Measurement of Ion Transport Driven by Magnetic Fluctuations in MST Edge

N. A. Crocker, G. Fiksel, S. C. Prager and D. Craig

Department of Physics, University of Wisconsin-Madison

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Measurement of Ion Transport Driven by Magnetic Fluctuations in MST Edge*, N. A. Crocker, G. Fiksel, S. C. Prager and D. Craig. Dept. of Physics University of Wisconsin, Madison, WI.

It has long been expected that magnetic fluctuation driven ion radial particle flux \( \langle \mathbf{r} \cdot \mathbf{E} + \mathbf{B} \rangle / eB \) in MST is large. Measurement, however, shows it to be small. Magnetic fluctuation driven electron, and total charge radial flux, \( \langle \mathbf{r} \cdot \mathbf{E} + \mathbf{B} \rangle / eB \) and \( \langle \mathbf{r} \cdot \mathbf{E} \rangle / eB \), have been measured using insertable probes. The magnetic fluctuation driven flux for total charge is measured as being small, indicating ambipolar particle flux, while for electrons it is measured as being large. This is inconsistent with the measurement of magnetic fluctuation driven radial ion flux. A robust upper bound can be placed on magnetic fluctuation driven ion flux, leading to the conclusion that the electron and/or charge flux measurements, both of which agree with prior well established measurements, must be flawed.

*Work supported by U.S. D.O.E.
Outline

Motivation: Expectations for Magnetic Fluctuation Driven Ion Transport

Discussion of Magnetic Fluctuation Driven Ion Transport

Comparison of Magnetic Fluctuation Driven Electron and Charge Transport

Discussion of Inconsistency in Transport Measurements

Discussion of Diagnostics

Conclusions
Magnetic fluctuation driven particle transport in MST has been measured to be ambipolar, in agreement with expectation.

Magnetic fluctuation driven electron transport has been measured to be large.

It has been expected that magnetic fluctuation driven transport of ions would be large.

Magnetic fluctuation driven ion transport was measured to test this expectation.
Magnetic Fluctuation Driven Ion Transport is Expected to be Large.

The magnetic fluctuation driven electron flux, $\Gamma_e$ has been measured\(^2\) in the MST edge to be large.

Magnetic fluctuation driven particle transport is expected to be ambipolar ($\Gamma_i \sim \Gamma_e$) since:

The magnetic fluctuation driven charge flux, $\Gamma_q$, has been measured\(^1\) to be much smaller than the electron flux.

Tearing modes dominate the magnetic fluctuations in RFPs. The phase relationship of $\mathbf{j}_\parallel$ and $\mathbf{b}_r$ for tearing modes leads to the expectation that $\Gamma_q = 0$.

In other words: $\Gamma_q = \Gamma_i - \Gamma_e$, $\Gamma_e$ large, $\Gamma_q$ small $\Rightarrow$ $\Gamma_i$ large

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Ion Transport Driven by Magnetic Fluctuations is Small

@ r/a = .86

\[ \Gamma_i = \langle j_{i||} \rangle b_r / eB = 0.5 \times 10^{20} / m^2 s \]

(|\langle j_{i||} \rangle b_r | / eB \sim 3 \times 10^{20} / m^2 s, \gamma \sim .14, \phi \sim -\pi \)

Total particle transport is estimated to be 
~10-50 \times 10^{20} / m^2 s.
Ion Transport at $r/a = 0.86$

$\Gamma_i = 0.5 \times 10^{20} / (m^2 \text{ sec})$
Ion Transport Spectral Characteristics at $r/a = 0.86$

\[
\frac{(d (|j_i|/|b_r|)/df)/(eB)}{10^{2/5} (m^2 \text{ sec kHz})}
\]
Measured $\mathbf{\tilde{b}}_r$-Driven Flux for Electrons Much Greater than for Total Charge

($@ r/a = .86$)

\[ \Gamma_e = \langle \mathbf{\tilde{j}}_e \parallel \mathbf{\tilde{b}}_r \rangle / eB = 12 \times 10^{20} / \text{m}^2 \text{s} \]

($|\mathbf{\tilde{j}}_e \parallel \mathbf{\tilde{b}}_r| / eB \sim 74 \times 10^{20} / \text{m}^2 \text{s}, \gamma \sim .16, \phi \sim 0$)

\[ \Gamma_q = \langle \mathbf{\tilde{j}} \parallel \mathbf{\tilde{b}}_r \rangle / eB = 3 \times 10^{20} / \text{m}^2 \text{s} \]

($|\mathbf{\tilde{j}} \parallel \mathbf{\tilde{b}}_r| / eB \sim 42 \times 10^{20} / \text{m}^2 \text{s}, \gamma \sim .12, \phi \sim -(3)\pi$)

Difference between $\Gamma_e$ and $\Gamma_q$ is due to difference of phases of $\mathbf{\tilde{j}}_e \parallel$ and $\mathbf{\tilde{j}} \parallel$ relative to $\mathbf{\tilde{b}}_r$. Phase for $\Gamma_q$ is near $\pi/2$, so $\Gamma_q$ has large relative uncertainty.
Electron Transport at $r/a = 0.86$

\[ \Gamma_e = 12 \times 10^{2.0}/(m^2 \text{ sec}) \]
Electron Transport Spectral Characteristics
at $r/a = .86$

\[\frac{d (|j_{\parallel}|/b_r)/df}{eB}\]
Charge Transport at r/a = .86

\[ \Gamma_q = 3 \times 10^{20}/(m^2 \text{ sec}) \]
Charge Transport Spectral Characteristics at $r/a = .86$

\[ \frac{(d(|j||b_r|)/df)/(eB)}{10^2/\mu (m^2 \text{sec kHz})} \]

Frequency (kHz)
Inconsistency in Transport Measurements

Measurements of $\Gamma_i$, $\Gamma_e$ and $\Gamma_q$ do not yield $\Gamma_i - \Gamma_e = \Gamma_q$

$|\tilde{j}_i||$ and $|\tilde{b}_r|$ place an upper bound on $\Gamma_i$ ($\max |\Gamma_i| \sim |\Gamma_q|$)

Since $\Gamma_e \gg \Gamma_q$, no error in $<\tilde{j}_i||\tilde{b}_r>$ could account for inconsistency.

Measurements of $\Gamma_e$ and/or $\Gamma_q$ are flawed
Measurement Techniques

**Measurement of \( \Gamma_e, \Gamma_i \)**

The magnetic fluctuation driven cross surface flux of species \( \alpha \) is given by

\[
\Gamma_\alpha = \frac{\langle j_{\alpha||} b_r \rangle}{eB}
\]

\( \langle \rangle \) indicates a flux surface average, achieved by averaging over an ensemble of many time records taken at a single location. \( \alpha \) refers to ions or electrons.

\( \tilde{j}_{\alpha||} \) can be measured using the Flux Probe (FP)

The FP is oriented to collect current parallel to the magnetic field.

The collectors are biased to repel electrons or ions.

\( J_{||\alpha} \) is obtained from difference of the collector currents divided by their respective aperture areas.

The aperture is wide-angle and shallow to reduce ion gyroradius effects on ion collection.

\( \tilde{b}_r \) is measured simultaneously by a coil inside the probe head.

**Measurement of \( \Gamma_q \)**

\[
\Gamma_q = \frac{\langle j_{||} \tilde{b}_r \rangle}{eB}
\]

is measured with an insertable Rogowskii with a built in \( \tilde{b}_r \) coil.
## Potential Flaws in Diagnostics

<table>
<thead>
<tr>
<th>FLOW PROBE</th>
<th>ROGOWSKII</th>
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<tbody>
<tr>
<td>Probe <strong>interrupts parallel current</strong>, which may self-consistently <strong>modify probe measurement</strong>. In particular, current collection by probe may locally change ambipolarity constraint. Probe also modifies trajectories of oscillating particles.</td>
<td>Rogowski geometry may result in scrape off of significant fraction of ions that would otherwise pass through. This would cause electrostatic barrier to passage of low energy electrons. Such a barrier would vary with ion density, which may correlate with magnetic fluctuations. This would could lead to a corruption of the measurement of charge transport.</td>
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<td><strong>Probe may ablate, producing local plasma.</strong> In the presence of fast electrons (which have a strongly drifted distribution) ablation would be assymetric, so that local plasma is seen by probe as a current source. Fast electrons may correlate with magnetic flucuations so that locally generated current may be seen as electron transport.</td>
<td></td>
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Approaches to Resolving Measurement Inconsistency

Build modified Rogowskii to reduce or eliminate geometric effects on measured current density.

Controlled comparison of Rogowskii and Flow Probe using electron gun.
Conclusions

$b_r$-driven ion transport is much smaller than total particle transport.

There is an inconsistency in the measurements of $\Gamma_i$, $\Gamma_e$ and $\Gamma_q$.

$\Gamma_e$ and/or $\Gamma_q$, measurements must be flawed.