Guide Field Effects on Hall Reconnection in the Magnetic Reconnection Experiment

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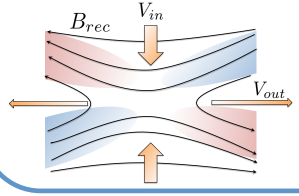
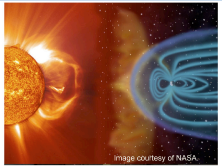
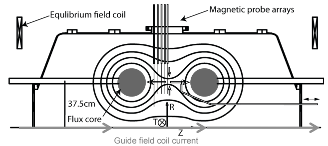
Introduction

Guide field effects can play a critical role in magnetic reconnection in both nature and the laboratory. Here, we show that guide field effects in MRX dramatically change the dynamics of reconnection.

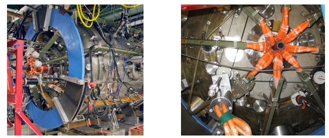




The magnetopause often contains a guide field that is more than 80% of the reconnecting field, while guide fields in fusion experiments can exceed 20 times the reconnection field.

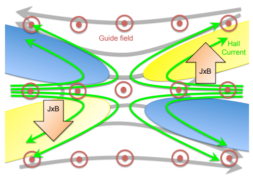


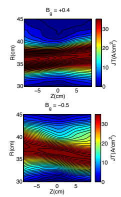
A guide field coil has been added to MRX plasmas to study the effects on two-fluid reconnection.

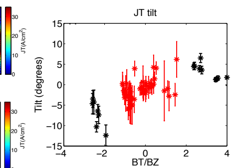


Current sheet tilting

The interaction of Hall currents with guide field can produce forces which act to twist the plasma and tilt the reconnection layer [see, e.g. A Frank et. al., Phys. Lett. A (2006)]. The tilt of the current density, JT, can be used as an indicator of this effect, and is seen to tilt slightly in opposite directions for positive and negative guide field cases.

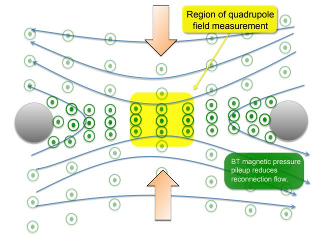


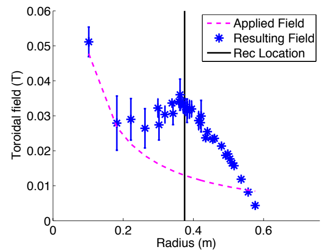


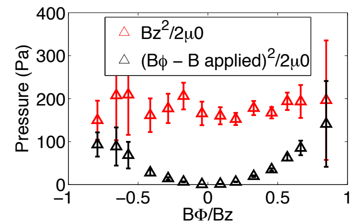


Guide Field Pileup

The measured guide field is significantly larger than the applied field. This occurs because the applied field is advected by the reconnection flow, and compressed within the reconnection layer. Unlike a simulation with open boundary conditions, the MRX flux cores prevent the ejection of toroidal field carried by the reconnection exhaust.



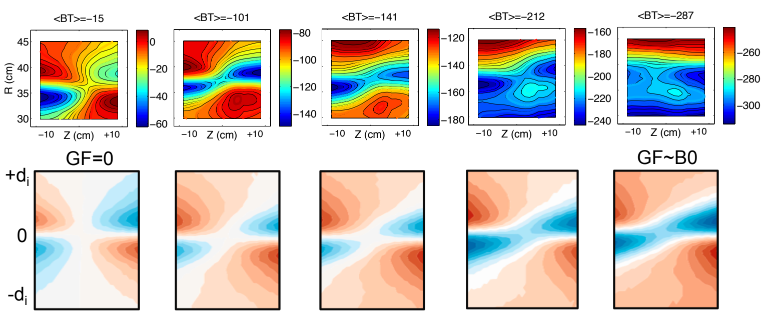


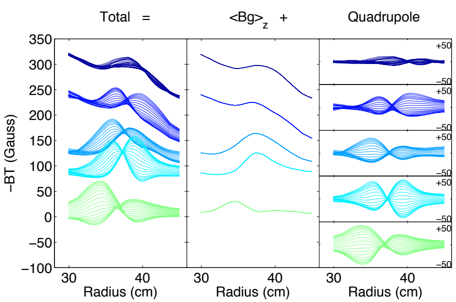


The applied vacuum field (~1/r) does not exert a net force on the plasma, however the compressed field can contribute a significant magnetic field pressure. In high guide field plasmas, the pressure due to pileup in the layer is significant compared to the pressure due to the reconnecting field, and therefore strongenough to explain the reduced reconnection rates.

Modification of the Quadrupole Field

Quadrupole field is typically present for zero guide-field plasmas. When external toroidal field is then applied, the Hall field is distorted in a manner that is qualitatively consistent with simulation.

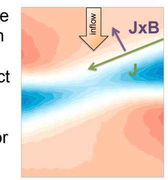


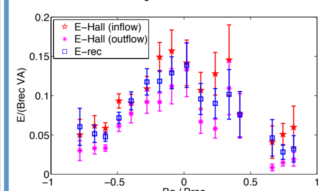


By identifying the "quadrupole component" of the measured out-of-plane field, the Hall field appears to be reduced in amplitude as guide field is added, but is still present up to guide fields $B_g \sim 1B_0$.

Reconnection Rate Reduction

Two-fluid simulations regularly find that the reconnection rate is weakly reduced when a guide field is applied. This occurs because the modified Hall currents interact with the guide field to produce a net force opposing the reconnection flow. The rate reduction is small, typically a factor of 2 for guide fields $B_g = 5B_0$.





A local relationship between the reconnection rate and the quadrupole field amplitude is expected based on the out-of-plane Ohm's law:

$$E_{rec} = \left(\frac{J_r \times B_z}{ne}\right)_{inflow} = \left(\frac{J_z \times B_r}{ne}\right)_{outflow}$$

This is experimentally verified, though the measured reconnection rate is reduced much more strongly than in simulations because of guide field pileup.