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Magnetic field effects on collective and single particle dynamics of two-dimensional cluster of charged dust particles in complex plasma

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Structures formed by trapping small number of charged particles in space occur in a variety of physical systems, such as those formed by ions in Paul and Penning traps, electrons in quantum dots etc [1, 2]. These finite systems exhibit many interesting properties which distinguishes them from bulk homogeneous systems.

In this work, collective and single particle dynamics of two-dimensional finite-sized clusters of charged dust particles in complex plasma is investigated as a function of external magnetic field applied perpendicular to the plane of the cluster via Langevin Dynamics simulation [3]. By varying the ratio of confining strengths $\alpha = \frac{\omega_{0x}}{\omega_{0y}}$, linear chain of particles as well as 2D isotropic Yukawa clusters can be realized. The collective oscillation spectra is obtained from the simulation at different magnetic field strengths and compared with the dispersion relation obtained from analytical calculation under harmonic approximation. The spectra of the linear chain consists of two branches namely the acoustic and optic branch, the former being purely longitudinal in character and the latter having mixed longitudinal and transverse character. The longitudinal optic branch disappears completely in the absence of magnetic field. The spectra of the 2D cluster also consists of two branches each having both longitudinal and transverse nature. At lower value of magnetic field the lower frequency branch is found to have more longitudinal character whereas the higher frequency branch has more transverse nature. At stronger magnetization the spectra clearly separates into two distinct branches and the higher frequency branch approaches cyclotron frequency (Figure 1). Mean Squared Displacement (MSD) is obtained for the 2D cluster as a probe of single particle dynamics at different values of magnetization (Figure 2). At a high coupling strength, the cluster exhibits a crossover from normal to superdiffusion as a function of the magnetic field strength, whereas at low coupling strength, the cluster remains subdiffusive at all field strengths. The observed single particle and collective phenomena are attributed to the interplay of different competing time scales within the system.

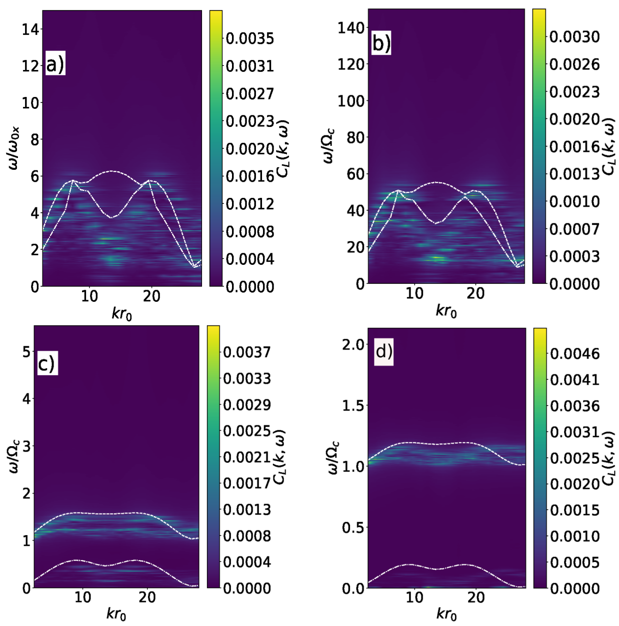

Figure 1. Longitudinal current autocorrelation spectra for different values of magnetic field strengths, (a) $\Omega_c' = 0.0$, (b) $\Omega_c' = 0.11$, (c) $\Omega_c' = 5.67$, and (d) $\Omega_c' = 11.33$ at coupling and screening parameters $\Gamma = 7274$ and $\kappa = 4.7$, respectively. The white dashed curve denotes the higher frequency branch, and the dash-dotted curve denotes the lower frequency branch obtained from analytical calculation [3].

References :

[1] D. H. Dubin and T. O neil, Reviews of Modern Physics 71, 87 (1999).
[2] R. Ashoori, Nature 379, 413 (1996).
[3] H. Sarma and N. Das, Phys. Plasmas 31, 063704 (2024).

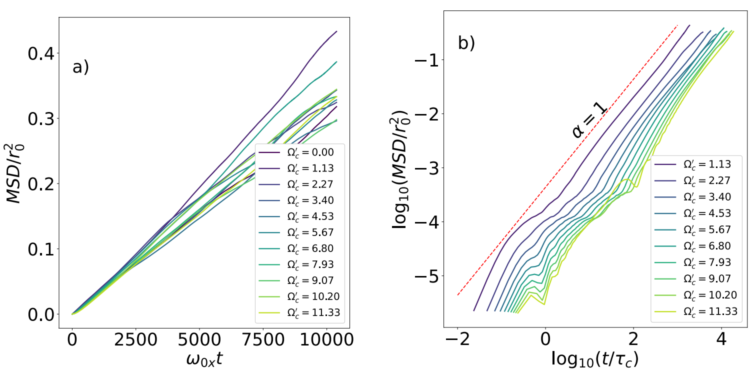

Figure 2. (a) MSD plotted as a function of time at different magnetic field strengths. (b) Log –log plot of MSD as a function of time. For both the figures, the coupling and screening parameters are fixed as $\Gamma = 7274$ and $\kappa = 4.7$, respectively [3].