Edge Turbulence Imaging During L-H Transitions in NSTX

US-European TTF, Napa, April 6-9, 2005
Contributed poster for "H-mode/Edge" session

S.J. Zweben, R.J. Maqueda (Nova Photonics), T. Munsat (Colorado), T. Biewer, C.E. Bush (ORNL), J. Krommes, R. Maingi (ORNL), D. P. Stotler, T. Stoltzfus-Dueck, and the NSTX Team

Princeton Plasma Physics Laboratory

Abstract

The time evolution of the radial and poloidal structure of edge turbulence has been measured during L-H transitions using the gas puff imaging technique in NSTX [1,2]. In videos of the raw data these transitions look as if the turbulence decays over ≈ 100 μsec without much change in the spatial structure or flows [3]. Preliminary analysis of the data shows a factor of ≈ 3 drop in the relative fluctuation level across the transition, but with little or no change in either the radial or poloidal correlation length of the turbulence. The average poloidal flow speed of the turbulence does not significantly change across the transition, but the peak of the poloidal cross-correlation function decays more slowly, i.e. the poloidal flow appears to be more "frozen" in H-mode. Additional analysis of the 2-D spatial structure and velocity fields before, during, and after the transition is in progress and will be presented.

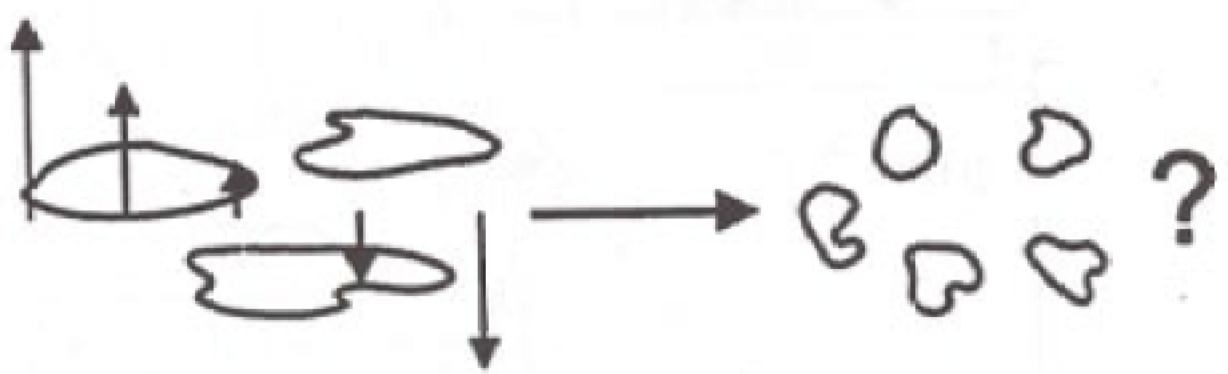
[1] R.J. Maqueda et al, Rev. Sci. Inst. **74**, 2020 (2003)
[2] S.J. Zweben et al, Nucl. Fusion **44**, 134 (2004)
[3] http://www.pppl.gov/~szweben/NSTX04/NSTX_04.html

Outline of This Poster

- Motivation and Goals
- GPI (Gas Puff Imaging) diagnostic
- Data set for NSTX ‘04 run
- 1-D radial and poloidal analysis
- 2-D structure and velocity analysis
- Summary and Plans

Motivations and Goals

- Conventional model for L-H transition involves poloidal shearing of turbulence, leading to transport barrier

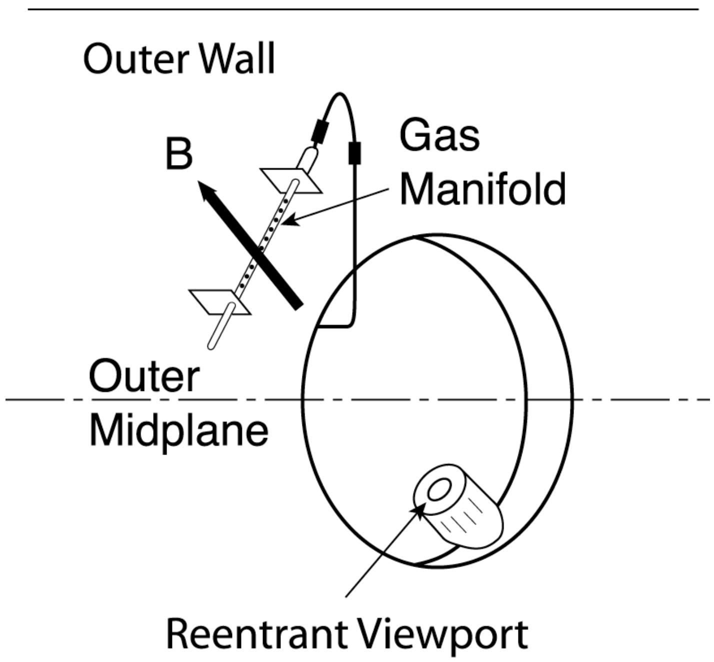


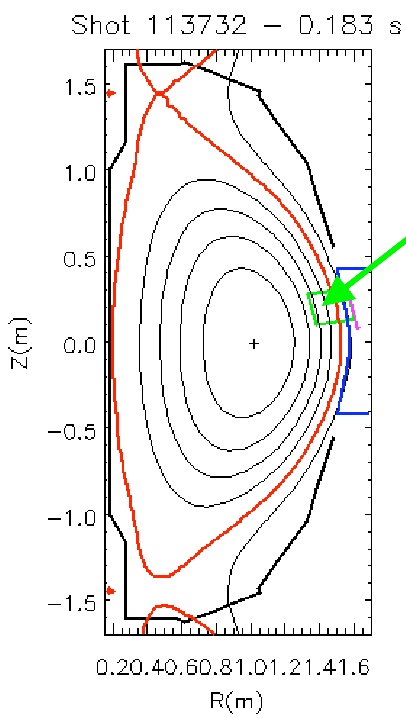
T.S. Hahm

- See if this is really happening in NSTX L-H transitions
  - measure 2-D turbulence structure vs. time
  - measure poloidal flows (DC and AC)
  - compare with theory / modeling

GPI Diagnostic in NSTX

- 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
- Images recorded by intensified ultra-fast PSI-5 camera





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

see: R.J. Maqueda et al, Rev. Sci. Inst. 2003

Interpretation of GPI Data

- Signal levels $I \propto n_e^{\alpha} T_e^{\beta}$ with roughly $0.5 < \alpha, \beta < 2$, so relative fluctuation level is not accurately known

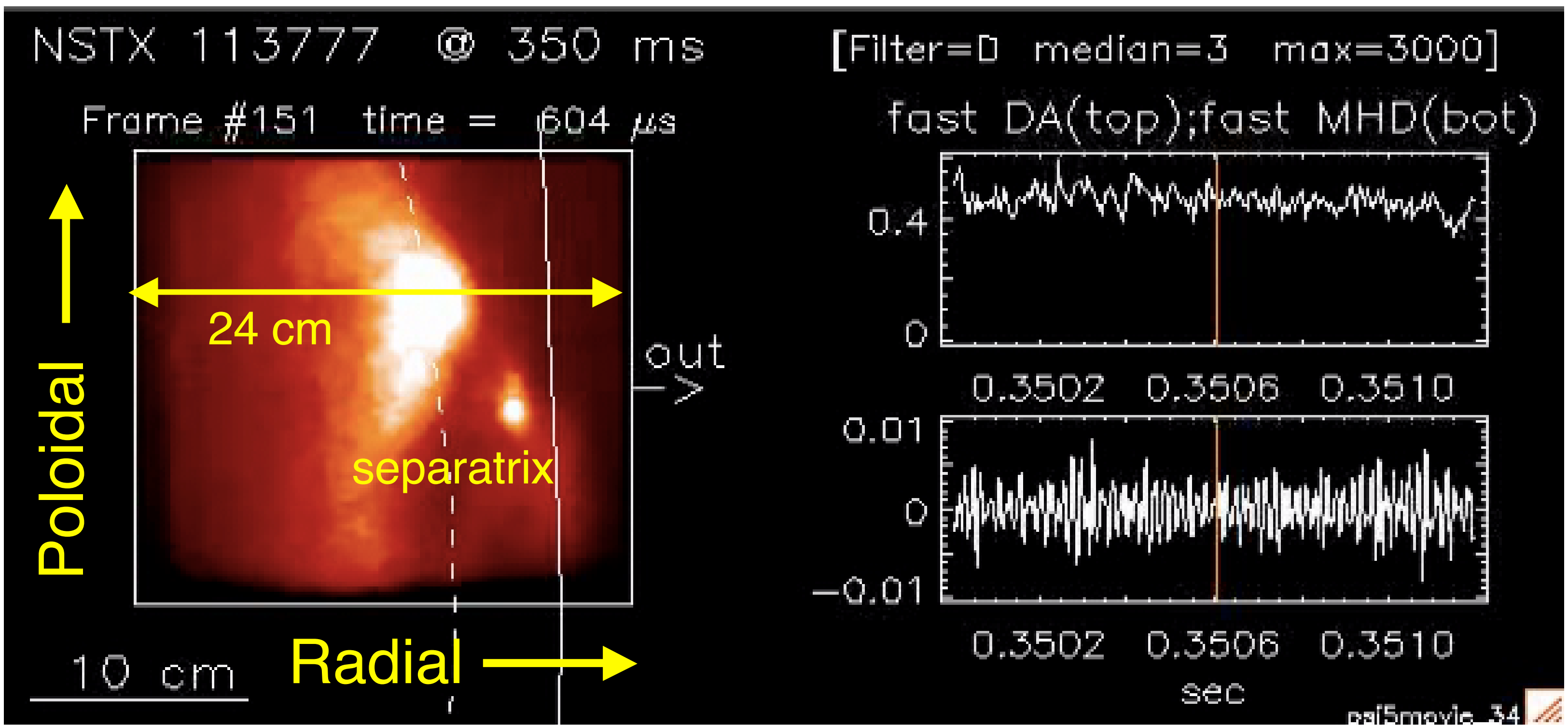
- However, cross-correlation functions of I are independent of α, β [Zweben et al, NF '04], so they should be the same as those for n_e and T_e (assuming n_e and T_e are highly correlated with each other)

- Velocity fields derived from time-dependent cross-correlation functions should have the same interpretation as those for Langmuir probes, i.e. group velocity (if not frequency resolved) and/or phase velocity (if frequency resolved)

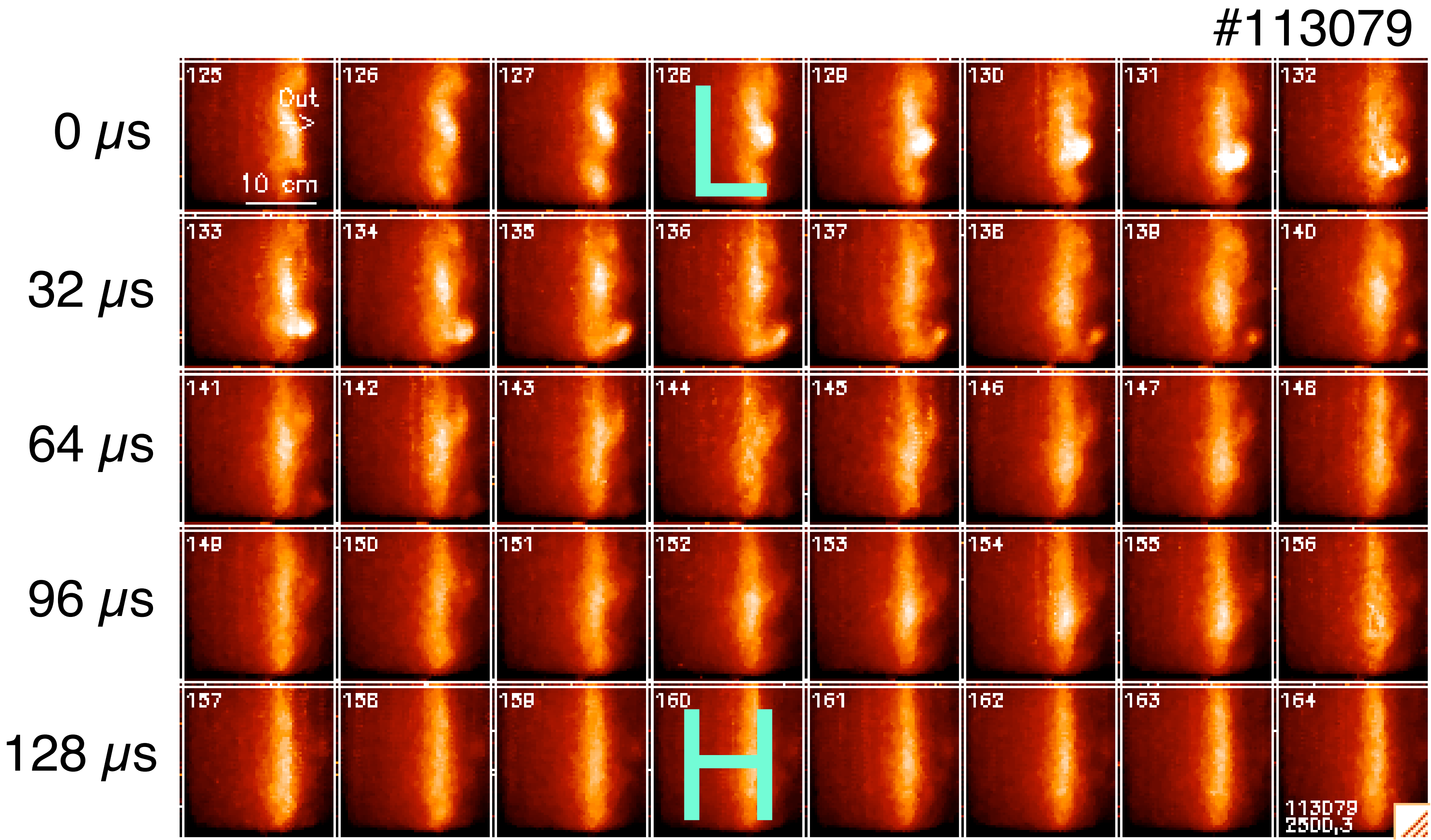
see: S.J. Zweben et al, Nucl. Fus. 2004

Camera Data for NSTX '04 Run

- PSI-5 camera records 300 frames/shot at ≤ 250,000 frames/s
- Each frame has 64x64 pixels with 10 bit dynamic range
- About 500 shots taken during '04, ≈ 10 with L-H transition



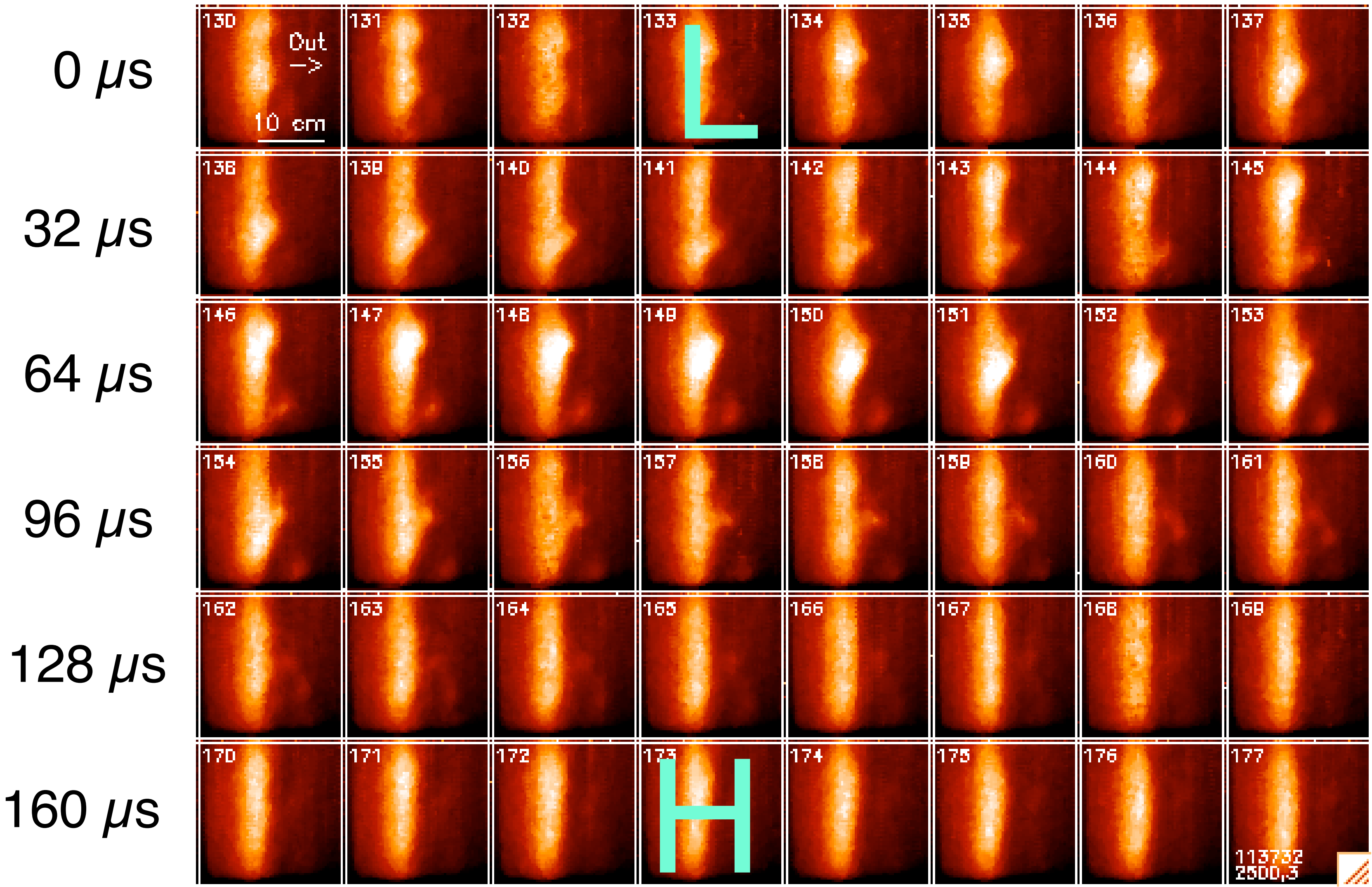
L-H Transition Example # 1



Movies: http://www.pppl.gov/~szweben/NSTX04/NSTX_4.html

L-H Transition Example # 2

#113732

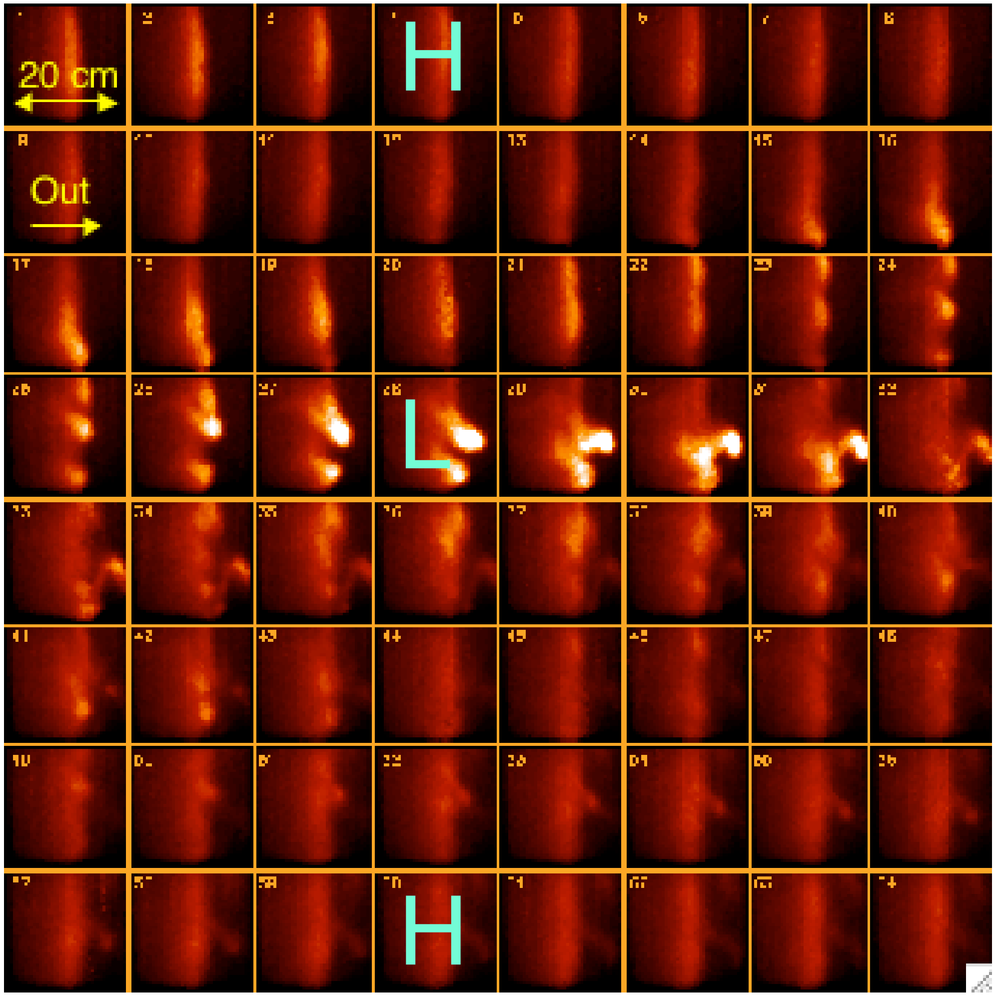


H-L-H Dithering Transitions

#113075

100,000 frames/sec

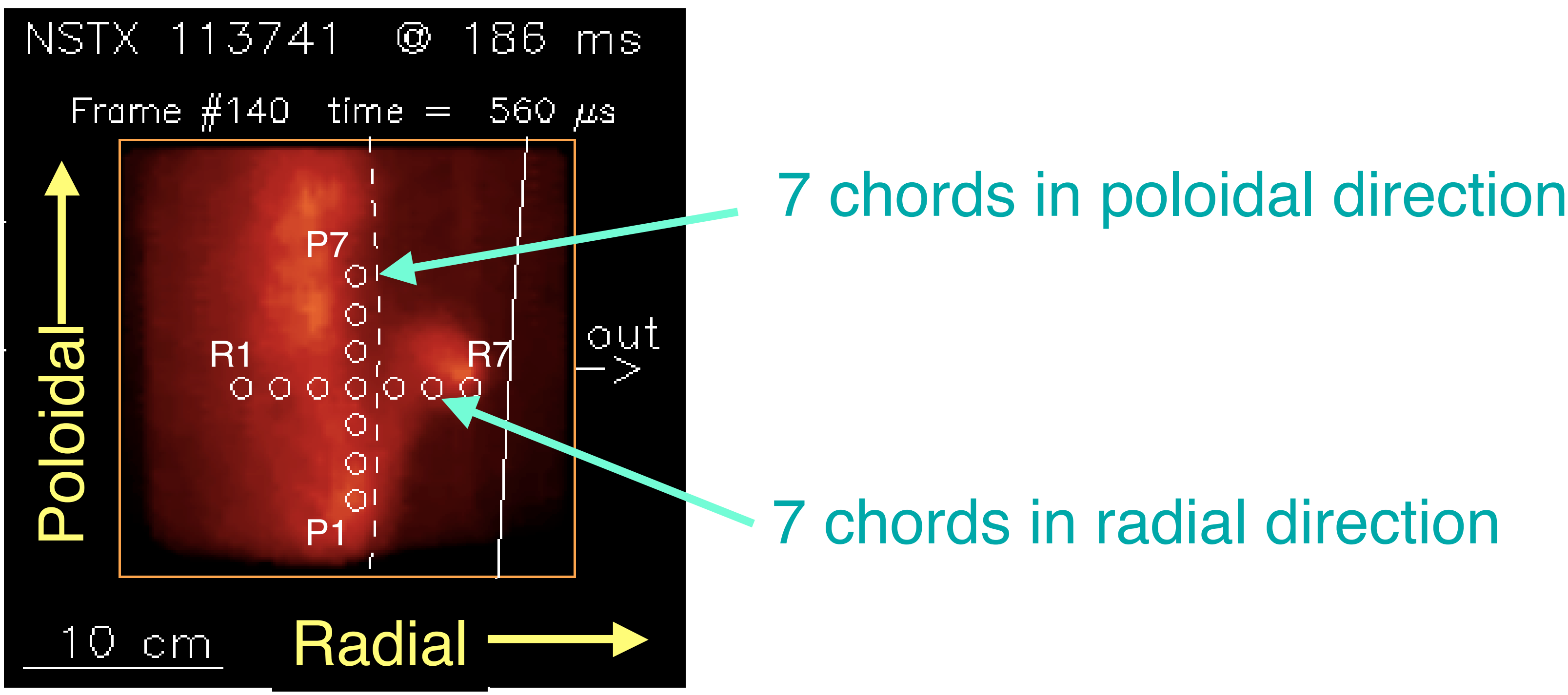
0 μs
80 μs
160 μs
240 μs
320 μs
400 μs
480 μs
560 μs



To be published in “Images in Plasma Science”, IEEE TPS ‘05

Chord Data for NSTX '04 Run

- Image split and 13 discrete ”chord” signals sent to PM tubes
- Each chord has 2 cm spatial resolution, 2 μs time resolution
- 64,000 time points per shot (0.128 sec @ 500 kHz)



1-D Radial and Poloidal Analysis

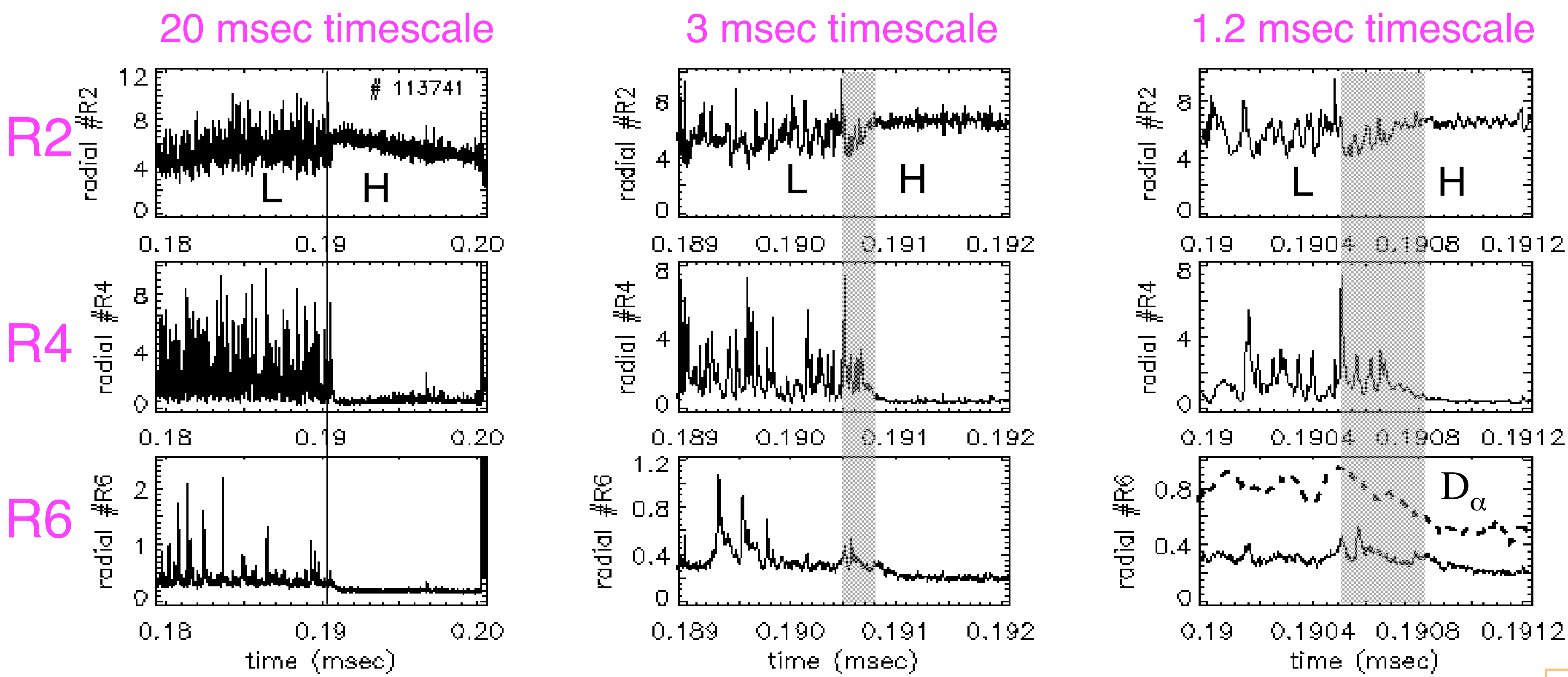
- Do 7-channel cross-correlation analysis of poloidal and radial "chord" arrays (separately)

- Look for slow changes ±10 msec around L-H transition
  - bin data in 1 msec intervals (500 points)
  - find poloidal and radial correlation lengths vs. time
  - find poloidal and radial group velocities vs. time
  - assemble data base of ≈ 15 similar L-H transitions

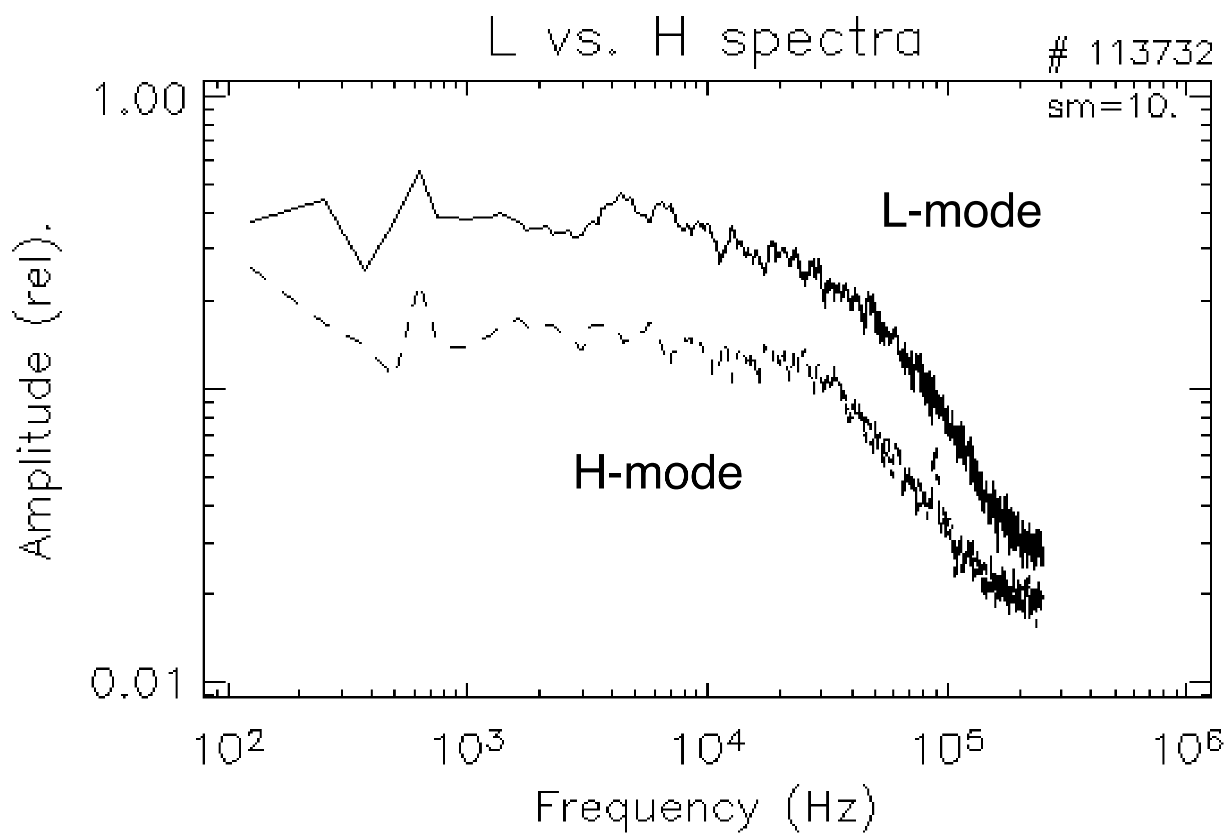
- Fast changes within ≈ 1 msec of transition will be analyzed with 2-D data only (not enough time points in chords)

Examples of Chord Data vs. Time

- No obvious changes in turbulence just before L-H transition
- Reduction in relative fluctuation level after L-H transition
- Transition occurs over ≈ 100 μsec at time of D_α drop



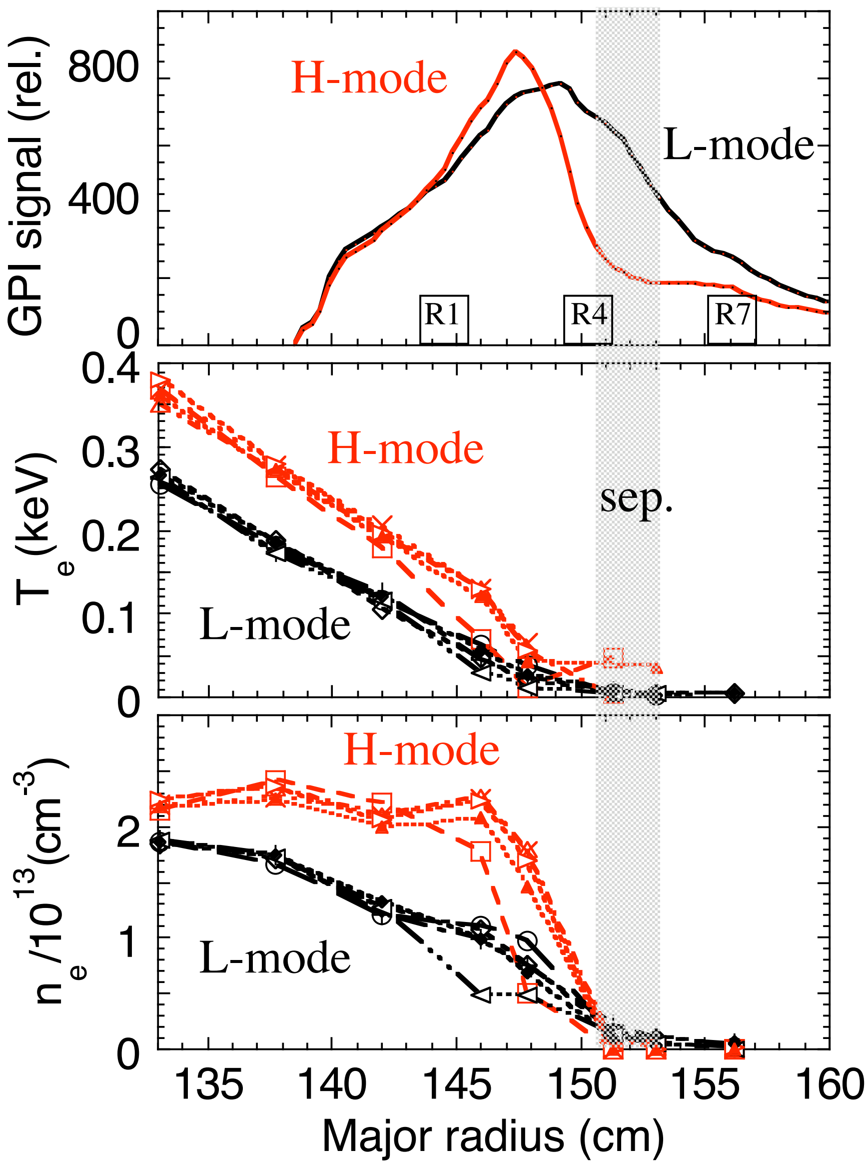
Little Change in Frequency from L to H



ch. # P4

- No significant change in frequency spectrum from L to H

Profile Changes at L-H Transition



black ≤ 8 msec before transition

red ≤ 8 msec after transition

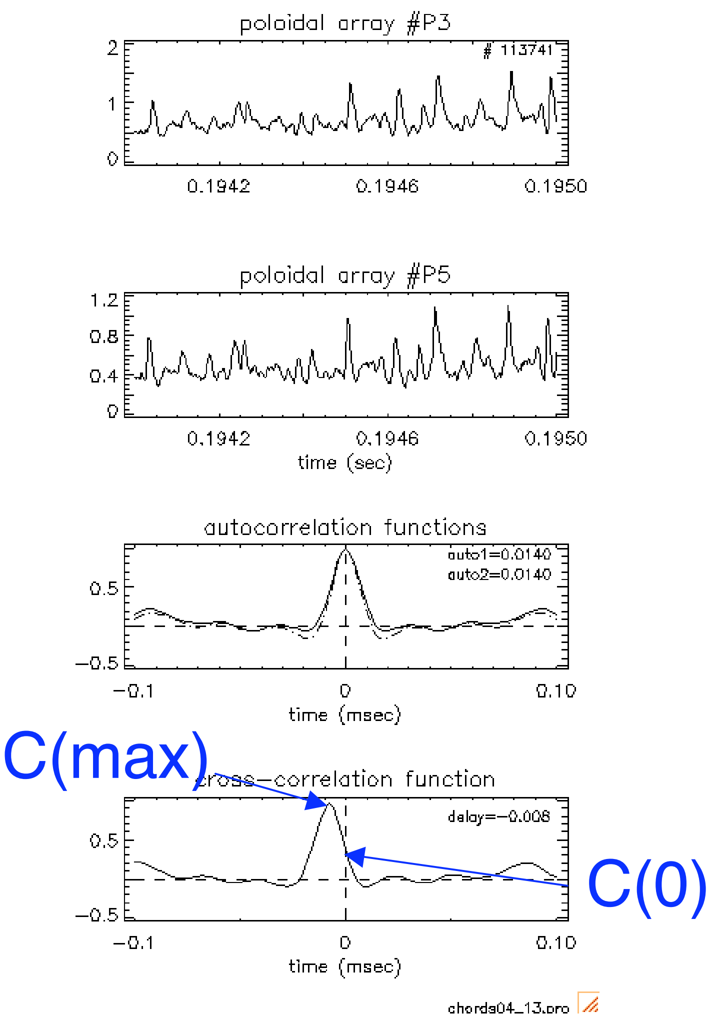
- GPI signal gets narrower and peaks a bit farther in
- T_e increases by almost x2
- n_e increases by almost x2

≈ 10 similar shots shown here

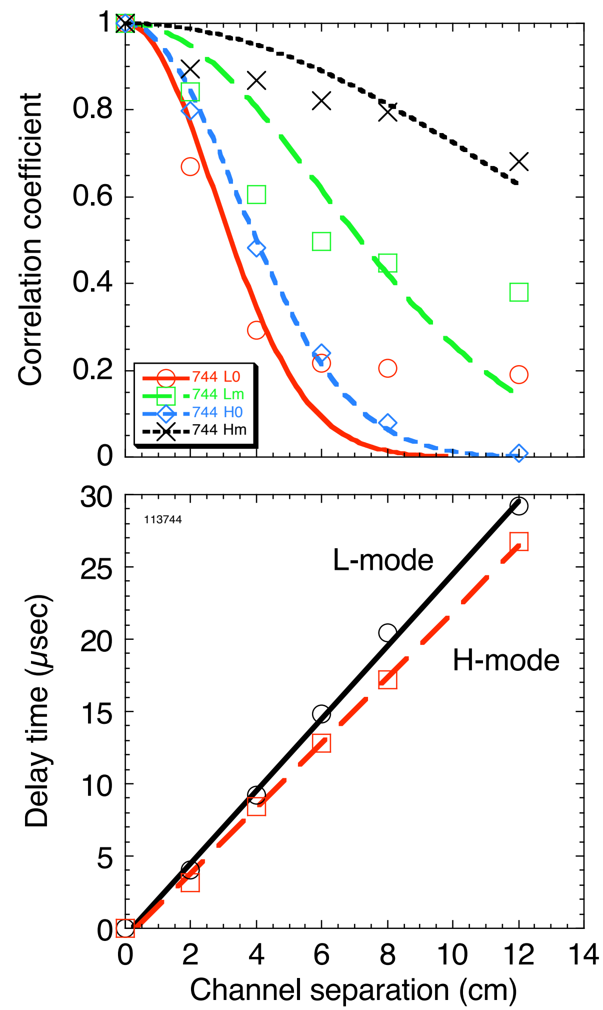
(separatrix uncertain ± 2 cm)

Example of Cross-Correlation Analysis

P3 vs. P5 (Δ_{pol} = 4 cm)



P1 vs. all other P's



x = C(max) in H-mode

□ = C(max) in L-mode

◊ = C(0) in H-mode

o = C(0) in L-mode

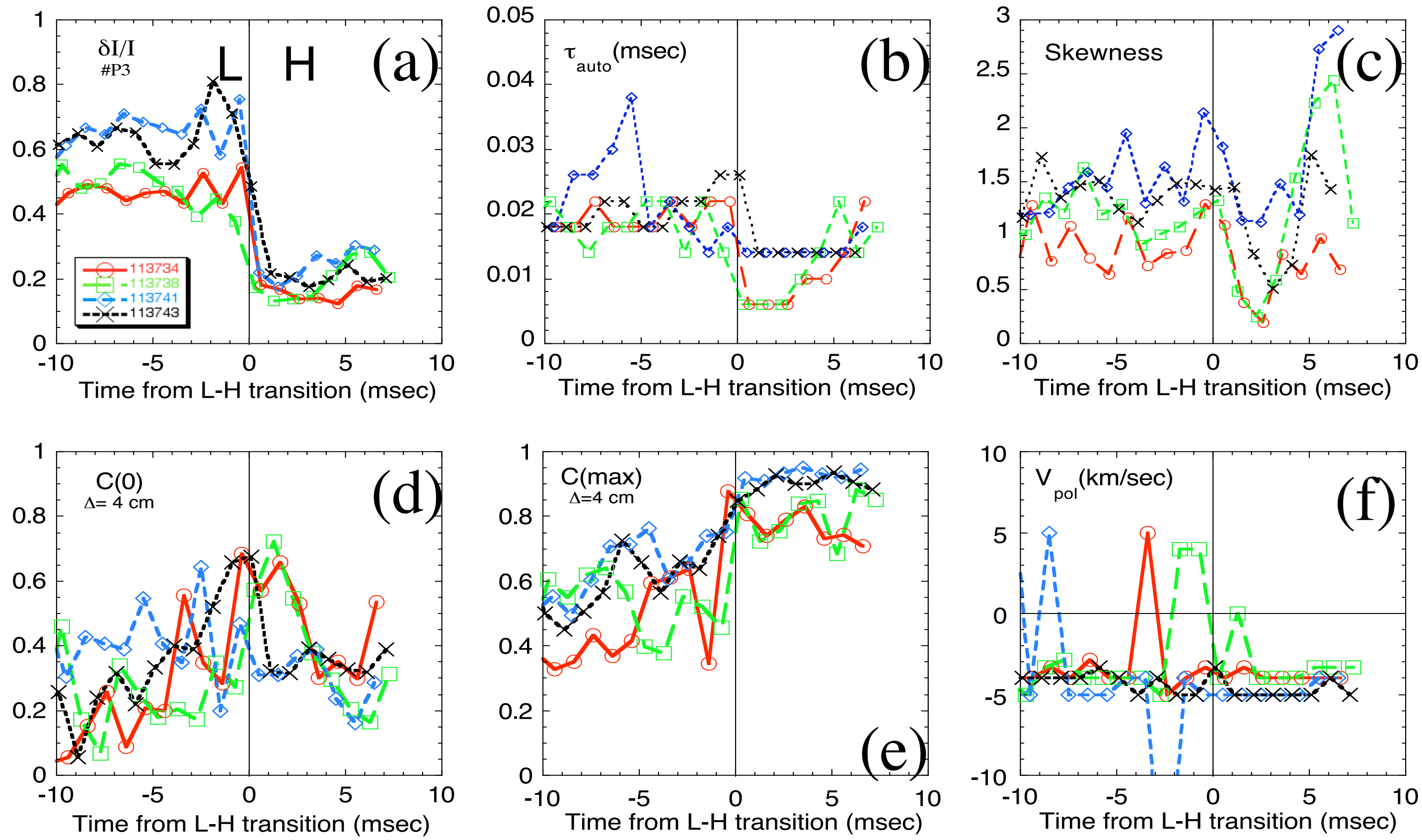
time to peak of cross-correlation function vs. channel separation

$V_{pol} = \Delta_{pol}$ / delay time

(poloidal group velocity)

Time Evolution around L-H Transition

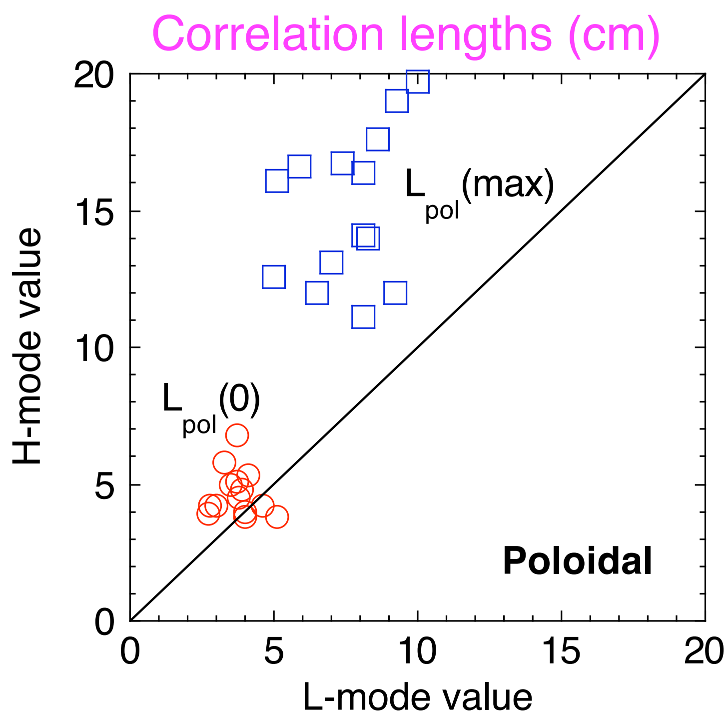
- Four typical shots from data set (#113732-113744)

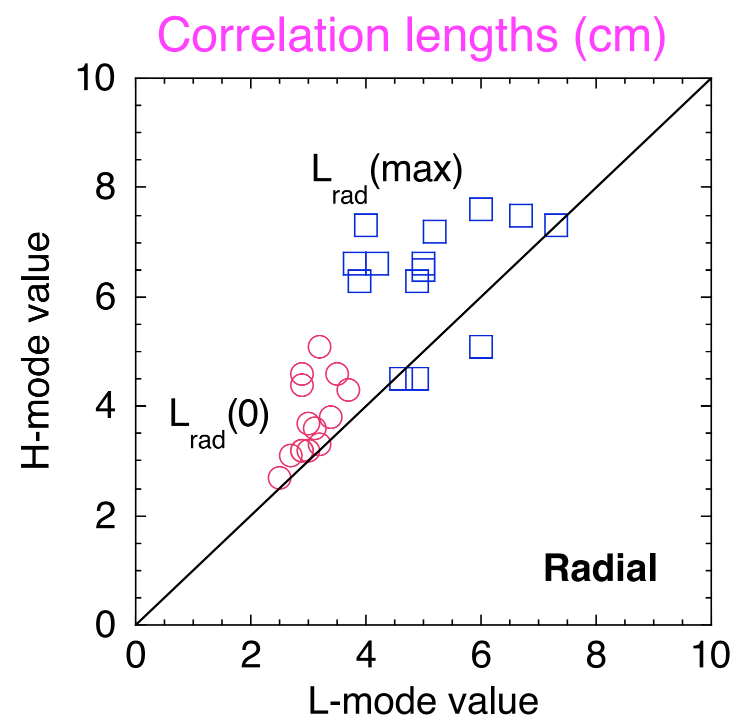


- Most surprising change is increase in C(max) from L to H

L_{pol}(max) increases in H-mode

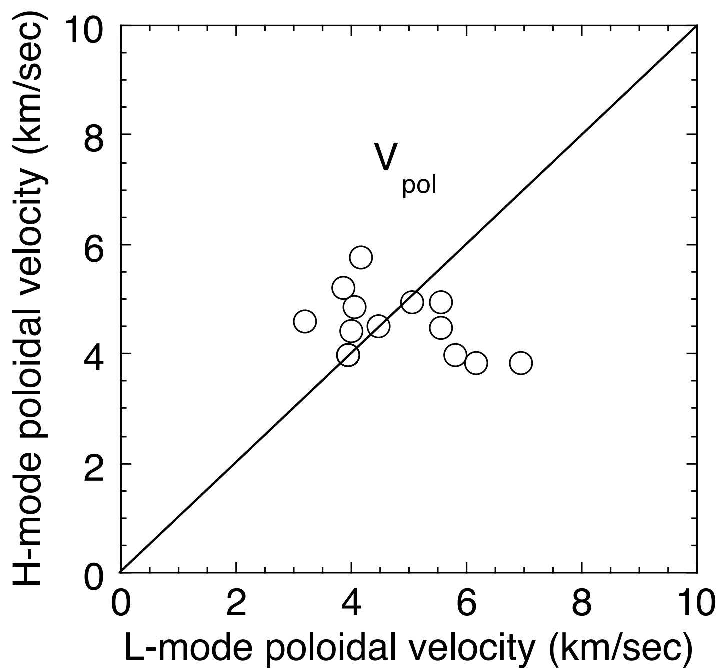
- Integrated over 5 msec before and after L-H transition





- Not much change in L_{pol}(0) or L_{rad}(0) from L to H
- Significant increase in L_{pol}(max) from L to H

Little Change in Vpol from L to H



- No significant change in V_{pol} from L to H (at this radius)

=> H-mode turbulence flow looks more "frozen" ?!

Conclusions from 1-D Analysis

Over a ± 10 msec period around the L-H transition :

- No significant change in the frequency spectrum
- Reduction in fluctuation level by x3 from L to H
- No significant change in L_{rad} or L_{pol} from L to H
- No significant change in V_{pol} from L to H
- Significant increase from L to H in the maximum distance over which the fluctuations are correlated in the poloidal direction, as if the turbulence was more "frozen" in the poloidal flow direction in H-mode

2-D Structure and Velocity Analysis

Goal: find coherent structures and velocity fields from images

Techniques being developed at this time:

- "Blob" tracking and algorithm for coherent structures
- Optical flow algorithm for 2-D velocity field vs. time

Open questions:

- How to define a coherent structure or "blob" ?
- What is the physical meaning of this velocity field ?

“Optical Flow” algorithm for velocity determination

Differential equations solved to satisfy “optical flow” condition for image brightness (ψ):

$$\frac{\partial\psi}{\partial t} + u\frac{\partial\psi}{\partial x} + v\frac{\partial\psi}{\partial y} = 0$$

Solved by decomposing velocity (u,v) profile into wavelet components.

“Dense” flow field produced:

Resulting flow field at resolution of original images (64x64x300).

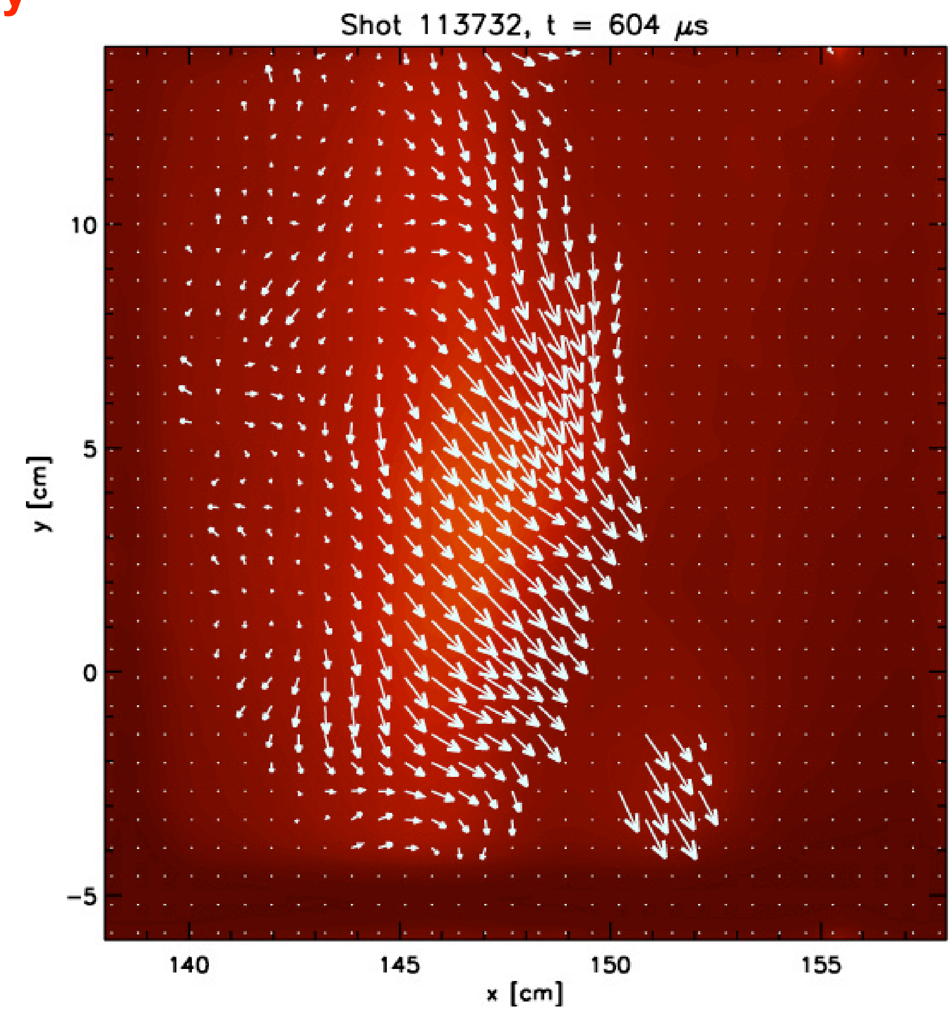
Allows calculations of spatial moments

Brightness normalization imposed to account for emission layer profile.

Blob velocities calculated:

Velocity of desired regions extracted by light intensity threshold.

(T. Munsat)



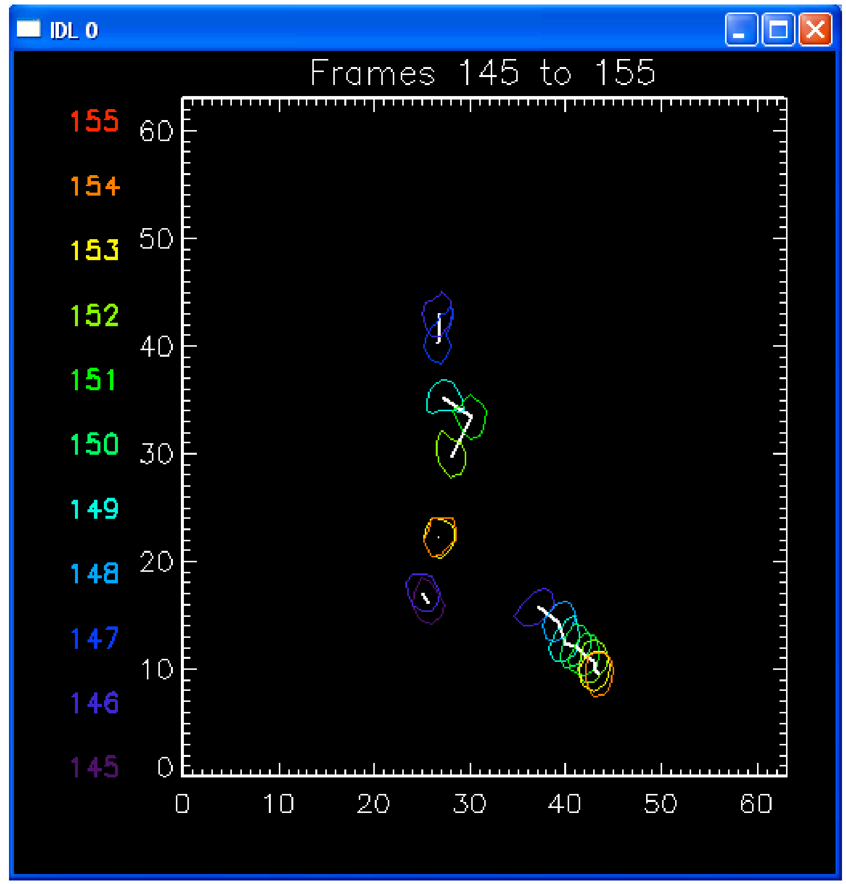
NSTX shot 113732, frame 151

Coherent structure (“ blob”) detection algorithms

Blobs searched within images:
Region containing at least one local maximum.
Conditions imposed regarding level of maximum, size of region and other local maxima possibly contained within region.

Tracks of blobs searched:
-Blobs from consecutive images related.
-Conditions imposed regarding proximity and changes in average blob brightness level.

Blob velocities calculated:
-Movement between frames of blob within track.



(R. Maqueda)

Tracks
NSTX shot 113732

Summary

- No significant change in radial or poloidal correlation lengths or poloidal flow speed within ± 5 msec around the L-H transition (in the cases examined)

- Relative fluctuation level in D_α was reduced by a factor of x3 over ≈ 100 msec at L-H transition

- Significant increase from L to H in the maximum distance over which the fluctuations are correlated in the poloidal direction, as if the turbulence was more “frozen” in the poloidal flow direction in H-mode

- Blob tracking and velocity field analysis in progress

Plans

- Compare structure and velocity results from cross-correlation, blob detection, and optical flow analysis
- Look for L-H transition precursors using bicoherence (as in Moyer PRL '01), or other techniques
- Understand the origin, dynamics and transport effects of coherent structures (with Lodestar group)
- Understand the limitations and proper interpretation of the velocity fields extracted from GPI data
- Compare GPI results with theory / simulation (e.g. BOUT)
- Get much more data with new Phantom 7 camera (Nova)

To get a copy of this poster:

download it from: http://www.pppl.gov/~szweben/Talks/talks.html

or, sign up for it here:

name	email