Seminar

Institute for Plasma Research

Title : Studies on driven dust vortex flow dynamics in dusty plasma

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Time : 10.45 AM

Venue : Seminar Hall, IPR

Abstract :

Dust clouds are formed in many experiments when micron size dust particles introduced in a plasma are confined by spatial non-uniformities of an effective potential. In their fluid-like phase, the dust clouds show self-organized flow dynamics like formation of vortex, boundary layers, and their interesting nonlinear dynamics. Essentially driven by non-conservative force fields arising either from the background plasma or other sources and stabilized by a dissipation, this system allows examining fundamental characteristics of many complex driven-dissipative systems surviving far away from the thermodynamic equilibrium.

Considering the unbounded sheared flow of the background plasma as a driver, the dynamics of dust clouds is studied by the first application of two-dimensional hydrodynamic model using its vorticity-streamfunction formulation. The characteristics of vortex and boundary flows in dust clouds are investigated for a wide range of system parameters, namely, the kinematic viscosity, ion drag co-efficient, neutral friction, boundary conditions and the driving field. In the low Reynolds number liner regime, the problem is treated as a non-homogeneous eigen value problem in a 2D domain with toroidal symmetry that confirms with the experimental set up in IPR laboratories. The collective flow is characterized by formation of vortices with induced multiplicity and departure of dust vorticity length scale spectrum from the driver eigen mode spectrum because of distinct scales introduced by the boundary layer structure. The boundary layer width and Reynolds number were recovered to scale as $\Delta r_b \approx \mu^{1/3}$ and $Re \approx \mu^{-2/3}$ with the kinematic viscosity μ. Equilibrium vortex structure or dimension is asserted by the boundary geometry and nature of driving field.

The nonlinear regime, allowing coupling across multiple scales, is addressed by iterative numerical solution of the nonlinear streamfunction formulation in the limit of small dust kinematic viscosity. Equilibrium vortex structure or dimension in nonlinear regime asserted by the dynamics rather than governed by the boundary geometry. The primary vortex in nonlinear regime are recovered scaling with the most dominant spacial scales of the domain, having a uniform vorticity core surrounded by highly sheared layer and secondary vortex near corner regions. This involves boundary layer separation developing virtual boundaries with highly convective flow of vorticity. This separation of boundary is triggered beyond a critical dust viscosity value μ^* and identified as a structural bifurcation of flow fields. The boundary layer scaling in the nonlinear regime is transformed into a velocity dependence form, $\Delta r_b \approx (\mu L_{||} / u)^{1/2}$, prescribing estimates of dust kinematic viscosity for experiments using velocimetric methods in both linear and nonlinear regimes. The new scale $L_{||}$ is found to be dependence on aspect ratio (L_z/L_r) of the bounded flow domain.

Further, a unique multiplicity of co-rotating vortices are recovered in nonlinear regime for the larger bounded domain of aspect ratio ($L_z : L_r >> 1$), explaining the recent experimental observations of similar structures in IPR. Emergence, in the nonlinear regime, of uniform vorticity core and secondary vortices with a newer level of identical dynamics through critical structural bifurcation highlight the applicability of the dust dynamics to giant vortex flow in nature, like Great red spot of Jupiter, to microscopic biophysical intracellular activity like cell division (mitosis).