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A non-dissipative closure model for mirror instability in a collisionless plasma

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The ideal magnetohydrodynamic (MHD) equations describing macroscopic behaviors of collisionless plasmas are completed by considering the moment-closure problem. It is well known that the CGL (Chew-Goldberger-Low) model, where the parallel heat flux is presumed to be zero, predicts a lower criterion of temperature anisotropy for the mirror instability than that of linear analysis of the Vlasov equation (by a factor of 6). The difference of the criteria is important not only as a fundamental problem in plasma physics but also as one of key factors determining temperature anisotropy in the Earth's magnetosheath. In order to resolve the problem in the CGL model, Kulsrud proposed a set of kinetic and fluid equations where two components of the pressure tensor $(p_\perp, p_\|)$ are directly given by second-order moments of a drift kinetic equation [1]. In the Kulsrud's approach, the fluid and kinetic equations are derived by $(1/e)$-ordering and gyrophase averaging of the Vlasov equation, and are coupled with each other to be solved. Here, it is called "kinetic MHD equations".

It has been desired to find a closure model for the kinetic MHD equations, since they are too complicated to be applied to numerical simulations although the derivation is strict and valid. Snyder and his co-authors have applied the 4+2 and/or 3+1 Landau-fluid models to closing the moment hierarchy [2]. It is, however, known that a dissipative closure relation such as the Landau-fluid model does not preserve the time-reversibility of linearly unstable modes. Thus, according to the idea of the non-dissipative closure model for the ion temperature gradient mode turbulence [3,4], we consider a closure relation between the heat flux $(q_{\perp 1}, q_{\| 1})$, the pressure $(p_{\perp 1}, p_{\| 1})$ and the parallel flow $U_\|$ with real-valued coefficients which are determined so as to reproduce the two conditions; the relation between $(q_{\perp 1}, q_{\| 1})$ and $(p_{\perp 1}, p_{\| 1})$ given by the kinetic MHD equations and the linear dispersion relation (where the subscript 1 denotes fluctuations). Applying the closure model to $(q_{\perp 1}, q_{\| 1})$ in equations for $(p_{\perp 1}, p_{\| 1})$ given by taking second-order moments of the kinetic equation, we have found a set of fluid equations which preserve the time-reversibility for unstable modes and give the same dispersion relation as that from the kinetic analysis.

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