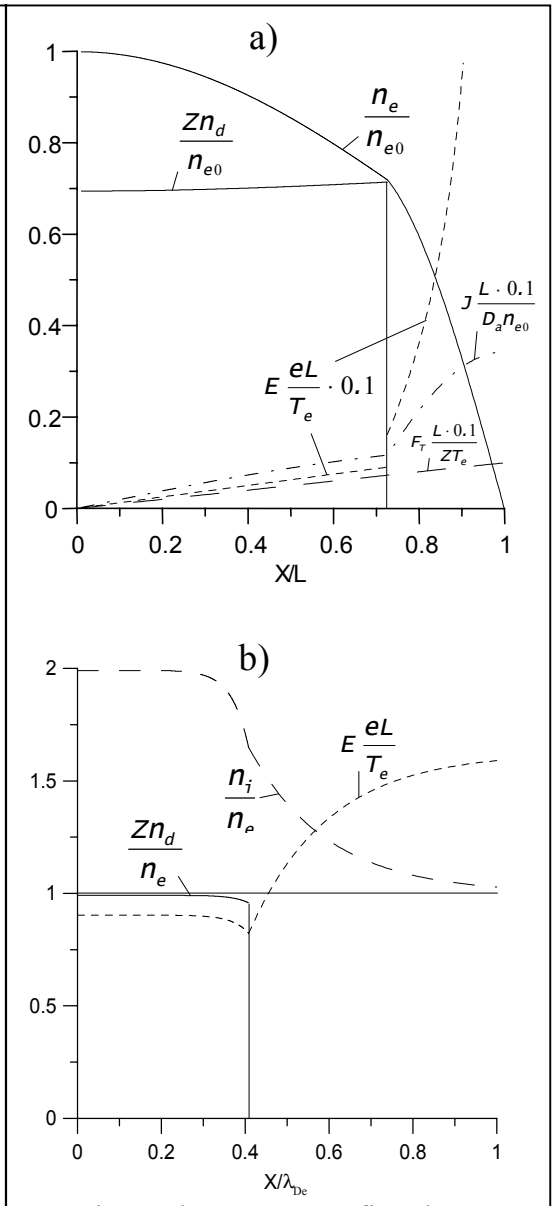

Fig. 2 The same as at fig.1 but F_T is in 10 times grater.

At the upper figures the zero coordinates correspond to the center of discharge chamber, the unity coordinates correspond to walls of chamber (or electrodes). A half of the chamber width was taken as 1 cm. Lower figures show boundary structures of clouds and have other spatial scales, corresponding to the local electron Debye lengths.

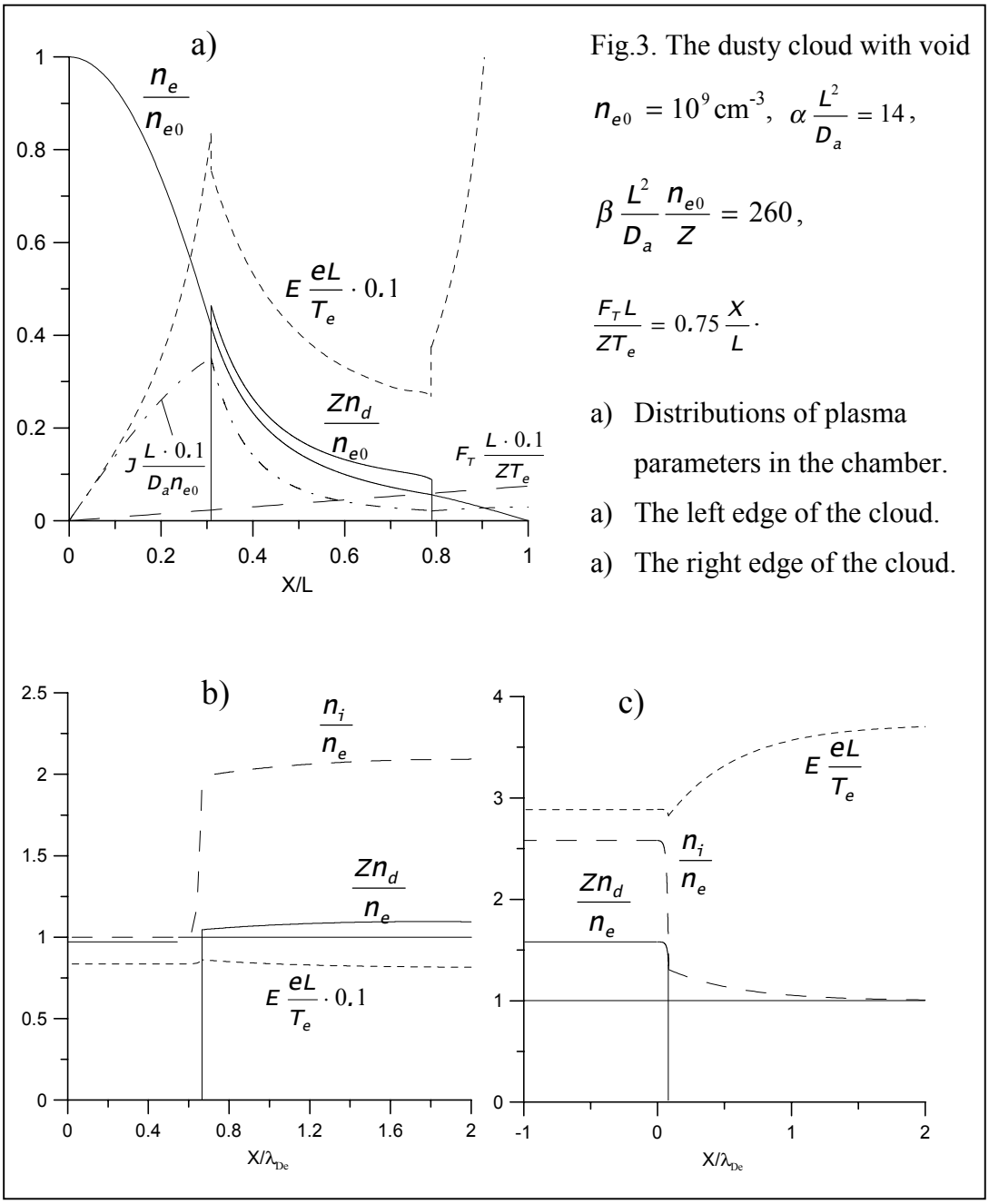

Fig.3. The dusty cloud with void

$n_{e0} = 10^9\,\mathrm{cm}^{-3},\ \alpha\frac{L^2}{D_a} = 14,$

$\beta\frac{L^2}{D_a}\frac{n_{e0}}{Z} = 260,$

$\frac{F_T L}{ZT_e} = 0.75\frac{X}{L}\cdot$

a) Distributions of plasma parameters in the chamber.
a) The left edge of the cloud.
a) The right edge of the cloud.

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