Seminar

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Institute for Plasma Research

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Title: Excitation of non-linear waves and instabilities in a flowing dusty plasma

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Abstract

Plasma flow is inevitable in astrophysical situations [1] as well as in laboratory conditions [2]. Flowing plasma creates various fascinating linear and non-linear structures when it flows past an obstacle akin to the hydrodynamic fluid. It also generates different kinds of instabilities, such as Kelvin-Helmholtz instability and Rayleigh-Taylor instability. To examine some of these spectacular phenomena, laboratory experiments are conducted using flowing dusty plasmas. Dusty (or complex) plasma consists of micron or sub-micron-sized charged particles, electrons, ions, and neutrals and has rich collective dynamics similar to conventional plasma. The experiments in this thesis works are performed in the Dusty Plasma Experimental (DPEx) device, in which a DC glow discharge Argon plasma is formed between a circular anode and a grounded tray-shaped cathode. A dusty plasma is created using kaolin particles, and flow in the dust fluid is initiated by employing different techniques over a range of subsonic to supersonic values. We have initially investigated the propagation characteristics of dust-acoustic soliton when it travels toward a charged object [3]. The dust-acoustic soliton is excited by modulating the plasma with a short negative Gaussian pulse that is superimposed over the discharge voltage. The soliton is seen to move toward a potential barrier, created by the sheath around a biased wire, and turn back after reflecting off the barrier. It is found that the distance of the closest approach of the soliton to the center of the barrier increases with the increase in the strength of the potential barrier and with the decrease in the initial wave amplitude. When the dust fluid is made to flow over this charged object with a subsonic speed, it produces typical wake patterns, whereas a slightly supersonic flow triggers the formation of different structures in the fore-wake region known as precursor solitons [4]. To investigate this remarkable phenomenon between two charged objects, a couple of copper wires is installed radially on the cathode, serving as charged objects in the plasma environment. Precursor solitons and wake structures are excited by each of the charged objects when the dust fluid flows supersonically over them. In the frame of the fluid, the solitons propagate in the upstream direction, whereas the smaller amplitude wake structures propagate in the downstream direction. The soliton gets excited by one of the charged objects and wake structure due to another charged object propagating towards each other in between two charged objects. They get dissipated before interacting with each other due to dust-neutral collisions. When the distance between two objects is reduced, the interaction of soliton with wake structure takes place [5]. After the interaction, the soliton continues to propagate with higher amplitude and velocity in the same direction, whereas the width of the soliton decreases. The further decrement of the distance between two charged objects results in the trapping of wake structures between them [6]. A dramatic change happens in the excitations when we replace the horizontally charged object with cylindrical or spherical charged objects. Instead of plane solitons, cylindrical (or spherical) precursor solitons get excited when the dust fluid flows over the cylindrical (or spherical) charged object with a supersonic speed. It is observed that the spherical soliton dissipated faster than the cylindrical soliton. The amplitude and velocity of both solitons increase with the velocity of the dust fluid, whereas the width decreases. Furthermore, the amplitude, velocity, and width follow the same trend when the strength of the charged object is increased. In another set of experiments, the excitation of the Kelvin-Helmholtz instability in flowing dusty plasma is carried out, in which shear is generated at the interface of two layers of the dust fluid using a gas-

pulsed valve [7]. The growth rate of the instability is seen to decrease with an increase in the gas flow velocity in the valve and the concomitant increase in the compressibility of the dust flow. The shear velocity is further increased by making the stationary layer flow in the opposite direction. The magnitude of the vorticity is found to become stronger while the vortex becomes smaller with such an increase in the shear velocity. The findings from the aforementioned experiments are either compared with the solution of the forced-KdV equation with one/two charged objects or with molecular dynamics simulations and found to be in good agreement.

[1] Meyer, Eileen T., et al., Nature 521, 7553 495 (2015)
[2] Drake, Glendinning, et al., Phy. Rev. Letters 81, 2068 (1998)
[3] Krishan Kumar et al. Phy. Plasmas 28, 103701 (2021)
[4] Jaiswal et al., Phy. Rev. E 93, 041201 (2016)
[5] Krishan Kumar et al. Accepted for publication in Phy. Plasmas (2023)
[6] Krishan Kumar et al. Phy. Plasmas 29, 123703 (2022)
[7] Krishan Kumar et al. Scientific Reports 13, 3979 (2023).