# Charging of Irregularly-Shaped Dust Grains near Surfaces in Space

David Lund*, Xiaoming He†, and Daoru Han‡
*Missouri University of Science and Technology, Rolla, Missouri 65409*

**This paper presents a fully-kinetic numerical investigation of charging of irregularly-shaped dust particulates near surfaces in space facing low temperature collisionless plasmas. The Parallel Immersed-Finite-Element Particle-in-Cell (PIFE-PIC) code is utilized to self-consistently resolve the plasma environment and charging of immersed materials. This model explicitly includes the materials property (dielectric constant) of dust grains. Effects of materials property, inter-dust distance, and plasma conditions (stationary and drifting) will be investigated for both single-dust and multi-dust configurations. Details and results will be discussed in the full paper.**

## I. Nomenclature

$v$ = velocity
$T$ = temperature
$n$ = number density
$r$ = radius

Greek letters
$\lambda_D$ = Debye length

Subscript
d = drifting
t = thermal

## II. Introduction

Plasmas that contain solid particulates (grains) much more massive than the ions present are usually referred to as "dusty plasmas" and are encountered in many fusion/laboratory and industrial plasmas and combustion processes, as well as in the space environment [1, 2]. The electrodynamical interactions among dust grains and plasmas can strongly influence the behavior of plasma devices such as tokamak and industrial combustion reactors. Previous efforts have been put into both microscopic dust charging and macroscopic dust transport scales. For instance, at the microscopic (grain) scale, particle-particle, particle-mesh (P3M) approach has been used to study charging process of micro-meter sized grains in low temperature plasmas [3]. The Particle-in-Cell (PIC) - Monte Carlo Collision (MCC) approach was used for plasma particles while the PIC - Molecular Dynamics (MD) approach was used for Coulomb interactions among the dust grains. Results show that the amount of charge on the dust grain $Q_d$ could be on the order of $Q_d/e$ ~3000-7000 negative ($e$ is the elementary charge) within the sheath. Other grain-scale charging models include a "patched charge model" using the capacitance of an isolated spherical dust grain and empirical constants based on experiment data, predicting the $Q_d$ on the order of $Q_d/e \sim 10^4$ [4], and a test-particle approach supercharging model using a boundary-element-based surface charging method with a multipole electric field solver, predicting the $Q_d$ on the order of $Q_d/e \sim 10^2$ [5] under similar plasma conditions to the patched charge model. The stochastic charging nature at the grain scale also leads to charge fluctuations [6], heating [7], and oscillations [8–10]. At the macroscopic (device/system) scale, electrodynamical

*Graduate Research Assistant, Department of Mechanical and Aerospace Engineering, 400 W. 13th St., Rolla, MO 65409, AIAA Student Member.
†Professor, Department of Mathematics and Statistics. 400 W. 12th St., Rolla, MO 65409.
‡Assistant Professor, Department of Mechanical and Aerospace Engineering, 400 W. 13th St., Rolla, MO 65409, AIAA Senior Member.

dust transport in rarefied partially-ionized plasma environments has been addressed by mostly particle-based approaches. Early modeling techniques include PIC-MCC for dusty plasma near spacecraft surfaces using a multi-step Monte Carlo algorithm to model the collisional absorption of plasma species by the dust grains [11–13]. This PIC-MCC approach has been implemented onto the European spacecraft charging software Spacecraft Plasma Interaction System (SPIS) to study dust cloud around spacecraft and lunar probes [14, 15]. Other approaches include the discrete element method (DEM) to track dust trajectories [16]. Despite these previous studies, a fundamental question about dusty plasma remains open: what is the net amount of charge and distribution/fluctuation (thus electrodynamic forces) on each individual dust grain in a dusty plasma?

This study focuses on the electrostatic interactions in dusty plasmas, particularly, charging of dust particulates in the collisionless regimes. A most recently developed fully-kinetic particle simulation code, namely, parallel immersed finite element particle-in-cell (PIFE-PIC), will be utilized to self-consistently resolve the plasma environment and charging of immersed materials. This model explicitly includes the materials property (dielectric constant) of dust grains. Effects of materials property and inter-dust distance will be investigated for multi-dust configurations. Section III briefly describes the PIFE-PIC code. Section IV presents the simulation setup and results of single dust charging in stationary and drifting plasmas. Section V presents the simulation setup and results of multi-dust charging in stationary and drifting plasmas. Section VI discusses the simulation results. Finally, Section VII contains a summary and conclusion.

# III. The PIFE-PIC Code

In PIFE-PIC, the computation domain is first decomposed into cubic blocks with the same PIC mesh size. Local (not necessarily uniform) IFE mesh is then generated for each sub-domain. The data interaction between IFE and PIC meshes within each sub-domain is described in detail in Ref. [17].

For the parallel electrostatic field solver, Dirichlet-Dirichlet domain decomposition with overlapping cells is used to distribute the sub-domains among multiple MPI processes [18]. For each sub-domain, the IFE solver is the same as the sequential IFE method with Dirichlet boundary conditions [19, 20]. These Dirichlet boundary conditions are imposed at the boundaries of the sub-domains, which are also interior for the neighboring sub-domains. Therefore, the field solution at respective neighboring sub-domains are used as Dirichlet boundary conditions for each sub-domain. Within each field-solve step, inner iterations are performed such that the solutions of the overlapping cells are exchanged and updated as the new Dirichlet boundary conditions for the respective neighboring sub-domains.

In the PIFE-PIC framework, simulation particles belonging to a certain sub-domain are stored together on the processor that solves the field of the same sub-domain. In this sense, "particle quantities" and "field quantities" of each sub-domain are handled by the same processor. Data communications are implemented at inner boundaries for needed calculations such as charge-weighting of the PIC method. More details of PIFE-PIC and its verification/validation studies are given in Ref. [21, 22].

# IV. Single Dust in Plasma

This section serves as the "baseline" case of the simulation setup, such as domain size and mesh resolution, as well as a summary of code verification of PIFE-PIC against the orbital-motion-limited (OML) results for spherical grains in stationary plasma [21, 22]. Configurations will include stationary and drifting plasma. Details and results will be presented in the full paper.

# V. Multiple Dusts in Plasma

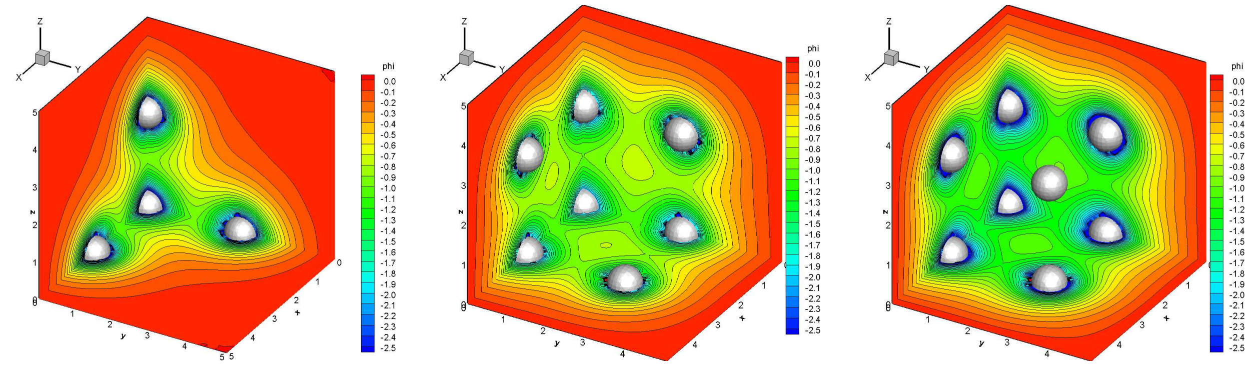
This section focuses on charging of multiple dust grains in stationary and drifting plasmas. Figures 1 and 2 show preliminary results of charging of multiple dust grains in a stationary plasma. Ongoing work is focused on investigating effects of dielectric constants of dust, inter-dust distance, presence of surfaces, and drifting velocities of plasmas.

# VI. Results and Discussions

Results and analysis will be given in the full paper.

# VII. Conclusion

Conclusions will be presented in the full paper.

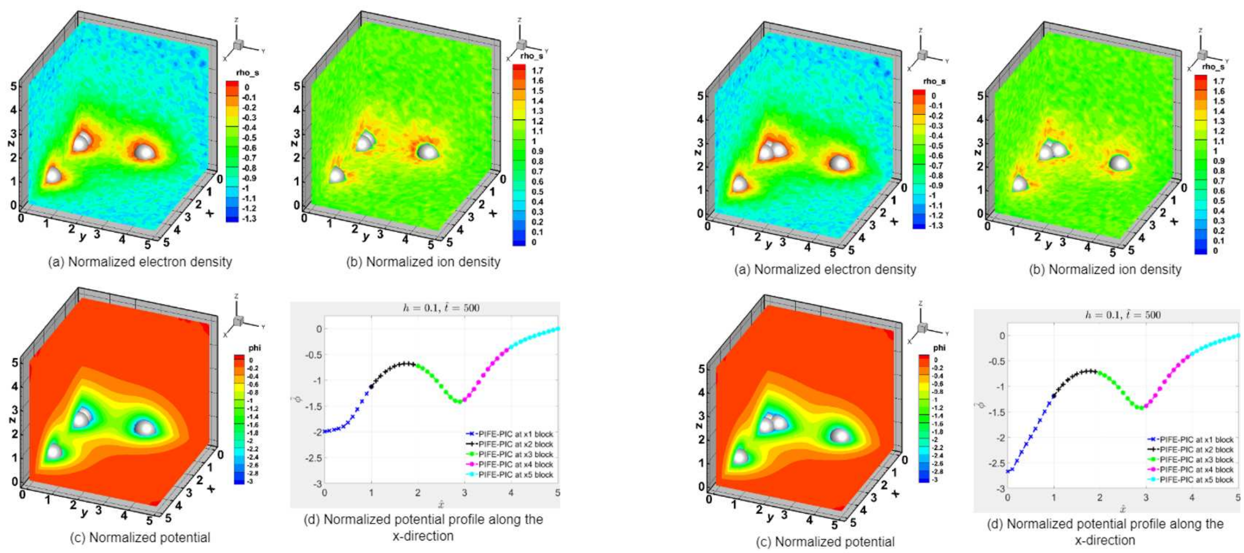


(a) Charging of 4 spherical dust grains in a stationary plasma.

(b) Charging of 7 spherical dust grains in a stationary plasma.

(c) Charging of 8 spherical dust grains in a stationary plasma.

**Fig. 1 Preliminary results of charging of multiple dust grains in a stationary plasma.**




(a) Charging of 1 double-sphere dust and 2 spherical dust in a stationary plasma.

(b) Charging of 1 triple-sphere dust and 2 spherical dust in a stationary plasma.

**Fig. 2 Preliminary results of charging of irregularly-shaped grains in a stationary plasma.**

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