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Role of Electron Kinetic Effects on the Macroscopic Structure and Evolution of Collisionless Reconnection in Simulations with Open Boundary Conditions.

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Summary: The final years of this grant have been dedicated to diagnosing the observable properties of Collisionless Magnetic Reconnection (CMR) as disclosed by the open boundary condition PIC simulations developed under this grant. Particular attention has focussed on identifying the Electron Diffusion Region (EDR), the short scale domain where the process is thought to be enabled. The critical issue has been the need for experimental closure for CMR that is widely invoked in astrophysics, but has actually rather little direct, incontrovertible evidence for its involvement. This difficulty arises because CMR is about topology change of the magnetic field - a concept that is not conducive to single, or even few point correlations as are beginning to be possible with spacecraft armada, like Cluster or the planned Magnetospheric Multi-Scale (MMS) mission to be launched in 2014. Alternate formulations about the time rate of magnetic flux inventoried by a moving observer, reformulate the needed evidence in terms of the curl of various weak vector fields, such as $\mathbf{E} + \mathbf{U}_e \times \mathbf{B}$, that is zero in ideal MHD. To sense $\mathbf{E} + \mathbf{U}_e \times \mathbf{B}$ from space measurements is already a heroic task. The curl of such a small vector field is outside the domain of the possible.

In our work we have used the “omniscient” state of the PIC simulator to compute quantities that are on the one hand (i) the theoretical quantities of the theory and, on the other (ii) are correlated with theoretically connected quantities that are nonetheless observable. Four extremely unusual observable quantities have been shown to accompany the theoretical sites where the PIC enabled computations of the curls mentioned above also indicate that CMR is underway. These observable quantities all stem from various antecedents or consequences of the electrons in the plasma being locally **demagnetized** in the EDR. These properties are (i) the non-perturbative size of the Guiding Center Theories (GCT) expansion parameters, (ii) the non-zero size of electron agyrotropy (that indexes the departure of the pressure tensor from cylindrical symmetry about $\mathbf{B}$); (iii) the order unity electron thermal mach number required in the current channel of the crossing orbit thickness; and (iv) the extremely large electron pressure anisotropies that are caused by the inductive electric fields as the particles approach the reduced field strengths of the EDR, while still being magnetized.

This approach makes use of the viewpoint that the small perturbation quantities for GCT are in essence statements of the relative importance of the electric and magnetic forces, the rate of energy transfer to the electrons per cyclotron period compared to kT which have both been shown to be directly observable with enhanced spacecraft

payloads (such as NASA's Polar spacecraft or MMS in the future) that measure the full vector E , B , and electron bulk velocity and trace of the temperature tensor. Agyrotropy has been measured on spacecraft and the present research has motivated reexamination of Polar plasma data to recover agyrotropy directly from the nearly model independent electron pressure tensor. In addition, layers in space that have been conjectured to be involved in CMR have been shown to possess these very extreme properties of electron thermal mach number in excess of unity, pressure anisotropies as high as 6 in the guide geometry, and order unity GCT expansion parameters.

In this way this research has provided a practical set of observables, that have been "bench tested" within self consistent PIC simulations, that are now servicable tools for identification of CMR in space plasma observations and 3-D reconnection configurations.

Publications:

The Electron Diffusion Region as a Non-Guiding Center Ordered Regime: Basis for Observable but Diagnostic Signatures of Demagnetization, Scudder, J.D. H. Karimabadi, W. Daughton, V. Roytershteyn, submitted to Phys. Plasmas.

An Electron Diffusion Region Documented Using Rare, Single Spacecraft Signatures of Electron Demagnetization, Scudder, J.D., R.D. Holdaway, W. Daughton, H. Karimabadi, V Roytershteyn, C.T. Russell, and F.S. Mozer, submitted to Phys. Rev.