§12. Simulation Study on Transport of Charged Dust Particles in Plasmas

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In plasmas, dust particles are negatively charged up to form so-called ``plasma crystals" under the strong Coulomb interaction among the dust particles. There have been many experiments on the dust particles and various interesting features of dust-particle plasma have been clarified [1,2]. Moreover, the dust particles have attracted a strong interest due to their important roles as contamination source in the material processing and fusion plasmas. It is an essential issue to understand and control the collective motion of dust particles levitating in plasmas in order to remove dust particles from the processing and fusion plasmas. Particularly, the control of an electrostatic field is quite important, because the large charged particles are very sensitive to the electric field in plasma, and new dust-particle structures such as vortices and void are generated and controlled by an appropriate potential structure.

In order to investigate the effect of ion drag force on dust transport, we carry out a two-dimensional numerical calculation on the dust-particle orbit by solving the equation of motion of dust particles, including the effects of the potential structure and the ion drag force. The equation of motion of dust particle is given by the following equation,

$$m_d \frac{d\vec{v}_d}{dt} = \sum_{j=1, i \neq j}^{N} \frac{Q_{p,i} Q_{p,j}}{4\pi\varepsilon_o |\vec{r_{ij}}|^2} \exp\left(-\frac{|\vec{r_{ij}}|}{\lambda_{De}}\right) \frac{\vec{r_{ij}}}{|\vec{r_{ij}}|} - Q_{p,i} \nabla \phi_e + \vec{F_i} + \vec{F_{Nd}}.$$

First term in the right-hand side shows the electrostatic interaction among dust particles. The inter-particle potential is assumed to be the Yukawa type. Second term represents the electrostatic force acting on the dust particle due to the external potential ϕ_e. We assume a parabolic confining potential in radial direction. Third term shows the ion drag force F_i due to the Coulomb collision between ion and dust particle. Some models on F_i has been reported and discussed and we adopt the simple model by M. S. Barrnes [3]. F_i is given by the sum of the force F_{ic} due to the collection of positive ion and the force F_{io} due to the Coulomb interaction (no collection of positive ion). F_{ic} and F_{io} are expressed by the following equations, respectively,

$$\vec{F_{ic}} = n_i v_{is} m_i \vec{v_i} \pi r_c^2,$$

$$\vec{F_{io}} = n_i v_{is} m_i \vec{v_i} \pi r_{\pi/2}^2 \Gamma_p,$$

where $v_{th,i}$ is the ion thermal velocity, v_i is the ion drift velocity, v_{is} is $(v_{th,i}^2 + v_i^2)^{1/2}$, r_c is the collection impact parameter, $r_{\pi/2}$ is the impact parameter with orbit angle of $\pi/2$, and Γ_p is the Coulomb logarithm.

We calculated on dust-particle motions and analyzed space profile of number density of dust particles as a parameter of ion density n_i. Here dust-particle diameter is 1 μm, and the negatively charge of dust particles is constant on time and space. As can be seen in Fig. 1(a), dust particles were confined in center area by external electrostatic force at $n_i = 1 \times 10^{14}$ cm^{-1}. On the other hand, the void structure appeared at 5×10^{14} cm^{-3} (see Fig. 1(b). This demonstrates that ion drag force plays an important role on dust-particle motion, and dust particles were pushed to the direction of ion flow by the drag force.

In conclusion, numerical calculation including the effect of the ion drag force well demonstrates the void structure as in the experiment. A mechanism of the dust void structure could be explained by effect of ion drag force toward outside. Detailed features of dust void structure would be quite useful for controlling the dust particles in the processing and fusion plasma.

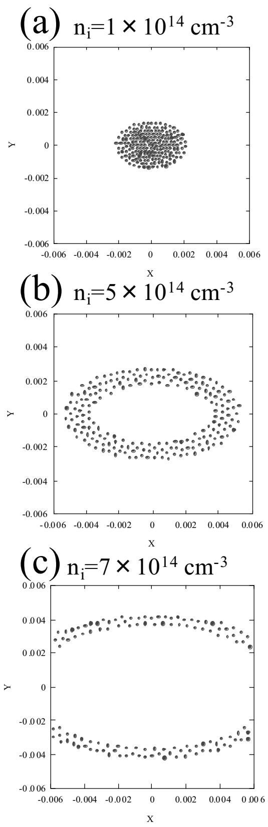

Fig. 1 Structure of charged dust-particles cloud. Ion drag force plays an important role on void structure of dust-particle cloud.

1) Uchida, G. et al.: Physics of Plasmas **16** (2009) 053707.
2) Iwashita, S., Uchida, G. et al.: Plasma Source Science and Technology **21** (2012) 032001.
3) Barnes, S. et al.: Physical Review Letters **68** (1992) 313.