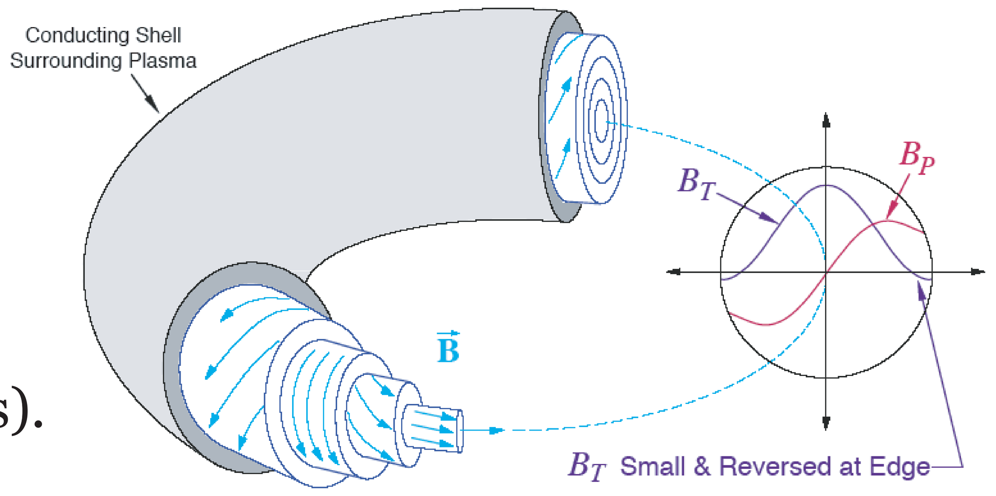
Overview

Magnetic reconnection occurs at the reversal surface of MST (as well as other locations).



This reconnection is explored using magnetic probes. Probe data is correlated to measurements of the magnetic field at the wall, in order to get a full mapping of the magnetic field structure.

We explore measurements of Ohm's Law terms during reconnection events. In particular, we measure the Hall term, which signifies the presence of two-fluid effects and Hall reconnection physics.

$$E + v \times B = \eta J + \frac{m_i}{\rho_M e} J \times B - \frac{m_i}{\rho_M e}\nabla \cdot P + \frac{m_e m_i}{\rho_M e^2}\frac{\partial J}{\partial t}$$

Electric Field | **MHD term** (partially included in E) | **Resistivity** | **Hall Term** | **Pressure Term** (not measured) | **Inertial term** (Negligibly small)

We restrict ourselves to the poloidal component of the m=0, n=1 mode. e.g., $(J \times B)^{(0,1)}_{\theta}$

Highlighted terms are inferred through magnetic probe measurements near the reversal surface.

E

$$-\frac{\partial \vec{B}}{\partial t} = \begin{pmatrix} \frac{im}{r}E_\phi - \frac{in}{R}E_\theta \\ \frac{in}{R}E_r - \frac{\partial}{\partial r}E_\phi \\ \frac{1}{r}\frac{\partial}{\partial r}(rE_\theta) - \frac{im}{r}E_r \end{pmatrix}$$

therefore, if m = 0,

$$E_\theta = -\frac{iR}{n}\frac{\partial B_r}{\partial t}$$

ηJ

Spitzer resistivity for a 100 eV plasma

$$\eta = \frac{\pi e^2 m^{\frac{1}{2}} \ln \Lambda}{(4\pi\epsilon_0)^2 (kT_e)^{\frac{3}{2}}} \approx 5 \times 10^{-7} \Omega m$$

J x B

$$\nabla \times B = \mu_0 J$$

$$J = \begin{pmatrix} \frac{1}{\mu_0}\frac{im}{r}B_\phi - \frac{1}{\mu_0}\frac{in}{R}B_\theta \\ \frac{1}{\mu_0}(\frac{in}{R}B_r - \frac{\partial}{\partial r}B_\phi) \\ \frac{1}{\mu_0}\frac{1}{r}\frac{\partial}{\partial r}(rB_\theta) - \frac{im}{r}B_r \end{pmatrix}$$

Linear Terms:

$$\begin{aligned}(J \times B)_{\theta,n} &= -J_{r,n}B_{\phi,0} + J_{\phi,n}B_{r,0} - J_{r,0}B_{\phi,1} + J_{\phi,n}B_{r,0} \\ &= -J_{r,n}B_{\phi,0} + J_{\phi,0}B_{r,n}\end{aligned}$$

$$\frac{m_i}{\rho_M e}(J \times B)_{\theta,n} \approx \frac{J_{\phi,0}B_{r,n} - J_{r,n}B_{\phi,0}}{1.6}$$

Nonlinear Terms are of the form

$$\{J\}_6 \times \{B\}_7 = \frac{\gamma}{2}|J_6||B_7|\cos(\phi + \delta_{J6} - \delta_{B7})$$

where γ is the bicoherence of the three modes (0,1) (1,6) and (1,7)

Other Terms

Linear MHD terms are zero, because we calculate the Electric Field in the reference frame of the moving mode. Nonlinear MHD terms may be important, but are as yet unmeasured.

The pressure term is zero for scalar pressures, but tensor contributions may be important.

The inertial term is easily calculated, but is found to be negligibly small.

Analysis

In a toroidal geometry, "fluctuations" can be defined by axisymmetry.

Axisymmetric Mean Field

$$J_0 \equiv < J > \text{ (Flux surface average)}$$

Non-axisymmetric "Fluctuations"

$$\widetilde{J} \equiv J - < J >$$

We divide Ohm's Law into two parts:

$$E = \eta J + \frac{m_i}{\rho_M e} J \times B - v \times B$$

Flux-Surface Averaged (Mean Field) Equation

$$E_0 = \eta J_0 + \frac{m_i}{\rho_M e} J_0 \times B_0 + \frac{m_i}{\rho_M e} < \widetilde{J} \times \widetilde{B} > - < \widetilde{v} \times \widetilde{B} >$$

Fluctuation (Reconnection) Equation

$$\widetilde{E} = \eta \widetilde{J} + \frac{m_i}{\rho_M e}(\widetilde{J} \times B_0 + J_0 \times \widetilde{B}) - (\widetilde{v} \times B_0 + v_0 \times \widetilde{B})$$

+ nonlinear terms: $\sum_{n,n'} < \left(\widetilde{J}_n e^{i(m\theta+n\phi)} \times \widetilde{B}_{n'} e^{i(m'\theta+n'\phi)}\right) e^{i\phi} > e^{i(\phi)}$

This poster will focus on the fluctuation equation, ignoring the mean field equation.

This (m=0,n=1) form of Ohm's Law should balance considering both the phase and amplitude of each term.

The toroidal array inside MST is used for correlation analysis, allowing us to measure non-axisymmetric fluctuations.

$\sum$ many sawteeth | Point Measurement of X + Toroidal array of magnetic probes

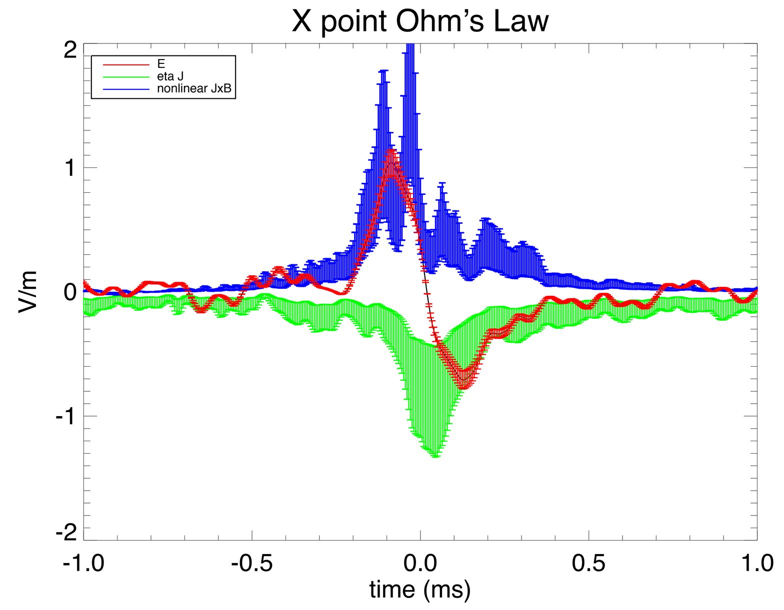
Correlation Techniques

Coefficients, x_{mn}, of the Fourier decomposition

$$X(\theta, \phi) = \sum_m \sum_n x_{mn} e^{i(m\theta + n\phi)}$$

Results

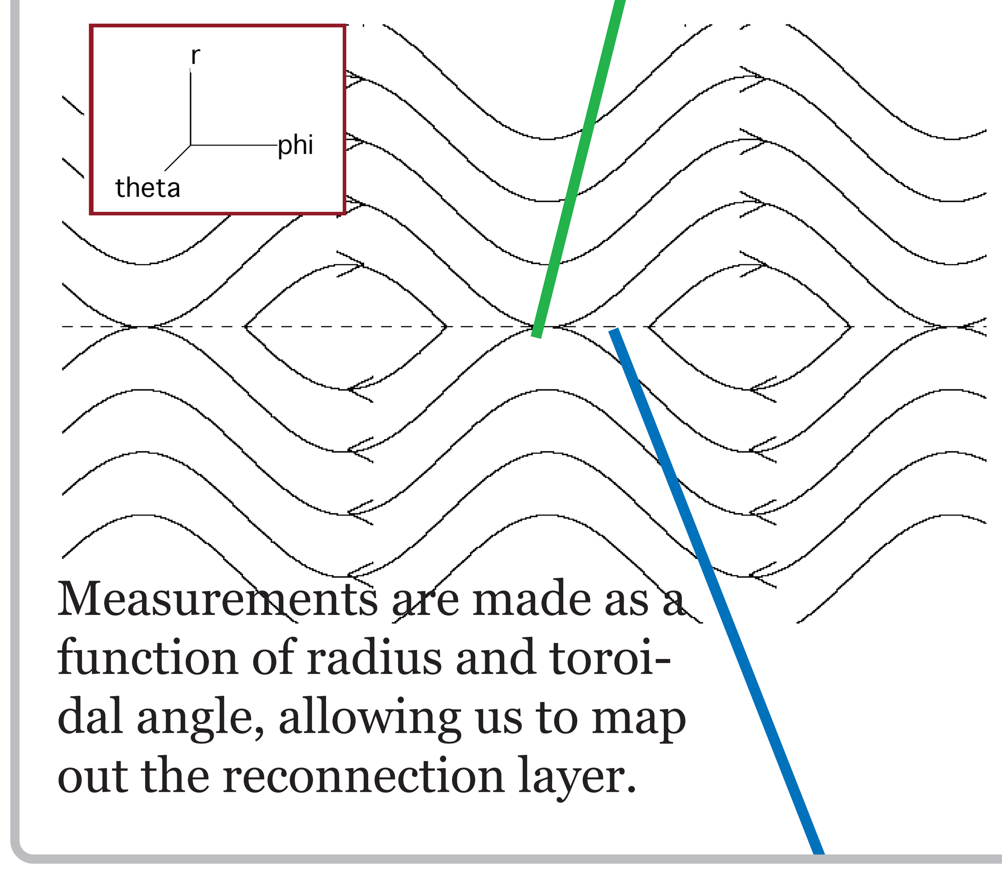
X-point Ohm's Law



At the x-point, we have measured the balance of Ohm's Law through a sawtooth cycle.

Here, the *nonlinear* Hall term is an important contributor

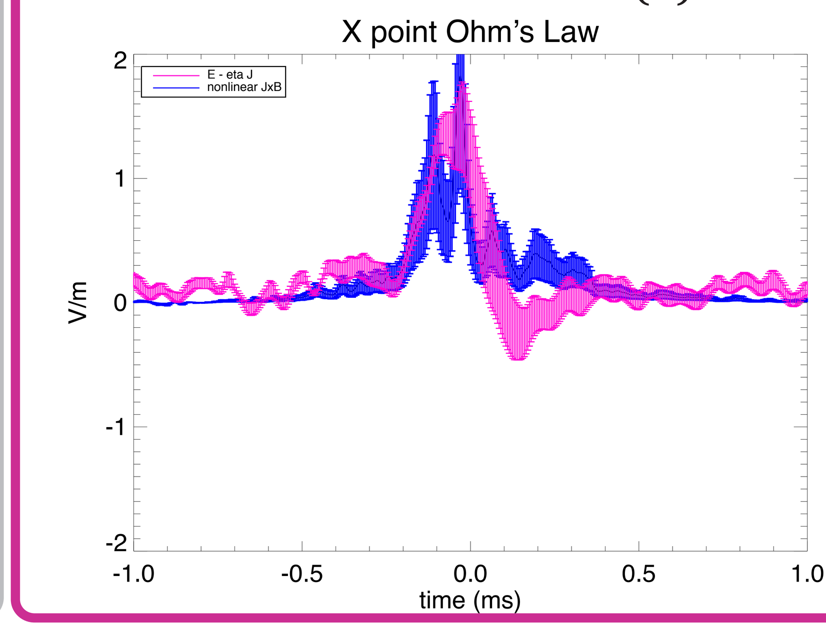
The bipolar nature of the electric field could be interpreted as Reconnection (island growth) and anti-Reconnection (island decay).



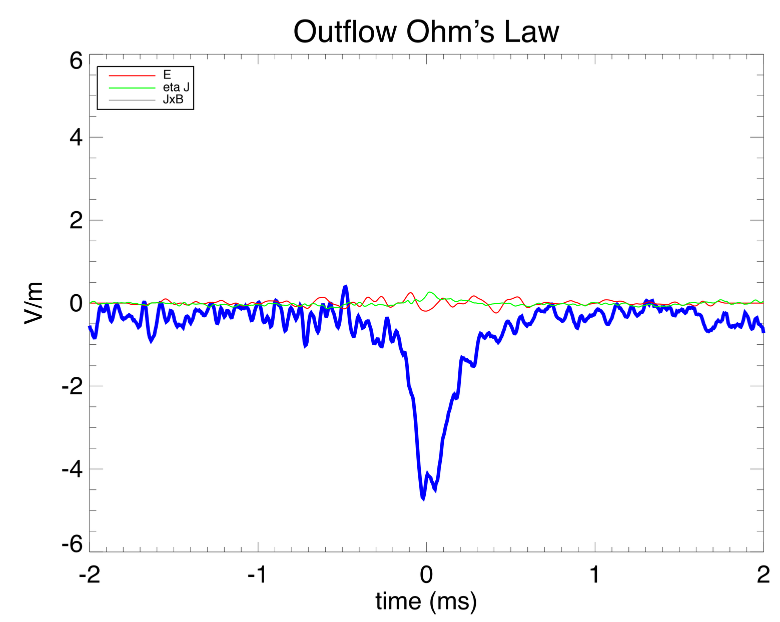
Measurements are made as a function of radius and toroidal angle, allowing us to map out the reconnection layer.

E−ηJ

To see the degree of imbalance remaining, we can compare the nonlinear Hall term to E - eta(J)



Outflow Ohm's Law



The linear Hall term is large, but out of phase with the electric field, and thus is not important to the physics of reconnection.

Ohm's Law should still, of course, be satisfied away from the X-point. There is no reason to disregard the unmeasured v x B terms in this region, so these may provide the balance.

Radial Profiles

Though the measured Ohm's Law appears to be balanced near the X-point, this is no longer the case inside the reversal surface.

Here, the electric field is small, but the nonlinear Hall term remains large. It is likely that nonlinear v x B terms are important in this region.