Collisionless magnetic reconnection

D. Grasso

Burning Plasma Research Group, INFM, Politecnico di Torino, Italy

Magnetic field line reconnection in high temperature plasmas is one of the frontier problems in plasma physics due to its relevance to astrophysical and laboratory plasmas. In collisionless regimes, the topology of the magnetic field is broken by the effect of electron inertia, and the reconnection process exhibits Hamiltonian properties. In recent years Important results have been reached by our group in the analysis of Hamiltonian reconnection in 2D configurations in the presence of a large magnetic guide field [1-4]. In particular, the topological invariance properties of the plasma dynamics and their influence on the nonlinear evolution and on the saturation of the reconnection instabilities have been clarified in comparison with dissipative reconnection.

Our analysis is based on a fluid Hamiltonian model, derived in Ref. [5], which 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. Due to the absence of physical dissipation, very small scales develop and the problem is computationally challenging. We carried out a numerical code based on a finite volumes scheme, where special filters have been introduced in order to deal with the small scales[6].

Numerical integrations of the adopted model in 2D configurations show the formation of current density and vorticity layers aligned with the separatrix of the magnetic island. These structures have been interpreted on the basis of the Lagrangian invariants [2]. In the nonlinear phase the magnetic island width saturates at a macroscopic amplitude superimposed to the fine spatial scales arising from the phase mixing of the lagrangian invariants [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 addition, 3D perturbations are not constrained by the same topological conservations as in 2D.

In order to address the three dimensional problem, the code has been parallelized adopting the MPI libraries. Tree-dimensional configurations where a single helicity mode is linearly unstable is equivalent to a 2D problem with non symmetric perturbations. On the contrary, the nonlinear interaction between two linearly unstable, resonant modes with different helicities, 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, by Poincarè maps and Lyapunov exponents, the development of magnetic field line stochasticity.

[1] M. Ottaviani and F. Porcelli, *Phys. Rev. Lett.* **71** (23), 3802 (1993).
[2] E. Cafaro *et al.*, *Phys. Rev. Lett*, **80** 20 (1998).
[3] D. Grasso *et al.*, *Plasma Phys. Control. Fusion* **41**, 1500 (1999).
[4] D. Grasso *et al.*, *Phys. Rev. Lett.* **86**, 5051 (2001).
[5] T.J. Schep *et al.*, *Phys. Plasmas* **1**, 2843 (1994).
[6] S.K. Lele *J.Comp. Phys.*, vol.103, 16 (1992).