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A novel collisionless fluid plasma model based on non-local closure incorporating cyclotron resonance effect

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There are two types of models of collisionless plasmas: fluid models and kinetic models. Fluid models consider a finite number of physical quantities per grid point (number density, velocity, etc.), and they are often used to describe macroscopic phenomena. However, conventional fluid models such as MHD completely ignore collisionless effects even though it has been pointed out that wave-particle interaction could also affect macroscopic dynamics. Full kinetic models that incorporate all kinetic effects demand much more computational resources than fluid models since we essentially have to solve the Vlasov equation on 6-dimensional phase space. Accordingly, high-resolution kinetic simulation of 3-dimensional macroscopic systems requires a massive amount of computational power. This motivates us to consider a novel fluid-based model that incorporates collisionless effects significant for macroscopic dynamics without much computational complexity.

Hammett and Perkins have developed a method called the Landau closure, which incorporates the Landau resonance effect for 1-dimensional electrostatic plasmas.[1] Starting from the moment equations of the Vlasov equation, they approximated the highest order moment by a linear combination of lower-order moments in the Fourier space. The resulting model can reproduce the linear Landau damping. Landau closure is often used with the well-known Chew-Goldberger-Low (CGL) model to determine the gyrotropic heat flux terms.

CGL model, together with a sufficient finite Larmor radius (FLR) correction and the Landau closure, is an example of a fluid-based description of collisionless plasmas, which can be used to analyze low-frequency phenomena of anisotropic systems[2]. However, because of the low-frequency approximation, CGL-based models do not take into account cyclotron resonance which is as crucial as Landau resonance in warm magnetized plasmas. Also, CGL-based models may not be best suited for nonlinear simulations where some high-frequency waves inevitably appear.

To incorporate cyclotron resonance, we have extended the Landau-type closure to the full pressure tensor by modeling the heat flux components that appear in the time evolution of off-diagonal pressure components.[3] This model can reproduce linear cyclotron damping of transverse waves propagating parallel to the ambient magnetic field. The dispersion relation of electromagnetic ion cyclotron is shown in Figure 1.

In addition, we have applied this model to EMIC temperature anisotropy instability simulation and found that qualitatively correct linear growth of the magnetic field and quasilinear relaxation of anisotropy can be simulated. No previous fluid models could reproduce this without *ad hoc* terms because cyclotron resonance is strongly related to EMIC instability. Figure 2 shows the time evolution.

References
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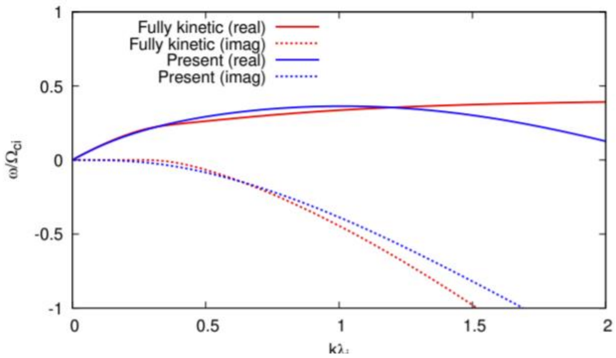

Figure 1. Dispersion relation of EMIC mode obtained with $\beta_i = \beta_e = 1$. The blue indicates our model, the red the fully kinetic result.

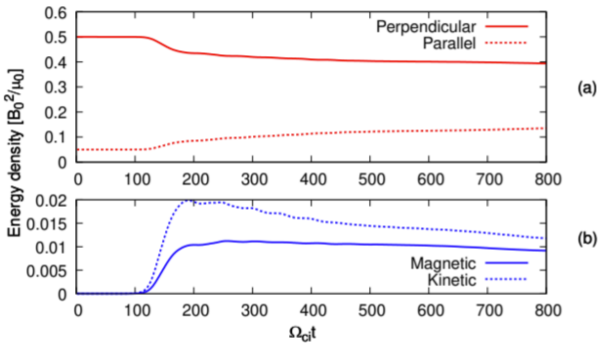

Figure 2. Time evolution of EMIC instability. (a) Plasma pressure $p_\perp$ and $p_\parallel/2$. (b) Magnetic energy $B_\perp^2/2\mu_0$ and kinetic energy $nmu^2/2$.