Structure and Motion of Edge Turbulence in NSTX and Alcator C-Mod


PPPL, MIT, Nova Photonics, Lodestar Research, ORNL, Columbia, Greifswald, Colorado, UCLA

APS DPP ‘05
Paper CI1.00001
Motivations

• Edge turbulence affects location of plasma-wall interaction

• Edge turbulence influences global tokamak confinement

• Cause of L-H transition is not yet completely understood

ExB flow shear

T.S. Hahm
Outline

• Gas puff imaging diagnostic
• NSTX GPI images (L, L-H and H)
• Analysis of Structure and Motion
• Comparison with C-Mod
• Comparisons with theory
National Spherical Torus Exp’t (NSTX)

**typical parameters for this talk**

- $R = 0.85$ m
- $a = 0.68$ m
- $B = 0.3$ T
- $I \approx 0.8$ MA
- $P_{\text{NBI}} \approx 2-4$ MW
- $\beta_T \approx 10\%$
Gas Puff Imaging (GPI) Diagnostic

- Looks at $D_{\alpha}$ line of neutral deuterium from a gas puff
- View $\approx$ along B field line to see 2-D structure $\perp$ B

view from center column

B
Gas Cloud
Blob
Outer Midplane
Reentrant Viewport
Filament

viewing area $\approx 25\times25$ cm
spatial resolution $\approx 1-2$ cm

Location of GPI Light Emission

- D is unexcited \( @ T_e < 5 \text{ eV} \)
- D is ionized \( @ T_e > 100 \text{ eV} \)

**NSTX Edge Parameters**

- \( n \sim 0.2-2 \times 10^{13} \text{ cm}^{-3} \)
- \( T_e \sim 5-50 \text{ eV} \)
- \( L_{\perp} \sim 2-5 \text{ cm} \)
- \( L_{||} \sim 5 \text{ m} \)
- \( \rho_s \sim 0.2 \text{ cm} \)
- \( \beta_e \sim 10^{-3} \)

\~ similar to many tokamak edge plasmas
GPI Fluctuation Data in NSTX

- PSI-5 camera records 300 frames at $\leq 250,000$ frames/sec with 64x64 pixels / frame => 1.2 msec of data per shot

- Additional PM tube array digitized radial vs. poloidal array at 500,000 Hz => 64 msec of data per shot
Interpretation of GPI Fluctuations

• Line emission signal levels $\propto n_e^\alpha T_e^\beta$ with $0.5 < \alpha, \beta < 2$, so measured signals are nonlinear functions of $n$ and $T_e$ [see Stotler et al, Cont. Plasma Phys. 44, 294, 2004]

• However, turbulence structure and motion are approximately independent of these nonlinearities (~“contrast knob”) [see S.J. Zweben et al, Nucl. Fusion 44, 134, 2004]

=> Assume that structure and motion of GPI light fluctuations represents structure and motion of the turbulence (not necessarily the same as the fluid motion)
• Gas puff imaging diagnostic
• **NSTX GPI images (L, L-H and H)**
• Analysis of Structure and Motion
• Comparison with C-Mod
• Comparisons with theory
Images During L-mode

- color scale the same for all images in each shot

movies at: http://www.pppl.gov/~szweben/
Images During L-H Transition

L-H Transition
NSTX #113732
B=3.0 kG, I=780 kA, 2.0 MW NBI
\(<n> = 2.2 \times 10^{13} \text{ cm}^{-3}\)
250,000 frames/sec
Images During (ELM-free) H-Mode

**H-mode**

NSTX #113745

*B*=3.0 kG, *I*=810 kA, 4.0 MW NBI

<\(n\)> = 2.7x10^{13} cm^{-3}

250,000 frames/sec
Analysis of Structure and Motion

- Use simplest analysis via 2-point cross-correlation function of fluctuations in GPI light signals vs. space and time:

\[ C(\Delta x, \Delta t) = \sum_{t} \tilde{S}_0(t) \tilde{S}_{\Delta x}(t+\Delta t) \]

- Correlation length from FWHM of \( C(\Delta x, 0) \) \[ \approx 1.6 \times \sigma_{\text{Gaussian}} \]

- Velocity from time the delay of the peak in \( C(\Delta x, \Delta t) \) vs. \( \Delta x \)

- \( C(\Delta x, \Delta t) \) averages over space and time spectrum of signals
2-D Structure from Chords

- No significant changes from L- to H-mode (13 shots)
- Maybe some increase in $L_{pol}$ over ~30 msec before L-H
2-D Structure from Images

- Evaluated near radial peak of GPI signal ~ separatrix
- No statistically significant changes from L- to H-mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>$L_{\text{rad}}$ (cm)</th>
<th>$L_{\text{pol}} / L_{\text{rad}}$</th>
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<tbody>
<tr>
<td>L</td>
<td>4.2±0.4</td>
<td>1.5±0.4</td>
</tr>
<tr>
<td>H</td>
<td>5.3±1.0</td>
<td>1.9±0.4</td>
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</table>
Poloidal Motion from Chords

- Poloidal motion generally in ion diamagnetic drift direction
- Poloidal flow more “frozen” in H-mode than L-mode ($\rho \sim 0$)

![Graph showing poloidal motion](image_url)

$V_{\text{pol}}$ (km/sec) (13 shots)

$V_{\text{Di}}$ ($\approx 4$ km/sec)
Poloidal Motion from Images

- Average flow is generally in ion diamagnetic drift direction
- $V_{pol}$ gradient tend to be lower for H-mode than L-mode

![L-mode Poloidal Speed](image1)

\[ \nabla V_{pol} \approx 1 \text{ km/sec/cm} \]

4 shots

![H-Mode Poloidal Velocity](image2)

\[ \nabla V_{pol} \approx 0.5 \text{ km/sec/cm} \]

4 shots
• Gas puff imaging diagnostic
• NSTX GPI images (L, L-H and H)
• Analysis of Structure and Motion
• **Comparison with C-Mod**
• Comparisons with theory
Images from Alcator C-Mod

H-mode

L-mode

C-Mod
Shot# 1031121030
ELMfree H-mode

1 cm

Upward

Radially outward

C-Mod
Shot# 1031204004
L-mode

1 cm

Upward

Radially outward

Terry et al, J. Nucl. Mater. ‘04
# NSTX vs. C-Mod (L-Mode)

<table>
<thead>
<tr>
<th></th>
<th>NSTX *</th>
<th>Alcator C-Mod**</th>
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<tr>
<td>$B_{\text{edge}}$</td>
<td>2-3 kG</td>
<td>40 kG</td>
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<tr>
<td>$n_{\text{edge}}$</td>
<td>0.2-2x10^{19} cm$^{-3}$</td>
<td>2-20x10^{19} cm$^{-3}$</td>
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<tr>
<td>$T_{e,\text{edge}}$</td>
<td>5-50 eV</td>
<td>20-80 eV</td>
</tr>
<tr>
<td>$L_{\text{pol}}$</td>
<td>5-9 cm</td>
<td>0.6-1.0 cm</td>
</tr>
<tr>
<td>$L_{\text{rad}}$</td>
<td>2-6 cm</td>
<td>0.7-1.5 cm</td>
</tr>
<tr>
<td>$V_{\text{pol}}$</td>
<td>$\leq 5$ km/sec</td>
<td>$\leq 1$ km/sec</td>
</tr>
<tr>
<td>$V_{\text{rad}}$</td>
<td>$\leq 1$-2 km/sec</td>
<td>$\leq 1.5$ km/sec</td>
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• Gas puff imaging diagnostic
• NSTX GPI images (L, L-H and H)
• Analysis of Structure and Motion
• Comparison with C-Mod
• Comparisons with theory
Comparison with L-H Transition Model

• Transition doesn’t look like standard ExB flow shear picture
  - little or no decrease in radial correlation length
  - little or no increase in poloidal shear flow

• Yet flow shear is near the usual stabilization criterion for L-H
  - $\nabla V_{pol}(L_{rad}/L_{pol}) \approx 30-40 \text{ kHz} \approx 1/\tau_{auto}$

Caveats:
- region causing transition may be outside GPI view
- poloidal velocities averaged over $\sim 1 \text{ msec}$
- no actual simulation of L-H transition
- relatively small data set
Comparison with “Blob Model”

- Model for dynamics of isolated structures in SOL
- Explains similar radial velocity on NSTX and C-Mod

\[ V_{\text{rad}} = 5.1 \times 10^6 \frac{L^{1/5} T_e^{7/10}}{B^{2/5} R^{3/5}} \]

\~ 2 \text{ km/s in both C-Mod & NSTX}

Myra et al, Poster RP1.00019
Thursday PM (NSTX)
Conclusions and Future Directions

• Lots of interesting things happening in edge turbulence

• Many directions for further improvements:
  - more data (Maqueda, RP1.00014)
  - better structure analysis (White, RP1.00016)
  - 2-D velocity field analysis (Munsat, RP1.00017
    Stoltzfus-Dueck RP1.00018)

=> Direct comparison of experiment and theory ?!

120k frames/sec
**Related Talks/Posters at this Meeting**

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<td>Myra: RP1.00019</td>
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<td>SOL model:</td>
<td>Russell: CP1.00045</td>
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<td>Velocity field:</td>
<td>Munsat: RP1.00017</td>
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<td>Stoltzfus-Dueck: RP1.00018</td>
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<th>ELMS with GPI:</th>
<th>Terry: RO3.00008</th>
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<td>L-H in BEA</td>
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