COMMUNICATIONS IN COMPUTATIONAL PHYSICS
Vol. 4, No. 3, pp. 719-728

Commun. Comput. Phys.
September 2008

Two-Fluid Formulation of Lower-Hybrid Drift Instabilities in Current-Sheet Equilibrium with a Guide Field

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Received 30 November 2007; Accepted (in revised version) 6 March 2008

Available online 21 April 2008

Abstract. A nonlocal two-fluid formulation has been constructed for describing lower-hybrid drift instabilities in current-sheet configuration with a finite guide magnetic field in the context of magnetic reconnection. As a benchmark and verification, a class of unstable modes with multiple eigenstates are found by numerical solutions with guide field turned off. It is found that the most unstable modes are the electrostatic, short-wavelength perturbations in the lower-hybrid frequency range, with wave functions localized at the edge of the current sheet where the density gradient reaches its maximum. It is also found that there exist electrostatic modes located near the center of the current sheet where the current density is maximum. These modes are low-frequency, long-wavelength perturbations. Attempts will be made to compare the current results with those from kinetic theory in the near future since the validity of the fluid theory ultimately needs to be checked with the more fundamental kinetic theory.

PACS: 52.35.Vd, 94.30.cp, 52.35.Kt

Key words: Lower-hybrid drift instability, guide field, two-fluid model, Harris equilibrium.

1 Introduction

Lower-hybrid drift instability (LHDI) is of interest mainly due to its possible connection to anomalous resistivity, which is believed to be a possible mechanism to increase the magnetic reconnection rate. Magnetic reconnection [1–3] is one of the most challenging problems in the field of space, astrophysical and laboratory plasmas. Magnetic reconnection plays an essential role in determining the evolution of magnetic topology

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in relaxation processes, usually accompanied by an observed rapid release of magnetic energy, in these highly conducting plasmas. However, the current simulation and theoretical results based on the Sweet-Parker model addressing the reconnection process predict a much slower reconnection rate than observed due to the extremely small resistivity. This makes it inevitable for the magnetic field to dissipate only in a very narrow sheet, which obstructs the mass outflow and as a consequence, limit the reconnection rate. Although the subsequent Petschek model [4] based on slow shocks allows large mass flows by opening up the outflow channel and thus results in the faster reconnection rates, it was shown later [5, 6] that the Petschek solution is not compatible with smooth resistivity profiles. On the other hand, microinstabilities may enhance resistivity in the reconnection region, where plenty of free energy exists in form of a large relative drift between ions and electrons and large inhomogeneities in pressure. As a result, this anomalous resistivity will increase the reconnection rate. LHDI is one candidate addressing the mechanisms responsible for such an anomalous resistivity. In fact, MRX experiments [7] reported a positive correlation between the lower-hybrid fluctuations and enhanced rates of magnetic reconnection in the center of a reconnecting current sheet.

LHDI is driven by inhomogeneous density, magnetic field, and/or temperature, with maximum growth believed to occur along directions orthogonal to both the magnetic field vector and the direction of the inhomogeneity, which is frequently assumed to be perpendicular to the direction of the magnetic field. The underlying microinstabilities have been considered to be predominantly electrostatic due to their effectiveness in wave-particle interactions.

LHDI without guide field [8–13, 15–18] has been extensively investigated by previous works. Specifically, Batchelor [8] and Davidson [9] formulated the nonlocal theory on LHDI in cylindrical plasma. LHDI type instabilities, for example, velocity-shear driven, Kelvin-Helmholtz-type instabilities, have been studied by Ganguli with his colleagues [10–12], and Gladd *et al.* [13]. The nonlocal theory on the LHDI in Harris equilibrium has been investigated by Huba *et al.* [17] and Yoon [18]. However, in the space and laboratory plasmas, a sheared magnetic field is usually accompanied by a guide magnetic field, which will significantly affect the evolution of instability and may also give rise to some new instabilities that could significantly impact the physics of magnetic reconnection. An implicit, fully kinetic approach by Daughton [21] and a gyrokinetic electron/full kinetic ion model by Lin have been developed to study the lower hybrid drift-instability with a guide field.

In the present paper we report an improved formulation of the nonlocal characteristics of LHDI in an equilibrium geometry with a finite guide field using a electrostatic two-fluid model. A wave function for the LHDI has been derived, which has been numerically solved for a set of parameters. This work is the first result of a series of analytical and numerical works on LHDI and magnetic reconnection, which will eventually lead to the kinetic simulations of fast reconnections with a finite guide field. Comparisons with kinetic theory will be made in the near future in order to verificate the validation of fluid and kinetic theory.