Project Completion Report
UGC Sponsored Major research project

Title of the UGC sponsored project: **A Study of the dynamics of dust particles in strongly coupled plasma**

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The advancement in plasma science in last two decades have expanded the common notion of plasma physics to a great extent. The presence of dust grains in plasma has added a new dimension to it. Plasma with solid dust exhibits significant features and characteristics which were absent in general electron-ion plasma. The discovery of dust crystal in experiment by two pioneering groups Chu et. al (1994) and Thomas et. al. (1994) has opened up various new possibilities in dusty plasma research to address unexplored areas of fundamental importance in physics. The visibility of dust in plasma through naked eye using low cost laser spectroscopy enables to get their full kinetic information, i.e., positions and velocities. This makes dusty plasma useful as a model system to study the statistical properties such as, phase transition, diffusion, viscosity and elasticity of correlated systems at macroscopic kinetic level. This enables dust-seeded plasma to gain a special status in contemporary physics and is considered as an an interdisciplinary research field covering all the four states of matter.

The underlying fact that leads the physics of dusty plasma towards a new paradigm of physics is the considerable amount of electronic charges on dust surface and the type of Debye screening depending upon local plasma environment. This makes dusty plasma quite complex to deal with. When the dust grains come in contact with plasma, they start collecting electron and ion currents and readily attains an equilibrium negative charge on its surface because of higher electron mobility as compared to ions.

The formation of self-organized structures in strongly coupled systems and the collective dynamics depend solely upon the interaction mechanism between the system constituents. The interaction between the charged dust and their strength of couplings result in various waves, instabilities and collective phenomena. Realizing the correct and appropriate effective interaction potential between the charged dust particles is a challenging job. Various experiments have been performed to investigate the type of interaction among the dust grains. It is clear from the experiments that dust grains interact mainly through repulsive Yukawa type of potential, where the Debye sphere is spherically symmetric. However, this is not something that holds good everywhere within a plasma chamber. In laboratory dusty plasma, the dust grains levitate above the plasma sheath and the plasma flow behavior is quite different in sheath region as compared to bulk plasma. This as a result, leads to a kind of effective asymmetric attractive interaction potential named as wake potential in addition to repulsive Yukawa potential in one component plasma (OCP) approximation. The resultant interplay between symmetric repulsive Yukawa and asymmetric attractive Wake interaction leaves a strong impact on coulomb crystallization and brings in significant contribution of fundamental importance to dusty plasma.

Moreover, in recent years the dusty plasma community has focused attention to under-stand the self-organization and collective dust dynamics in presence of external magnetic field. It is necessary to study the influence of external magnetic field on dusty plasma properties in a way to make it relevant towards its natural occurrence. The presence of external magnetic field modifies the plasma flow behavior and this as a result leads to the modification of interaction mechanism between charged dust. It is very difficult to formulate a theory for interaction potential which is valid for a

wide range of magnetic field. The present research involves the moderate strength of magnetic field that is suitable for dust crystallization.

A considerable research done under this project is devoted to model the interaction potential between the test dust particulate near plasma sheath both in presence and absence of magnetic field. The expression for potential thus obtained is characterized in terms of background plasma, dust parameters and external magnetic field. The two dimensional self-organization of dust grains named as coulomb crystallization and their structural behavior have been investigated in terms of radial distribution function using Molecular Dynamic (MD) simulation. The nature of Dust Lattice Wave (DLW) has been studied in the presence of external magnetic field to get the essence of the effect of inter grain interaction mechanisms involving both Yukawa and Wake potential on the collective nature of charged dust. In addition, the role of dust charge fluctuation on the strength of the wake potential has also been studied. The effect of dust charging on the Linear and Non-Linear Dust Ion Acoustic (DIA) mode and its role on dust dynamics in presence of gravity is also discussed in details. Moreover, in the present research we have compared our simulation results on the coulomb crystallization in presence of external magnetic field with the experimental results. In dusty plasma experiments, the background neutral pressure plays a significant role in coulomb crystallization. Therefore, we have modified our MD code to include the collision of dust grains with background neutral particles and compared our simulated results with experiment. Our results are based on the interaction potential that have been derived theoretically. The detail of paper wise description of the work is stated below:

In publication [1] we have theoretically formulated the interaction mechanism between dust grains in presence of asymmetric ion flow and external magnetic field. The potential thus obtained includes Yukawa type as well as wake potential modified in terms of asymmetric ion flow and external magnetic field. The strength of wake potential is found to be driven by the ion flow speed and external magnetic field, which is in accordance with the recent experimental and numerical study on particle-wake interaction. The effect of particle-wake interaction on coulomb crystallization has also been investigated using MD simulation.

We have used the Brownian Dynamic simulation to compare our simulated results with experiment. The simulation is performed using the interaction potentials modified in presence of magnetic field. The study shows a good agreement between simulation and experiment.

In publication [2] we have studied the Dust Lattice (DL) mode in 2D Yukawa crystal in presence of asymmetric ion flow and external magnetic field perpendicular to the crystal plane. The study is aimed to get an essence of the role of asymmetric particle-wake inter-action on the collective behavior of 2D Yukawa crystal in presence of magnetic field. The presence of external magnetic field results in the mixing up of the longitudinal and transverse DL modes and as a consequence it gives rise to two new hybrid DL mode of low and high frequencies. The hybrid modes have been studied as a characteristic of ion flow speed and magnetic field strength. The results show an anomaly of dust lattice mode driven by the particle-wake interaction. The study infers an indirect possible mechanism towards the anomalous phase transition in complex plasma.

Publication [3] includes the effect of dust charge fluctuation on the interaction mechanism between dust grains near the plasma sheath. The dynamical charging of dust arises due to background plasma responses on dust surface and it plays a significant role on the nature of modified

Yukawa as well as Wake interaction. The strength of interaction potentials is found to be characteristic of dust size as well as ion flow speed. The study shows a change in focal length of ion lensing in particle-wake interaction in terms of grain size.

The publication [4] deals with a study on the role of dust charging dynamics on the linear and non-linear DIA mode. The effect of dust charging dynamics on the stability of linear DIA mode has been discussed invoking typical dusty plasma parameters. The strength of non-linearity and their existence domains are studied in terms of dusty plasma parameters. As dust is ubiquitous in interstellar medium (ISM) with plasma background, the study on the linear and non-linear electrostatic nature of the DIA mode in presence of dynamical charging of dust is important to understand the stability of dust molecular clouds (DMCs) through possible gravito-electrostatic coupling. The observations are interesting towards the understanding of dust settling mechanism and formation of dust environments in different regions of space.

List of papers published under this project

1. S. Bhattacharjee and N. Das, Effect of wake potential on Coulomb crystallization in the presence of magnetic field, Physics of Plasmas, 19, 103707 (2012).

2. S. Bhattacharjee and N. Das, Ion-Wake induced anomaly of Dust Lattice Mode in presence of external Magnetic field, Phys. Rev. E, 88, 043106 (2013).

3. S. Bhattacharjee and N. Das , Ion wake formation with dust charge fluctuation in complex plasma, Physics of Plasmas, 20, 113701 (2013).

4. S. Bhattacharjee and N. Das, The linear and non-linear characterization of dust ion acoustic

mode in complex plasma in presence of dynamical charging of dust, Physics of Plasmas, 22, 103701 (2015).