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Investigation of attractive forces associated with overlapping Debye spheres using N-body simulations

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Dust grains are quite common in space. They are thought to exist in, e.g., molecular clouds, protoplanetary disks, Earth's magnetosphere, and planetary rings. In addition, also in laboratories, the lattice formation of dust grains is the well-known phenomena and called Coulomb crystallization. Dust grains immersed in plasmas usually acquire large amount of charges due to several charging processes such as collisions with plasma partilcles and photoemission. Then the charged grains and the ambient plasma are strongly coupled with each other, and such plasmas are called dusty plasmas or complex plasmas. Since in situ observations in the solar system or Ikezi's prediction of Coulomb crystallization, dusty plasmas have been studied for not only astrophysical applications but also industrial applications.

When collisions between dust grains and plasma particles dominate charging processes, the dust grains are nagatively charged because generally the flux of electrons is larger than that of ions. Thus we expect that they repel each other. However, in realty, the force on dust grains is quite complex due to the interaction with the ambient plasma and several types of forces have been proposed (e.g., Shukla and Eliasson [2009]). Interestingly, some attractive forces may also exist and play important roles in aggregation or crystallization of dusty plsamas.

One of proposed attractive forces is that of due to the overlapping of Debye spheres (ODS). Resendes et al. [1998] showed that the potential between two dust grains is similar to Lennard-Jones potentials, which is repulsive at short distance and weakly attractive at longer distance. Moreover, Hou et al. [2009] showed that this type of attractive interaction has, if indeed it exists, the drastic aggregation and crystallization effect in dusty plasmas. On the other hand, it was suggested that the ODS attractive force does not exist when particles electrically trapped by grains are negligible ,i.e., the orbital motion limited (OML) theory is valid (Lampe et al. [2000]), and it has not been confirmed experimentally.

The aim of our study is to investigate the possibility of the ODS potential, by using direct N-body simulations, which allow us to investigate the electrostatic potential structure around the dust grains with minimun assumptions. By using a newly developed N-body simulation code implementing Ewald's sum algorithm, in which the short-range part of the potential is calculated in real space and the long-range part is calculated in wavenumber space, we have shown that in plasmas with a low plasma parameter there does not exist the ODS attractive force. In this study, we introduce the mesh and extend the code to implement the PM (particle-mesh) or PPPM (particle-particle particle-mesh) method allowing us to perform simulations with a much more particles to attempt the investigation of plasmas with the large plasma palameter.