F-I30 AAPPS-DPP2020

4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Pattern formation via asymmetric vortex mergers

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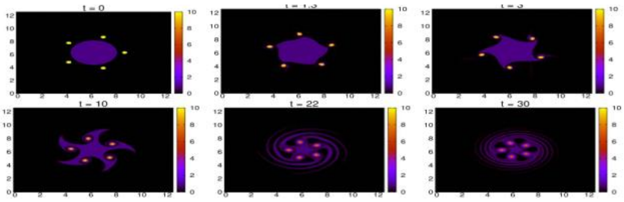
Intense vortices have been observed to form in decaying two-dimensional turbulence [1]. The nonlinear interaction between intense vortex and hole (regions of zero vorticity) with a background decaying two-dimensional turbulence is known to play a crucial role in determining the later stages of the turbulence. Consequently, the generation of coherent-structures (vortex and hole) in the background of a decaying turbulence has attracted a great deal of interest from the community of pattern formation in nonlinear dynamics and plasma physics.

Magnetized ideal plasma columns and incompressible, inviscid, two-dimensional turbulence are known to be governed by the same equations [2]. This homology between the two-dimensional drift-Poisson model of strongly magnetized plasmas and the equations governing two dimensional Euler flows has given rise to a spurt of experimental studies [3-7] related to the dynamics of intense point-like vortices with a background flow. Consequently, thorough numerical simulations are employed to study such pattern formations in nonlinear relaxation of toroidal pure electron plasmas [8-9].

An isolated circular vortex-patch (also called Rankine vortex) is known to support marginally stable (ω=0) surface waves (also known as “Kelvin waves”) with m-fold symmetry (or “V-states”) [10]. The “filamentation” (thin filaments of vorticity drawn out of the patch vortex) of the Rankine vortex, occurs as a late time phenomenon of the Kelvin-Helmholtz instability seeded due to infinitesimal perturbation to the V-states of the Rankine vortex. Havelock [11] analytically calculated the critical number of stable point-vortices around a patch-vortex while Lansky [12] performed the stability analysis of a ring-like point vortices around a patch-vortex of arbitrary strength. The failure of analytical and contour dynamics methods to study phenomena beyond ‘wave-breaking’, motivates the ab-initio numerical simulation of such point and patch vortex patterns.



Both PIC [13] and fluid [14] simulations of such patch and point vortex patterns have been found to generate identical quasi-stationary vortex-crystal and transient holes up to at least *15* largest eddy-turnover time conserving the individual Casimirs. The study is extended to compressible fluids [14-15] as well as fluids having memory - popularly called as visco-elastic fluids [16]. For compressible flows, the acoustic modes mediated via nonlinear interaction between the point-vortices, have been found to strike the vortex-crystals generated in late-times causing the destruction of the crystal as the Mach number increases. The acoustic modes are found to generate harmonics and beats with its own harmonics which accelerate the melting of the vortex-crystals while the strength of these modes are found to vary as the inverse square of the Mach number. For non-Newtonian fluids, modelled via generalized-hydrodynamic (GHD) equations [17], the wave-front-like rings generated from the point-vortices, propagate in elliptical orbits keeping the footprint of their corresponding initial position. The rings collide with each other even within the patch vortex region forming regions of high vorticity at the point of intersection and most interestingly, they pass through each other keeping the forms of the rings intact. Few quantitative comparisons with a reduced analytical model with the results of ab-initio numerical simulation will be presented for such asymmetric vortex mergers.

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