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

S.J. Zweben, R.J. Maqueda, J.L. Terry,
T. Munsat, J.R. Myra, T. Stoltzfus-Dueck, D.P Stotler,
C.E. Bush, D. D'Ippolito, O. Grulke, J.A. Krommes,
B. LeBlanc, R. Maingi, D.A. Russell, S.A. Sabbagh, A.E. White,
K.M. Williams, and the NSTX and Alcator C-Mod Teams

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

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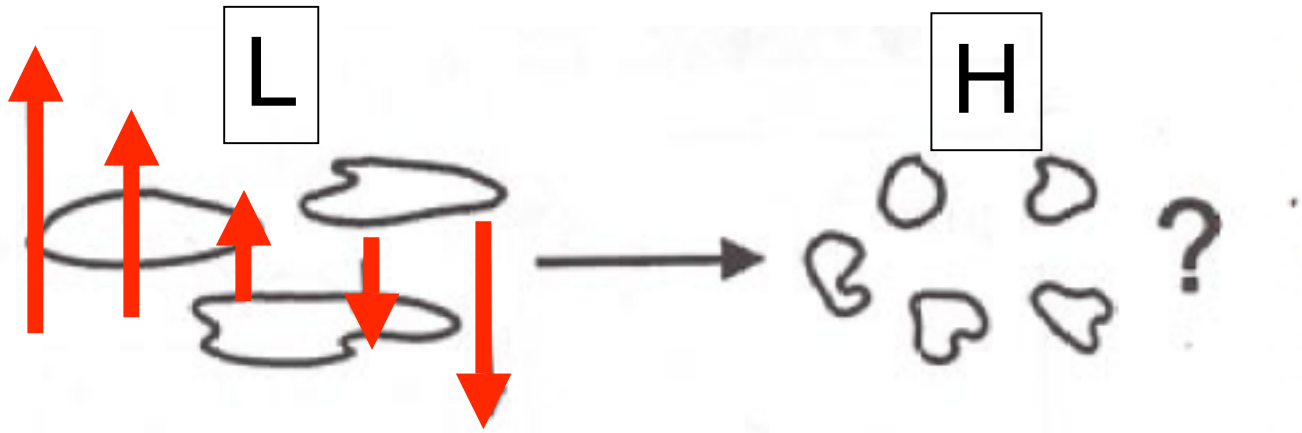
Motivations

- Edge turbulence affects location of plasma-wall interaction
- Edge turbulence influences global tokamak confinement
- Cause of L-H transition is not yet completely understood

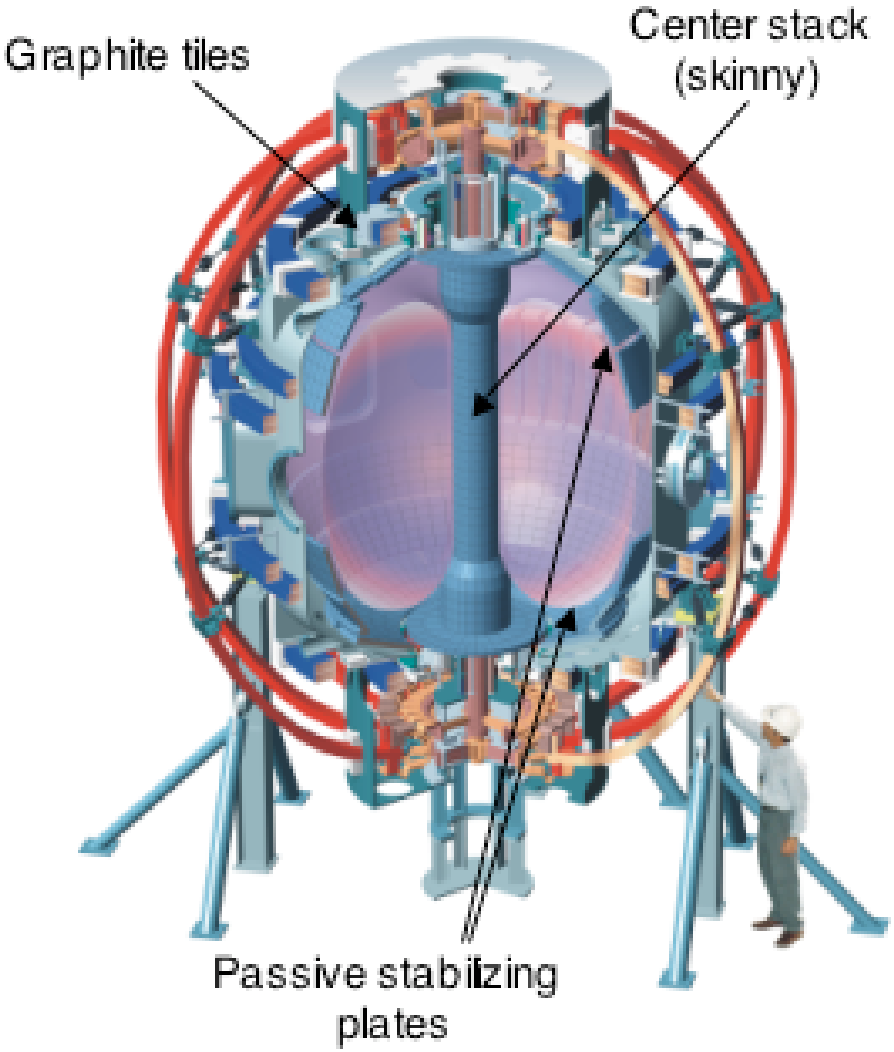


T.S. Hahm

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)



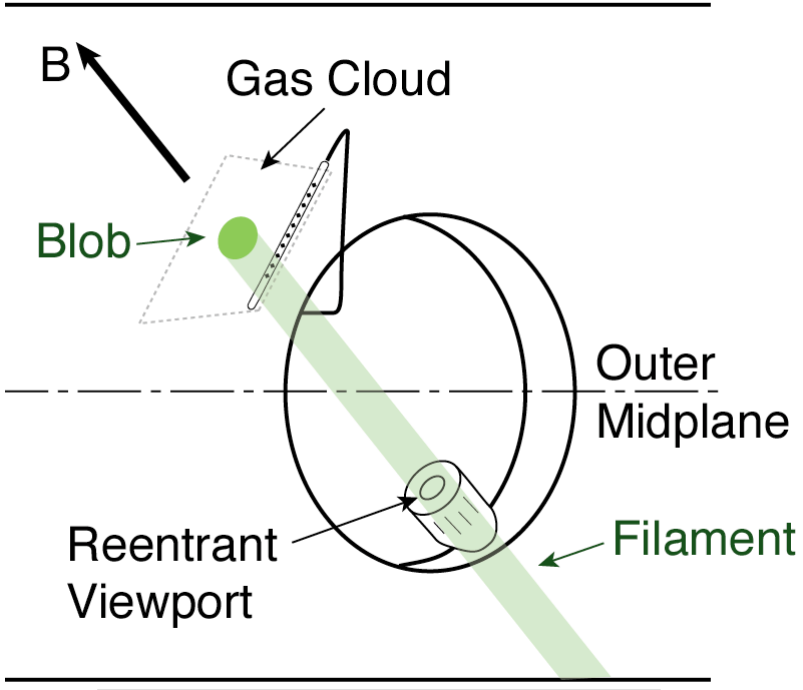
typical parameters for this talk

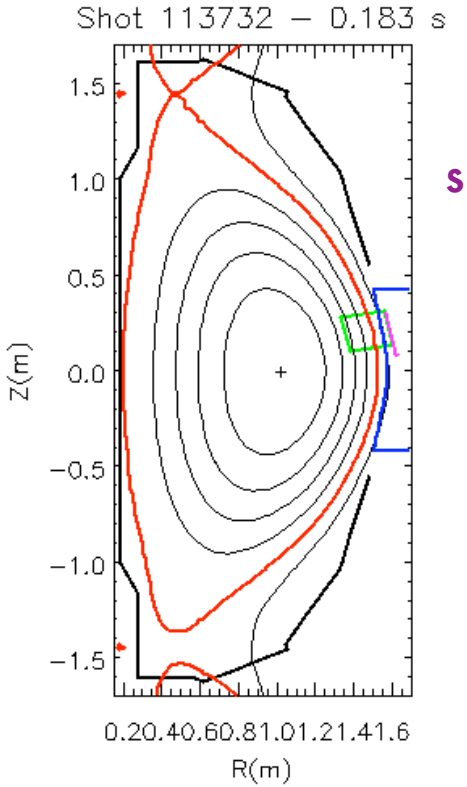
R = 0.85 m
a = 0.68 m
B = 0.3 T
I ≈ 0.8 MA
P_{NBI} ≈ 2-4 MW
β_T ≈ 10%

Gas Puff Imaging (GPI) Diagnostic

- Looks at D_α line of neutral deuterium from a gas puff
- View ≈ along B field line to see 2-D structure ⊥ B

view from center column

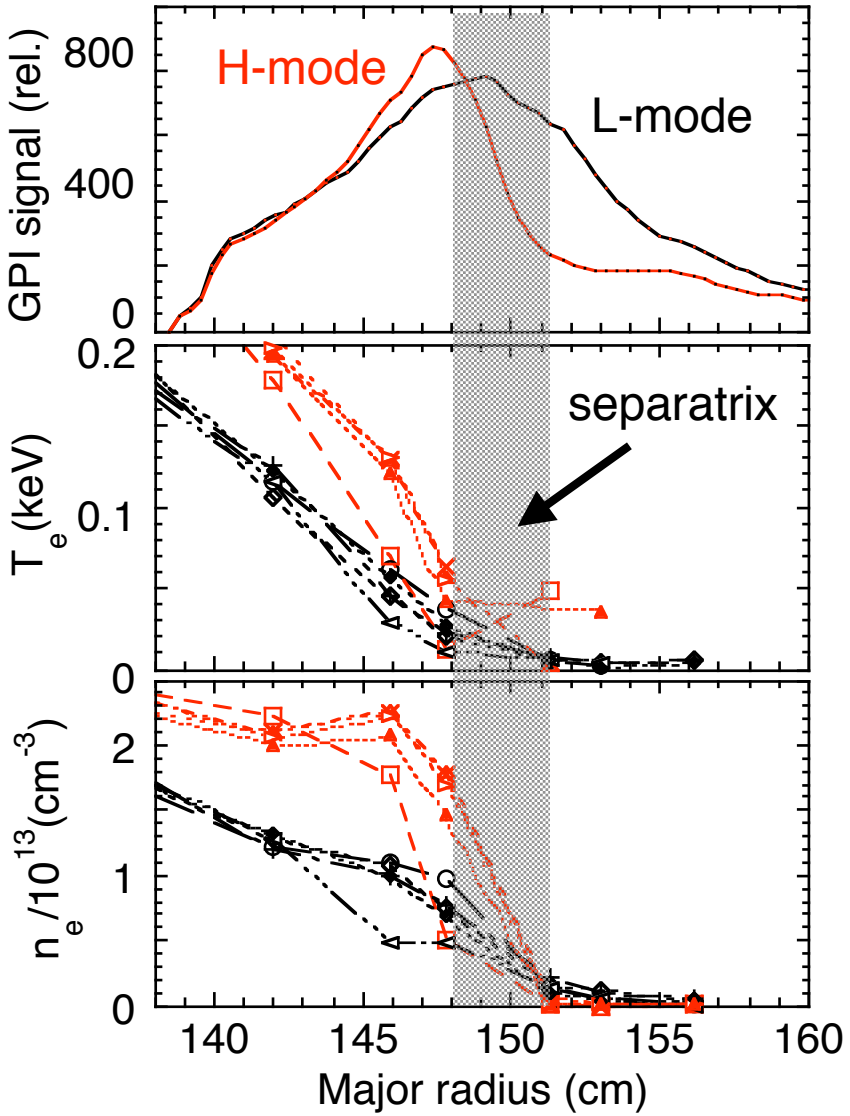




viewing area
≈ 25x25 cm
spatial resolution
≈ 1-2 cm

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

Location of GPI Light Emission



- D is unexcited @ $T_e < 5$ eV
- D is ionized @$T_e > 100$ eV

NSTX Edge Parameters

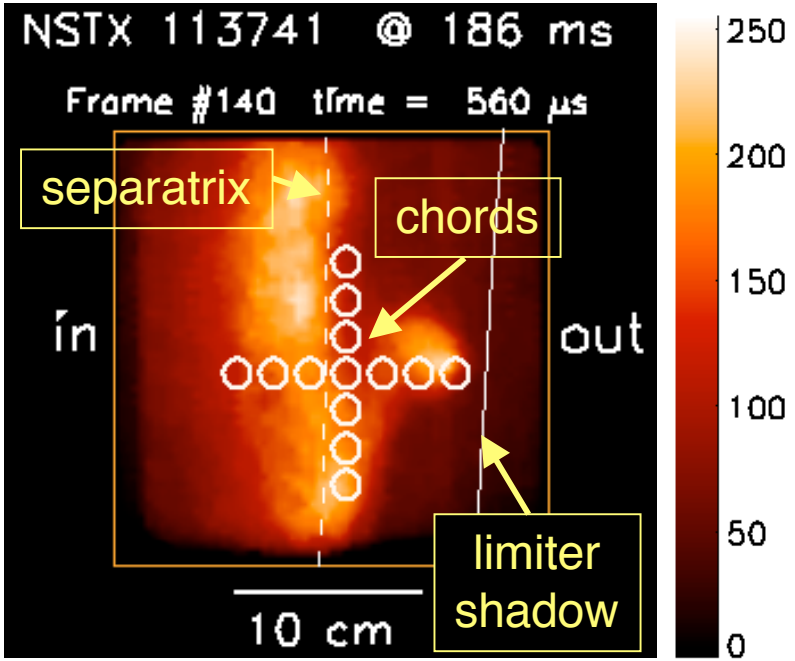
$n \sim 0.2\text{-}2 \times 10^{13}$ cm^{-3}
$T_e \sim 5\text{-}50$ eV
$L_\perp \sim 2\text{-}5$ cm
$L_{||} \sim 5$ m
$\rho_s \sim 0.2$ cm
$\beta_e \sim 10^{-3}$

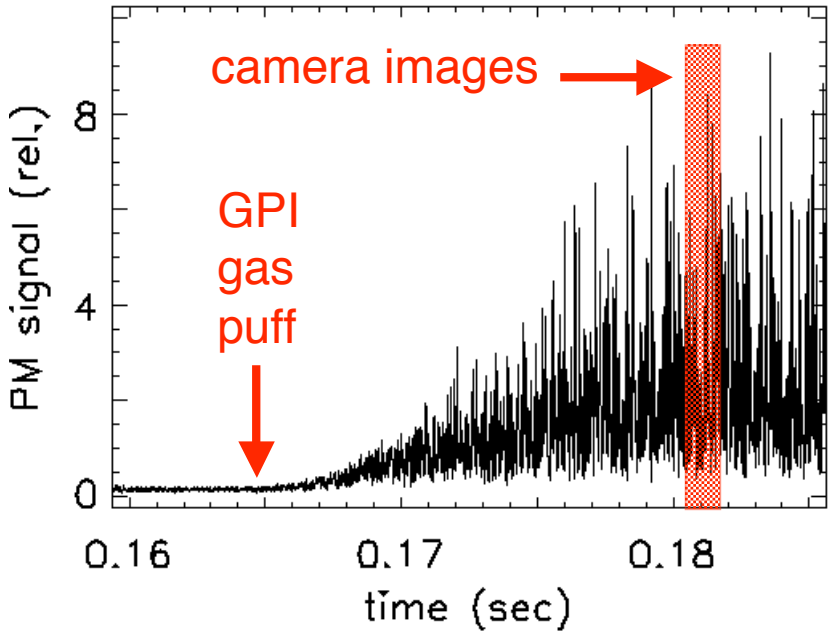
~ similar to many tokamak edge plasmas

GPI Fluctuation Data in NSTX

- PSI-5 camera records 300 frames at ≤ 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)

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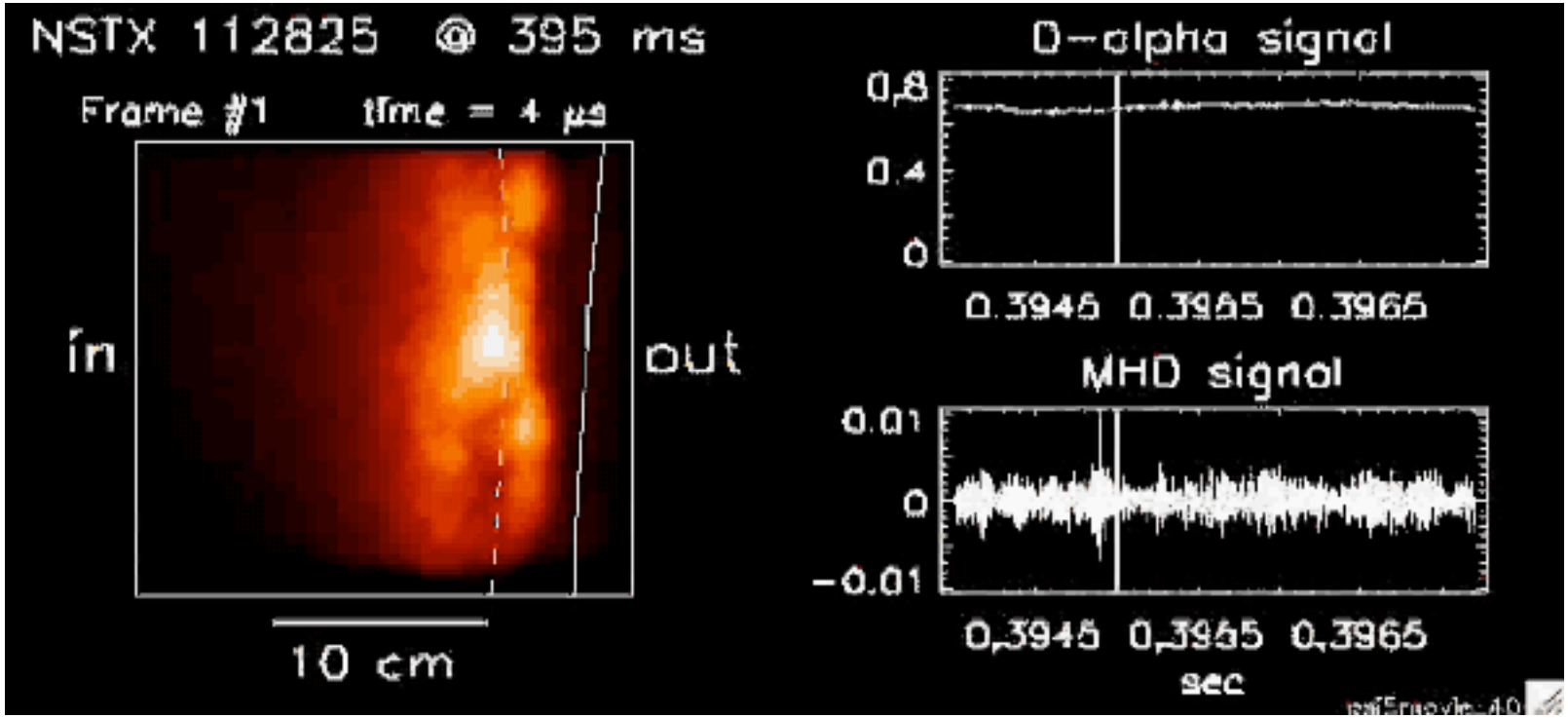
Images During L-mode

- 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

$\langle n \rangle = 2.2 \times 10^{13}$ 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

$\langle n \rangle = 2.7 \times 10^{13}$ cm^{-3}

250,000 frames/sec

Analysis of Structure and Motion

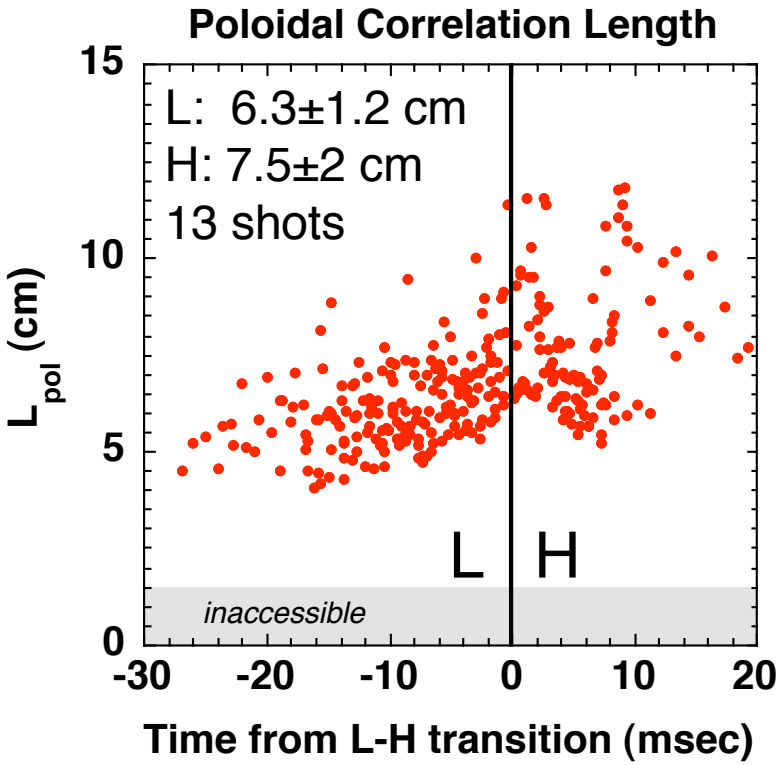
- Use simplest analysis via 2-point cross-correlation function of fluctuations in GPI light signals vs. space and time:

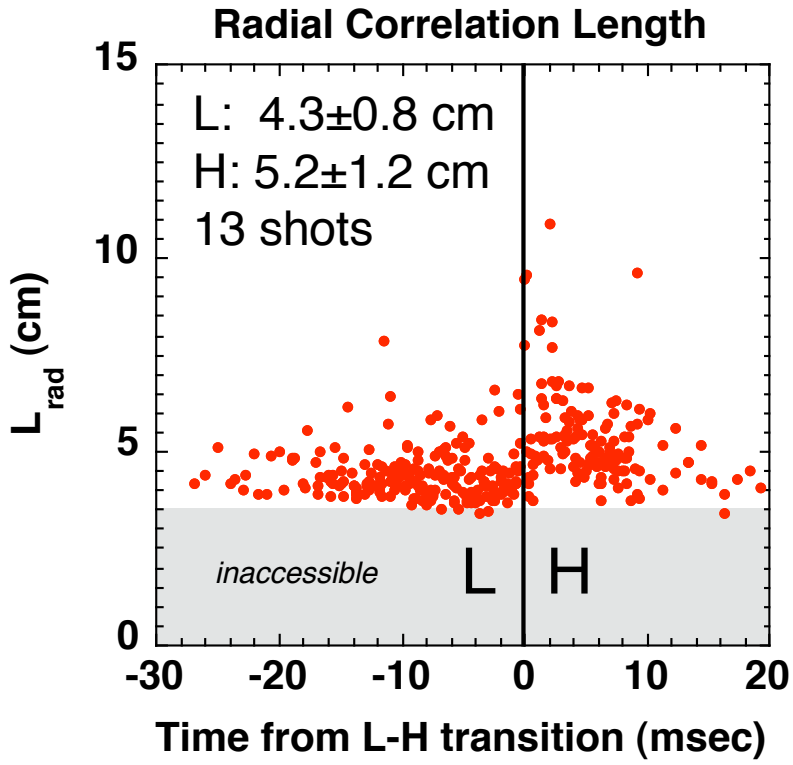
$$C(\Delta x, \Delta t) = \sum_{t} \tilde{S}_0(t)\, \tilde{S}_{\Delta x}(t+\Delta t)$$

- Correlation length from FWHM of $C(\Delta x, 0)$ [$\approx 1.6 \times \sigma_{Gaussian}$]
- Velocity from time the delay of the peak in $C(\Delta x, \Delta t)$ vs. Δx
- $C(\Delta x, \Delta t)$ averages over space and time spectrum of signals

2-D Structure from Chords

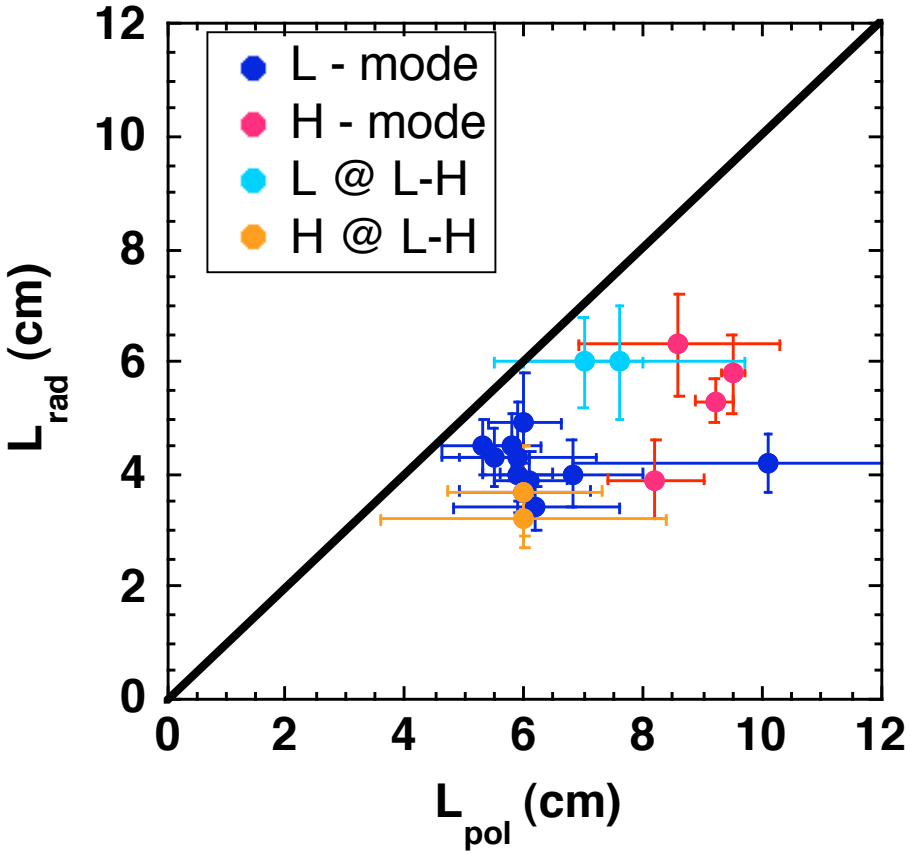
- No significant changes from L- to H-mode (13 shots)
- Maybe some increase in L_{pol} over ~ 30 msec before L-H





2-D Structure from Images

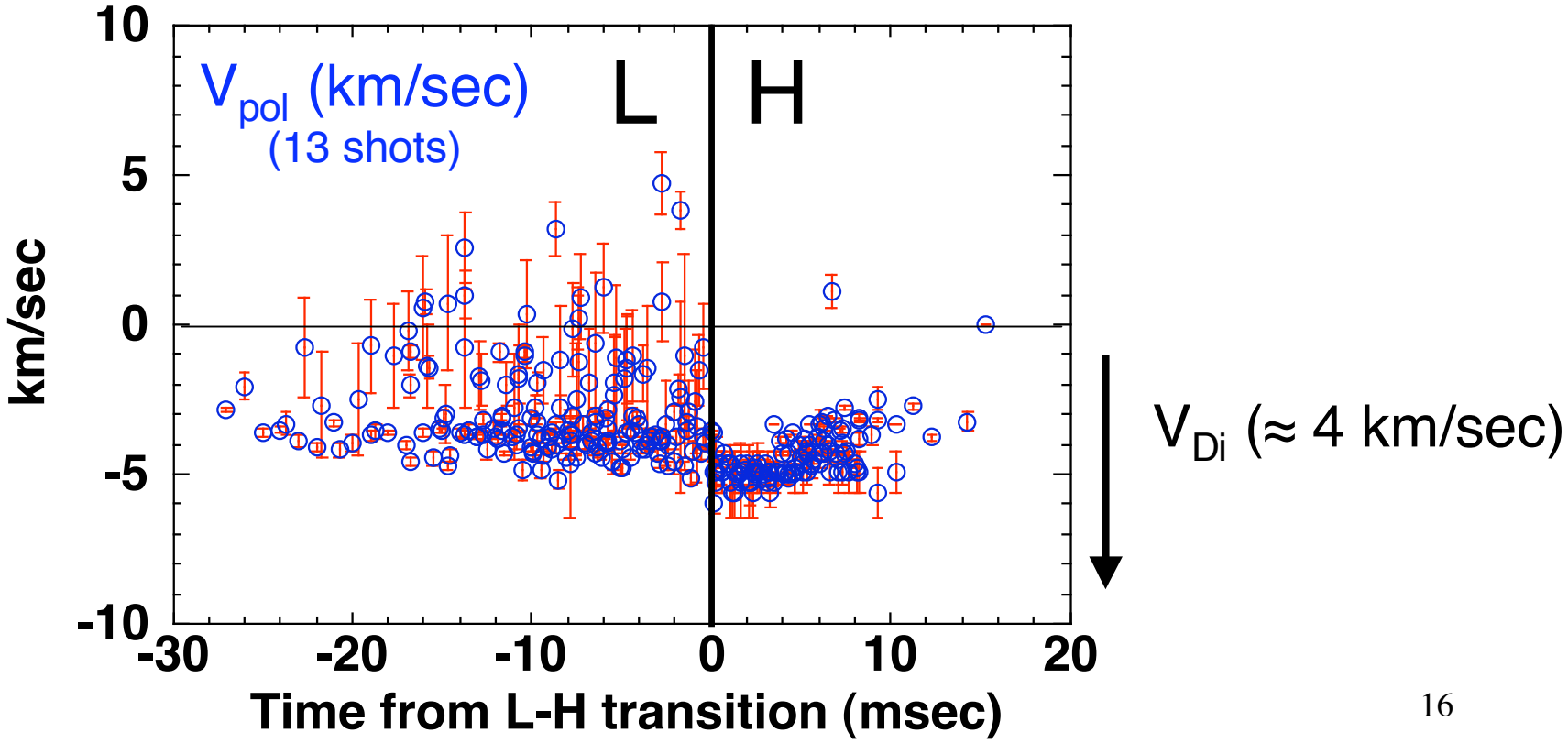
- Evaluated near radial peak of GPI signal ~ separatrix
- No statistically significant changes from L- to H-mode



	L_{rad} (cm)	L_{pol} / L_{rad}
L	4.2±0.4	1.5±0.4
H	5.3±1.0	1.9±0.4

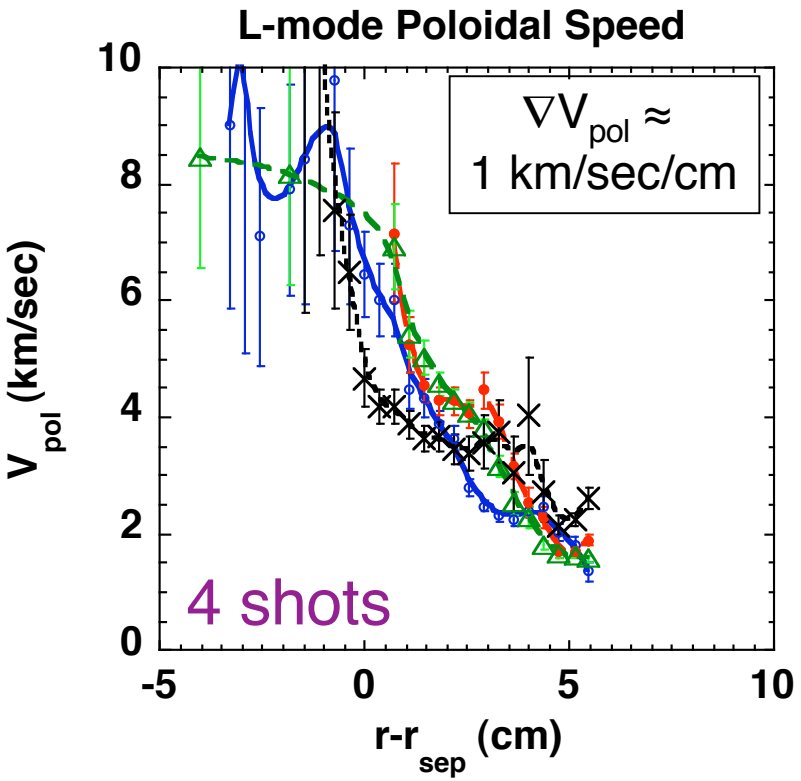
Poloidal Motion from Chords

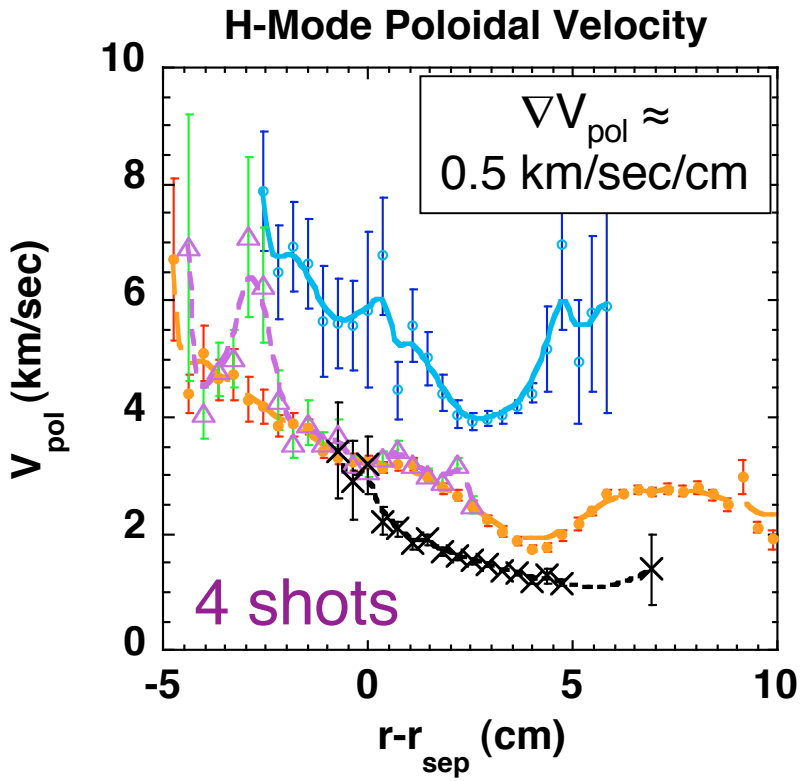
- Poloidal motion generally in ion diamagnetic drift direction
- Poloidal flow more "frozen" in H-mode than L-mode ($\rho \sim 0$)



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





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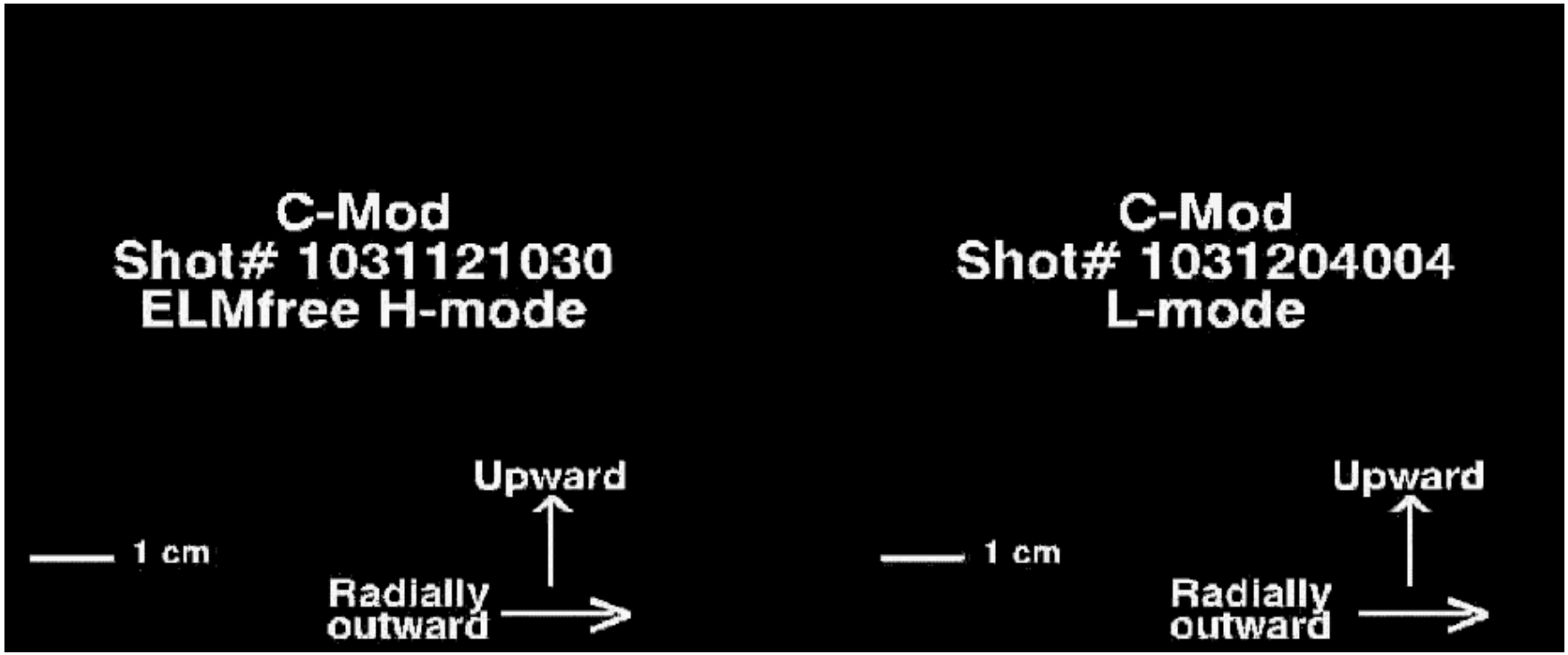
Images from Alcator C-Mod

H-mode

L-mode



Terry et al, J. Nucl. Mater. '04

NSTX vs. C-Mod (L-Mode)

	NSTX *	Alcator C-Mod**
B_{edge}	2-3 kG	40 kG
n_{edge}	0.2-2x10^{19} cm^{-3}	2-20x10^{19} cm^{-3}
$T_{e,edge}$	5-50 eV	20-80 eV
L_{pol}	5-9 cm	0.6-1.0 cm
L_{rad}	2-6 cm	0.7-1.5 cm
V_{pol}	≤ 5 km/sec	≤ 1 km/sec
V_{rad}	≤ 1-2 km/sec	≤ 1.5 km/sec

* S.J. Zweben et al, Nucl. Fusion 44, p. 134 (2004)

** J.L. Terry et al, submitted to Fusion Science and Technology (2005)

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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

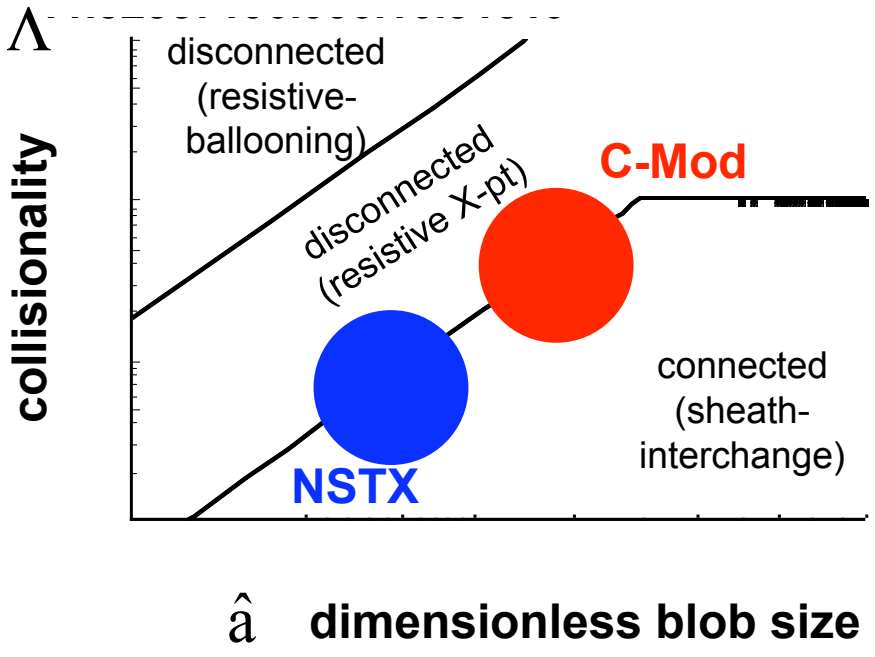
- Yet flow shear is near the usual stabilization criterion for L-H
  - $\nabla V_{pol}(L_{rad}/L_{pol}) \approx$ 30-40 kHz $\approx 1/\tau_{auto}$

Caveats:

- region causing transition may be outside GPI view
- poloidal velocities averaged over ~ 1 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



$$V_{rad} = 5.1\times10^{6}\,\frac{L_{\parallel}^{1/5}T_e^{7/10}}{B^{2/5}R^{3/5}}$$

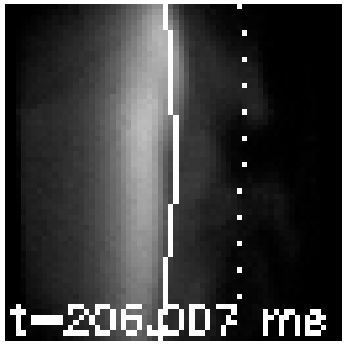
~ 2 km/s in both C-Mod & NSTX

Myra et al, Poster RP1.00019
Thursday PM (NSTX)

Lodestar

Conclusions and Future Directions

- Lots of interesting things happening in edge turbulence



120k frames/sec

- 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 ?!

Related Talks/Posters at this Meeting

NSTX :	Orals	GO3 Tues PM
	Posters	RP1 Thurs PM
	Blob model:	Myra: RP1.00019
	SOL model:	Russell: CP1.00045
	Velocity field:	Munsat: RP1.00017
	Velocity field:	Stoltzfus-Dueck: RP1.00018
	Bicoherence:	White: RP1.00016
	Scaling:	Williams: RP1.00015
	Ohmic H-mode:	Bush: RP1.00028
	Fast imaging:	Maqueda: RP00014
	Fast imaging:	Roquemore: RP1.00013
C-Mod:	ELMS with GPI:	Terry: RO3.00008
DIII-D:	L-H in BEA	Scholossberg: QP1.00015