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The behavior of current/vortex sheets in extended MHD: a system-scale theory for fast reconnection?

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Abstract

Magnetic reconnection is a fundamental process whereby magnetic energy stored in sheared magnetic fields is released and converted into plasma energy. Of particular relevance is understanding fast (explosive) reconnection phenomena. It is now generally accepted that electron Hall physics is the culprit of fast reconnection physics [1]. Recent work [2] has shown that the reconnection rate in Hall MHD scales as $(d_i/\delta)^{1/2}$, where d_i is the ion skin depth, and δ is the current sheet thickness. However, there are still situations (e.g., the solar corona) in which fast reconnection is frequently observed but $d_i \ll \delta$, and hence the importance of Hall physics cannot be justified *a priori*.

Since fast Hall reconnection requires $d_i \sim \delta$, a successful system-level theory of fast magnetic reconnection for such situations should provide a viable mechanism for self-consistent, dynamic current sheet “thinning” to Hall-relevant scales. Here, we propose current-vortex sheets (in which a sheared magnetic field and a sheared flow co-exist) as the basis for such a mechanism.

In the configuration of interest, the magnetic and ion velocity fields are parallel and identically sheared. We have studied the nonlinear behavior of this current-vortex sheet configuration numerically in the framework of 2D incompressible resistive and Hall MHD. In resistive MHD ($d_i \ll \delta$), KHI occurs for super-Alfvénic sheared flow, and a tearing mode instability (TMI) occurs otherwise. Resistive MHD results [3] demonstrate that, in the KHI-dominated regime, fast reconnection rates (in the KHI time scale) are possible which are independent of resistivity η for a large range of resistivity, and that the current sheet thickness δ at the time of the maximum reconnection rate scales as $\eta^{1/2}$. Therefore, KHI in the resistive MHD limit is in fact a very effective current sheet thinning mechanism when η is small.

The thinning process may stall due to magnetic pressure buildup. Determining the conditions under which this occurs before $d_i \sim \delta$ is still subject of ongoing research. However, once δ is comparable to d_i, Hall MHD allows electrons and ions to decouple within the ion skin depth, enriching both the linear and nonlinear behavior of the current-vortex sheet configuration [4]. Linearly, both modes are allowed to grow in a wide range of sub- and super-Alfvénic flows. This implies that a collisionless (fast) electron TM can grow in the presence of a strong ion flow, which is fundamental to allow fast reconnection to proceed. Nonlinearly, both a magnetic island and an ion flow vortex are present at saturation, and the electron flow shows very good alignment with the magnetic field. This saturation state is remarkably independent of the magnitude of the ion shear flow, being observed for both sub- and super-Alfvénic flows.

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[2] X. Wang et al., *Phys. Rev. Lett.* **87**, art. no. 265003 (2001); J. Dorelli, in preparation (2003).

[3] D. A. Knoll and L. Chacon, *Phys. Rev. Lett.* **88**, art. no. 215003 (2002).

[4] L. Chacon, D. A. Knoll, J. M. Finn, *Phys. Lett.: A* **308**, 187 (2003).