Edge Turbulence Imaging Results and Plans

S. Zweben, T. Munsat, R. Maqueda, D. Stotler,
C. Bush, W. Davis, S. Kubota, K.C. Lee, D. D'Ippolito,
J. Myra, D. Russell, M. Umansky, X. Xu, et al

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- Motivations
- GPI hardware, orientation, and camera
- Images and questions for images analysis

Motivations

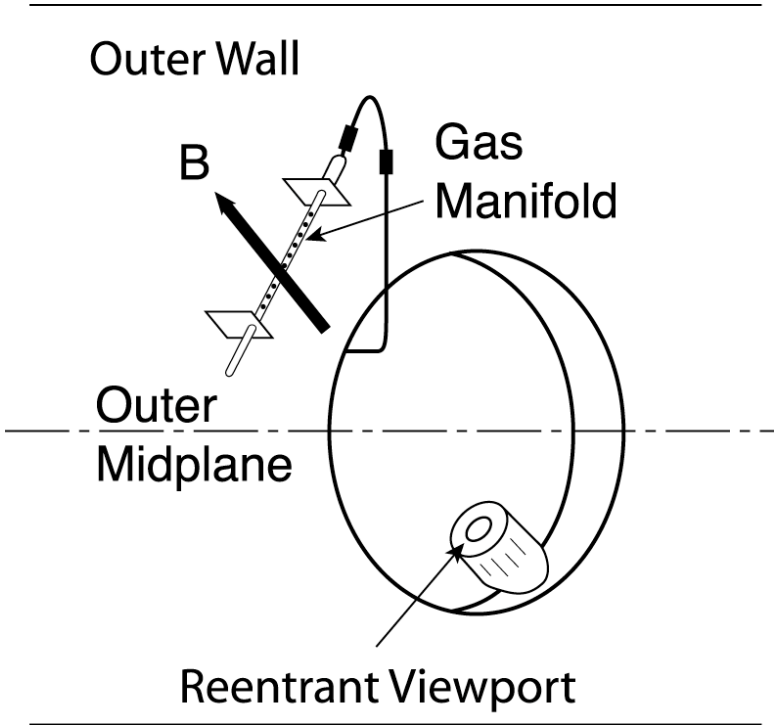
- Edge turbulence probably determines edge and SOL parameters, which can strongly affect the global confinement and plasma-wall interactions

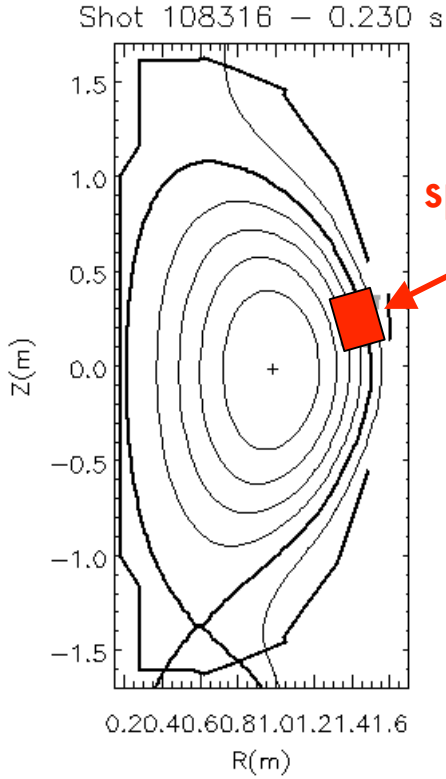
- Edge turbulence can probably be understood from first principles by comparing turbulence data with theory

  - simulations (e.g. BOUT)
  - simplified models (e.g. blobs)
  - other...?

GPI Hardware and Orientation

- Looks at D_α or HeI light from gas puff $I \propto n_o n_e f(n_e, T_e)$
- View ≈ along B field line to see 2-D structure ⊥ B
- Image coupled to camera with 800 x 1000 fiber bundle



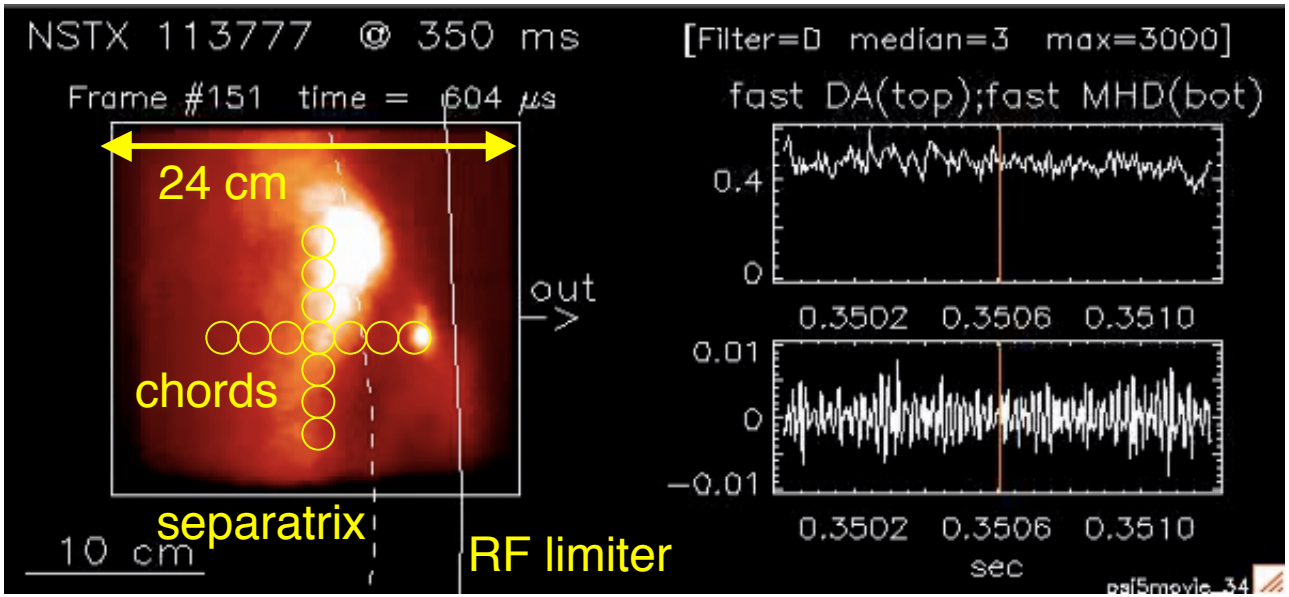


viewing area
≈ 25x25 cm
spatial resolution
≈ 1-2 cm

GPI Data for ‘04 Run

- Princeton Scientific Instruments PSI-5 camera
  - ≤ 250,000 frames/sec @ 64 x 64 pixels/frame
  - 300 frames/shot, 14 bit digitizer, intensified

- Fast chord array (13 channels/shot):
  - 2 cm spots into PM tubes with 200 kHz bandwidth



Types of GPI Data in '04

- About 500 shots (almost all with D_α) with:
  - Ohmic, L-mode, H-mode
  - L-H and H-L transitions
  - ELMs and high-n modes
  - LSN vs. USN vs. limited
  - MHD and RF effects
  - High beta and RWM coil
  - He puff and CIII light
- Shot list and sample movies at:

http://www.pppl.gov/~szweben/NSTX04/NSTX_04.html

Ohmic Cases

Ohmic Plasma
NSTX #113348
B=4.0 kG, I=800 kA
$\langle n \rangle = 2.4 \times 10^{13}$ cm^{-3}
250,000 frames/sec

L-mode Cases

NBI L-mode

NSTX #113830

B=3.0 kG, I=650 kA, 2.7 MW NBI

$\langle n \rangle = 3.3 \times 10^{13}$ cm^{-3}

250,000 frames/sec

H-Mode Cases

ELM-free H-mode

NSTX #113139

B=4.5 kG, I=825 kA, 0.9 MW NBI

250,000 frames/sec

General Observations

- Turbulence is *qualitatively* similar in Ohmic and L-mode, and also in LSN, USN, DN, and limited cases

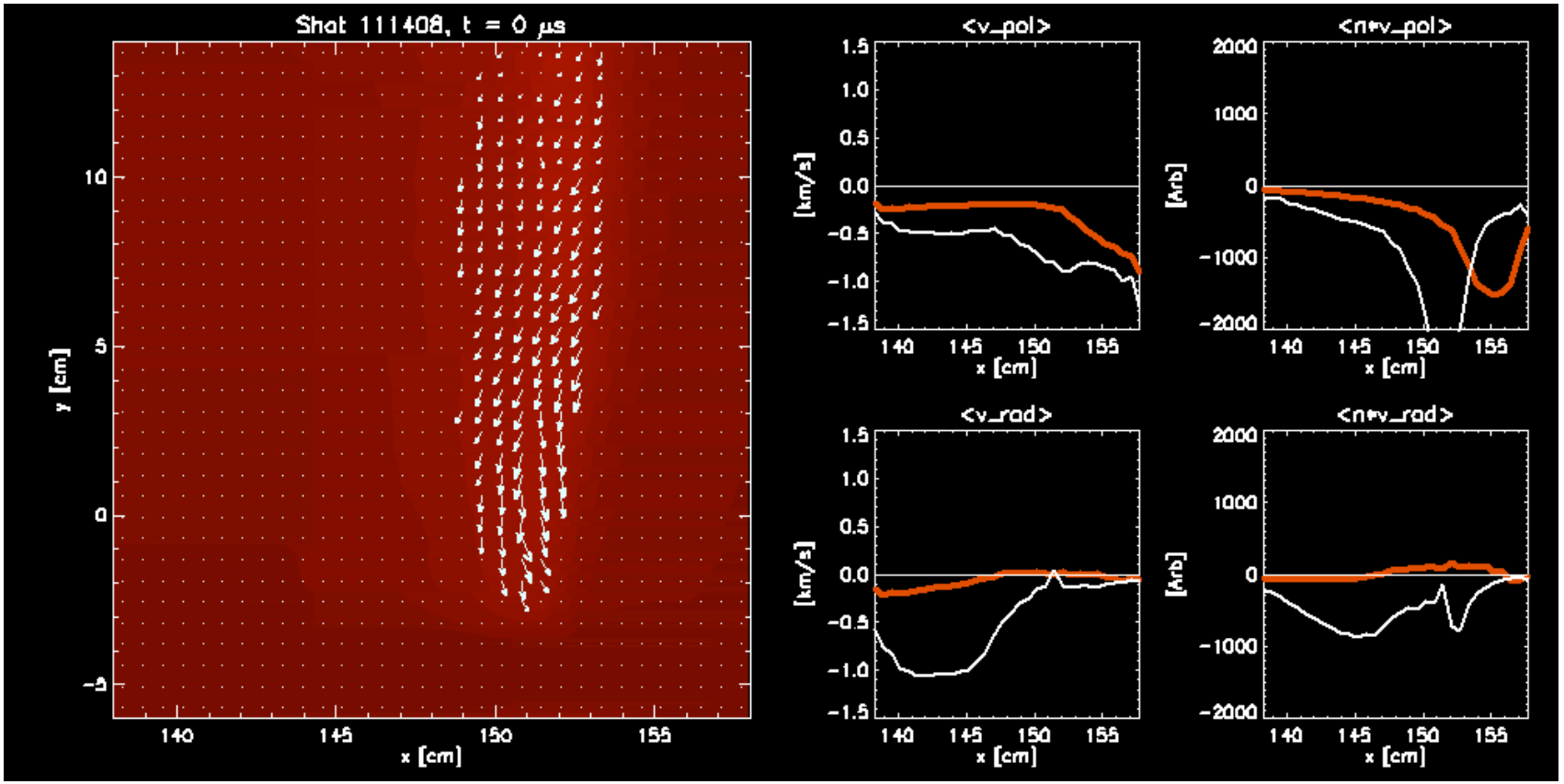
  - size scale $\Delta \approx 4$ cm (see Nucl. Fus. '04)
  - autocorrelation time $\tau \approx 50$ μsec
  - light fluctuation level $\approx 50\%$

- Turbulence is *often* very quiescent in H-mode

  - quiet periods can last ≈ 100 msec
  - but also "blobs" and "waves" form

Example of Velocity Field Analysis

(Tobin Munsat)



General Image Analysis Questions

- Are there any patterns or structures in this turbulence ?
  - compare to blob theory & BOUT (e.g. Russell et al)
  - calculate statistical "mode-coupling" coefficients ?
  - try to match with simple dynamics (e.g. SOC, CA)

- Are there shear or zonal flows or radial streamers ?
  - calculate flow spectra from velocity maps
  - estimate vorticity, divergence, intermittency, etc.
  - compare with theory (e.g. Diamond, Hahm et al)

- Can turbulence be correlated with radial transport ?
  - roughly $D_{\perp} \sim \Delta^2/\tau \sim 10^5$ cm^2/sec $\sim D_{Bohm}$ ($> D_{nc}$?)
  - compare $\langle v_r \rangle_{turb}$ with $\langle v_r \rangle_{plasma} = \Gamma/n$
  - estimate $\Gamma = \langle n\, v_r \rangle$ directly from images ?

Some Other Questions

- Are there differences in OH, L, USN, LSN, DN, limited ?
- How does GPI compare with reflectometer, Firetip, probe ?
- Does turbulence poloidal rotation agree with ERD ?
- Where is H-mode GPI line with respect to edge “ears” ?
- What triggers blob formation in quiescent H-modes ?
- Where is D_α emission region with respect to separatrix ?
- How well can D_α emission be explained by DEGAS-2 ?

L-H Transition Cases

L-H Transition

NSTX #113079

B=4.4 kG, I=800 kA, 2.8 MW NBI

$\langle n \rangle = 1.9 \times 10^{13}$ cm^{-3}

250,000 frames/sec

Just Before L-H Transition

1 msec Before L-H Transition

NSTX #113735

B=3.0 kG, I=790 kA, 4.4 MW NBI

$\langle n \rangle = 2.3 \times 10^{13}$ cm^{-3}

250,000 frames/sec

H-L Transition Cases

Dithering H-L Transition

NSTX #113062

B=4.4 kG, I=780 kA, 2.6 MW NBI

$\langle n \rangle = 2.1 \times 10^{13}$ cm^{-3}

100,000 frames/sec

Observations on L-H Transitions

- L-H transitions look like a continuous evolution from turbulent blobs to a quiescent state in ≤ 0.1 ms, apparently without new spatial features or flows

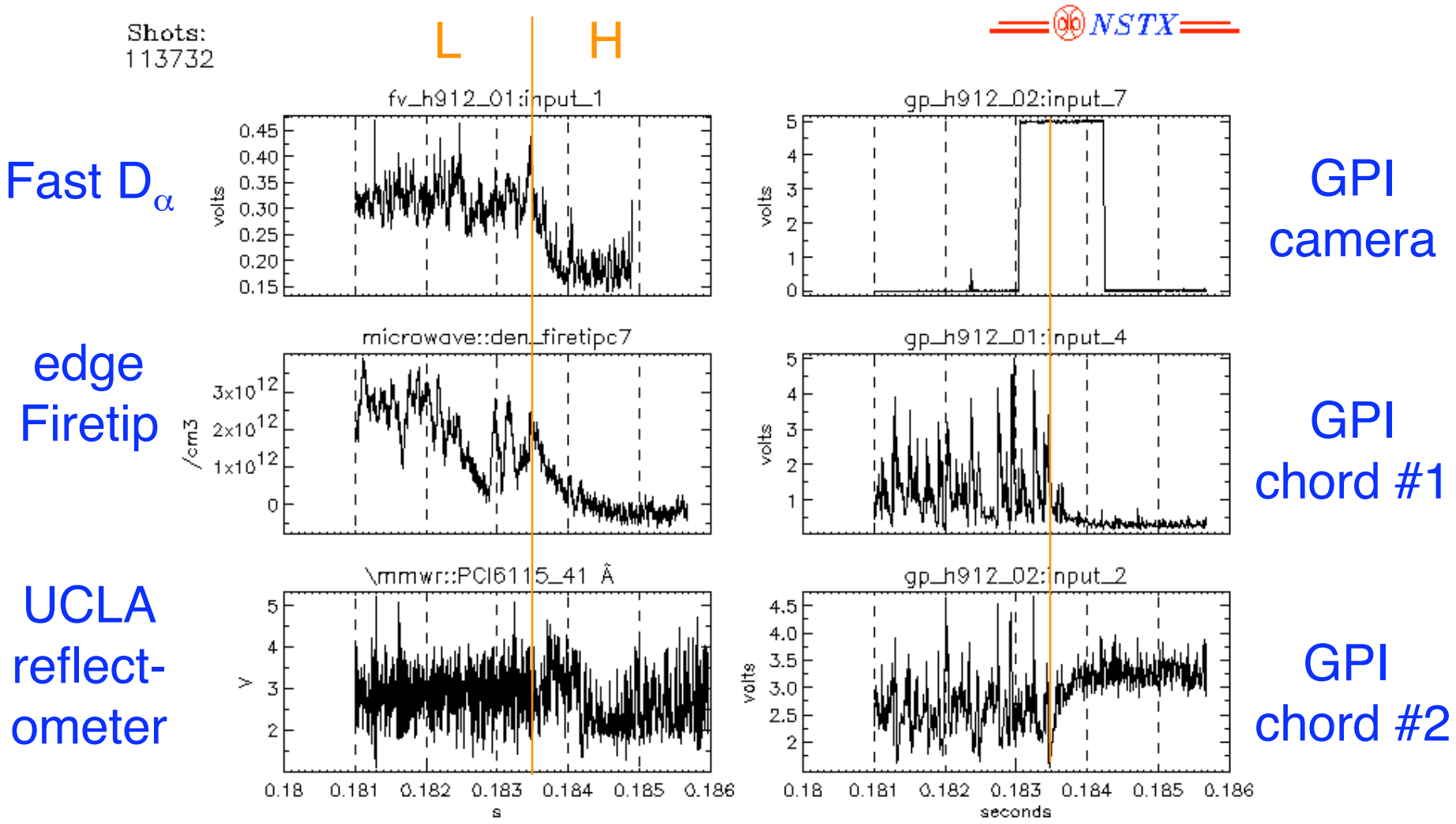
- H-L transitions generally appear as high-n poloidal modes which evolve into radially moving blobs

- Transient periods of H-like quiescence occur ≤10 msec before the main L-H transition

Questions for Image Analysis

- Is there an increase in poloidal flows (shear or zonal) just before the L-H transition (as in theory) ?
- How much does the turbulence “dither” from L- to H-type as a function of time before the main L-H transition ?
- Is there a consistent instability pattern leading from H-L ?
- How do the transitions seen in GPI compare with those in the reflectometer, Firetip and probe diagnostics ?

Example of Diagnostic Comparison



Fast D_α

edge Firetip

UCLA reflect-ometer

GPI camera

GPI chord #1

GPI chord #2

ELMs

Medium ELM

NSTX #113835

B=3.0 kG, I=650 kA, 1.7 MW NBI

$\langle n \rangle = 3.2 \times 10^{13}$ cm^{-3}

250,000 frames/sec

Observations on ELMs

- Most ELMs look like a transient burst of L-like turbulence, but often with stronger “blobiness” (intermittency)
- But there are also transient bursts of L-like turbulence in H-mode *without* any ELMs (in divertor D_α)
- Some ELMs show little change in GPI view

ELM Image Analysis

- How closely are ELMs like transient L-mode periods?
- Is the start of the ELM similar to H-L transition ?
- Is there a correlation of GPI with magnetic fluctuations ?
- Is there a time delay between ELM-induced increase of D_α in GPI and D_α in divertor ? (C.S. Chang)

MHD Effects

Breathing MHD

NSTX #113012

B=4.4 kG, I=1020 kA, 4.0 MW NBI

$\langle n \rangle = 5.3 \times 10^{13}$ cm^{-3}

250,000 frames/sec

MHD Image Analysis

- Does radial movement in “breathing” correspond to the magnetic flux surface displacement ?
- What causes bouncing ? (fast ion loss => charging ?)
- What causes blinking ?
- Are there MHD events which don’t show up in GPI ? (sawtooth, AEs ?)

High-n Modes

High-n Mode (+ MHD)

NSTX #111100

B=4.0 kG, I=1000 kA, 5.2 MW NB

D puff, no filter

250,000 frames/sec

High-n Image Analysis

- Are high-n modes correlated with high frequency MHD ?
- Are they like QCM in C-mod, EHO in D-IIID ?
- Why are they tilted in radial-poloidal plane ?

RF Effects ?

RF Effect ?

NSTX #113802

B=3.0 kG, I=800 kA, 3.3 MW RF

$\langle n \rangle = 1.5 \times 10^{13}$ cm^{-3}

250,000 frames/sec

RF Image Analysis

- What is the ≈ 10 kHz quasi-coherent edge oscillation ?
- Does this ≈ 10 kHz mode cause a large transport ?
- Why is D_α light double-peaked is some cases ?
- Is this a direct RF effect (e.g. sheath generation) or an edge profile effect ?

Summary

- Lots of image data showing many interesting things
- Now needs considerable data analysis to:
  - quantify what we see
  - compare it with other diagnostics
  - relate it to edge turbulence modeling