Particle Transport and Density Fluctuations in HSX

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Key Points

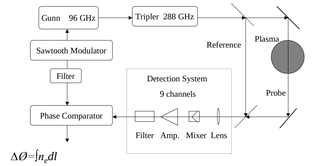
1. Peaked Electron Density Profiles with both QHS mode and Mirror Mode
2. Perturbative Particle Transport Study shows: D ~ 1m^3/sec , and decreased with electron density
3. Density Fluctuations with Frequency ~ 50kHz were observed in QHS mode ECRH Plasma

1. Interferometer on HSX

Interferometer Capabilities

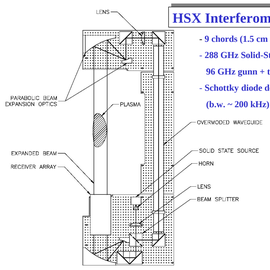
- **Spatial resolution**: 9 chords, 1.5cm spacing and width.
- **Fast time response**: analog: 100-200 μsec, real time
  digital: <10 μsec
  maximum bandwidth 250 kHz [with 2 MHz sampling]
- **Low phase noise**: 24 mrad (1.6°)
  $(\Delta n_e dl)_{min} = 9 \times 10^{11}$ cm^{-2}
  0.4% level density fluctuations can be measured
- **Density fluctuations**: wavenumber resolution
  (i) $k_\perp < 2.1$ cm^{-1}, (ii) $k_\parallel < 0.07$ cm^{-1}

Interferometer Schematic



$\Delta\Phi = \int n_e dl$

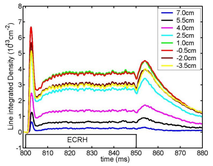
HSX Interferometer System



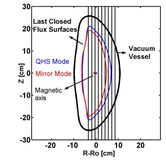
- 9 chords (1.5 cm width)
- 288 GHz Solid-State source
  96 GHz gunn + tripler; ~ 3 mW
- Schottky diode detectors
  (b.w. ~ 200 kHz)

2. Equilibrium Density Profile

Density Evolution for QHS Plasma



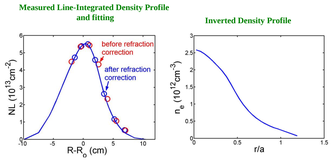
Flux Surfaces and Interferometer Chords



Inversion Process:

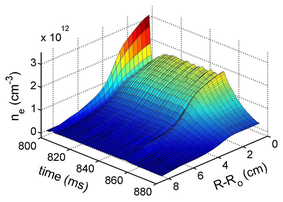
1. spline fit $\Phi = n_e dl$
2. construct path length matrix
   $L \cdot n = \Phi$ ($= n_e dl$)
3. solve using SVD

HSX Density Profile (QHS)



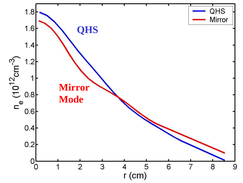
t=840 ms

Density Evolution for QHS Plasma



QHS and Mirror Mode Density Profile

n_e~ 1x10^{12} cm^{-3}

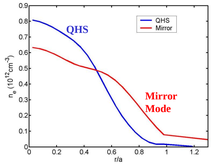


W$_{QHS}$=W$_{MM}$~

Profile shapes a
(1) centrally pe
(2) similar shap

QHS and Mirror Mode Density Profiles

n_e~ 0.4x10^{12} cm^{-3}

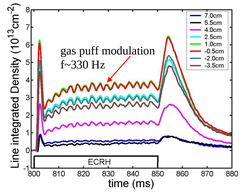


W$_{QHS}$ ~ 30 J
W$_{MM}$ ~ 7 J

Profile is broader for Mirror Mode at low density

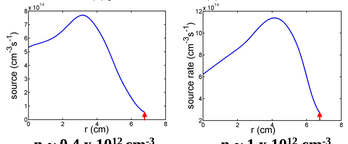
3. Perturbative Particle Transport

Perturbative Transport



DEGAS code and H$_\alpha$ Measurements used to estimate the neutral particle distribution in HSX

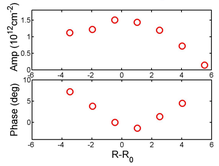
(1) peaked in the core (2) broad



n_e~ 0.4 x 10^{12} cm^{-3} **n_e~ 1 x 10^{12} cm^{-3}**

Density profile peaked due to source peaking in plasma core (no pinch required)

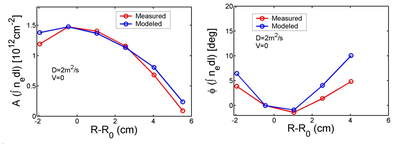
Density Perturbation Amplitude and Phase



- Analysis approach computes Fourier coefficients of the line integral $\tilde{n}_e = \int \tilde{n} d$
- Linearize the continuity equation for small density perturbations, model $\left(= D\nabla n_e\right)$, and solve for amplitude and phase.
- Use ~10 cycles (f~200-400 Hz), $\tilde{n}/n_e \leq 10\,\%$

Reasonable Fit (to amplitude) using D$_{mod}$=2 m^2/s

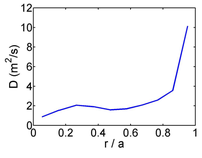
n_e~ 1.0x10^{12} cm^{-3}



- Results very sensitive to source profile,
- No pinch term required

Solving the Continuity Eq. for Steady-State Plasma

$\nabla \bullet \Gamma = S \quad where \quad \Gamma = -D_o \nabla n_e$

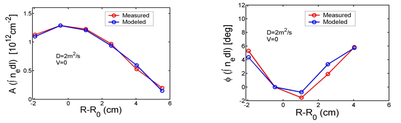


D_o ~ D_{mod} ~ 2 m^2/s

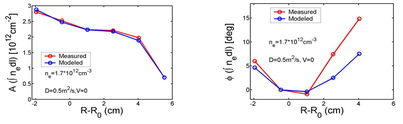
n_e~ 1.0x10^{12} cm^{-3}

For details, see J. Canik poster

D$_{mod}$=2.0 m^2/s at n_e~ 0.5x10^{12} cm^{-3}



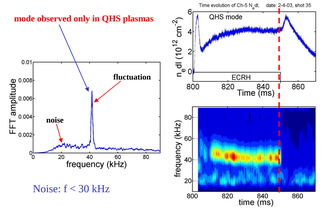
D$_{mod}$=0.5 m^2/s at n_e~ 1.7x10^{12} cm^{-3}



4. Density Fluctuations on HSX

Density Fluctuations

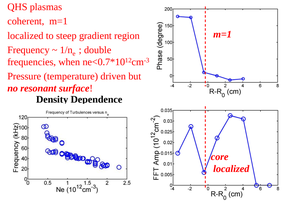
mode observed only in QHS plasmas



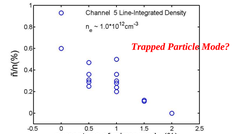
Noise: f < 30 kHz

Fluctuation Features

- QHS plasmas
- coherent, m=1
- localized to steep gradient region
- Frequency ~ 1/n$_e$; double frequencies, when ne<0.7*10^{12}cm^{-3}
- Pressure (temperature) driven but ***no resonant surface***!

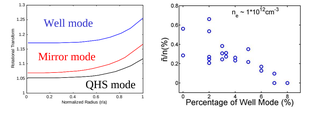


Density fluctuations decrease with introduction of symmetry breaking (toroidal mirror) term



toroidal mirror component

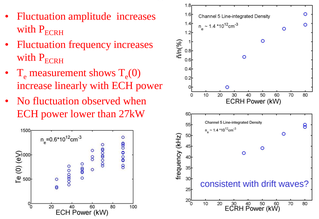
Fluctuation observed at higher rotation transform



Density fluctuation not connected to resonant surface!

Fluctuations Scaling with ECRH Power

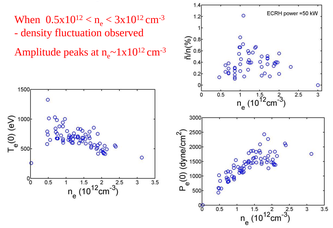
- Fluctuation amplitude increases with P$_{ECRH}$
- Fluctuation frequency increases with P$_{ECRH}$
- T$_e$ measurement shows T$_e$(0) increase linearly with ECH power
- No fluctuation observed when ECH power lower than 27kW



Density Fluctuation Parameter Window

When 0.5x10^{12} < n_e < 3x10^{12} cm^{-3}
- density fluctuation observed

Amplitude peaks at n_e~1x10^{12} cm^{-3}



5. Summary

1. **Equilibrium electron density profile is peaked for both the QHS and Mirror Mode configurations (at low density, Mirror Mode plasmas are broader than QHS)**
2. **Peaking on axis likely arises because the source profile is broad and extended to the plasma core.**
3. **Modulated gas feed studies indicate constant D$_{mod}$ ~ 2 m^2/s, and decreased with density. No inward pinch required due to centrally peaked source profile.**
4. **Future operation at higher density should move the source to the plasma edge allowing particle transport issues to be addressed**
5. **High-frequency density fluctuations (f~25-120 kHz, m=1) are observed for QHS plasmas.**
6. **These fluctuations are clearly associated with temperature or pressure gradients (but no resonant surface). Trapped Particle Modes?**