MEASUREMENTS OF FLUCTUATIONS IN DENSITY AND POTENTIAL USING A HEAVY ION BEAM PROBE IN IMPROVED CONFINEMENT MST DISCHARGES

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OUTLINE

• The Heavy Ion Beam Probe Diagnostic
• Operation in MST Improved Confinement Discharges
• Single discharge fluctuation measurements
• Multi-point and ensemble fluctuation measurements
A HEAVY ION BEAM PROBE IS IN OPERATION ON THE MADISON SYMMETRIC TORUS

- Singly charged particles are injected into the plasma

- Electron impact ionization creates a spray of doubly charged (secondary) ions
  - Collected by an energy analyzer on three detectors

- The magnetic field separates the doubly charged from the singly charged particles
  - \( r_L = \frac{Mv}{qB} \)

- Seven pairs of electrostatic plates steer the beam before it enters and after it leaves the plasma
THE HIBP HAS THE UNIQUE ABILITY TO MAKE MEASUREMENTS OF $\bar{n}$ AND $\bar{\phi}$ FROM THE EDGE TO THE CORE

- The measurements are
  - Spatially localized
  - Concurrent
  - Non-perturbing
    (current density $\sim 15$ A/m$^2$)

- 2-3 volumes are sampled simultaneously

- Each $\sim 3.6 \times 0.9 \times 0.2$ cm

- Data that will be shown are from SVs in the region $r/a = 0.4$

- Other commonly measured and inferred quantities include
  - $\Phi$ and $E_r$
  - Wavenumber
  - $\Gamma_{ES}$
IMPROVED CONFINEMENT PLASMAS WHICH EXHIBIT REDUCED MAGNETIC FLUCTUATION ACTIVITY ARE BEING STUDIED

- Improved confinement discharges are produced through pulsed poloidal current drive (PPCD)
  - an inductive technique to drive poloidal current in the edge by ramping of the toroidal magnetic field

- A transient reduction of dynamo activity yields an improved confinement period that lasts ~10 ms

- **GOAL:** Characterize $\bar{n}/n$ and $\bar{\phi}$ as a function of time to assess the characteristics and role of electrostatic fluctuations when magnetic turbulence and transport are suppressed

- Discharge parameters:
  - $I_p \sim 375$ kA, $n_e \sim 0.6 \times 10^{19}$ m$^{-3}$, $T_e \sim 800$ eV
HIBP DATA ARE ACQUIRED THROUGHOUT THE IMPROVED CONFINEMENT PERIOD

- Secondary ion currents from neighboring sample volumes are acquired simultaneously.

- These currents are a measure of local fluctuations.

- Variations from one sample volume to the next are not fully understood:
  - proximity of sample volumes with islands?

\[
\frac{\widetilde{I}_s}{\langle I_s \rangle} = \frac{I_s - \langle I_s \rangle}{\langle I_s \rangle} = \frac{\tilde{n}_e}{\langle n_e \rangle}
\]
SIGNIFICANT CHALLENGES TO HIBP OPERATION AND DATA ANALYSIS ARE PRESENTED AT MST

- Comparable toroidal and poloidal fields - $|B_T| \sim |B_p|$ - result in complex 3D beam trajectories

- Magnetic field shear twists the secondary ion-tan angle away from its optimal orientation

- Equilibrium evolve as a function of time resulting in beam motion and signal loss

- High levels of UV light from the plasma induce secondary electron noise that can exceed secondary ion signals

These effects are pervasive during all discharges

Alternative methods of HIBP operation and data analysis have been developed and continue to evolve
DENSITY AND POTENTIAL FLUCTUATIONS ARE HIGHLY COHERENT AT NEIGHBORING SAMPLE VOLUMES

- This is illustrated with measurements from a single discharge, but two locations.
- Identical data are used to infer $\tilde{n}/n$ and $\tilde{\phi}$.
  - spacing between sample volumes $\sim 1$ cm.
- RFP features and instrumental effects necessitate use of short windows of data.
- Broadband sensitivity levels of $-\tilde{n} \sim 0.5\%$
  $\tilde{\phi} \sim 2-5$ V.
PEAKS IN THE LOW FREQUENCY FLUCTUATION POWER CORRELATE LARGELY WITH THOSE OF THE TEARING MODES

- Magnetic mode amplitudes and frequencies vary from shot-to-shot although discharges are produced with identical PPCD programming.

- Peaks in the power of $\tilde{n}/n$ and $\tilde{\phi}$ correlate with those of the tearing modes at low frequencies:
  - Spectral analysis of HIBP and edge magnetic pick-up coil data.

- Sample volumes are near the $m=1$, $n=8$ rational surface:
  - but, the $m=1$, $n=6$ is the dominant tearing mode in MST.

- Large ensembles may allow us to resolve core $\tilde{n}/n$ and $\tilde{\phi}$ fluctuations within islands.
ENSEMBLED DATA REVEALS THAT THE PHASE BETWEEN $\tilde{n}$ AND $\tilde{\phi}$ VARIES WITH FREQUENCY

- Ensembles
  Critical measurement analysis was used to identify data having minimal instrumental features

- Fluctuations are broadband with most power below 300 kHz

- The coherence, and phase between $\tilde{n}/n$ and $\tilde{\phi}$ are computed from single-point data

- The phase - $\alpha_{n\phi}$ – varies with frequency
  $\sim 180^\circ$ in the (0-40 kHz) tearing mode range
  $\sim 0^\circ$ to $45^\circ$ from 100 - 300 kHz
SIMULTANEOUS TWO-POINT MEASUREMENTS MAY BE USED TO STUDY DRIFT WAVE FLUCTUATIONS

- Drift wave like fluctuations are likely in MST

- They are expected to propagate in the bi-normal direction (perpendicular to \( B \) on the flux surface)

- SVs in improved confinement are aligned primarily along \( B \)
  - They will resolve a combination of \( k_\parallel \) and \( k_r \)
  - Their alignment limits the inference of \( k_\perp \)

- \[ < k_{\varphi\varphi} > \sim \frac{\alpha_{\varphi\varphi}}{d} \]
  - \[ < k_{nn} > \sim \frac{\alpha_{nn}}{d} \]
  - \( d = \) distance btw. sample volumes
WAVENUMBER INFORMATION IS INFERRED FROM NEIGHBORING FLUCTUATION MEASUREMENTS

- Criteria that both measurements must be free of instrumental effects severely limits usable data

- \( \alpha_\phi \sim \alpha_{nn} \sim 0 \) implying \( k_\parallel \) is small

- Wavelength sensitivity \( k < 4.6 \text{ cm}^{-1} \) (\( \lambda > 1.35 \text{ cm} \)) at \( r/a = 0.4 \)
The HIBP is measuring $\bar{n}/n$ and $\bar{\phi}$ in the core of improved confinement discharges.

Significant challenges presented by MST have resulted in innovative HIBP operation and data analysis methods.

Low frequency fluctuation power peaks correlate largely with those of the tearing modes.

$\alpha_{n\phi} \sim 180^\circ$ in the range of the tearing modes (< 40 kHz), and 0 - 45° between 100 and 300 kHz.

The sample volumes in improved confinement are aligned primarily along $B$.

- Neighboring measurements indicate $\alpha_{\phi\phi} \sim \alpha_{nn} \sim 0$, implying $k_\parallel$ is small.