Formation and Instability of Phase Space Structures

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Abstract

Near marginal stability of a kinetic system, when an instability drive of a kinetic distribution is in near balance with background dissipation, spontaneous phase space structures can develop in the form of holes and clumps[1] that support nonlinear waves. These waves are similar, but more general than Bernstein, Greene, Kruskal waves, as they can occur in a complex geometry (such as a global mode in a tokamak) . The theory used has a universal character, and predictions from the paradigm, bump-on-tail problem, for which numerical simulation is straight forward, can be applied to more complex problems. Background dissipation induces frequency sweeping from the changing velocity of these structures, and experimentally observed sweeping signals suggest that these structures may be responsible for frequency sweeping observed in several experiments. The observation of how much the frequency shifts in a given time may even be the basis of a diagnostic to determine the magnitude of the internal fields[2]. Once a phase space structure is formed, the dynamics of the phase structures can be followed accurately using a self-consistent theory for the adiabatic evolution of both the particles and the wave. However, the adiabatic evolution may eventually reach a point where this theory intrinsically breaks down; either because the termination of frequency sweeping is predicted which would then imply the breakdown of the adiabatic assumption, or because the adiabatic evolution equations reach a singular point where the equations can no longer make a unique prediction[3]. The kinetic linear instability analysis of the nonlinear wave supported by the phase space structure will be discussed here. It is shown that these "difficult" points are precisely the marginal points for linear instability of the structure when the wavelength of the perturbation is identical with the wavelength of the nonlinear mode (note that geometrical considerations can prevent the excitation of sideband instabilities where the unstable wavelengths differs from the wavelength of the nonlinear wave, but here we have shown that instability cannot be avoided when the adiabatic theory becomes internally inconsistent or non-predictive). A simulation with a delta-f particle code shows that the adiabatic theory is quite accurate to the point of instability. Then instability is triggered and in the nonlinear phase coherent oscillations arise. After they damp, it is found that phase space structures still survive at a somewhat smaller size and frequency sweeping continues, albeit at a slower rate.

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