Flux-conversion dynamo in a lab plasma
The lab toroidal plasma dynamo

- Converts poloidal to toroidal flux
- Redistributes magnetic field
- Half of a classical dynamo
- Relevant to jets

Flux conversion in both the jet column and the lobe, mechanisms similar to that of the lab
Mechanisms

• MHD alpha effect
  (with fluctuations arising from tearing instability)

• Effects beyond MHD
reconnection
(current-driven instability)

- global magnetic structure (dynamo effects)
- global flow structure (momentum transport)
Outline

• MST description

• Observation of flux conversion dynamo events

• Mechanisms for dynamo
Magnetic field is helical

Reversed field pinch (RFP)
The MST experiment

\[ R = 1.5 \text{ m}, \ a = 0.5 \text{ m}, \ i \sim 0.5 \text{ MA} (B \sim 0.4 \text{ T}), \]
\[ T \leq 2 \text{ keV}, \ n \leq 4 \times 10^{13} \text{ cm}^{-3} \]
laser Faraday rotation (for B, j)

active spectroscopy (for v)
reconnection/dynamo events

Reconnection magnetic field (%)

Reconnection magnetic field (%)

core: spontaneous

edge: driven

Time (ms)
The origin of reconnection

• Core reconnection is a linear tearing instability: **spontaneous reconnection**

• Edge reconnection is driven nonlinearly by the core modes: **driven reconnection**
Tearing instability

- Current-driven, by $\nabla (J_{||}/B)$
- Resistive MHD instability
- Causes reconnection and dynamo
Manifestations of the dynamo
Rearranging the magnetic structure

Radial transport of parallel current
(or field redistribution, flux conversion)

\[ \langle E \rangle_\parallel \neq \eta \langle j \rangle_\parallel \]

between events

Radial transport of parallel current

\[ V/m \]

\[ \rho/a \]

radius
During a reconnection event

\[ \langle E \rangle_{\parallel} \gg \eta \langle j \rangle_{\parallel} \]
Flux conversion

half of a large-scale dynamo converts poloidal to toroidal flux; not the inverse
The Standard MHD model

Mean field ohm’s law

\[ \langle E \rangle + \langle \tilde{v} \times \tilde{B} \rangle = \eta \langle j \rangle \]

dynamo effect

\( \tilde{v}, \tilde{B} \) are fluctuations from tearing modes

\( \langle \rangle \) denotes mean quantities,

average over poloidal, toroidal directions;
depends on radius only
Altering the magnetic structure

\[ \langle E \rangle \xrightarrow{\text{energy source}} \langle j \rangle \xrightarrow{\text{instability}} \langle \tilde{v} \rangle, \langle \tilde{B} \rangle \]

\[ \langle j \rangle \xrightarrow{\text{current diffusion}} \]

Dynamo physics

Quasilinear theory: \[ \langle \tilde{v} \times \tilde{B} \rangle \sim \nabla \cdot D \nabla \frac{\langle j \rangle}{\langle B \rangle} \]

(Bhattacharjee, Hamieri; Strauss; Boozer.....)

Nonlinear MHD computation: a complete description
From nonlinear MHD computation:

\[ \langle E \rangle_{\parallel} \]

\[ \eta \langle j \rangle_{\parallel} \]

\[ -\langle \tilde{v} \times \tilde{B} \rangle_{\parallel} \]

Predicts details of dominant magnetic fluctuations
MHD dynamo in experiment

MHD explains dynamo at some locations in MST

but not all locations..

\[ \langle \tilde{v} \times \tilde{B} \rangle \]

\[ \eta \langle j \rangle - \langle E \rangle \]

Volts m

r/a = 0.9

time (ms)
another dynamo mechanism must be active
\[ \langle E \rangle = \eta \langle j \rangle + \langle \tilde{v} \times \tilde{B} \rangle + \langle \tilde{j} \times \tilde{B} \rangle / ne + .... \]

MHD  Hall dynamo

dynamo
MHD and non-MHD dynamo effects add to produce self-organized state
From quasilinear theory

\[ \langle \tilde{j} \times \tilde{B} \rangle_{\parallel} \]
\[ ne \]

\[ \langle \tilde{v} \times \tilde{B} \rangle_{\parallel} \times 100 \]

reconnection surface

Electron skin depth

gyroradius

radius

Two-fluid nonlinear computation underway
## Compare to magnetorotational instability

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Hall dynamo = Lorentz force

\[ \rho \frac{\partial \langle \mathbf{v} \rangle_{||}}{\partial t} = -\rho \langle \mathbf{v} \cdot \nabla \mathbf{v} \rangle_{||} + \langle \mathbf{j} \times \mathbf{B} \rangle_{||} \]

Reynolds stress
Maxwell stress

Hall dynamo \xrightarrow{\rightarrow} \text{plasma flow altered}

dynamo and momentum transport are coupled
Summary

• Flux conversion robust in lab plasma

• Two-fluid effects are important
  (related to two-fluid reconnection, but dynamo is a nonlinear effect)

• Indicates strong effect of correlated intermediate-scale flows and fields

• Two-fluid effects possibly important in flux conversion in jets