# Neutral Transport Simulations of Gas Puff Imaging Experiments on NSTX


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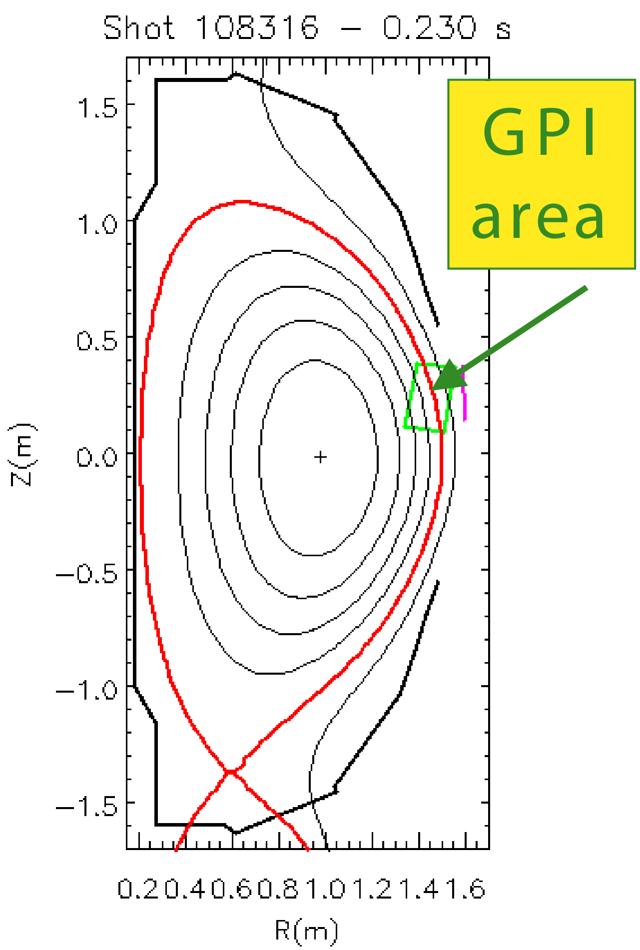
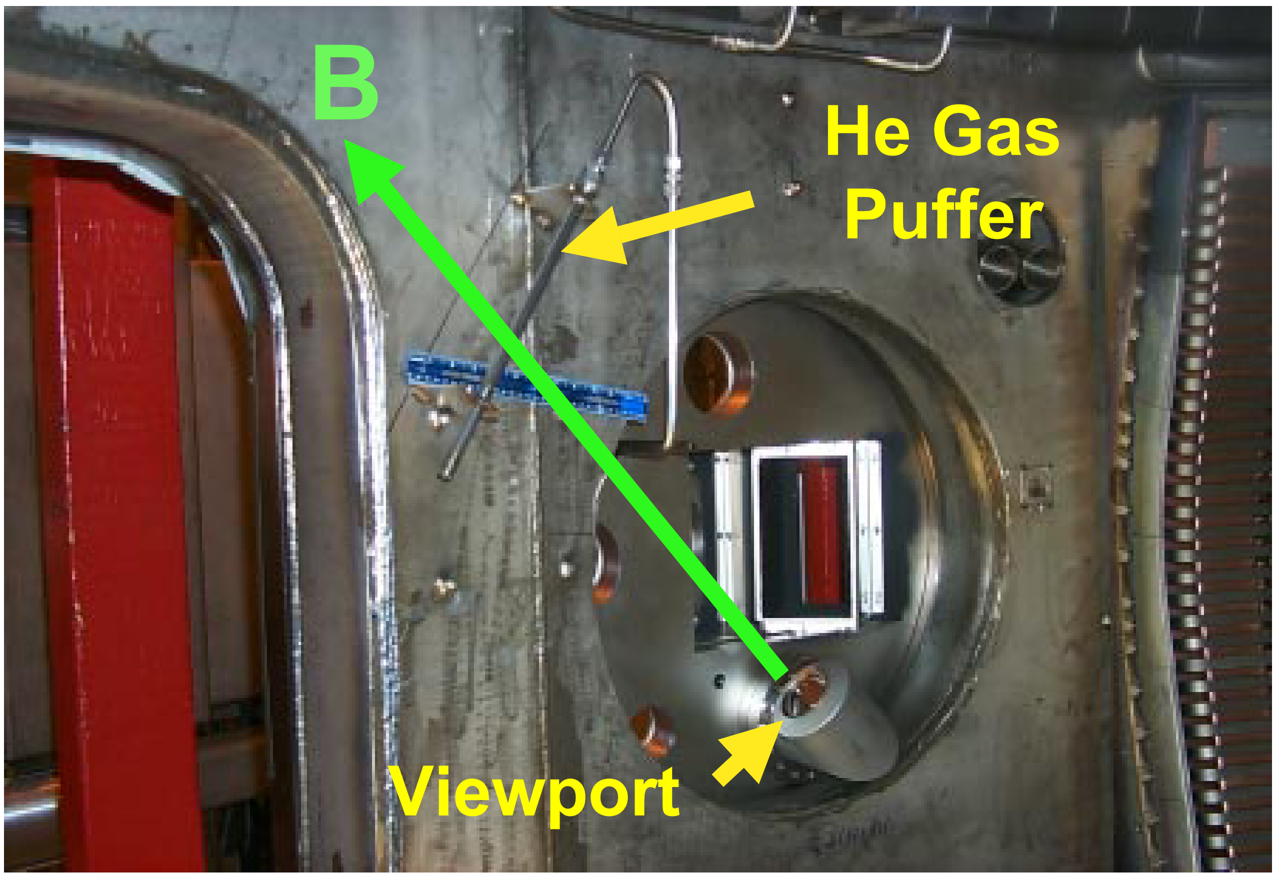
Note: This poster is available on the Web at:
`http://w3.pppl.gov/degas2/`

# Gas Puff Imaging (GPI) Experiments Designed to Measure 2-D Structure of Edge Turbulence

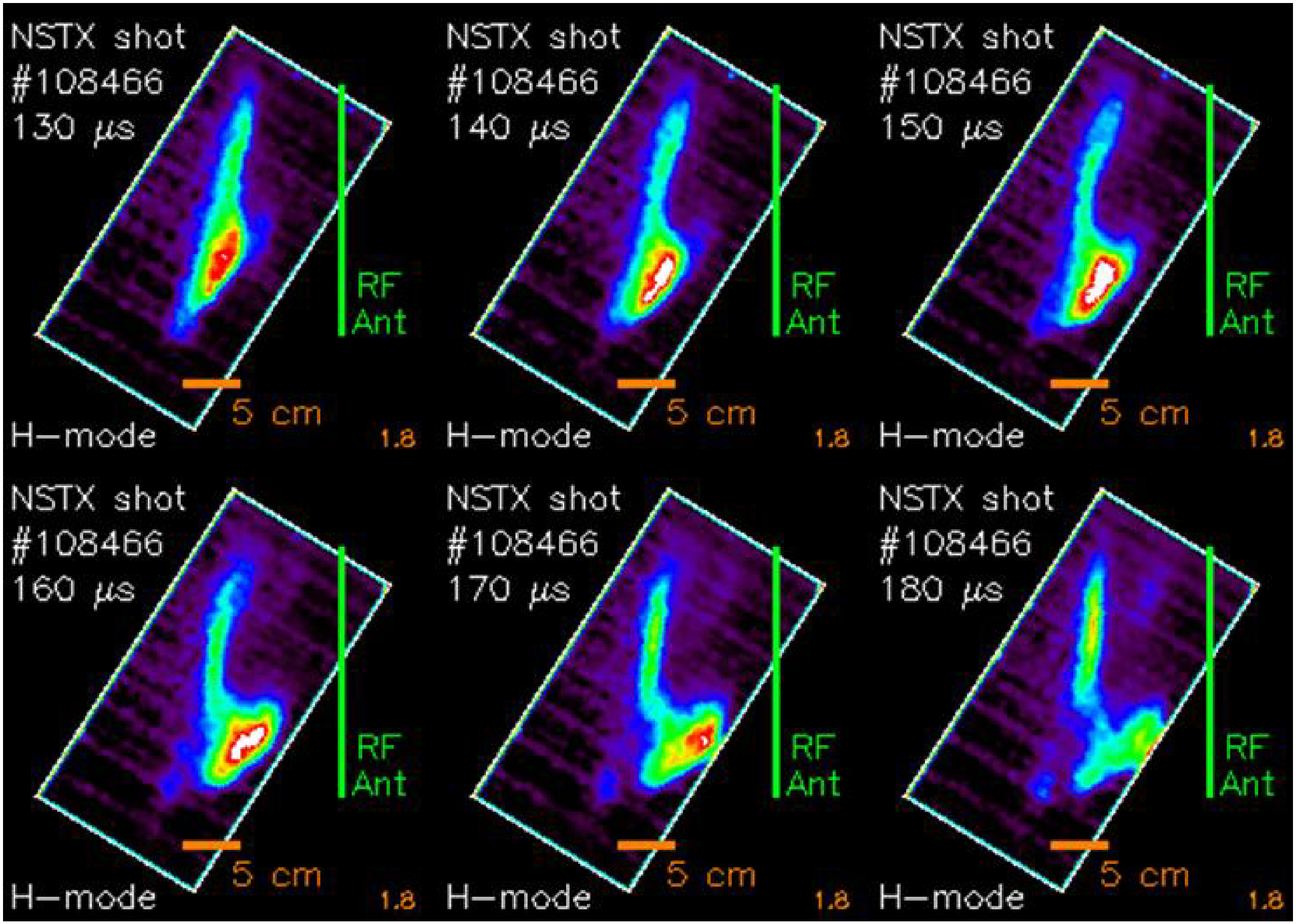
- Puff neutral gas near outer wall,
- View with fast camera fluctuating visible emission resulting from electron impact excitation of that gas,
- Use sightline $\parallel \vec{B}$ to see radial & poloidal structure.
  - Compare with turbulence measured by probes,
  - And with output from plasma turbulence codes.

# Gas Puff Imaging Hardware Configuration in NSTX

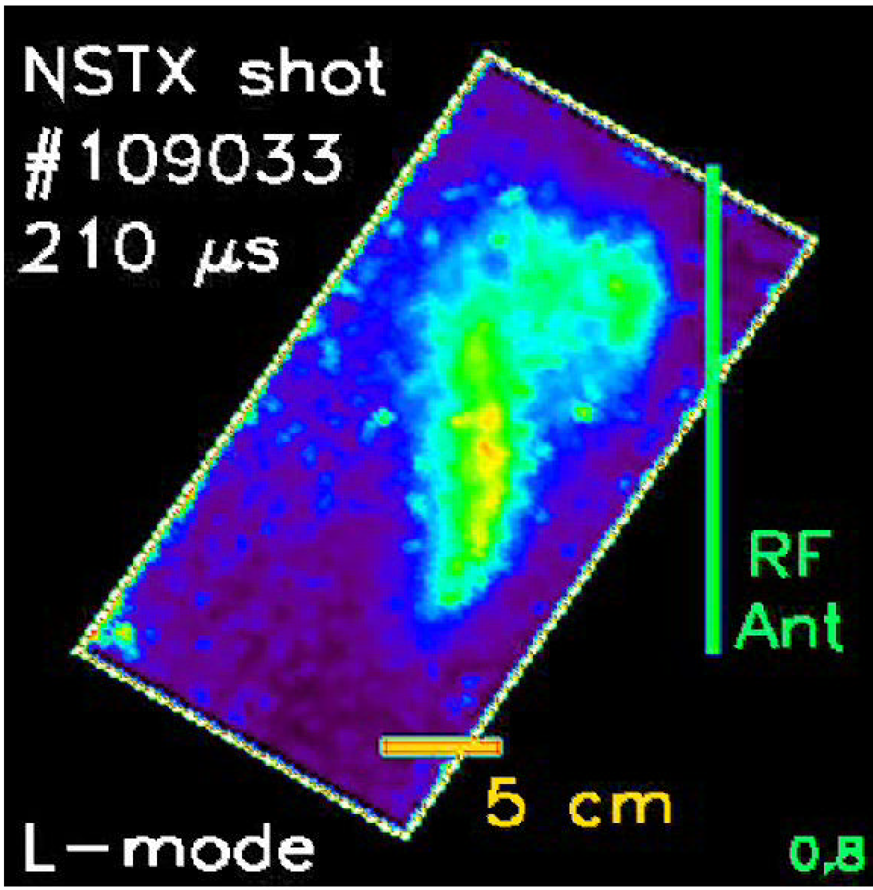


# Camera Records Fluctuating Emission for 28 Frames @10μs/frame



# Examine Relationship Between Observed Emission Patterns & Underlying Plasma Turbulence




Maqueda & Zweben

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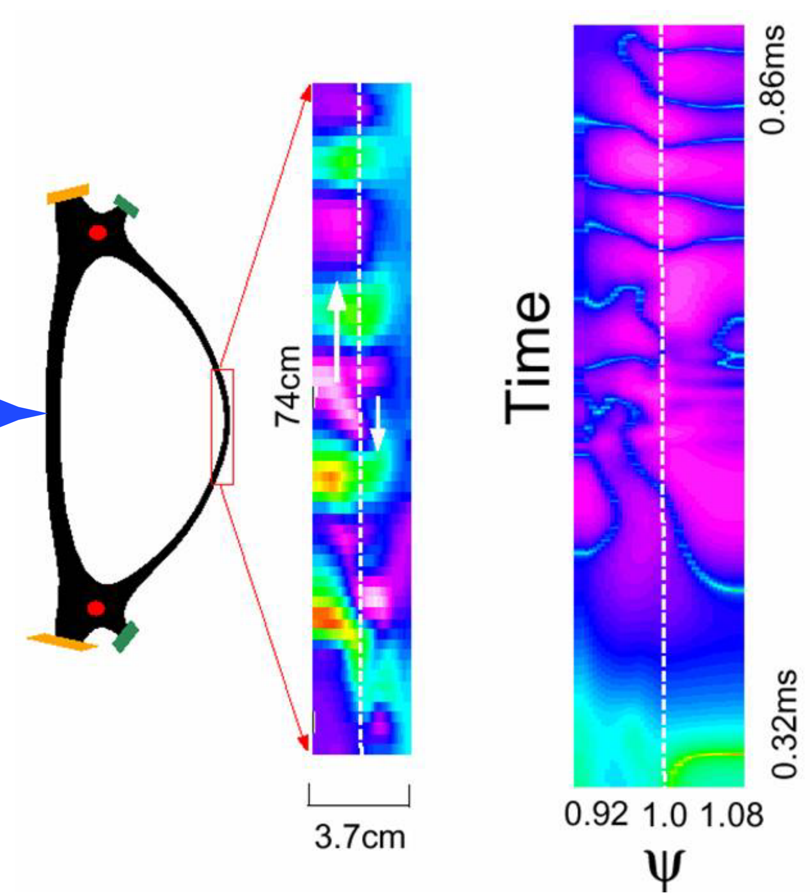



X. Q. Xu

# Results Outline

Objective: model behavior of neutral gas that experiences plasma fluctuations & gives rise to emission patterns.

1. Simulations of single time-slice plasma qualitatively similar to time-average experimental results.

2. Relationship between plasma turbulence and emission patterns consists of two components:

   (a) $n_e$, $T_e$ dependence of emission rate,

   - Messy, but straightforward.

   (b) Neutral density profile,

   - Can pick up spatial structure from turbulence $\Rightarrow$ emission pattern & plasma turbulence $k$-spectra may differ.

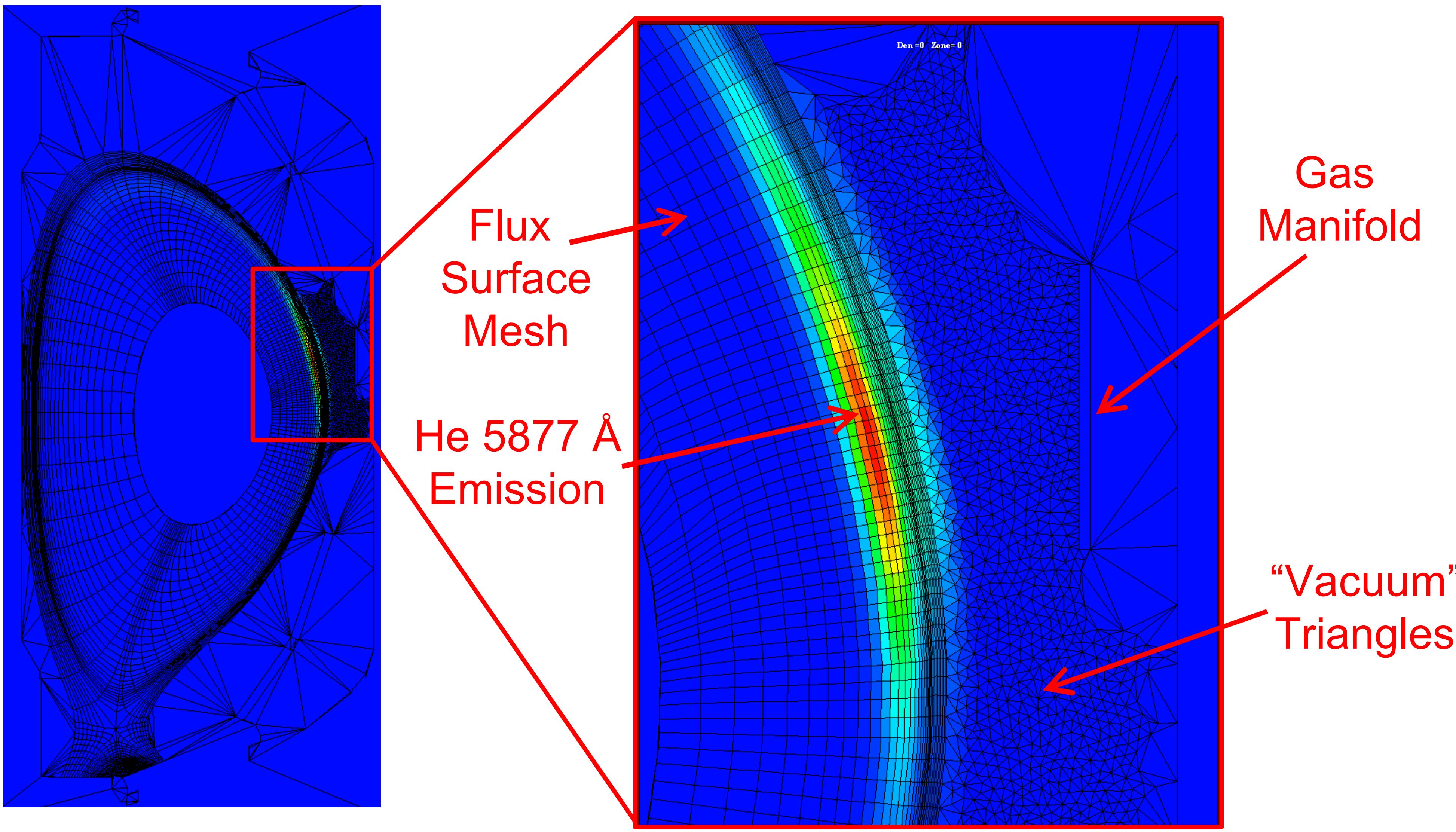
   - Effect decreases with smaller turbulence amplitude,

   - May be of less concern for higher $k$.

# DEGAS 2 Simulations

- 2-D, steady-state neutral transport,
  - Plasma data input to code,
  - Compute neutral density & line (D$_\alpha$ or He 5877 Å) emission,
  - Get emission in poloidal plane $\sim$ camera view.
- Use single time-slice $n_e(R)$ & $T_e(R)$,
- Or, add ad-hoc 2-D perturbation,
  - Compare spatial structure of emission with perturbation.

# Realistic, High Resolution Geometry
# NSTX Shot 108321, 187 ms



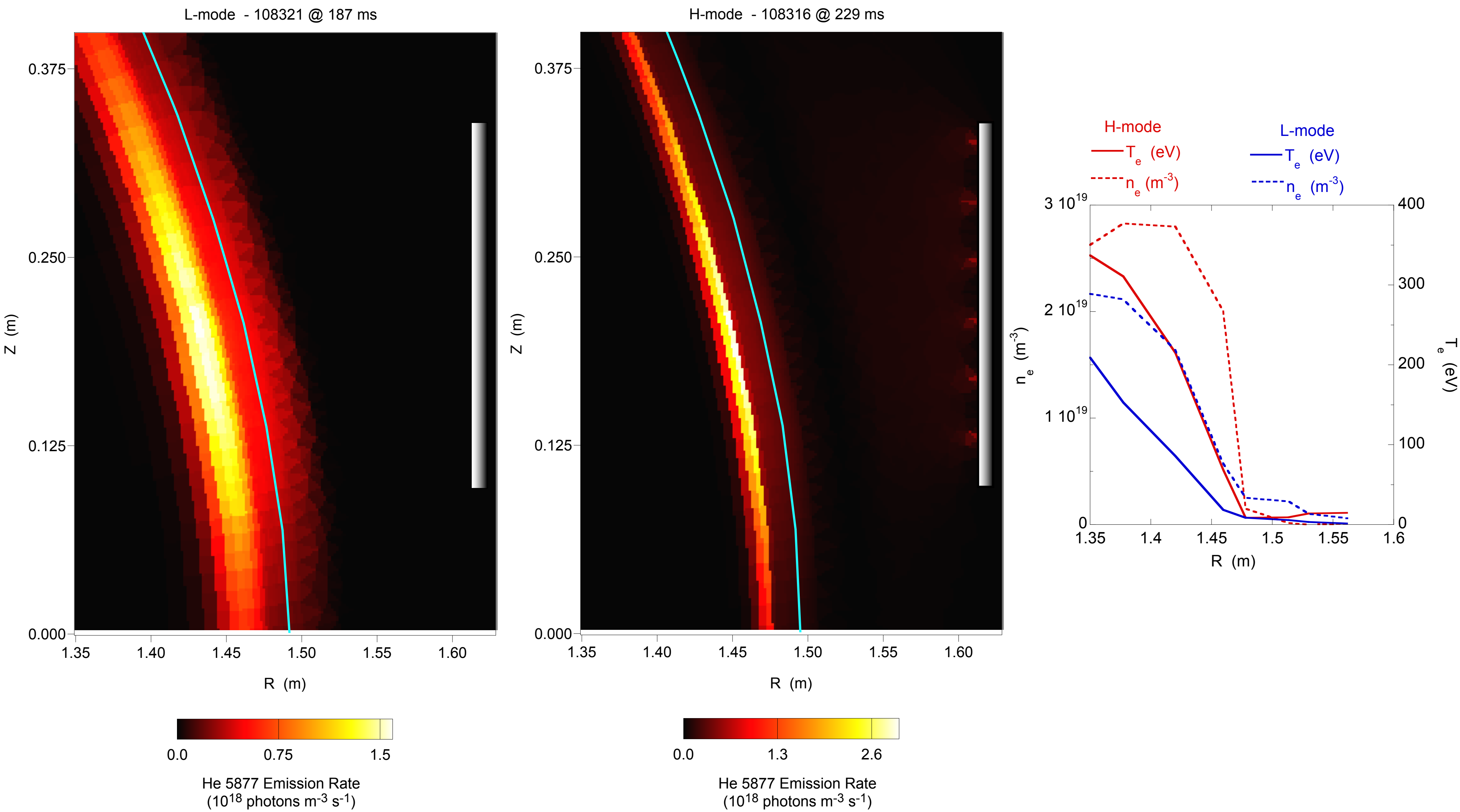
# 1. Simulations of Single

# Time-Slice Plasma

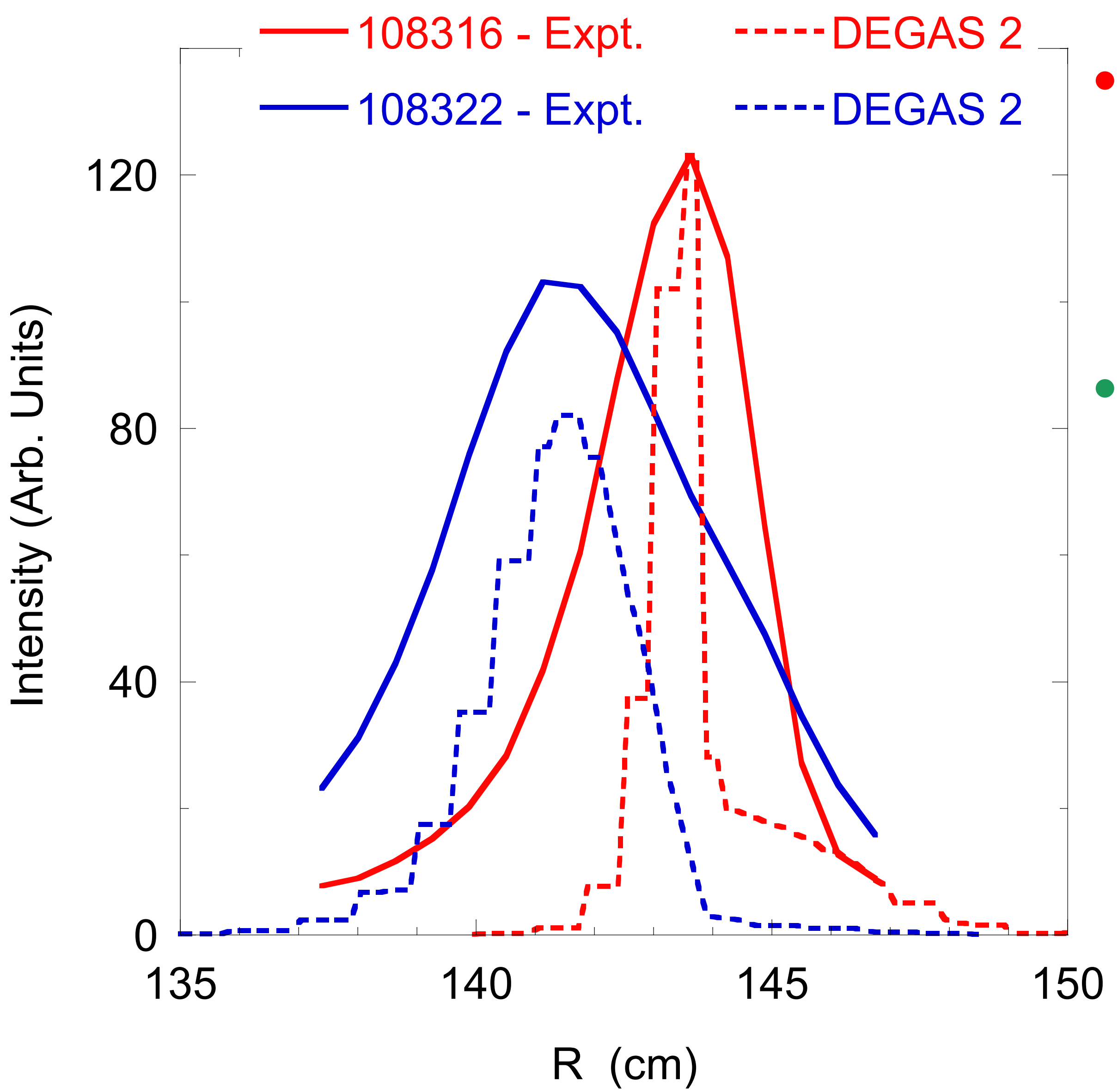
# Qualitatively Similar to

# Time-Average Experimental Results

# Width of Emission in NSTX Simulations Determined by Profiles

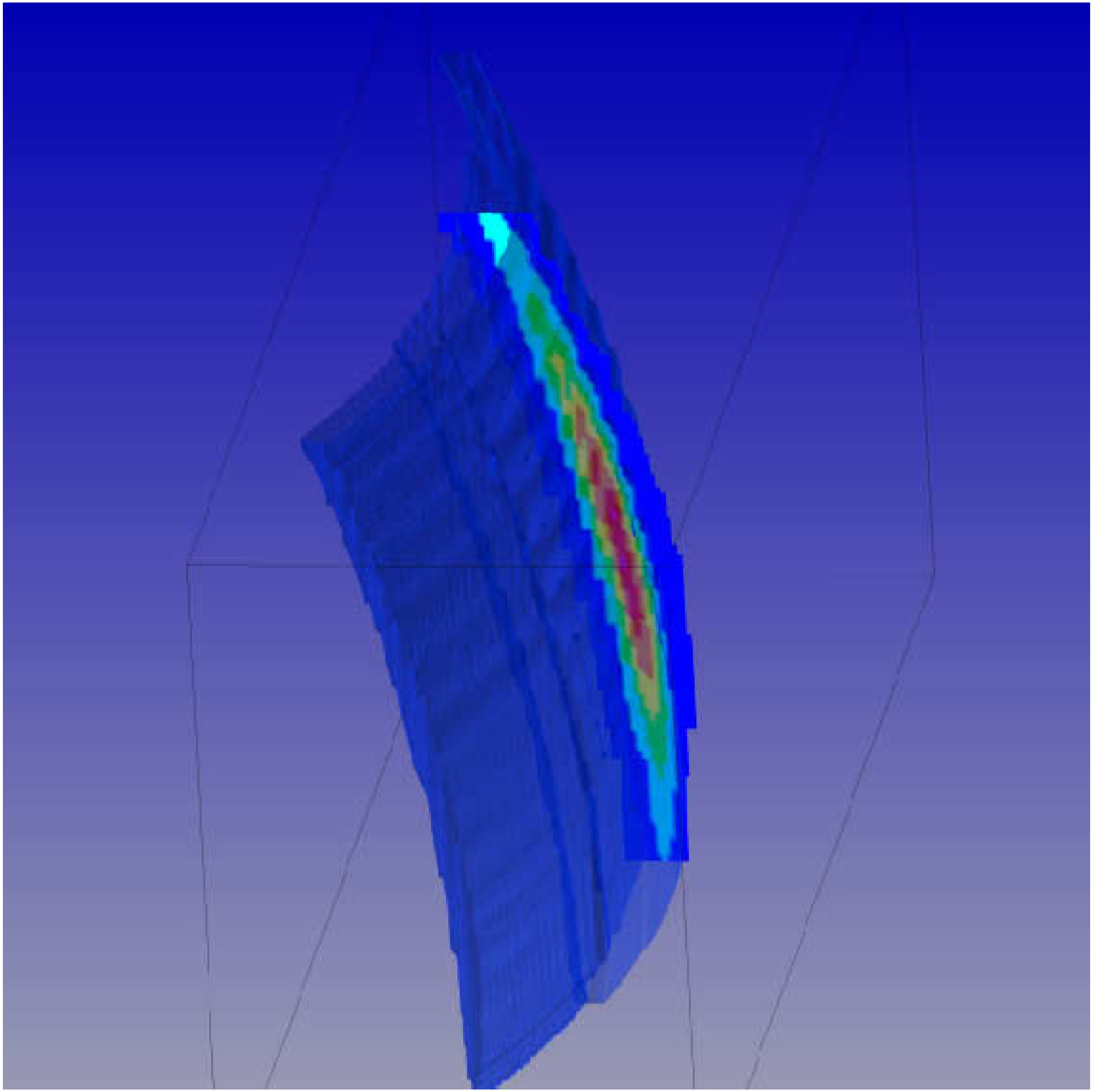


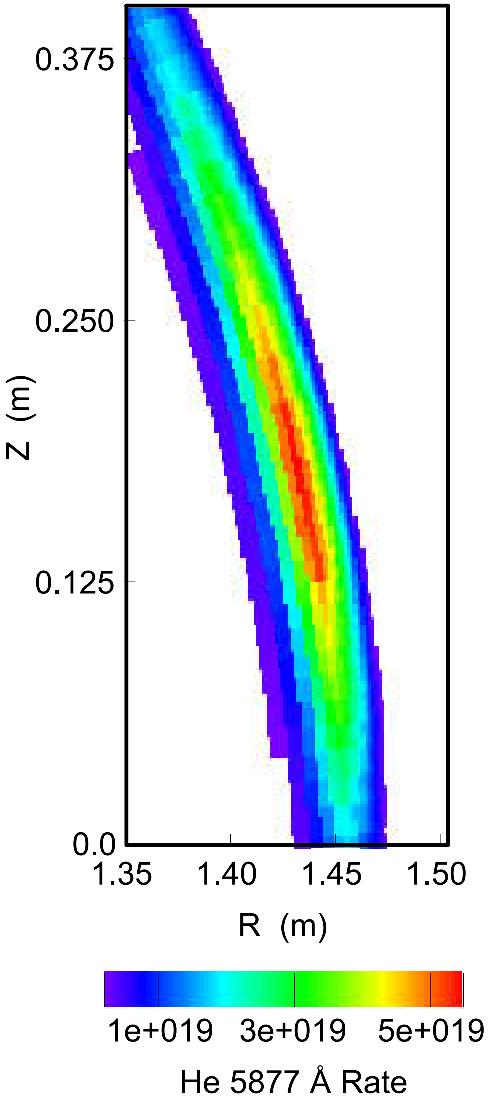
# Simulated NSTX 5877Å Profiles Narrower Than Observed




- Simulated H-mode (108316) intensity & peak radius adjusted to match,
  - L-mode profile modified in same way.
- Many possible explanations for width differences,
  - Including 3-D effects,
  - & Simulation of camera views.

# Initial 3-D DEGAS 2 Simulation of NSTX Shot 108322






Visualization by S. Klasky

# Initial 3-D Simulation

- Toroidally resolved gas puff, neutral density & 5877 Å emission.

- $\Rightarrow$ FWHM emission cloud 28 cm,
  - Maqueda (HTPD 2002): 24 cm from view across torus,
  - Toroidal extent of cloud limits GPI radial resolution.

- Additional improvements needed to 3-D simulation:
  1. Gas manifold tilted $\perp \vec{B}$,
  2. Simulate camera view.

# 2.(a) Relationship Between

# Plasma Turbulence

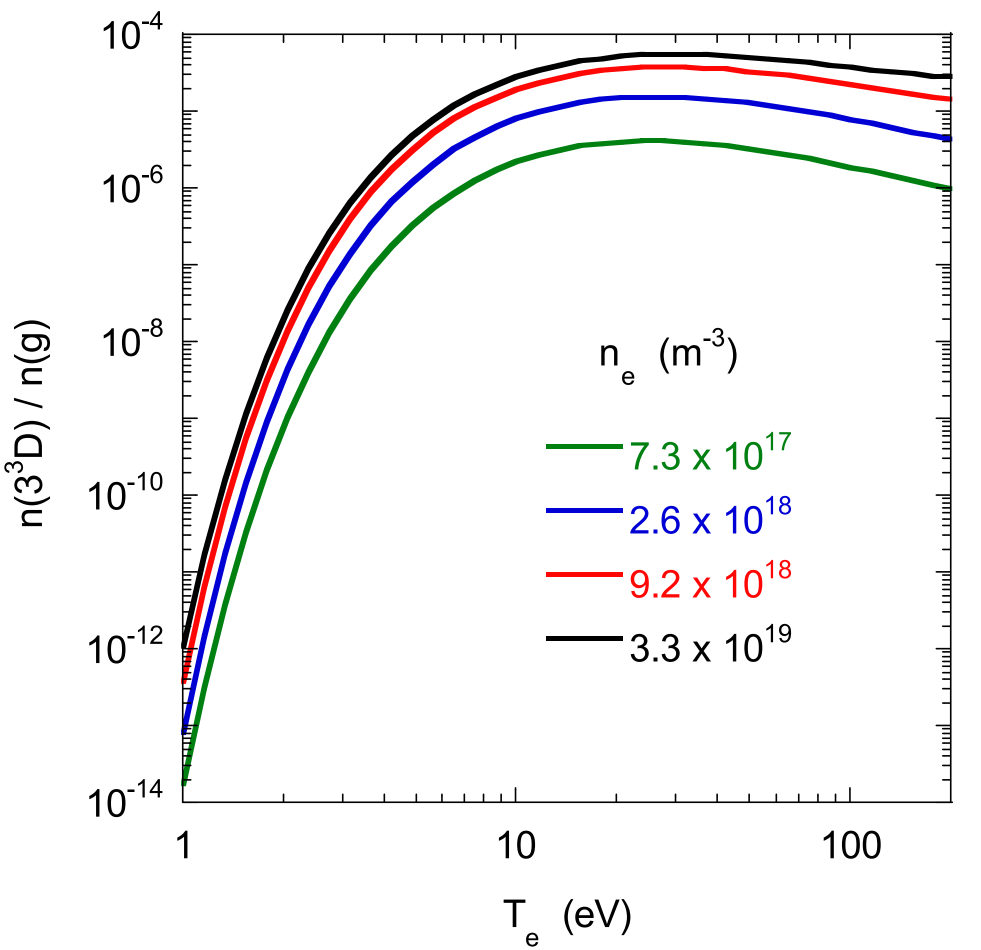
# & Emission Patterns:

## $n_e$, $T_e$ Dependence of Emission Rate

# Scaling of Emission Rate for He 5877Å Varies Across Profile

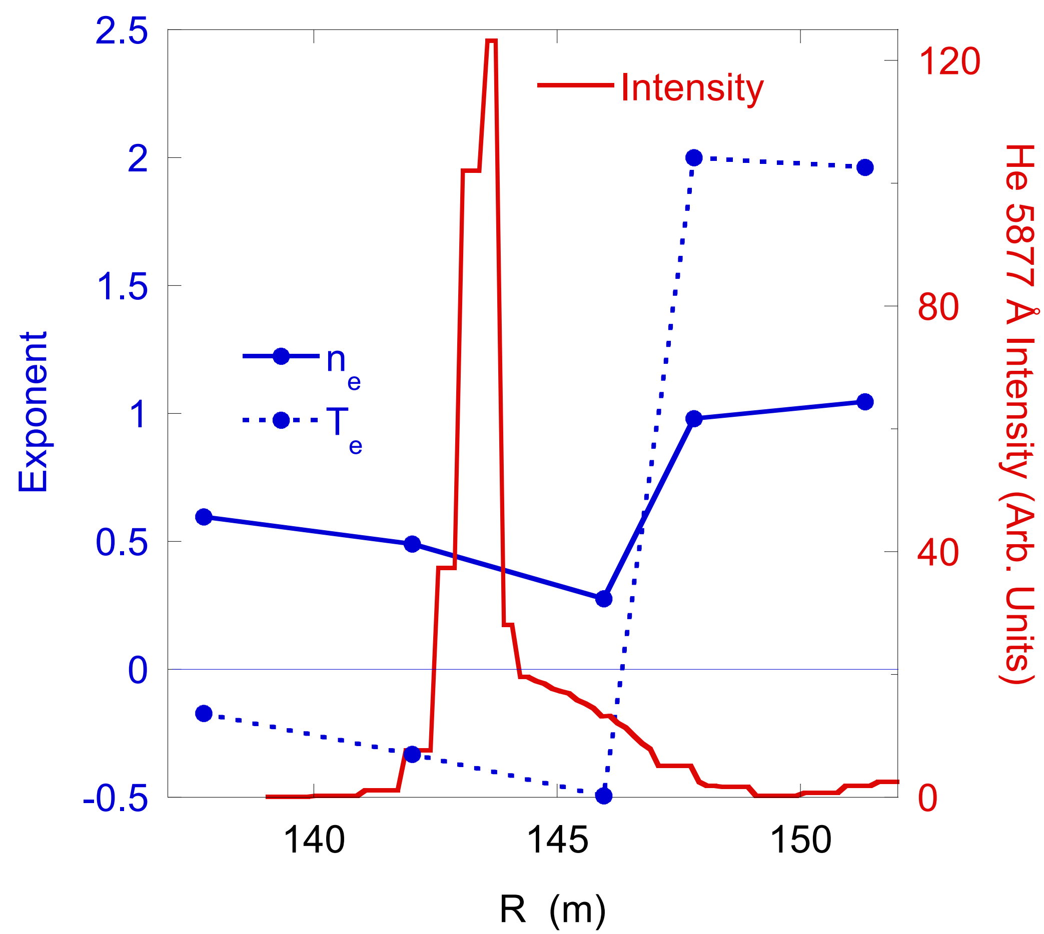
$$S = \sum_j n_j f_j(n_e, T_e)$$

$n_e$, $T_e$ Dependence of *f* for He 5877 Å




Scaling of *f*

in NSTX H-mode Shot 108316



# 2.(b) Relationship Between

# Plasma Turbulence

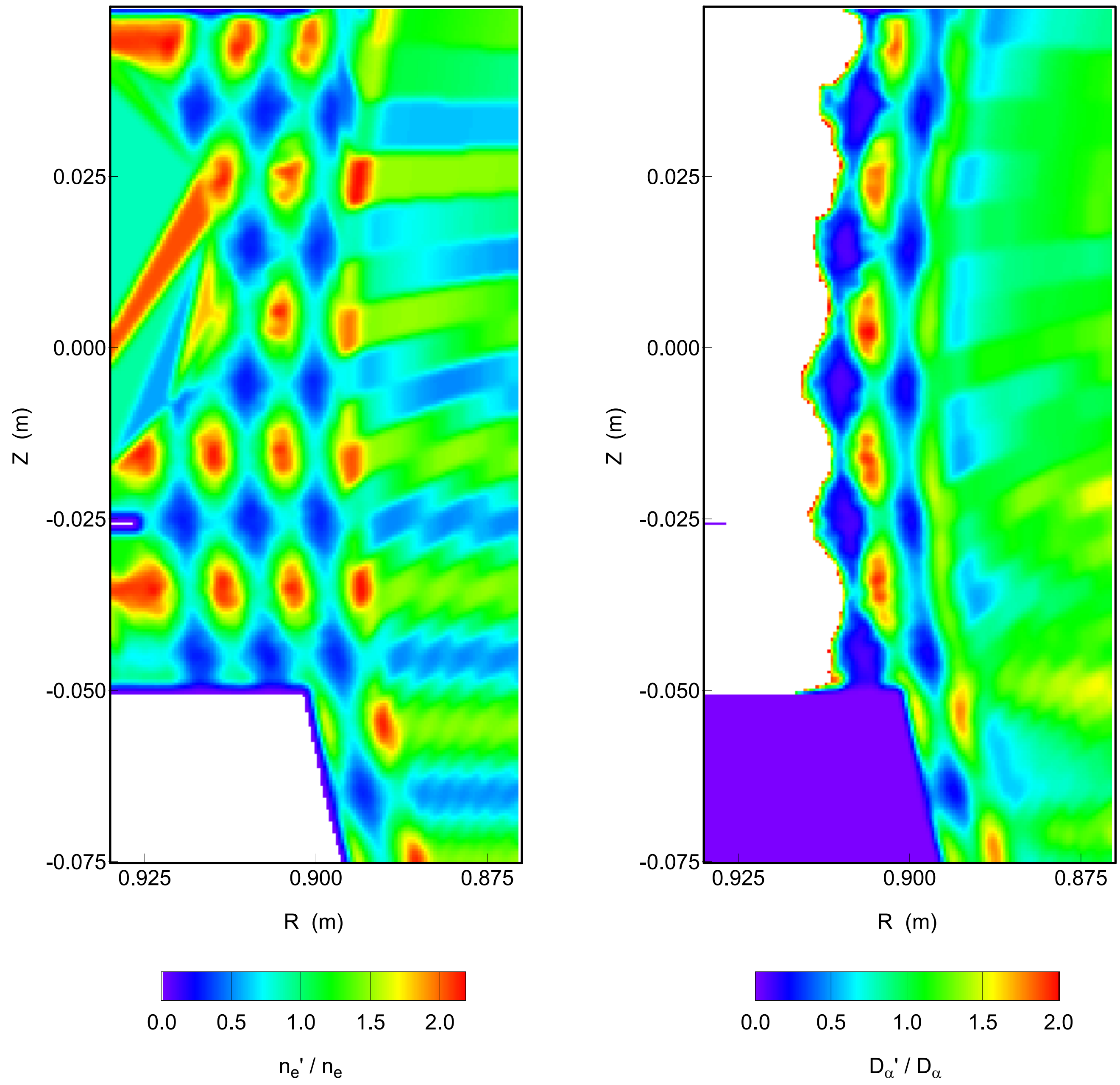
# & Emission Patterns:

## Neutral Density Profile

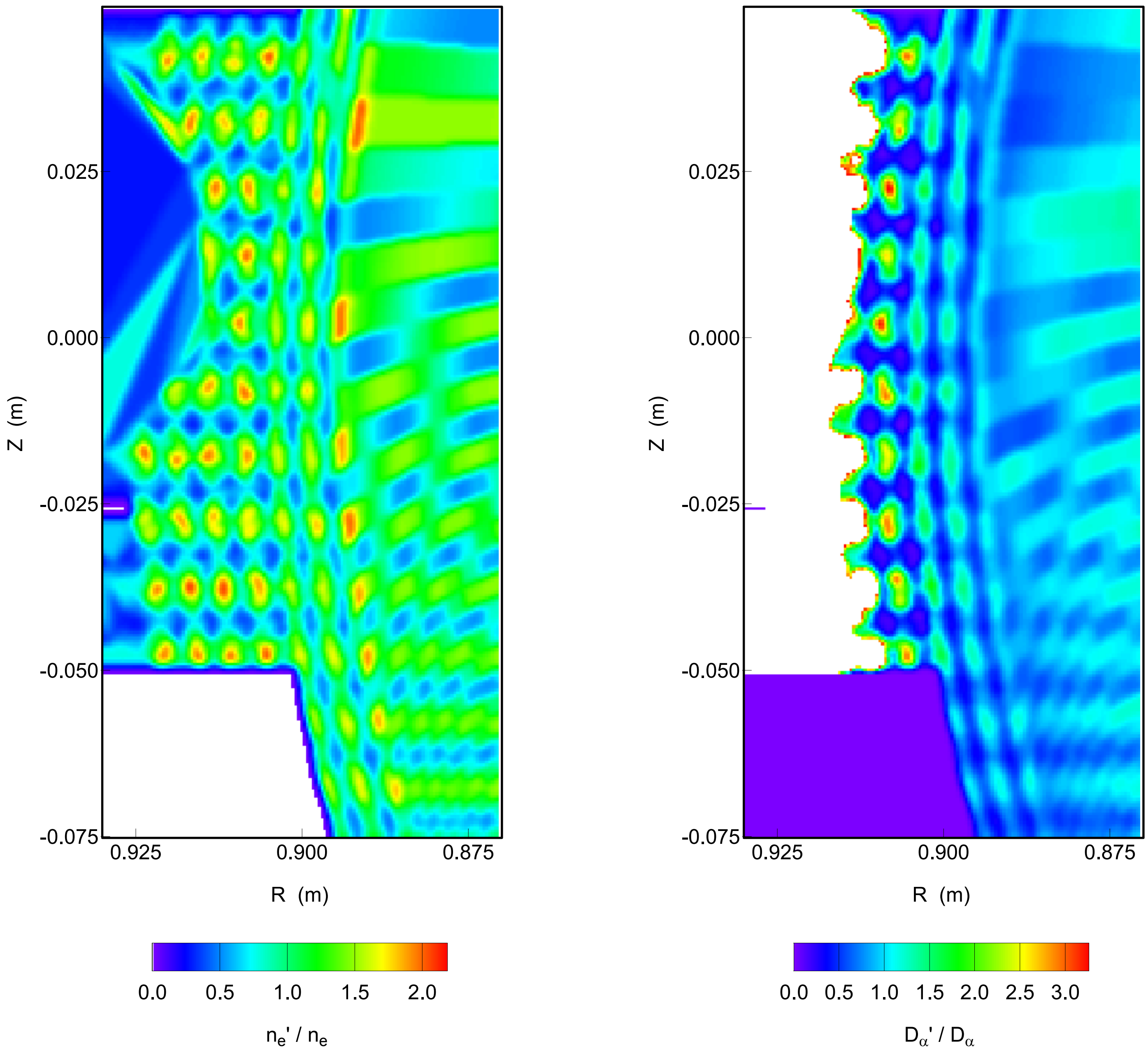
# Impact of Plasma Perturbations on Neutral Density

- Ideally, $n_j$ is uniform & unaffected by plasma turbulence,
  - $\Rightarrow$ emission depends mostly on $f_j(n_e, T_e)$.
- But, $n_e$, $T_e$ fluctuations can modify neutral flow via ionization, dissociation, charge exchange,
  - Transfers structure of plasma turbulence onto neutral density.
  - $\Rightarrow$ local $n_j$ depends on plasma “seen” en route by neutrals.

# Applied $k_z$ = 3 $cm^{-1}$ Perturbation in C-Mod Simulation & Normalized $D_\alpha$ Response



# Applied $k_z$ = 6 $cm^{-1}$ Perturbation in C-Mod Simulation & Normalized $D_\alpha$ Response



# Perturbed Neutral Density Affects Visible Image & Spatial Spectrum

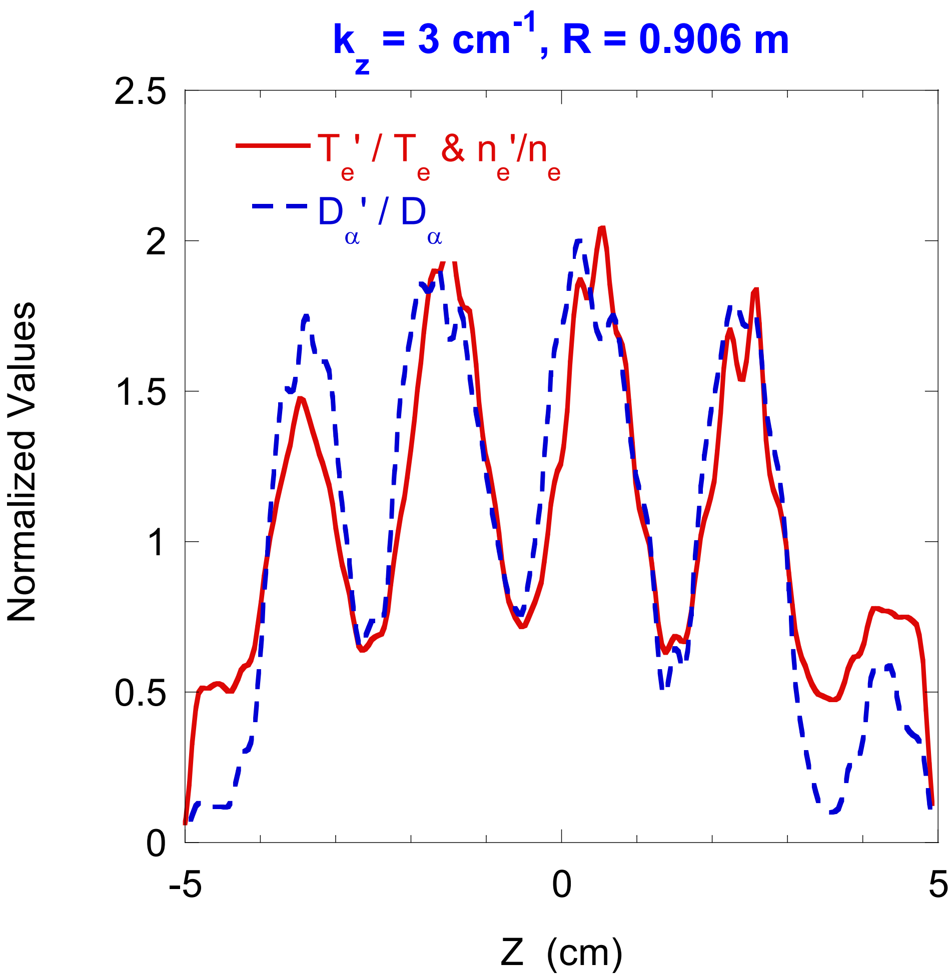
- Principally compare GPI experiments & turbulence simulations using wavenumber spectra,
  - I.e., relative frequency of structures of various sizes.
  - Experiments: FFT of vertical slices through 2-D images,
  - Codes: slices through 2-D plasma profiles.

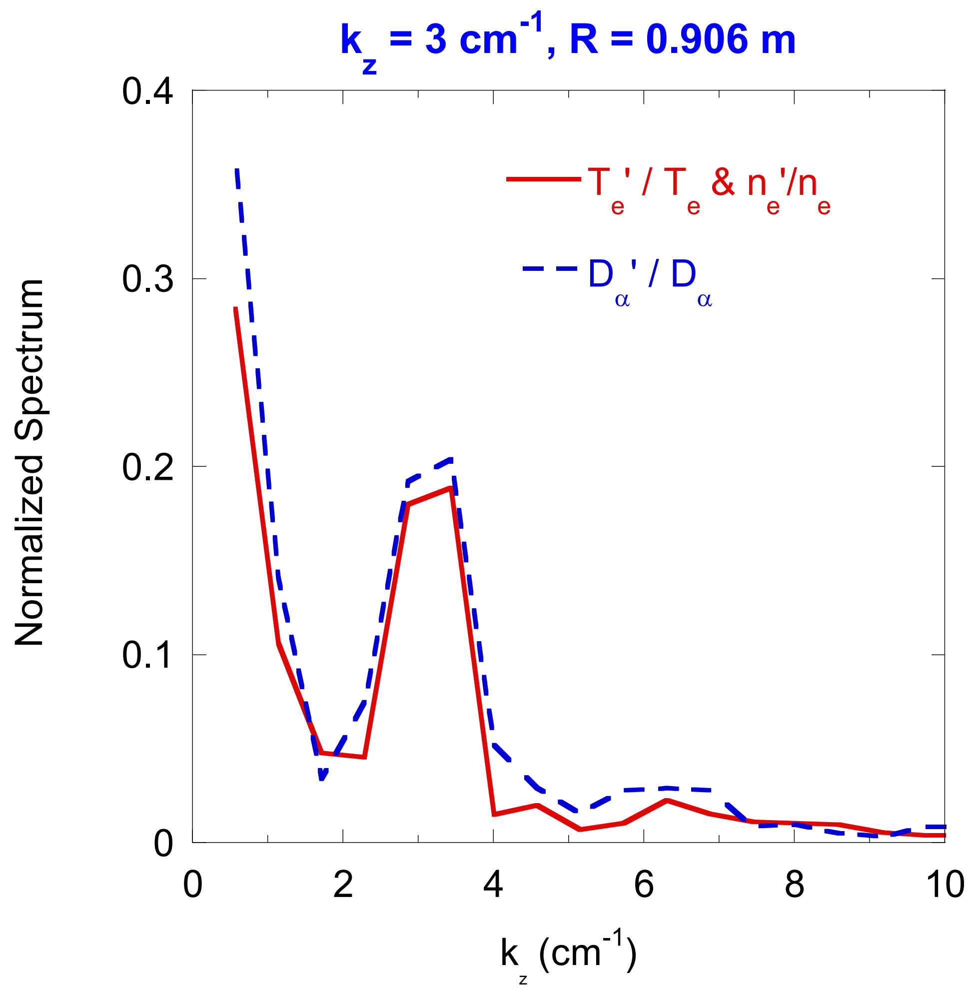
- Perturbations to $n_j$ manifested in two ways:

**Shadowing** $\Rightarrow$ decrease of $n_j$ "behind" $n_e$, $T_e$ peaks,

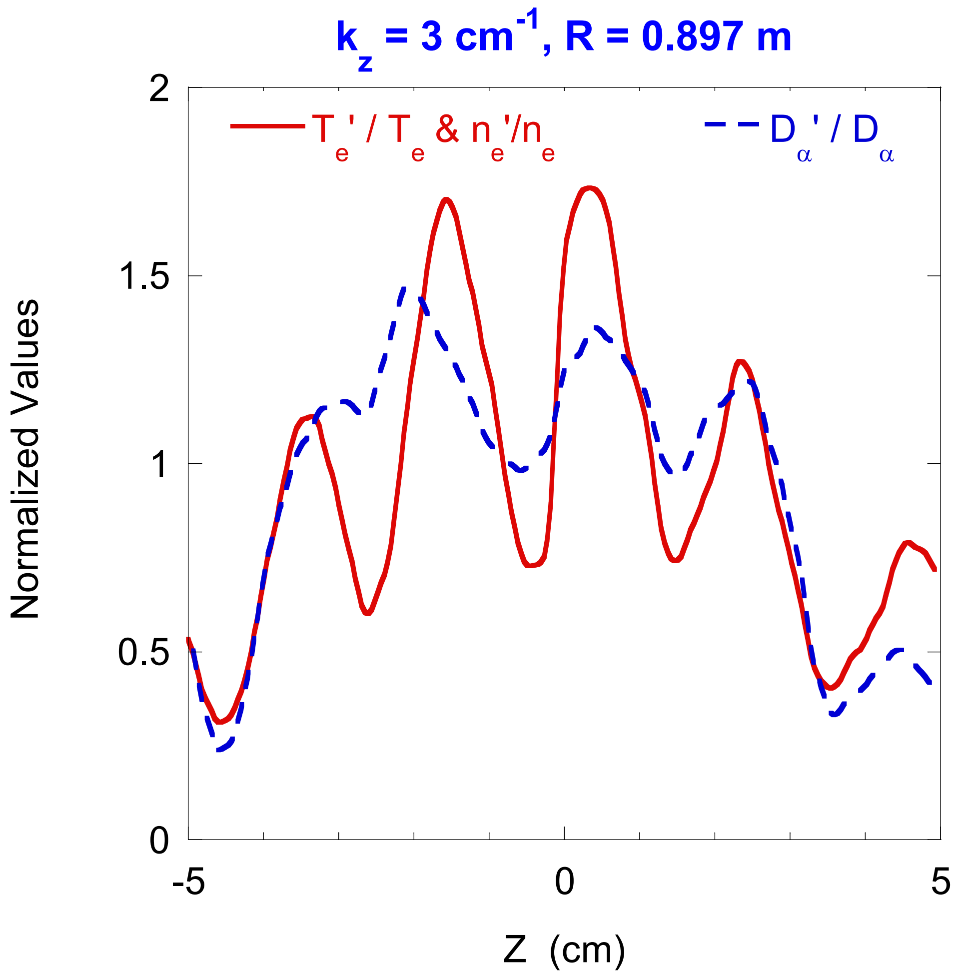
**Smearing** The inverse effect, $n_j$ increase behind plasma minima, can combine with shadowing to "smear" out structures.

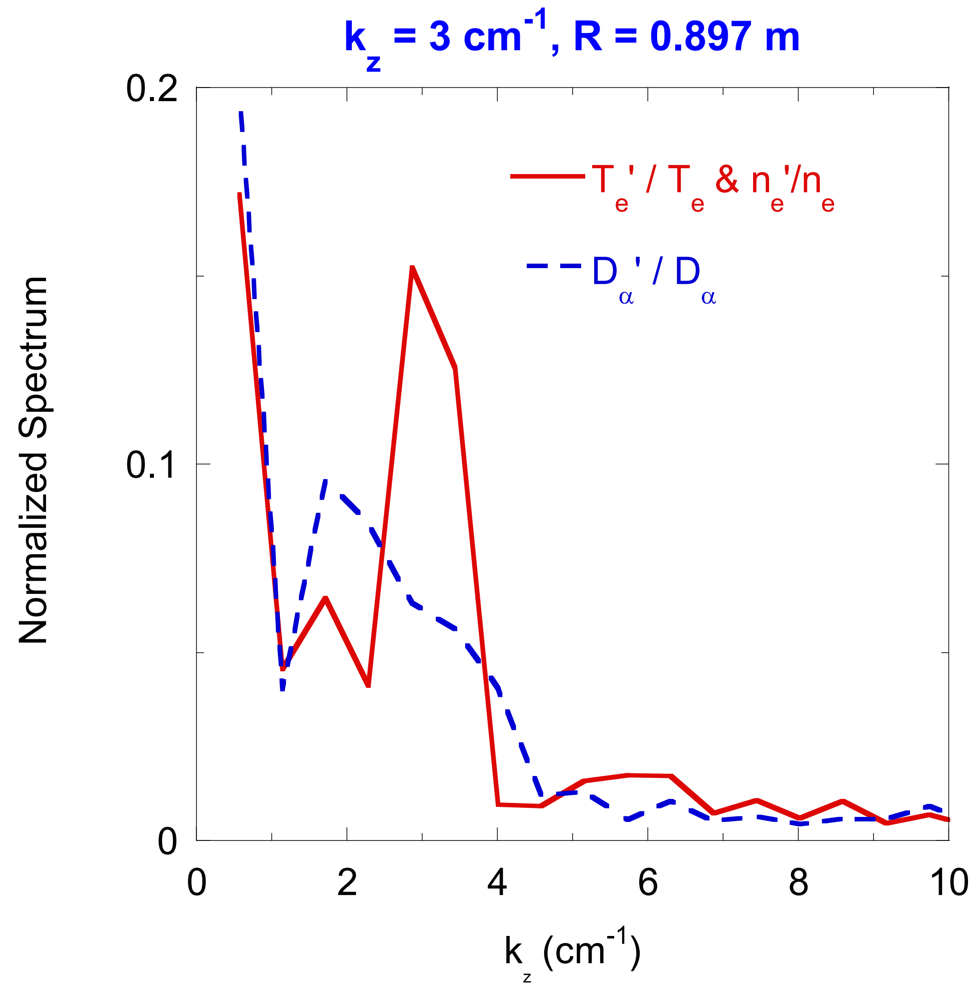
# At Outermost Radii, Spatial & Spectral Variations Similar



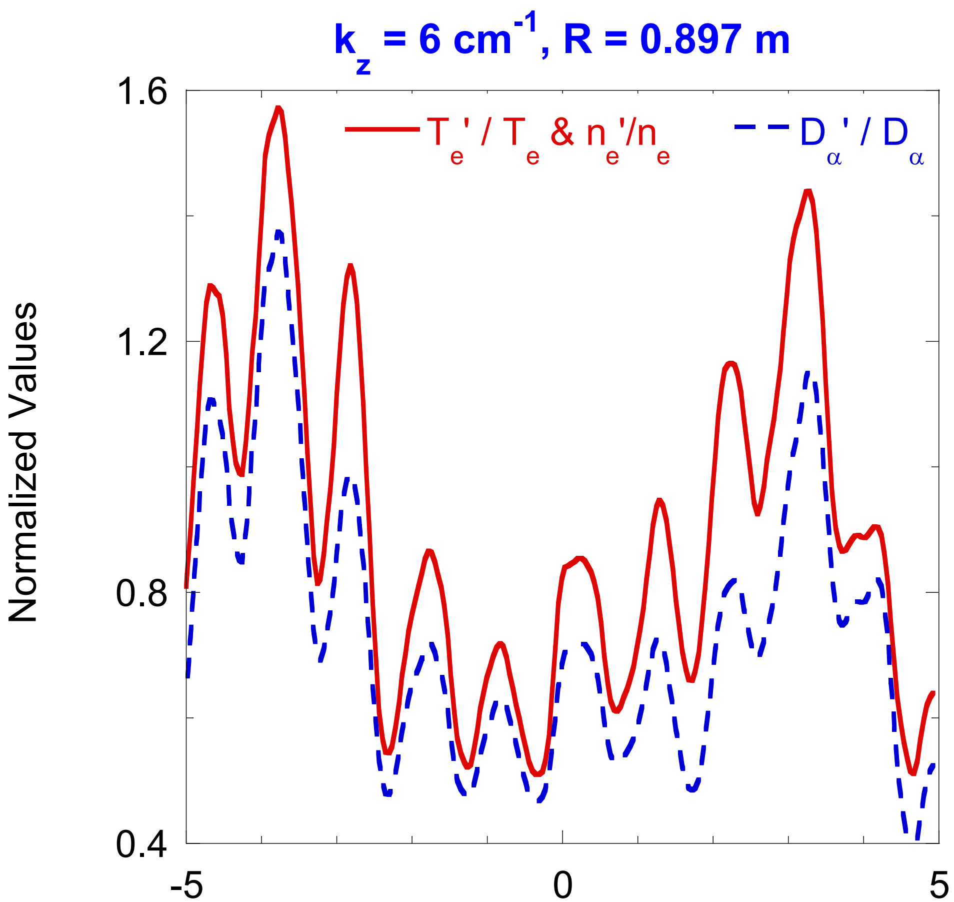



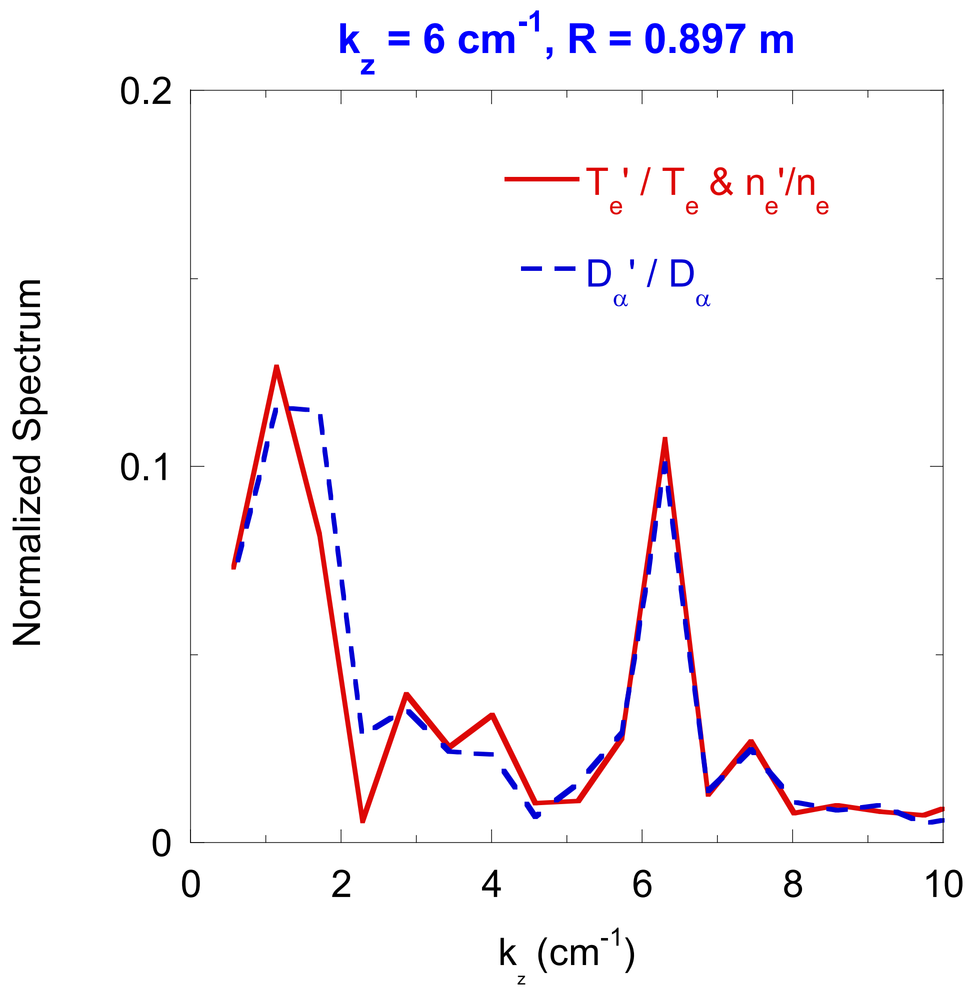
# At Inner Radii, Smearing Apparent in Profiles & Spectra



# Smearing Not Discernable in Higher $k_z$ Runs



# Shadow Fraction $F_s$ Quantifies Impact on 2-D Images

- $F_s =$ normalized difference between perturbed D$_\alpha$ profile and D$_\alpha$ computed with the unperturbed $n_j$,

$$F_s = \left[ \sum_j (n'_j - n_j) f'_j \right] / \sum_j n_j f_j,$$

  – Primes indicate peturbed quantities.

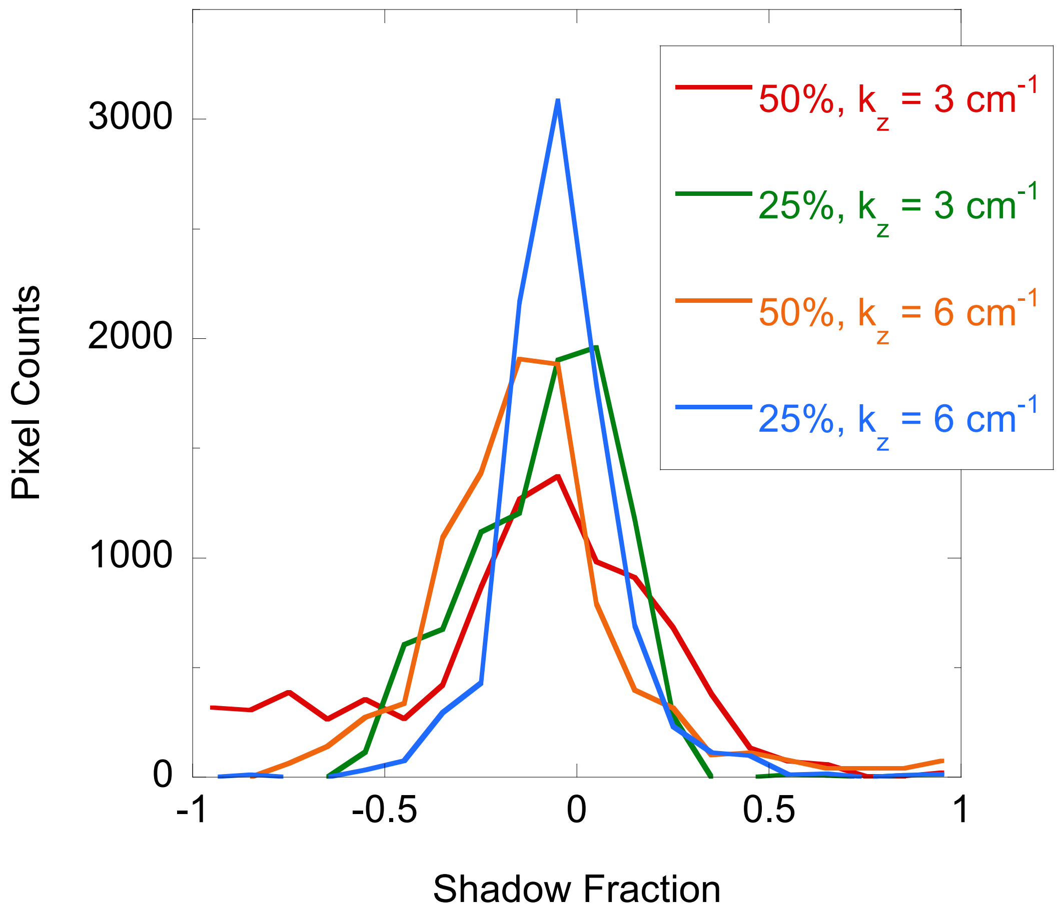
- $F_s$ indicates extent to which effects of plasma perturbation on $n_j$ have impacted $S$,

  – Structure is complicated & difficult to explain,

  – Instead, summarize $F_s$ images for current runs as histogram data.

# Shadowing / Smearing Decreases with Size of Perturbation

- Best case: $k_z = 6\ \text{cm}^{-1}$, 25% perturbation,
- Worst case: $k_z = 3\ \text{cm}^{-1}$, 50% perturbation,
- "Shadowing" $\leftrightarrow F_s < 0$,
- "Smearing" $\leftrightarrow$ symmetric histogram.



# CONCLUSIONS

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2. Relationship between plasma turbulence and emission patterns:

   (a) $n_e$, $T_e$ dependence of emission rate messy, but straightforward.

   (b) Neutral density can pick up spatial structure from turbulence $\Rightarrow$ emission pattern & plasma turbulence $k$-spectra may differ,

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