Transport and evolution of ion gyro-scale plasma blobs in perpendicular magnetic fields

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Hybrid Models

A hybrid model can capture the non-linear interaction between ion gyration and plasma inhomogeneity. Capture cross-coupling between ion gyro-scale kinetic modes and fluid MHD-like modes, resolve phenomena on much shorter timescales than fluid models, and study inhomogeneous physics in configuration space and non-Gaussian ion velocity distributions. The features of our hybrid code are as follows:

- It combines a particle-in-cell (PIC) algorithm for kinetic ions with an electron fluid.
- PIC codes subject weighted pseudo-particles to the Lorentz force in a continuous phase space, with $E$, $B$ fields on a staggered grid.
- The code used is “2DV” - a 2d simulation plane with 3 field and velocity components, e.g. $E_1$, $E_2$, $B_1$, $B_2$.

For our model we make the following assumptions:

- betrav loss ions, $\mu = 0$.
- $\mathbf{E}$ is negligible on length scales of interest, implying charge neutrality $e\mu = 0$.
- Collisionless plasma.
- Isothermal electron gas, $\nabla \cdot \mathbf{E} = 0 \Rightarrow \mathbf{E} = \nabla \psi$.
- We take the Darwin limit of Maxwell’s equations, neglecting displacement current.

From the electron fluid momentum equation and Ampère’s law, we arrive at the equation used to update the electric field in the code:

$$ \mathbf{E} = \frac{1}{\mu} \left( \frac{\partial \nabla \cdot \mathbf{E}}{\partial t} + \mathbf{v} \times \mathbf{B} \right) + \left( \nabla \times \mathbf{E} \right) \times \mathbf{B} $$

Under these assumptions electric fields cannot arise from charge separation, hence electric fields are purely motional in origin. This model allows for the propagation of Alfvén and magnetosonic waves, ion cyclotron waves, ion kinetic waves, hybrid waves and whistler waves.

Blobs

The outer regions of tokamak plasma, near the last closed flux surface, are observed to generate coherent propagating blobs [5], which undergo transport, and can break free of the confinement region. Blobs with sufficient radial velocity can strike the walls of the tokamak, increasing local particle and energy fluxes, reducing divertor efficiency, and increasing impurity levels. Models for blob transport and evolution have primarily focused on analytical and numerical fluid and multi-fluid descriptions; see, for example, Refs [6-4]. Here we pursue a hybrid method which combines kinetic ions with fluid electrons. For a recent review of edge plasma physics in tokamaks we refer to Ref. [5].

Hybrid particle and energy fluxes, reducing divertor efficiency, and storing kinetic energy in the tokamak...