Core Density Fluctuations in the HSX Stellarator

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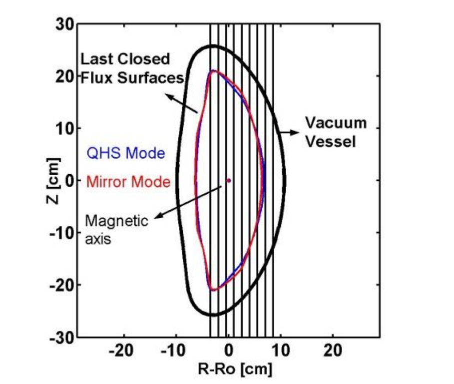
Abstract

Density fluctuation measurements on the HSX stellarator reveal broadband turbulence that correlates with plasma density gradient and flow. For quasi-helically symmetric plasmas, significant increases in the turbulent density fluctuations are observed when plasma heating location is moved from on-axis to inboard high-field side. Measurements show that the plasma flow velocity also decreases significantly for off-axis heating. In addition, as the electron-cyclotron-resonance-heating power is decreased, core density fluctuations rise while the plasma parallel flow is reduced. When HSX is operated without quasi-helical symmetry, both plasma flow and turbulence characteristics are little changed. No sensitivity to electron temperature gradient is observed. Increased fluctuation amplitude correlates with both increasing density gradient and reduced flow, suggesting a causal relation. In addition to improved neoclassical confinement, quasi-helical symmetry can also lead to increased flow (and flow shear) in the direction of symmetry along with reduced fluctuations and anomalous transport.*Supported by USDOE grants DE-FG03-01ER54615 and DE-FG02-93ER54222.

Interferometry System

Flux Surface and Chord Positions



Interferometer System:

1. 9 chords
2. 1 MHz bandwidth
3. 1.5 cm chord spacing, width
4. $k_\perp < 2\ cm^{-1}$

Density fluctuations can be measured from information of:

(i) Amplitude
(ii) Phase
(iii) Differential

Interferometry (phase measurement)

$$\phi_{Interferometry}(x) = \int (n_o + \tilde{n}) dl$$

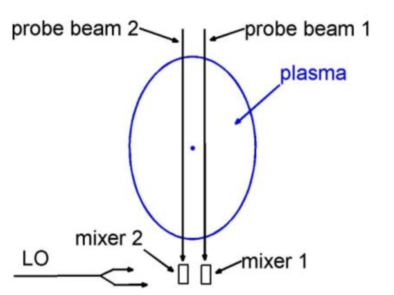
Far-forward Scattering- amplitude

$$P_{scatt} \sim P_{inc}\tilde{n}^2 \sim (amplitude)^2$$

Differential Interferometry Measurement

(1) For density gradient and gradient fluctuations [differential interferometry]

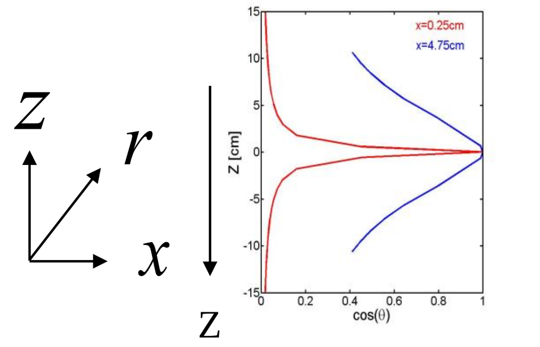
$$\frac{\partial \phi(x)}{\partial x} = \int_x \frac{\partial n_e(r)}{\partial r}\frac{\partial r}{\partial x} dz = \int_x \frac{\partial n_e(r)}{\partial r} \cos\theta dz$$



(2) For density fluctuations (m=1) [standard interferometry]

$$\tilde{\phi}(x) = \int \tilde{n}_e(r) \cos\theta dz \ ,$$

$$\cos\theta = \frac{x}{r}$$

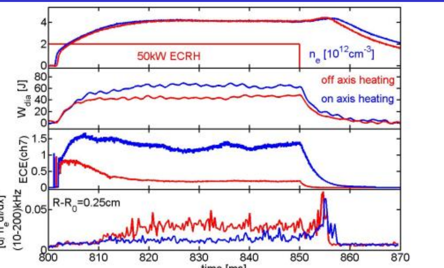


Density Fluctuations Increase with off-axis Heating (QHS plasma, Bt=1T in CCW)

Plasma Parameter Time Traces

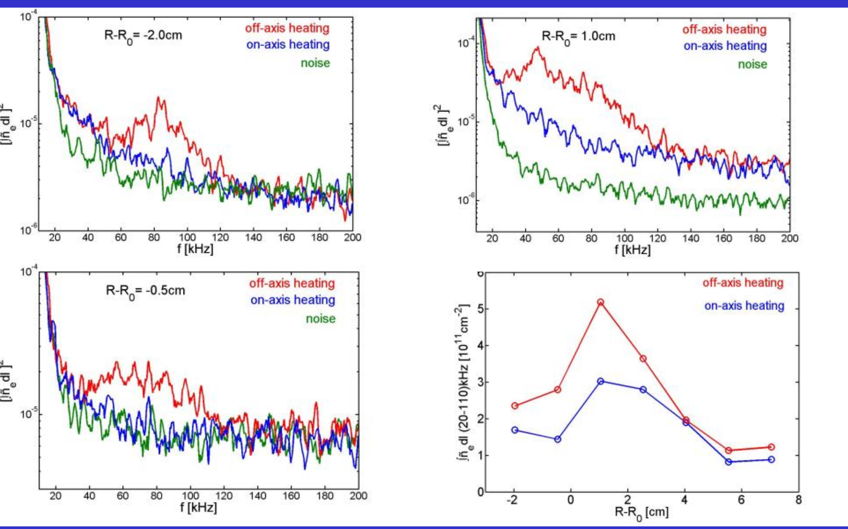
Plasma Parameters

on axis heating: I_B=11000A
off axis heating: I_B=10600A

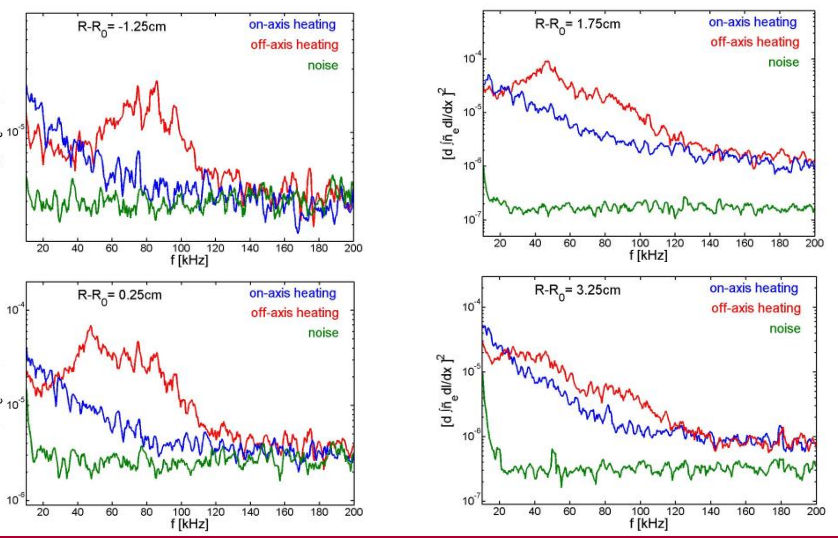


Significantly lower stored energy for off-axis heated plasma. In addition, Measured density fluctuations are larger amplitude and higher frequency for off-axis heating.

Change in Density Fluctuations with Heating Locations



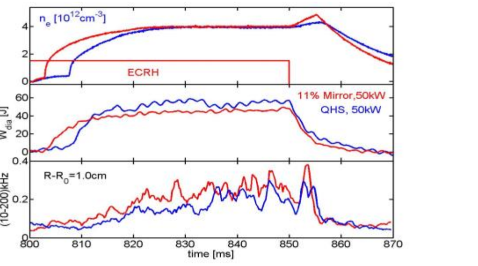
Core Localized Measurement of Density Gradient Fluctuations Shows Large Increase in Amplitude for Off-axis Heating

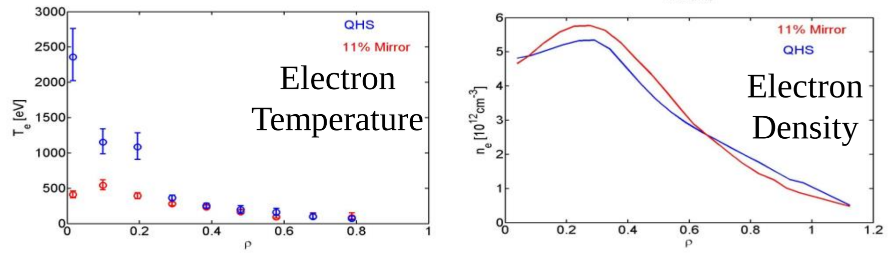


Density Fluctuations Lever Similar in QHS 11% Mirror Plasma

Plasma Parameters

on axis heating:
QHS – 50 kW
11% Mirror – 50 kW

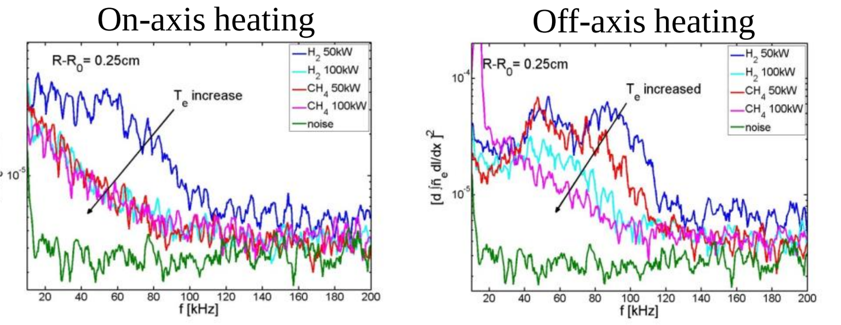




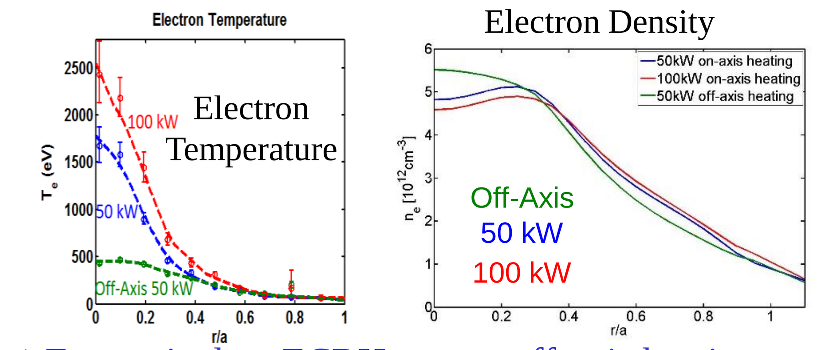
Plasma stored energy and density are comparable: Core temperature gradient is much larger for QHS plasma

Core Density Fluctuations Decrease with ECRH Power

1) On-Axis: as ECRH power increases, core density fluctuations are reduced in amplitude and frequency (significant increase in T_e gradient)
2) Off-axis (inboard): as ECRH power increases, core density fluctuations are reduced in amplitude and frequency
3) Density profile unchanged for both cases



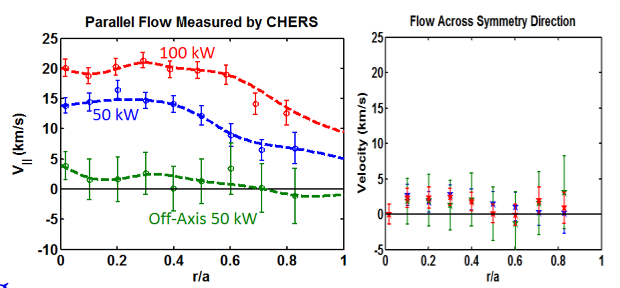
3 Different Electron Heating Scenarios



1) For equivalent ECRH power, off-axis heating results in lower stored energy and lower core temperature
2) Plasma flow is significantly reduced with off-axis heating. Doppler shift cannot account for change in frequency
3) Increased core density fluctuations with off-axis heating ; appear related to density gradient, not temperature (electron drift waves?), and correlate with degraded energy confinement

Flows Approximately Follow the Helical Direction of Symmetry

1) Flow (parallel) is largest for on-axis heating and increases with heating power.

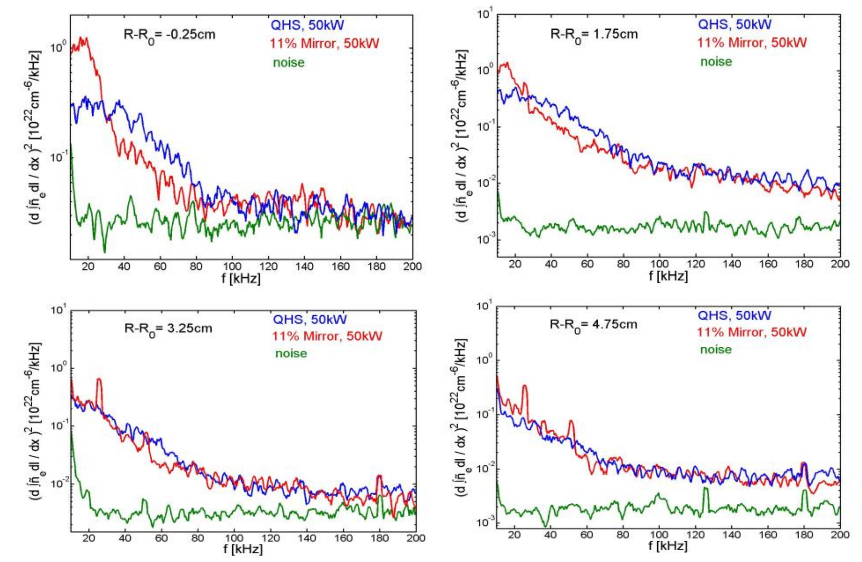


2) Doppler shift from plasma flow cannot account for higher frequency density fluctuations with off-axis ECRH

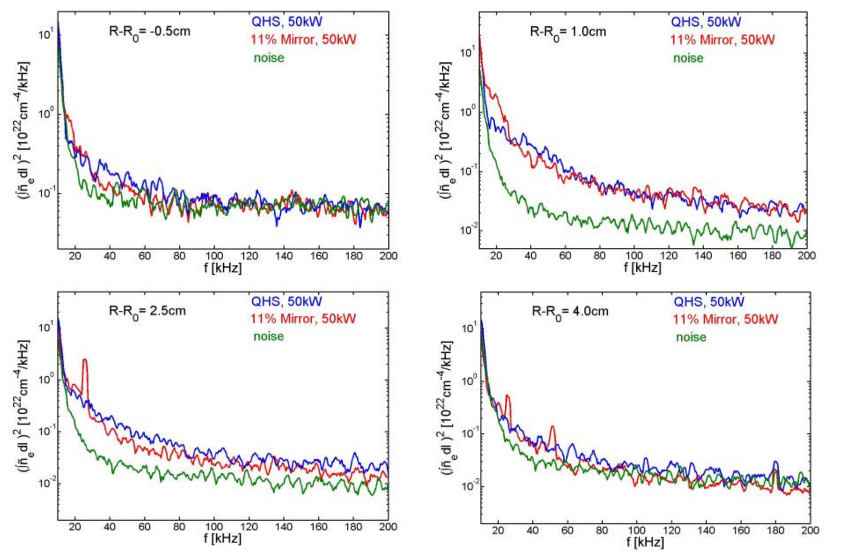
3) Density turbulence largest for case with reduced flow (off-axis heating or lower power)

Density Fluctuations Lever Similar in QHS 11% Mirror Plasma

Density Gradient Fluctuations Show Little Change for QHS and 11% Mirror Configurations



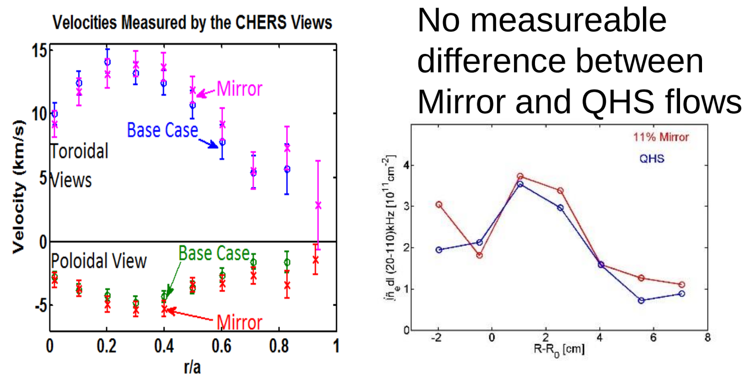
Density Fluctuations Show Little Change for QHS and 11% Mirror



Density fluctuations unchanged between QHS and 11% Mirror Configurations except a f~30kHz coherent mode in 11% Mirror plasma

Plasma Flow and Density Fluctuations Unchanged between QHS and 11% Mirror

1) **QHS**: transport dominated by anomalous effects
2) **11% Mirror**: transport dominated by neoclassical effects
3) Plasma turbulence and flow are little changed between the 2 different magnetic configurations

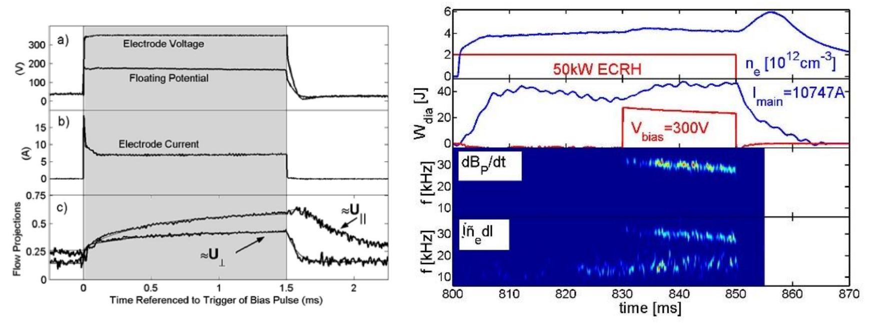


No measureable difference between Mirror and QHS flows

Density Fluctuations in biased QHS plasma

Time Evolutions for Biasing Experiment (n_e=4.0x$10^{12}cm^{-3}$)

At n_e=4.0x$10^{12}cm^{-3}$
•Two coherent modes were observed:
•Coherent mode at 15 kHz (density fluctuation only), frequency does not change with Biasing (core localized)

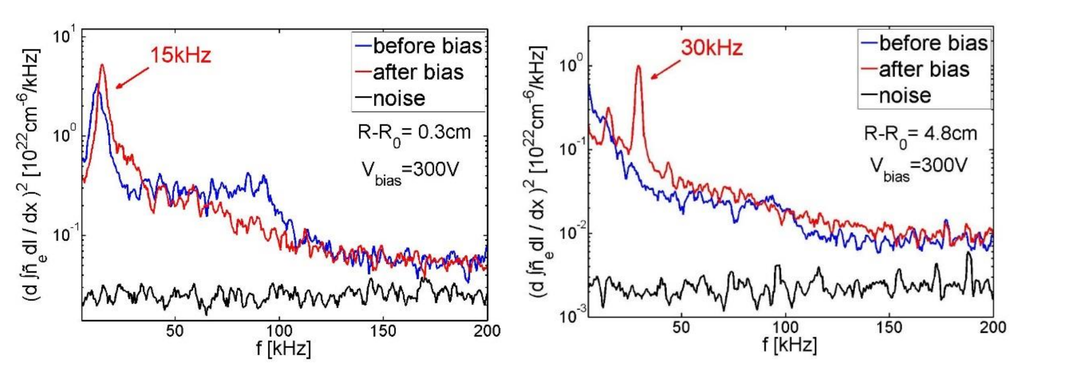


• Coherent mode at 30kHz is excited by biasing, strong frequency change with biasing (edge localized) – frequency scales with V_{bias} (plasma flow)
•Both parallel and perpendicular plasma flow increase with biasing (in the edge).

Bias Excited Mode Located at the Edge, 15kHz Mode Located in Plasma Core (n_e=4.0x$10^{12}cm^{-3}$)

Differential interferometer measurement at the core

Differential interferometer measurement at the edge

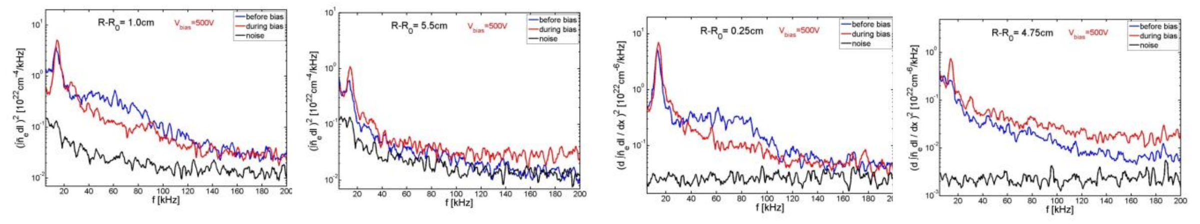


•Bias-induced mode is not observed by core differential interferometer measurement - but was observed for the edge chords.
•Coherent mode at 15kHz observed, frequency did not change with Biasing (core localized)

Broadband Density Fluctuations Suppressed During +500V Biasing

Interferometer Results

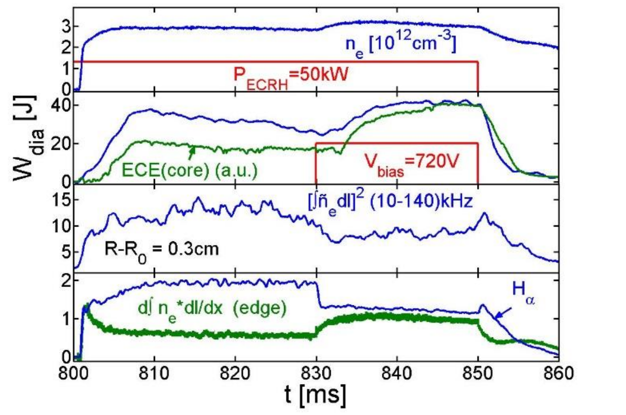
Differential Interferometer Results



Positive Biasing suppresses core density fluctuations for f=(40-100)kHz and the coherent mode not observed for higher biasing voltage (+500V)

Time Evolutions for Bias Voltage Scan Experiment (n_e=3.0x$10^{12}cm^{-3}$)

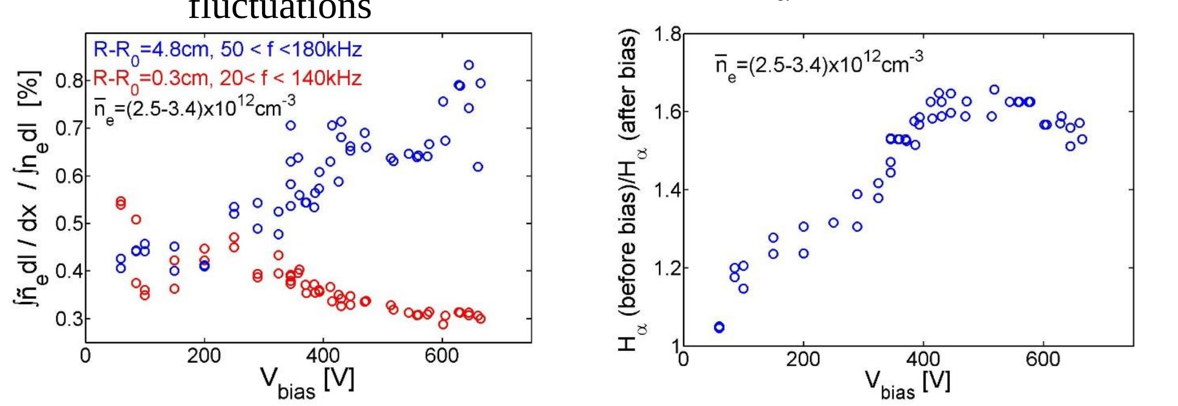
With plasmas biased:
• Plasma stored energy increases
• Core ECE increases
•Density fluctuations suppressed
•Hα decreased
•Edge density gradient increased.
•Edge plasma flow increases.



Core Density Fluctuations Decrease, Hα Reduction Increases with Bias Voltage (n_e=3.0x$10^{12}cm^{-3}$)

Core and edge density fluctuations

Hα emission ratio

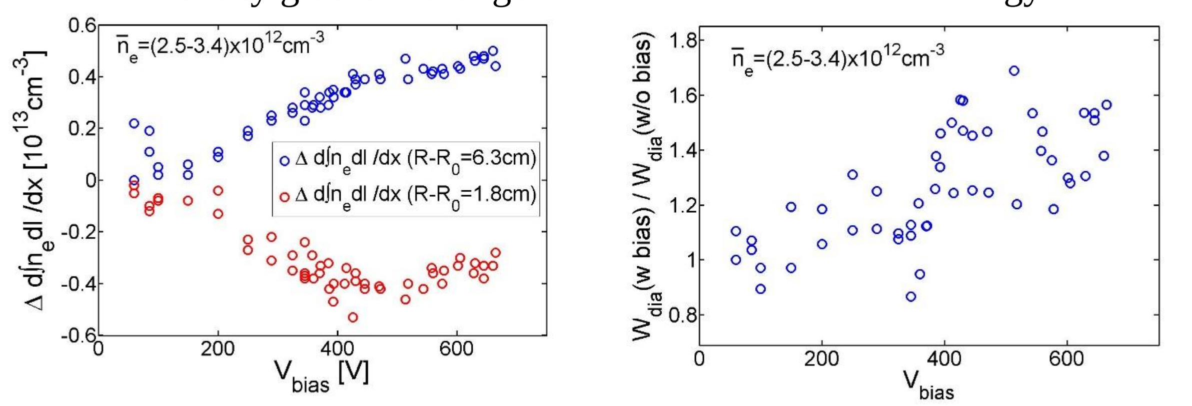


When bias voltage increases:
• Core density fluctuations (20 < f < 140 kHz) decrease (increasing flow)
• Edge density fluctuation increase
• Reduction of H_α emission

Edge Density Gradient and Plasma Stored Energy Increase with Bias Voltage (n_e=3.0x$10^{12}cm^{-3}$)

Density gradient change

Plasma stored energy ratio



When bias voltage increases:
• Edge density gradients increase and core density gradient is reduced
• Plasma stored energy increases
•Change in density fluctuations consistent with density gradient drive

Summary and Future Plans

1. Interferometry and Differential Interferometry are used to measure density fluctuations in HSX
- line-integrated measurements; spatial information available by comparing chords
- differential interferometry is used to obtain core localized measurements

2. Both coherent modes and broadband fluctuations are observed

3. For QHS plasma
- Significant changes (amplitude and frequency) of fluctuations are observed with changes in heating location and power
- measured density fluctuation changes consistent with density gradient drive (not T_e gradient)
- Reduction of density fluctuations is accompanied by increase in plasma flow.
- Positive biasing can excite coherent oscillations in the plasma edge.
- changes in density fluctuation amplitude (edge & core) consistent with density gradient drive

4. Mirror plasma:
- Coherent mode observed on density fluctuation signal only
- broadband fluctuations and plasma flow similar to those in QHS plasma.

Future work will focus on identification of fluctuations and relation to transport