Self-Organization of Plasmas with Flows

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Self-organization in a two-fluid plasma has been studied by nonlinear 3D simulation. The theory[1] predicts creation of the "double Beltrami (DB) field" represented by,

$$\boldsymbol{B} = a(\boldsymbol{V} - \epsilon\nabla\times\boldsymbol{B}), \boldsymbol{B} + \epsilon\nabla\times\boldsymbol{V} = b\boldsymbol{B}, \quad (1)$$

where $\boldsymbol{B}, \boldsymbol{V}$ are a magnetic field and an ion flow velocity, $\epsilon \equiv \lambda/L$ (λ : ion skin depth, L : system size), and a, b are constants. The Hall term in the two-fluid model leads to a singular perturbation that enables the formation of an equilibrium given by a pair of two different Beltrami fields (eigenfunctions of the curl operator). The DB states can span a richer set of plasma conditions than the single Beltrami states (the Taylor states).

The compressible Hall-MHD equations,

$$\frac{\partial n}{\partial t} + \nabla\cdot(n\boldsymbol{V}) = 0, \quad (2)$$

$$\frac{\partial \boldsymbol{V}}{\partial t} + (\boldsymbol{V}\cdot\nabla)\boldsymbol{V} \quad (3)$$

$$= -\nabla p_i + \boldsymbol{j}\times\boldsymbol{B} + \nabla\cdot\boldsymbol{\Pi}, \quad (4)$$

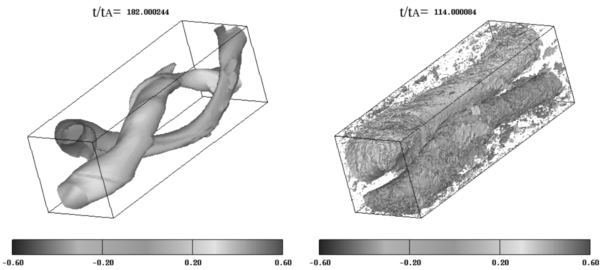
$$\nabla\cdot\boldsymbol{\Pi} = \nu(\nabla^2\boldsymbol{V} + \frac{1}{3}\nabla(\nabla\cdot\boldsymbol{V})), \quad (5)$$

$$\frac{\partial \boldsymbol{B}}{\partial t} = -\nabla\times\boldsymbol{E}, \quad (6)$$

$$\boldsymbol{E} = -\boldsymbol{V}\times\boldsymbol{B} + \frac{\epsilon}{n}(\boldsymbol{j}\times\boldsymbol{B} - \nabla p_e) + \eta\boldsymbol{j}, \quad (7)$$

$$\frac{\partial p}{\partial t} + (\boldsymbol{V}\cdot\nabla)p + \gamma p\nabla\cdot\boldsymbol{V} = 0, \quad (8)$$

(n: number density, $\boldsymbol{j}$: current density, $\boldsymbol{E}$: electric field, p: pressure, ν: viscosity, η: resistivity, γ: ratio of specific heat) are solved by the finite difference and the Runge-Kutta-Gill methods in a 3 dimensional rectangular domain. The quasi-neutrality $n = n_i = n_e$, and $p = p_e = p_i$ are assumed. Figure shows isosurfaces of the relaxed toroidal magnetic field. We see that, compared with the single fluid case (a)[2], fine structures are imposed on global modes in the two-fluid case (b). Variational principles in the two-fluid system will be discussed.



(a) ε=0 (b) ε=0.1

Isosurfaces of the toroidal magnetic field.

[1] S.M. Mahajan and Z. Yoshida, Phys. Rev. Lett. **81**, 4863 (1998).

[2] R. Horiuchi and T. Sato, Phys. Rev. Lett. **55**, 211 (1985).