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Fluid modeling of collisionless plasmas with a non-local kinetic closure

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Modeling of collisionless plasmas can be divided into two categories: fluid models and kinetic models. Generally speaking, fluid models require less computational resources than kinetic models, so they are suited for large-scale simulations. However, conventional fluid models such as MHD ignores wave-particle interaction (WPI). It has been pointed out that WPI affects microscopic and macroscopic dynamics and should not be ignored even in MHD scales. This creates a demand for a fluid model of collisionless plasma that takes into account WPI effects.

We have developed a fluid model called the cyclotron resonance closure (CRC) model [1]. The CRC model reproduces linear cyclotron resonance effects using a non-local closure method similar to the Landau closure model. The CRC model reproduces the linear cyclotron resonance and linear growth of ion temperature anisotropy instabilities qualitatively correct. We have also shown that the quasilinear relaxation of temperature anisotropy via resonant waves incorporated in the CRC model.

Another example of a kinetic fluid model is the well-known Chew-Goldberger-Low (CGL) model. The CGL model is used to analyze low-frequency waves in collisionless plasmas. The CGL model enriched by finite Larmor radius correction and Landau closure predicts the growth rate of firehose instability with reasonable accuracy. However, the CGL model cannot reproduce cyclotron resonance effects such as cyclotron damping and electromagnetic ion cyclotron (EMIC) instability because of the low-frequency assumption.

We will discuss some basic concepts of these kinetic fluid models and their range of application, especially in nonlinear simulation. The CRC model is not limited by frequency (at least up to cyclotron frequency) and can be used for both EMIC and parallel firehose instabilities but need improvement for quantitative agreement with fully kinetic models.

The CGL model can be very accurate in linear analysis of low-frequency waves. We compared the CRC and the CGL model using a simulation of an initially parallel firehose unstable system [2]. We found that the low-frequency approximation of the CGL model fails in some parameters after the appearance of high-frequency oscillation in the nonlinear stage. Also, the absence of cyclotron damping in the CGL model results in a quasi-steady final state that is not consistent with marginal stability analysis.

We conclude that a kinetic fluid model that does not make the low-frequency approximation should be considered instead of the CGL-based approach. The CRC model is a candidate for such a model that can be used in a wide range of parameters.

[References]

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