Multiple helicity modes in 3D collisionless magnetic reconnection

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Abstract

Nonlinear magnetic reconnection in collisionless regimes has been extensively analyzed in recent years in 2D configurations in the presence of a large magnetic guide field [1-4]. The removal of the 2D constraint is expected to show new phenomena. In particular, it leads to coupling between modes with different helicities and with different resonant surfaces and to magnetic field line stochasticity.

In our investigation we adopt a fluid Hamiltonian 3D model, derived in Ref. [5]. This model describes drift-Alfvén perturbations in a plasma immersed in a strong, uniform, externally imposed magnetic field, where spatial variations along the field lines are assumed to be small compared to variations normal to it. This system consists of two fluid equations, where small scale effects related to the electron temperature (ρ_s) and to electron inertia (d_e) are retained, but magnetic curvature effects are neglected.

First, we discuss the nonlinear structures of the current density and vorticity layers starting from an initial configuration where a single helicity mode is linearly unstable. This problem is equivalent to a 2D problem with non symmetric perturbations.

Second, we consider the case where two linearly unstable, resonant modes with different helicities interact nonlinearly. This interaction drives higher order harmonics which modify the nonlinear structure of the reconnection region significantly. In this case the magnetic flux function depends on all three spatial coordinates. Thus, the Hamiltonian function of the equivalent dynamical system that describes the spatial structure of the magnetic field lines is no longer integrable, as in the case of single helicity perturbations, and we observe the development of magnetic field line stochasticity.

The chaotic structure of magnetic field lines observed numerically is characterized in terms of Poincaré maps and Lyapunov exponents. These results suggest a modification of the adopted model, so as to account for the fact that the current density is expected to become uniformly distributed within the stochastic region.

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