FORMATION DYNAMICS OF ORDERED STRUCTURES IN A THERMAL DUSTY PLASMA

Yaroslav K. Khodataev, Sergei A. Khrapak, Anatoli P. Nefedov,
Oleg F. Petrov and **Alex A. Samarian**

High Energy Density Research Center, Russian Academy of Sciences,
Izhorskaya 13/19, 127412, Moscow, Russia

The dynamics of the ensemble of interacting dust grains under conditions of thermal plasma was studied, and the formation of the liquid-like structure observed in the experiment was investigated. The numerical simulations have been carried out by means of code *KARAT* [1] using molecular dynamics method in *2D* geometry. It includes solution of the equation of motion for each dust grain taking into account the interaction between dust grains, friction force and random force arising from asymmetric molecular bombardment (Brownian force):

$$m_d \frac{d^2\vec{r}_k}{dt^2} = \sum_j \Phi(r)\Big|_{r=|\vec{r}_k-\vec{r}_j|} \frac{\vec{r}_k-\vec{r}_j}{|\vec{r}_k-\vec{r}_j|} - m_d \nu_{fr} \frac{d\vec{r}_k}{dt} + \vec{F}_{br} \qquad (1)$$

where m_d is the grain mass, ν_{fr} is the friction decrement, F_{br} is the random force providing the Brownian motion. $\Phi(r)$ is taken in the following form:

$$\Phi(r) = \Phi_D(r) = -Q_d e \frac{\partial \phi_D}{\partial r} \qquad (2)$$

where

$$\phi_D = \frac{Q_d e}{r} \exp\left(-\frac{r}{d}\right) \qquad (3)$$

Here, d is the Debye length, ϕ_D is the Debye potential. It should be noted that the system under consideration can be studied with MD without friction and Brownian force (see for example [2]). However these forces represent a physical process and some results [3] indicate that they may have important effects on ordering structure formation.

The computation area is of square form with the side length L_0. In order to emulate an infinite system we use periodic boundary conditions, so that the basic simulation area is surrounded by neighboring copies of itself, and each particle in the basic computation area interacts not only with the particles in the basic area but also with the “mirror” particles. The emergence of the grains leaving the basic computation square on it's opposite edge is also included. Such periodic boundary conditions give the possibility to avoid boundary effects and fix the mean dust density. Initially charged dust grains are situated in random positions inside the computation area after which the process of self-organization starts. Such consideration

corresponds to the real process in experiment where initially neutral and disordered dust grains come into the plasma region, acquire electric charge very quickly and start interacting.

Figure 1 presents the time evolution of the pair correlation function *R(r)* calculated from the grains positions at the moment taken. The last picture in Fig. 1 was obtained through time averaging of *R* which is possible because on the final stage of the simulation (40 *ms* < *t* <70 *ms*) the system approach as the equilibrium state and the pair correlation function does not evolve in time. In the calculation of the pair correlation function the step along *r* was taken to be 0.1*l*, a smaller one would result in too large of a chance of calculation error. One can see

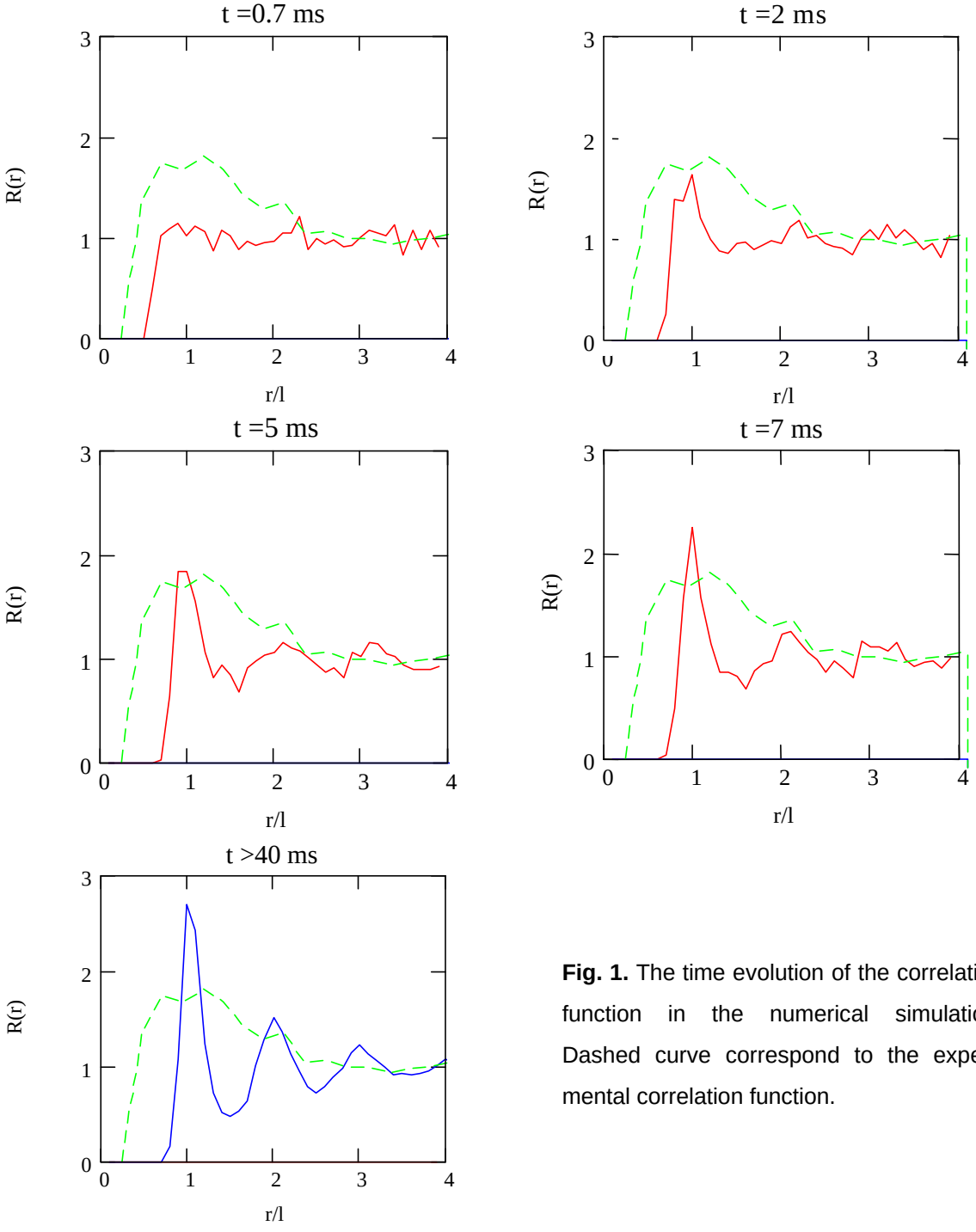

Fig. 1. The time evolution of the correlation function in the numerical simulation. Dashed curve correspond to the experimental correlation function.

from Fig.1 that first of all, the particles at small distances disappear with the area of zero correlation function at small *r* being formed. This process takes place very quickly because the electric repulsive force at small distance is very strong. Then the sharp nearest-neighbor peak develops (*t=5 ms*). Further this peak grows and simultaneously the high-order peaks develop. The final correlation function is characterized by many sharp oscillations. The definition of the structure formation time t_f remains to be to some extent uncertain because it depends on the distance range where the evolution of the correlation function is of interest. The bigger distance the longer time required for the correlation function to approach the final form on this distance. In practice one may take into account only the distance range where the appreciable oscillations of the final correlation function take place. In the case in hand one may take only first three peaks, then t_f can be estimated $t_f \approx 35ms$. Also it is convenient to introduce the time of the sharp nearest-neighbor peak emergence t_1. This is in fact the time required for any type of the short order to appear in the system. One can estimate from the simulation $t_1 \approx 5ms$. This time can be also estimated analytically:

$$t_1 \approx \frac{l m_d \nu_{fr}}{|\Phi(l)|} \tag{4}$$

which gives $t_1 \approx 25$ *ms*. The inaccuracy of this estimation is related with strong dependence of the interaction force on distance because of Debye screening. The initial ordering stage is related with the grains diverging on small distance $r < l$. Substituting $0.7l$ instead of l in (4) one would obtain $t_1 = 6$ *ms* in good agreement with the simulation.

The simulation results showed that ordering of the dust structure manifested in the experiment can be explained by the electric interaction of dust grains. It is found that the structure obtained in the experiment is far from equilibrium because the plasma flight time is less than the time of structure formation. It conforms to the emergence of the experimental correlation function characterized by a sharp main peak with no high-order ones. At the same time the comparison of the simulation correlation function with the experimental one indicates some discrepancy, in particular the peak of the experimental correlation function is extremely wide which does not agree with the simulation results and in general seems to be unusual for known liquid structures. This peak broadening is likely to be related to the structure inhomogeneity, the generation mechanism of which requires special investigation.

References

[1] V. Tarakanov: “User manual for code KARAT”. BRA inc., 1992.

[2] M. J. Stevens and M.O. Robbins: J. Chem. Phys. **98**, 2319 (1993).

[3] X.H. Zheng and J.C. Earnshaw: Phys. Rev. Lett. **75**, 4214 (1995).