

High Speed Imaging of Edge Turbulence in NSTX

S.J. Zweben, R. Maqueda¹, D. Stotler, A. Keesee²,
J. Boedo³, C. Bush⁴, M. Gilmore⁵, S. Kaye, S. Kubota⁵,
B. LeBlanc, J. Lowrance⁶, R. Maingi⁴, W. M. Nevins⁷,
D. Swain⁴, J. Wilgen⁴, X. Xu⁷

Princeton Plasma Physics Laboratory, 1- LANL,
2-West Virginia University, 3-UCSD, 4-ORNL, 5-UCLA,
6-Princeton Scientific Instruments, 7-LLNL

- Diagnostic
- Videos
- Image analysis
- Fast chords

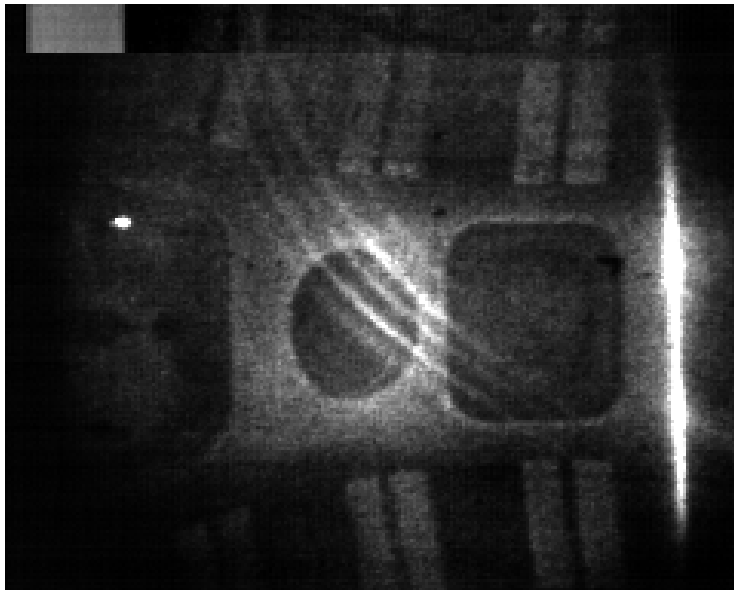
STW '02



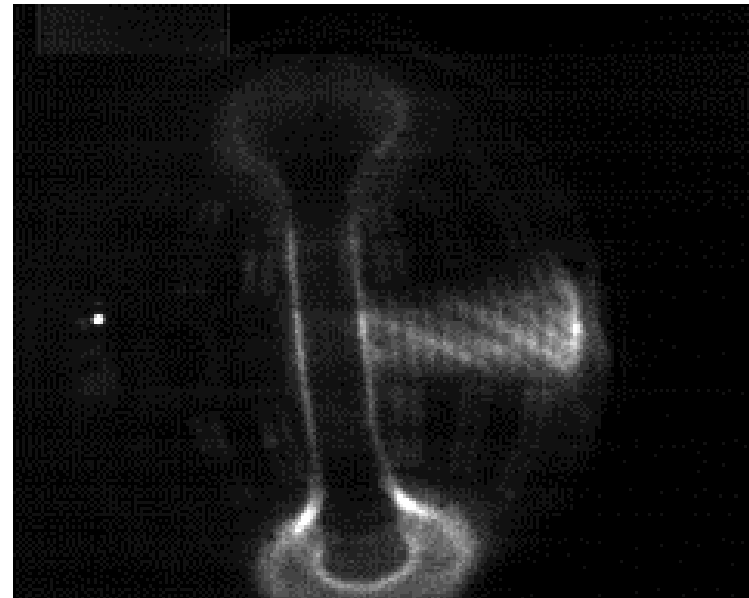
Edge is Normally Turbulent in NSTX

- Side view with LANL camera @ 10 μ sec/frame (no filter)

D puff from big port



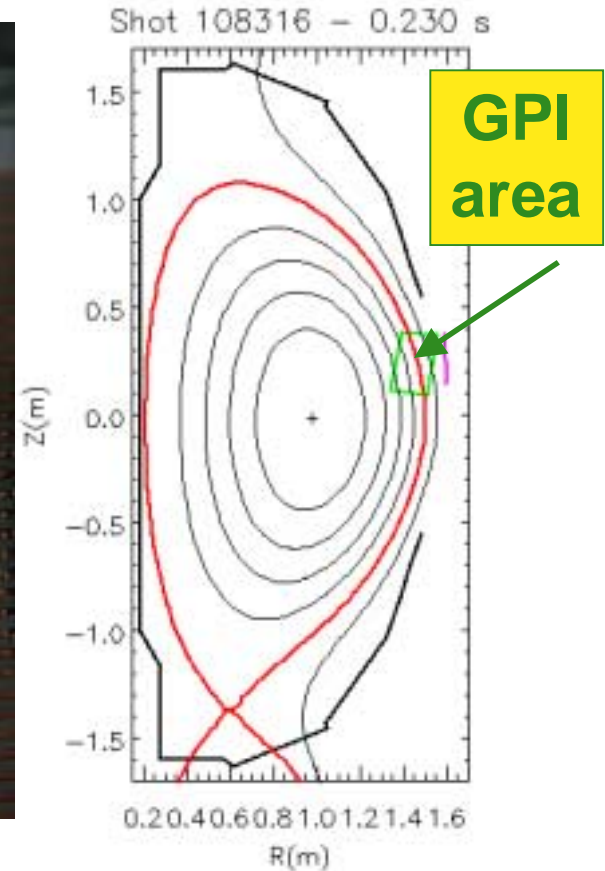
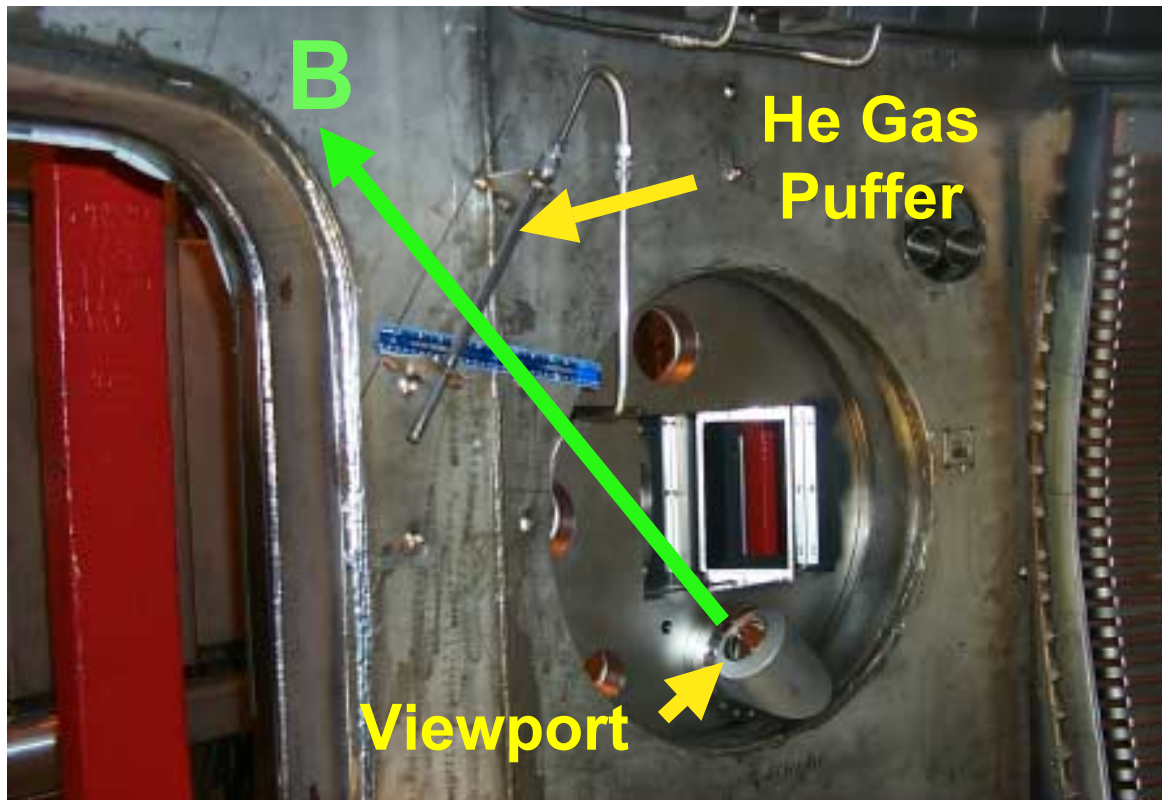
Recycling from antenna



- Similar structures seen by Nishino on NSTX and MAST
- Qualitatively similar to edge turbulence on tokamaks

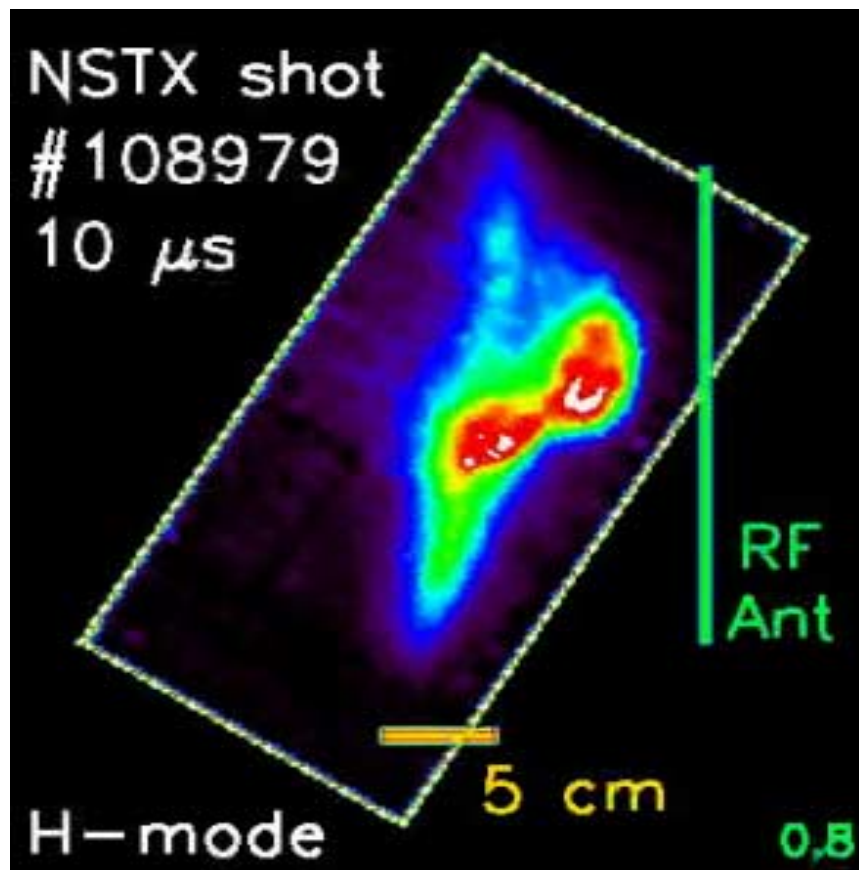
Gas Puff Imaging Diagnostic in NSTX

- View light from local He gas puff in HeI (587.6 nm)
- Look along B to make images in radial vs. poloidal plane



Typical Image in NSTX

- Taken with Princeton Scientific Instruments PSI-4 camera with 80x160 pixels @ 10 μ sec/frame for 28 frames



Radially outward toward right,
ion ∇B and ion diam. down

Separatrix is near “5 cm”

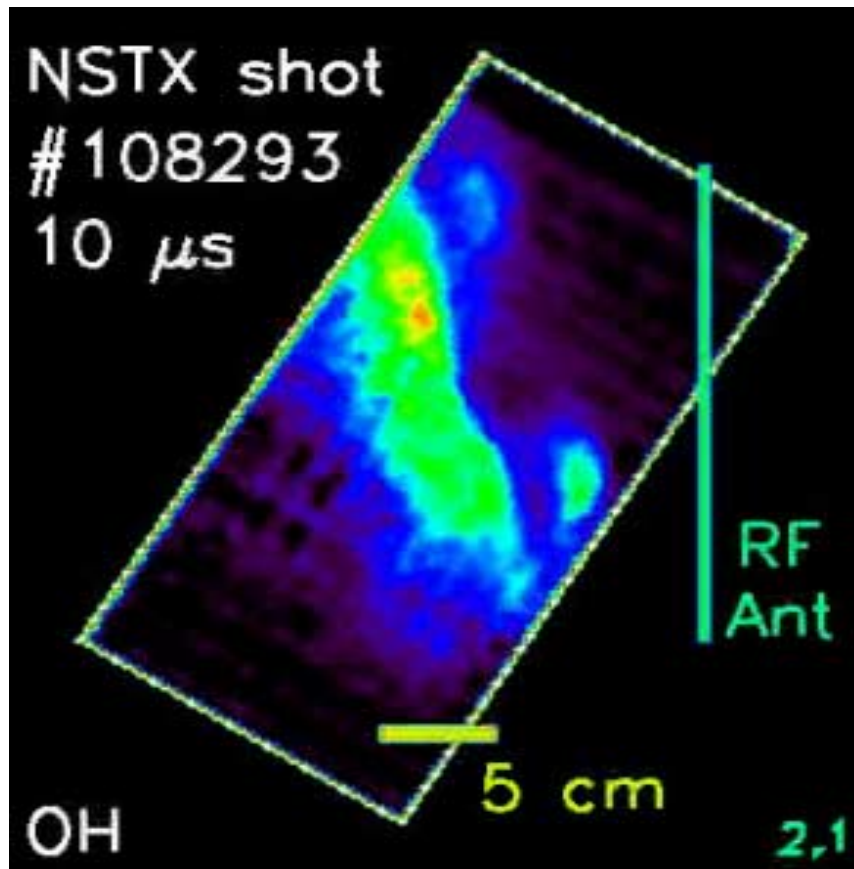
HeI peaks @ $T_e \approx 10$ eV where:

$$\delta I/I \approx (0.5-1)\delta n_e/n_e + (0-2)\delta T_e/T_e$$

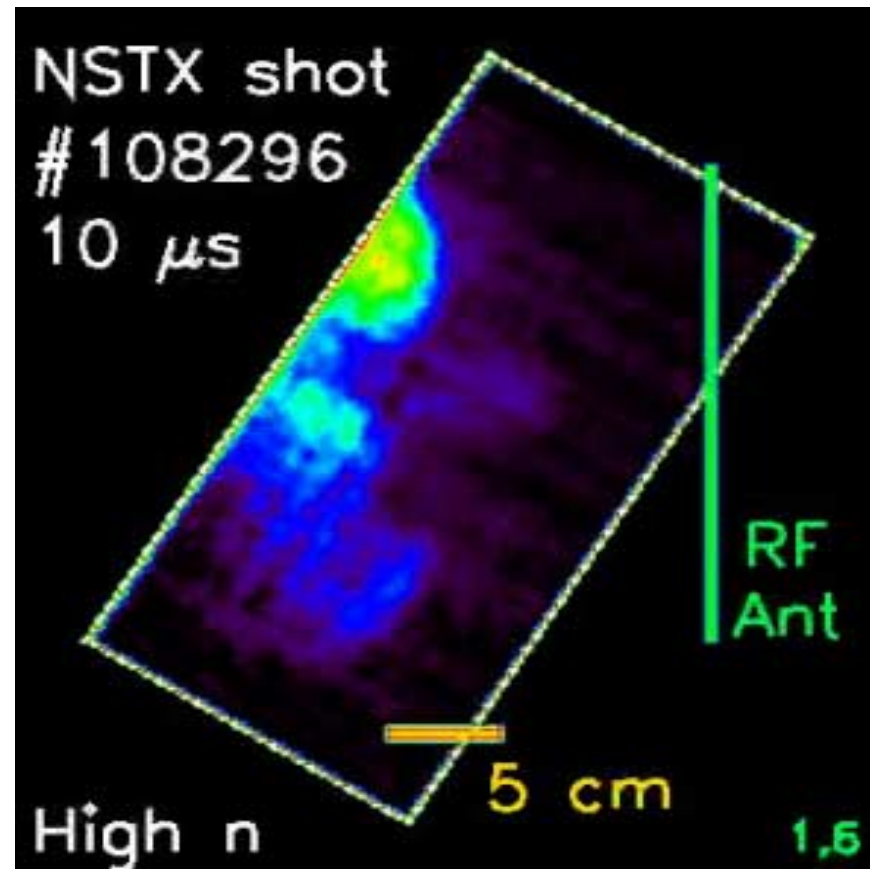
[see Stotler, JNM '02]

Ohmic Cases

$I=770$ kA, $B=3$ kG



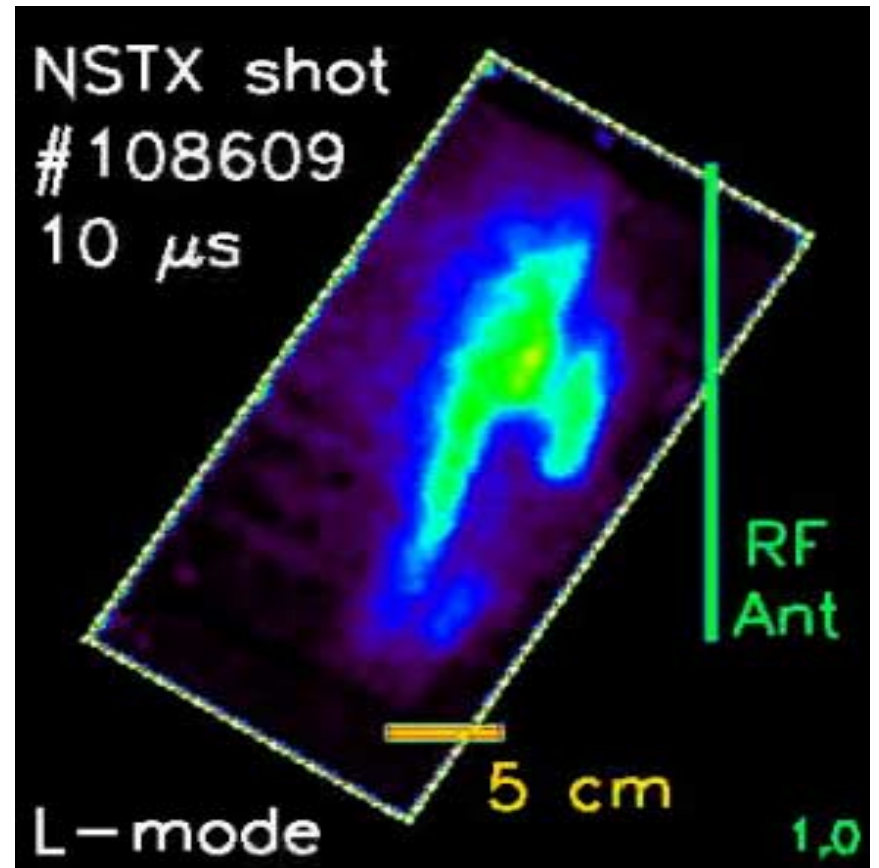
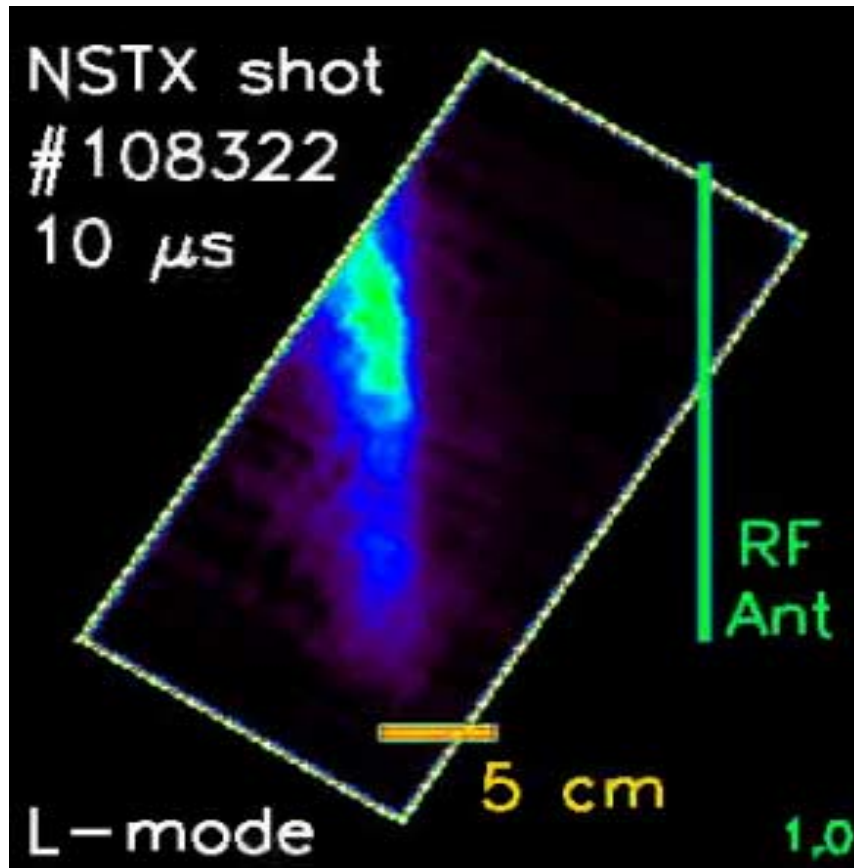
$I=780$ kA, $B=3$ kG



L-mode Cases

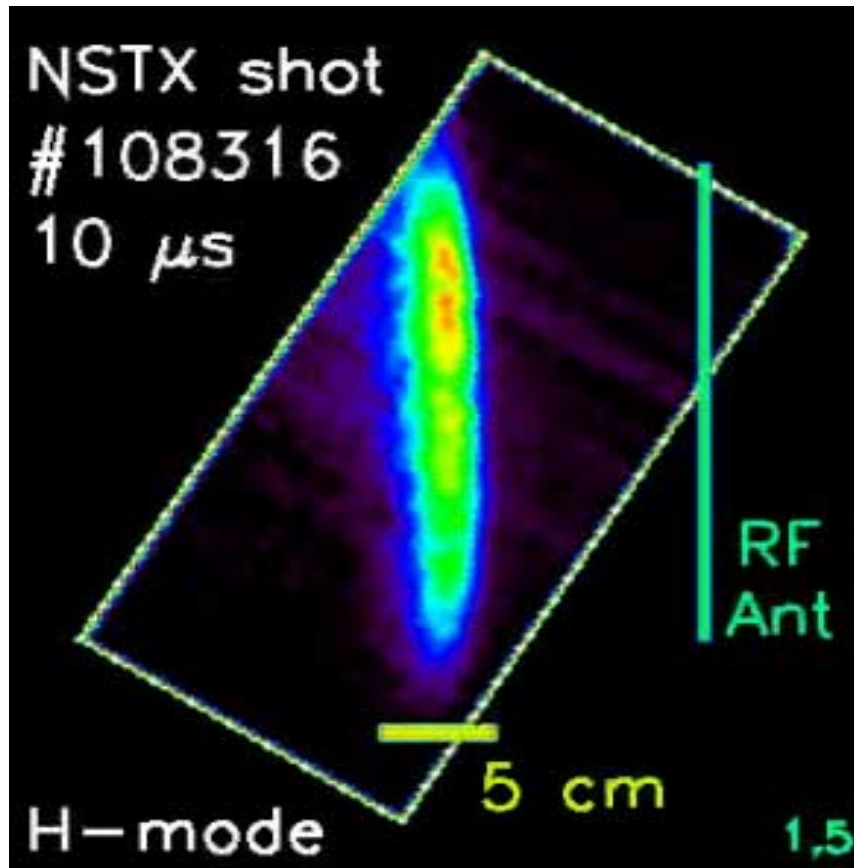
I=920 kA, B=3.5 kG

I=900 kA, B=4.5 kG

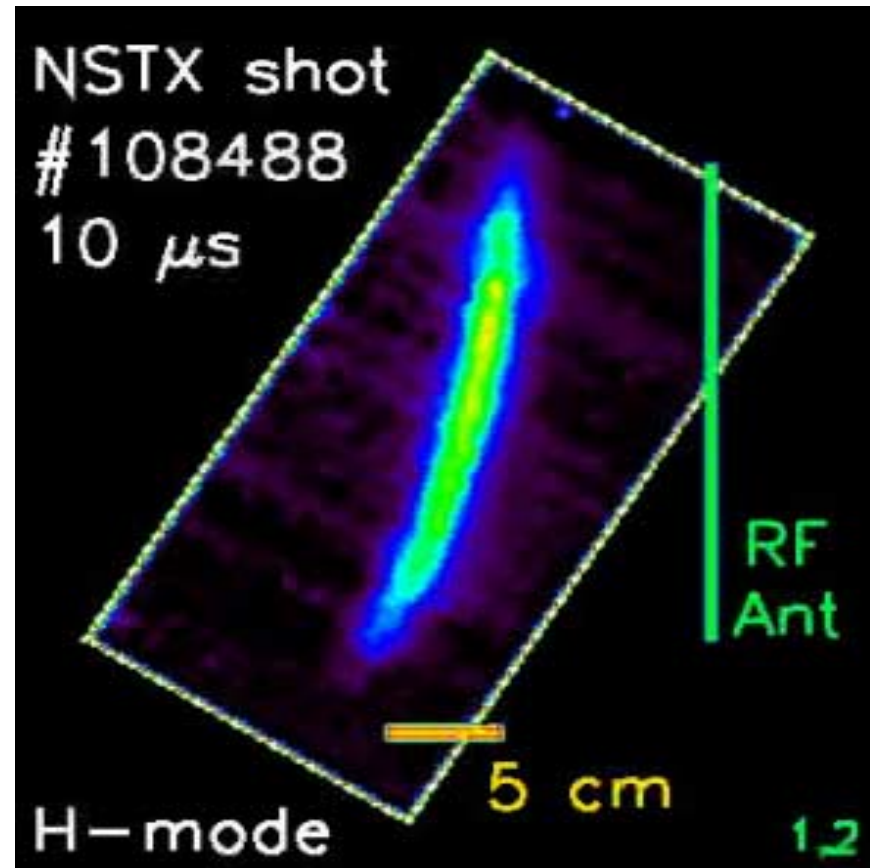


Quiescent H-mode Cases

$I=880$ kA, $B=3.5$ kG

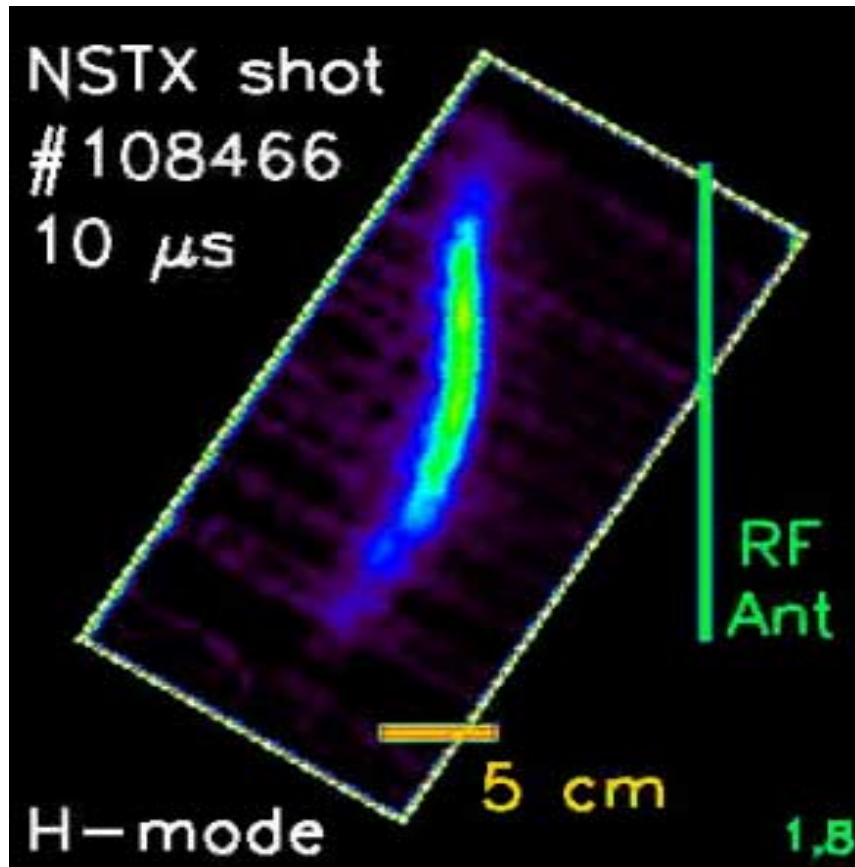


$I=920$ kA, $B=4.5$ kG

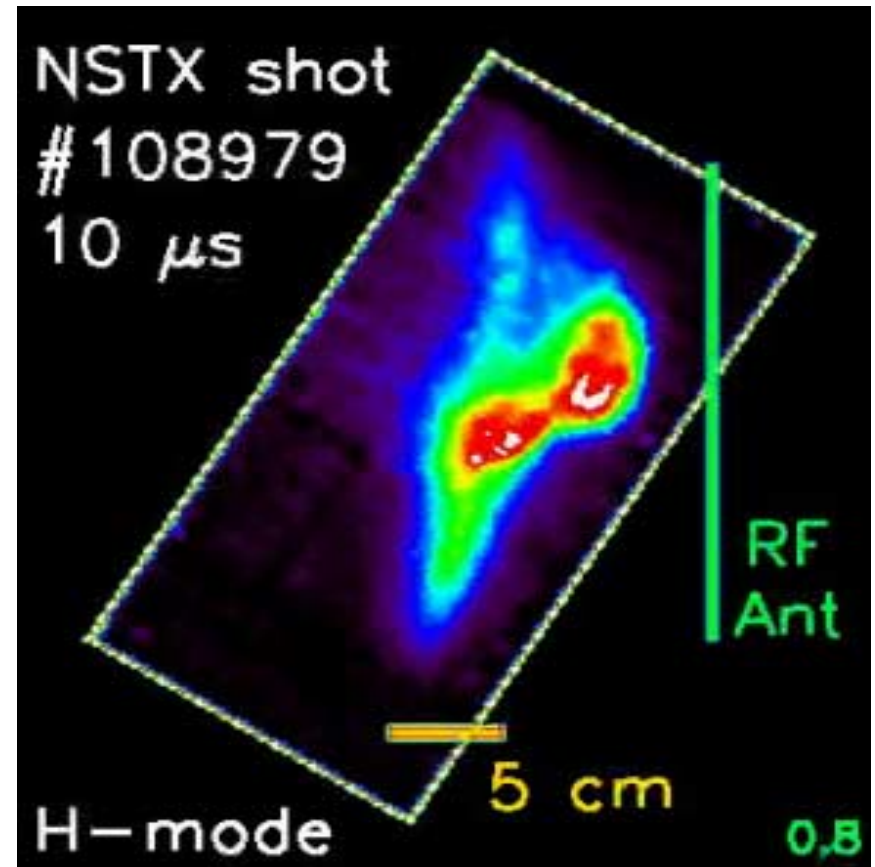


Non-quietescent H-modes

I=900 kA, B=4.5 kG



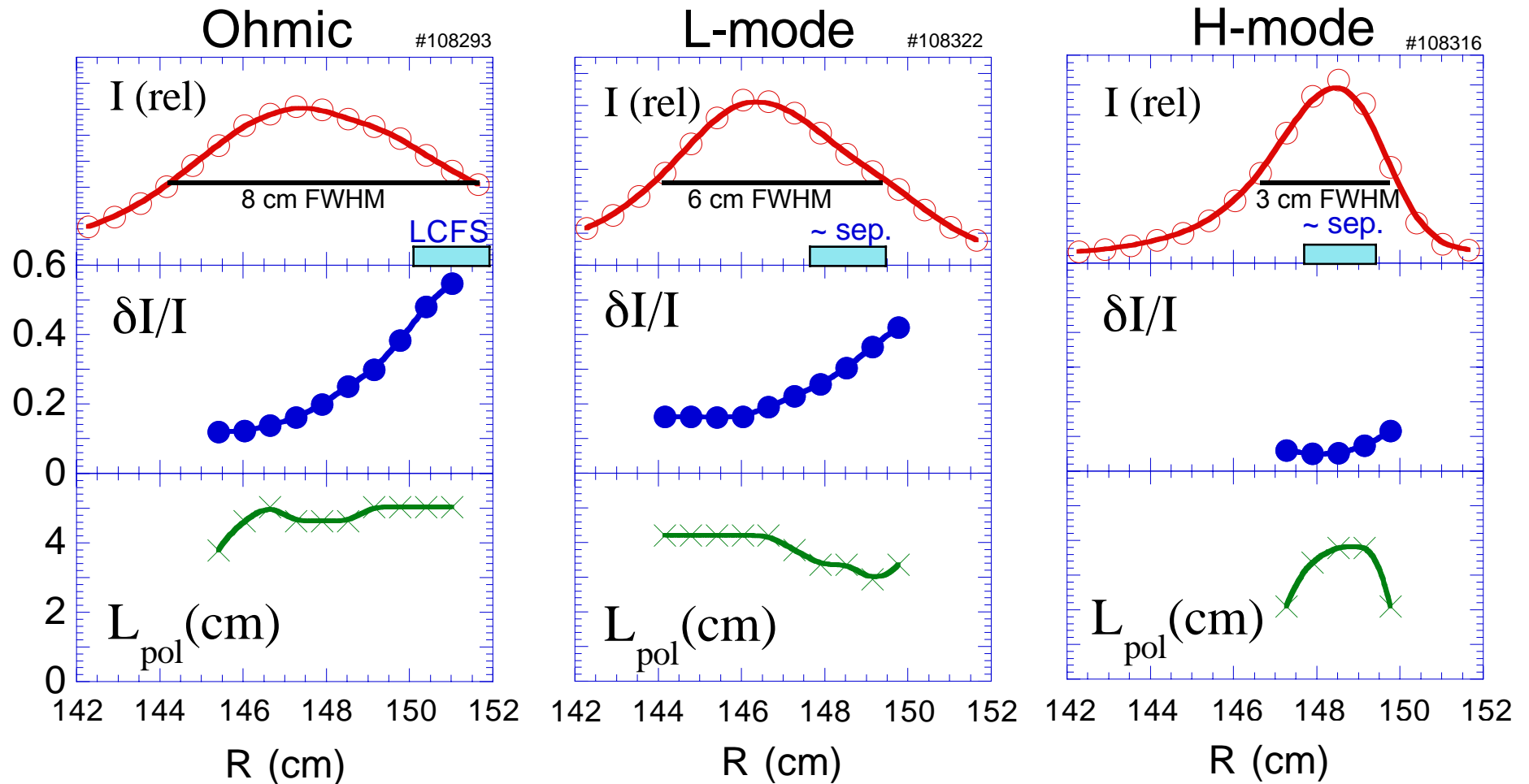
I=880 kA, B=3.5 kG



http://www.pppl.gov/~szweben/NSTXcolor/ColorNSTX_video.html

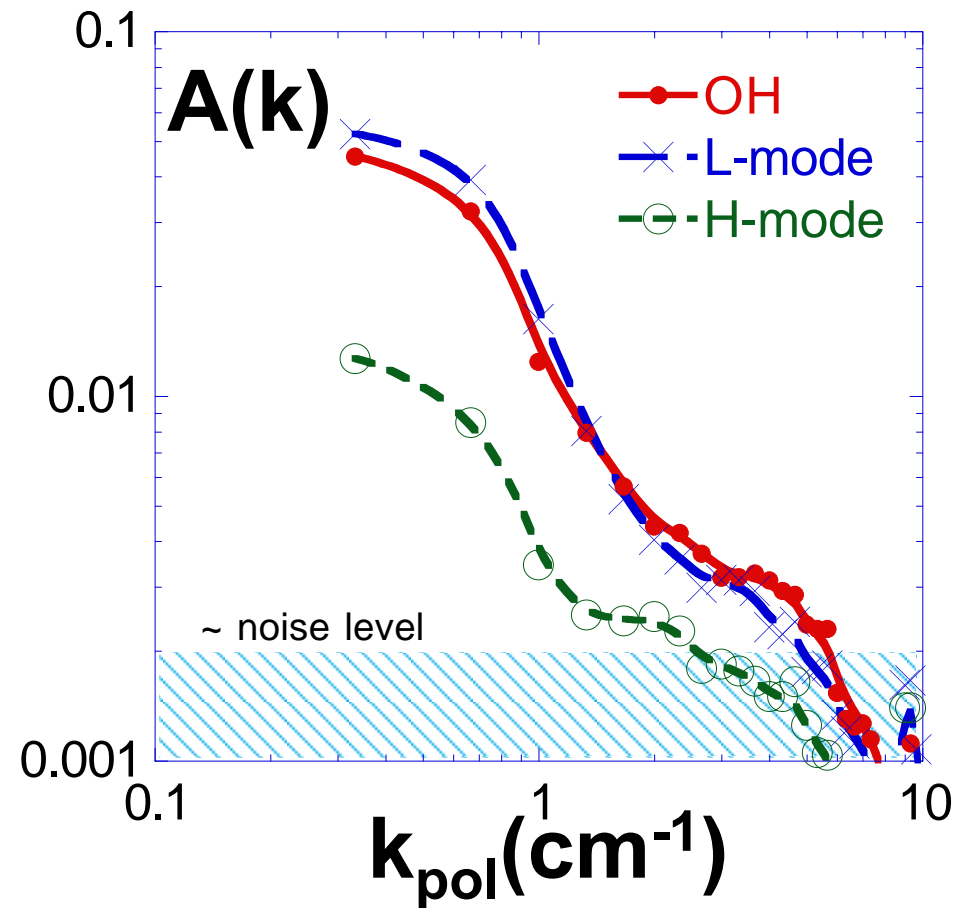
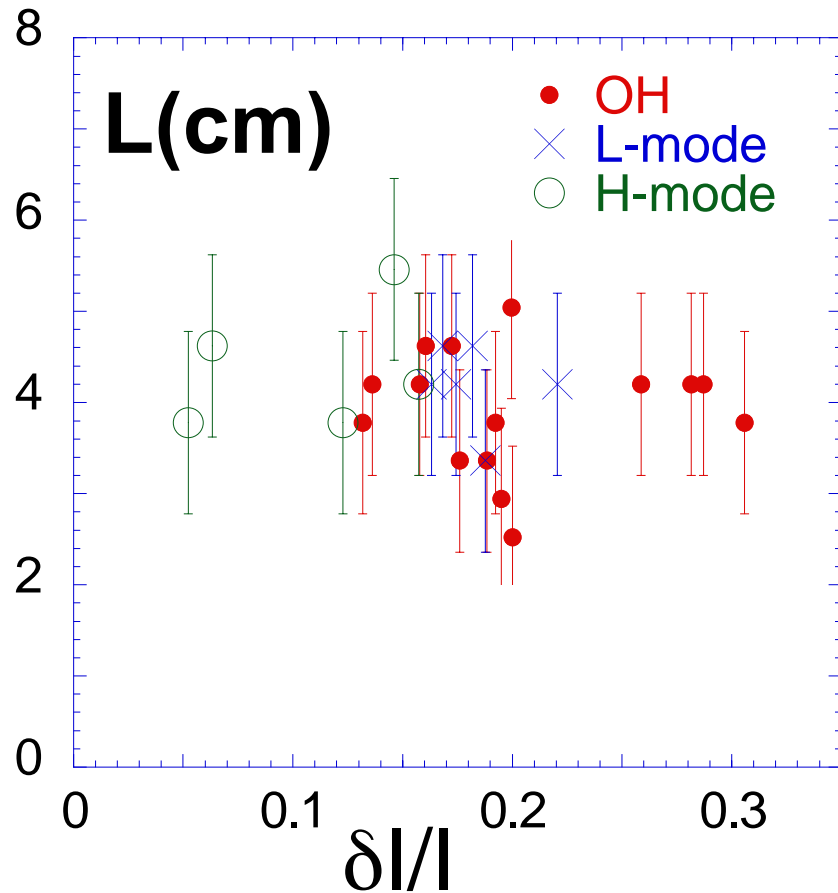
Profiles of $\delta I/I$ and L_{pol} from Images

- GPI signal within $T_e \approx 5 - 20$ eV and $n_e \approx 10^{12} - 10^{13}$ cm $^{-3}$
- Width of GPI emission varies with shape of n and T profiles



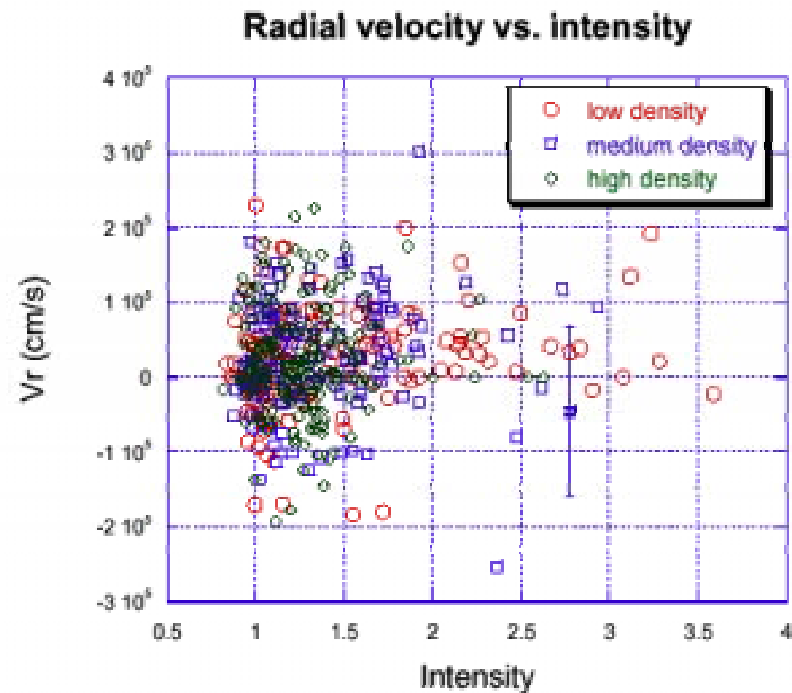
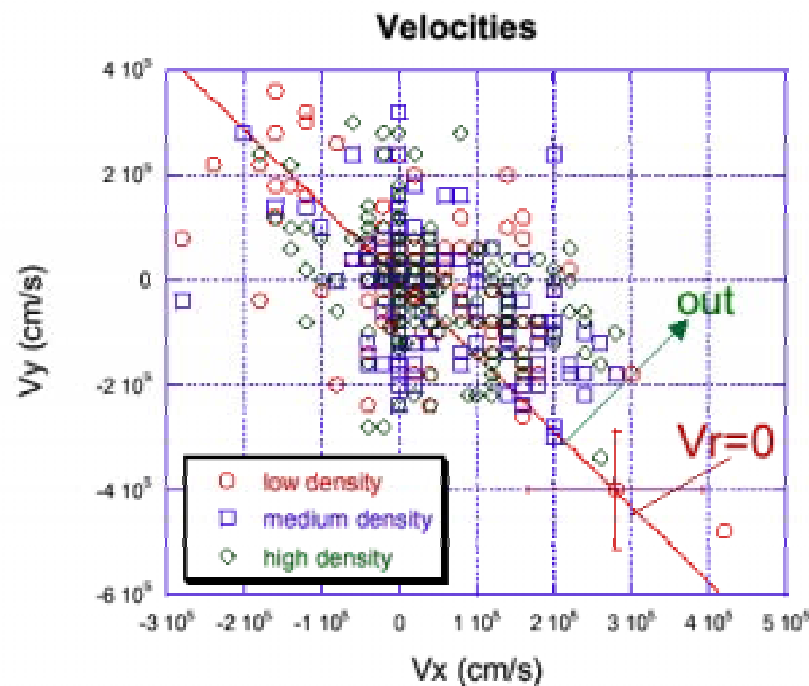
Poloidal Correlation Length (FWHM) and k-spectra are similar in OH, L- and H-mode

- Evaluated near peak of GPI signals at $T_e \approx 10$ eV
- Spatial structure is relatively insensitive to atomic physics



Preliminary “Blob” Analysis

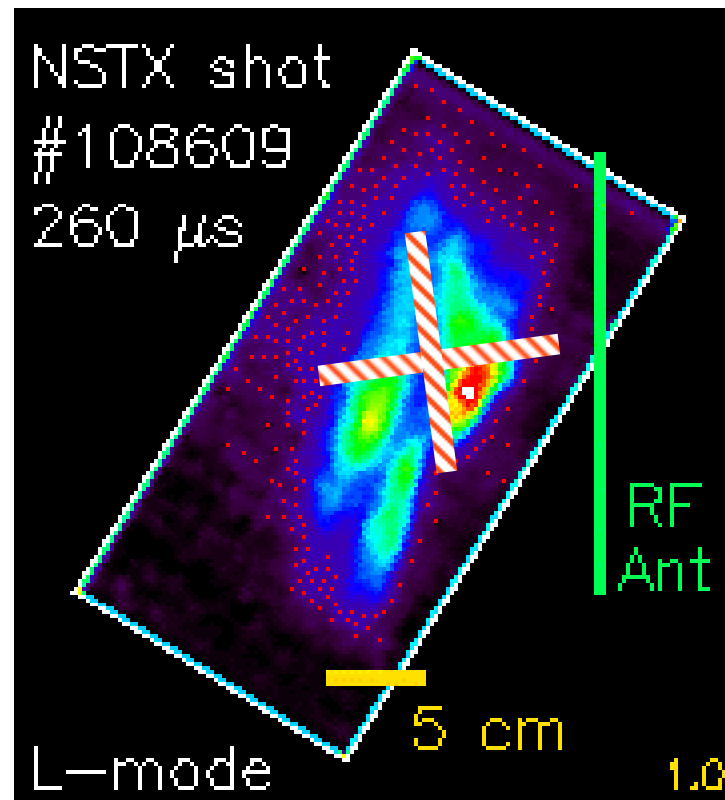
- Track local maxima (“blobs”) in videos and plot statistical summary of velocities, trajectories, sizes, lifetimes
- Typical radial velocity $v_r \approx 500$ m/sec, independent of size



- Physics-based “blob” analysis just starting (Lodestar)

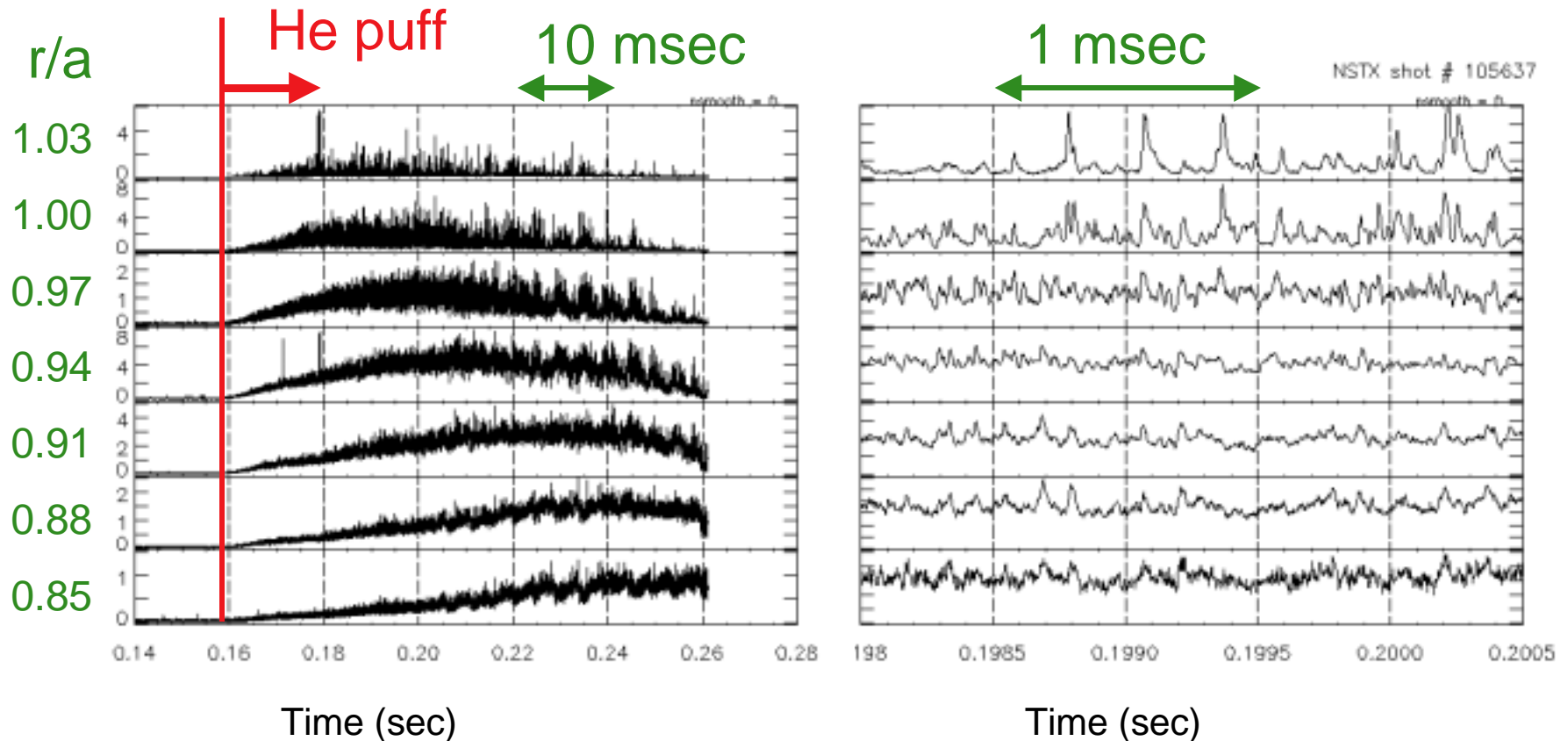
GPI Fast Chords

- GPI image split and picked up by 13 discrete chords
- Chords arrayed in “cross” with ≈ 1.5 cm diameter each
- Signals detected by PM tubes with ≈ 100 kHz bandwidth



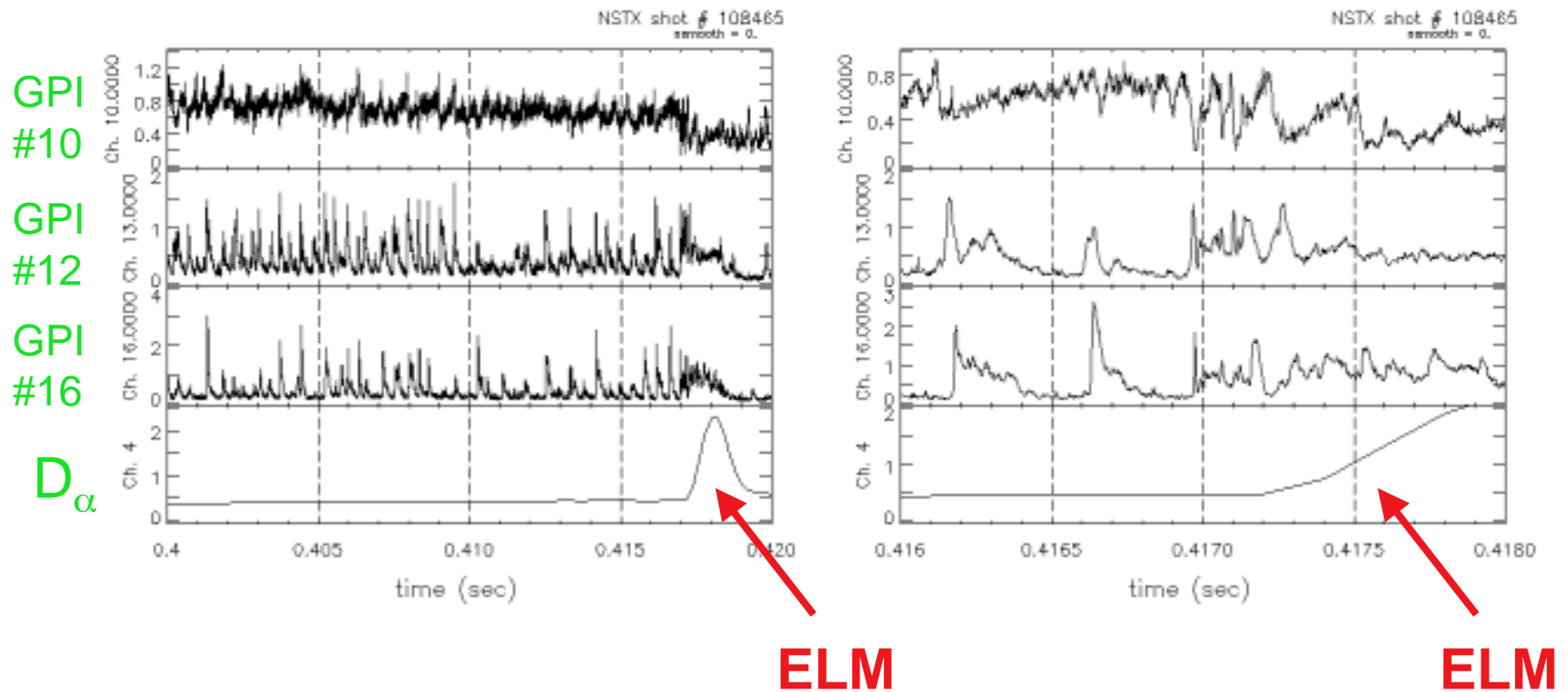
Typical Signals from Fast GPI Chords

- Near outer wall see “intermittent” $\geq 50\%$ fluctuations
- Nearer plasma center, see “Gaussian” $\approx 10\%$ fluctuations



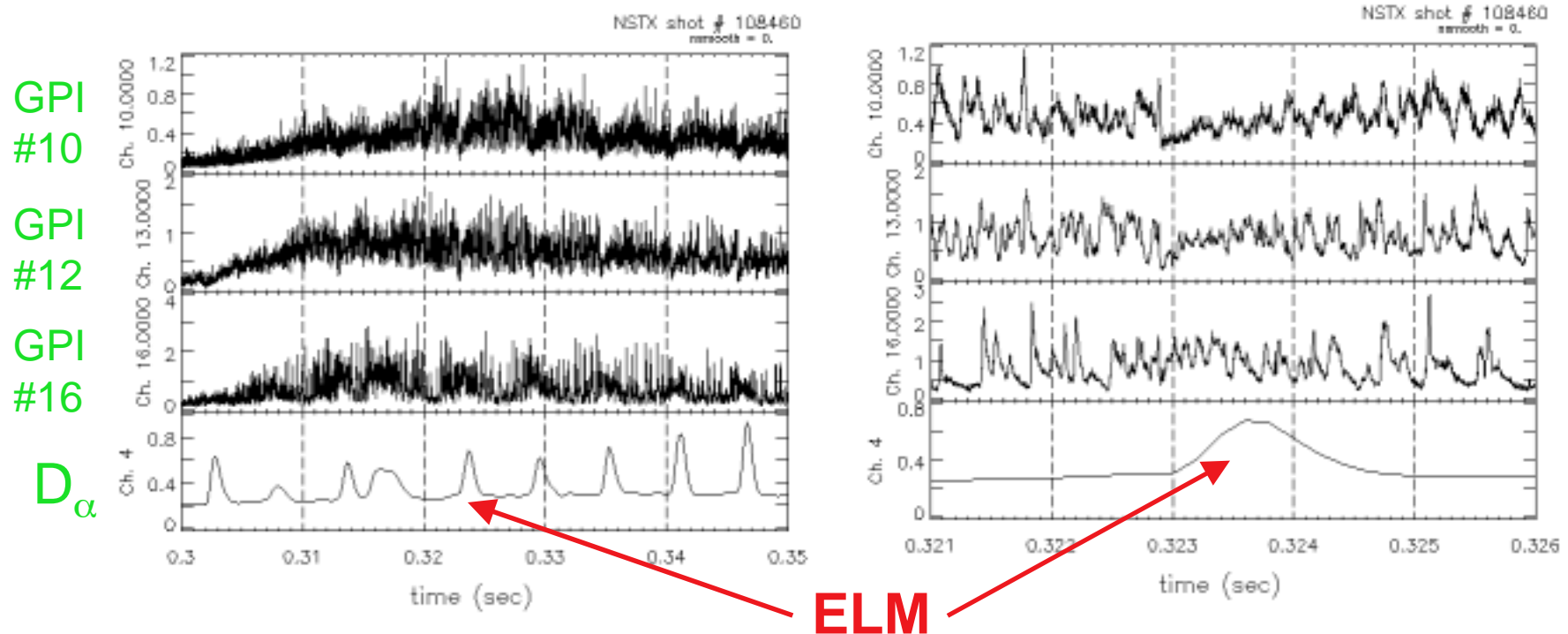
Blobs During ELM-Free H-mode

- Bursting activity seen GPI chords during “ELM-free” phase, typically with duration ≤ 0.2 msec (\approx same as images)



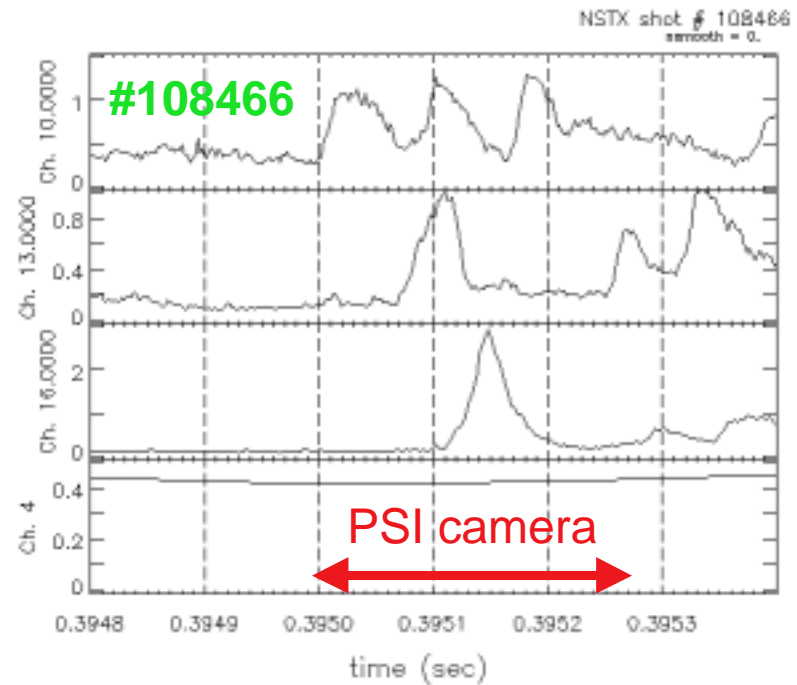
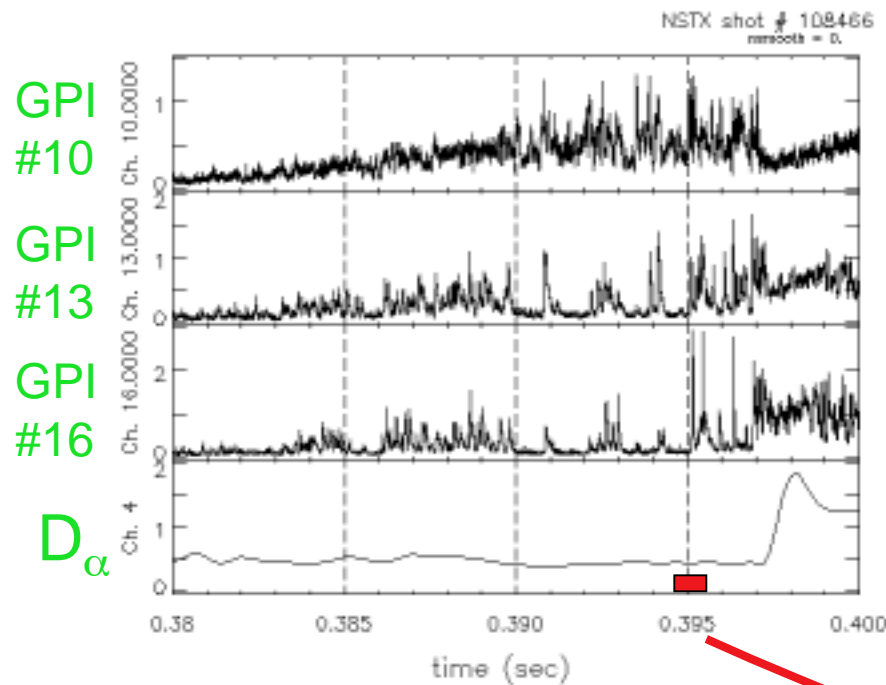
Fewer Blobs During Large ELMs ?

- Many short bursts between large ELMs, but no increase in burst size before or during large ELM
- Apparently these bursts and ELMs are different things



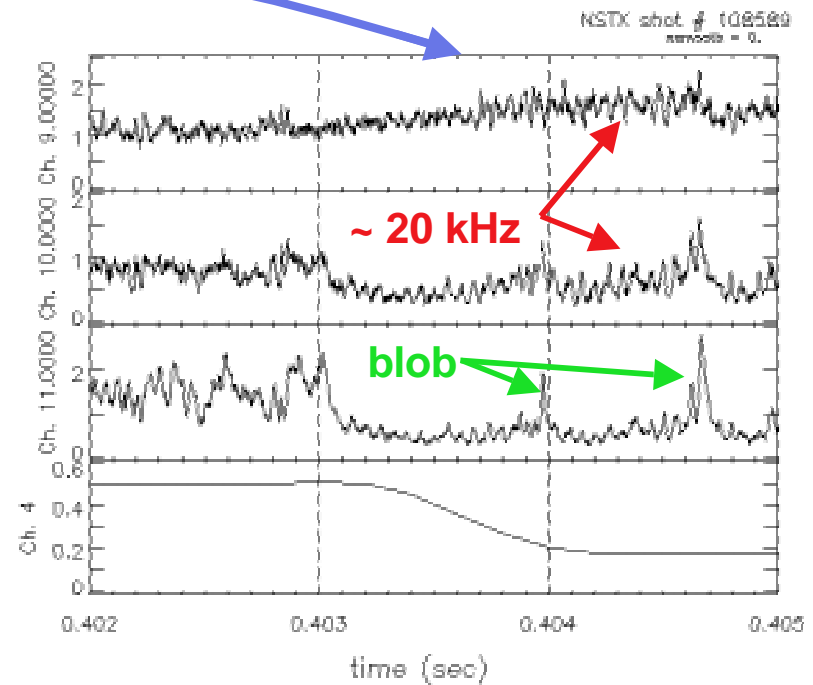
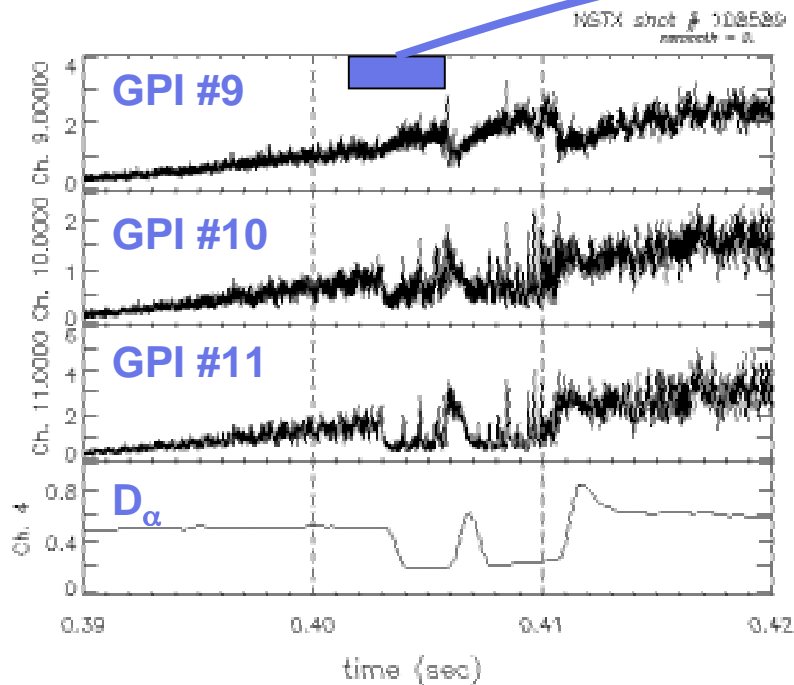
Quasi-coherent Signal During H-mode ?

- Clear high-m coherent oscillation sometimes seen in images with ≈ 20 cm poloidal wavelength and $f \approx 10$ kHz
- Coincides with brief burst of coherent mode in chords, not a stationary continuous mode in this case



L-H Transition

- L-H transition seen in GPI occurs within ≤ 0.5 msec, but no obvious “precursors” in fast chords (no video yet)
- After L-H transition, see intermittent “blobs” + 20 kHz MHD



Summary

- Poloidal correlation length $\approx 4 \pm 1$ cm were $T_e \approx 5-20$ eV
 - significantly larger than higher B field machines
 - “drift wave” scaling with $L_{\text{pol}} / \rho_s \sim 10-20$
 - “ballooning mode” scaling $L_{\text{pol}} / L_o(\text{RBM}) \sim 2-4$
- Coherent structure sometimes seen in 2-D images
 - radial or poloidal propagation of localized blobs
 - wave-like structure in H-mode (QCM ?)
 - possible small-scale zonal flows” (?)
- Time series look similar to edge turbulence seen elsewhere
 - intermittency (“blobs”) seen in SOL
 - ELMs seem to be different than blobs
 - spectra of GPI similar to reflectometers and probe

Plans

- Improve GPI optics for '03 run to get x10 higher signal levels
 - reduce gas puff to check for perturbation effect
 - use 1 μ sec framing time with 300 frame camera
 - better S/N for study of L-H transition and ELMS
- Compare with simulation / theory
 - BOUT runs for L- and H-modes in progress
 - test of blob model by Lodestar in progress
 - are there any features unique to STs ?
- Try potential edge turbulence control techniques
 - low voltage wall biasing using CHI electrodes
 - RF wave interaction with edge (e.g. ORNL results)
 - varying fueling, gaps, current ramps, etc.