

Impurity Flow, Turbulence, and Behavior of the Edge Plasma of NSTX

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- 4) Hiroshima University
- 5) Nova Photonics

- 6) University of Washington
- 7) Columbia University
- 8) LLNL
- 9) Johns Hopkins University
- 10) LANL

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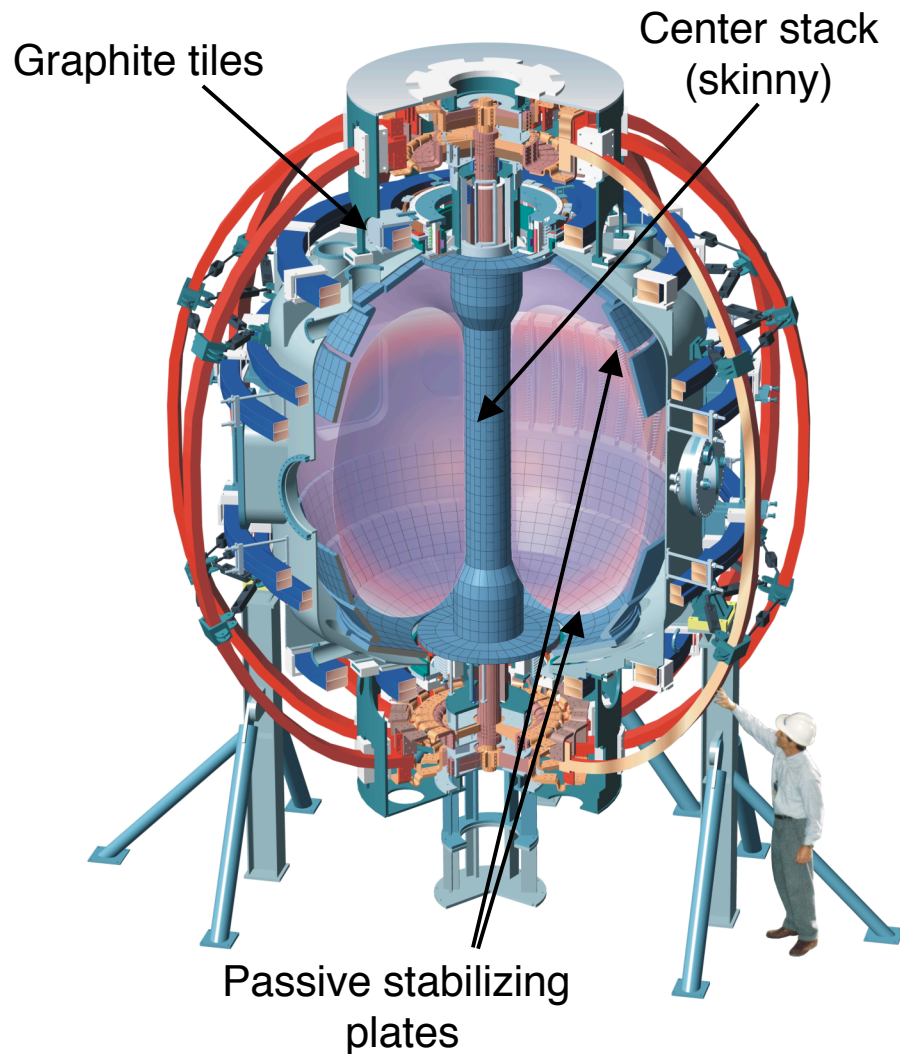
Columbia U
Comp-X
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
NYU
ORNL
PPPL
PSI
SNL
UC Davis
UC Irvine
UCLA
UCSD
U Maryland
U New Mexico
U Rochester
U Washington
U Wisconsin
Culham Sci Ctr
Hiroshima U
HIST
Kyushu Tokai U
Niigata U
Tsukuba U
U Tokyo
JAERI
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KBSI
KAIST
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
U Quebec

Abstract



Studies of plasma dynamics, impurity flow, and edge turbulent fluctuations and plasma behavior have been done on NSTX in a variety of regimes and configurations. These include L- and H-mode plasmas in double null and lower single null divertor configurations. A fast camera running at 1000 frames/sec with a fisheye lens and filter wheel (C I, C III, D_α and Li I filters) images the entire plasma. Images show very clear dynamics and phenomena on the plasma surfaces when using a C III filter. Moving helical patterns (“flows”) are seen in the visible emissions on the outboard and inboard (near center stack) surfaces of the plasma. Gas puff imaging (GPI) using an ultrafast camera (100,000 and 250,000 frames/sec) shows turbulent fluctuation structures at the outer plasma edge, and a reflectometer is used to study turbulence in the edge of H-modes. An edge rotation diagnostic (ERD) shows the edge electric field becoming more negative about 10 to 20 ms prior to the L-H transition in Ohmic H-modes.

NSTX Explores Low Aspect Ratio ($R/a \geq 1.27$) Physics Regime



Enabling Capabilities:

- 350° C bakeout of graphite tiles
- Regular boronization (~3 weeks)
- Helium Glow between discharges
- Center stack gas injection
- Error field reduction

Parameters Achieved:

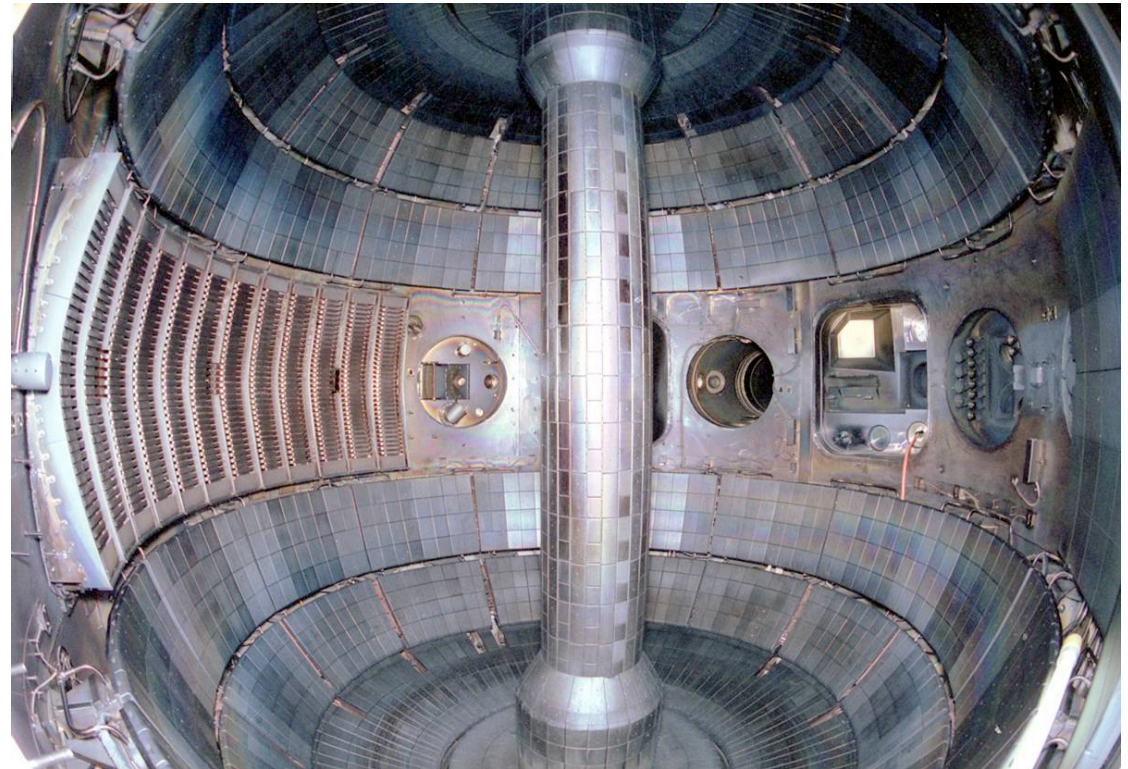
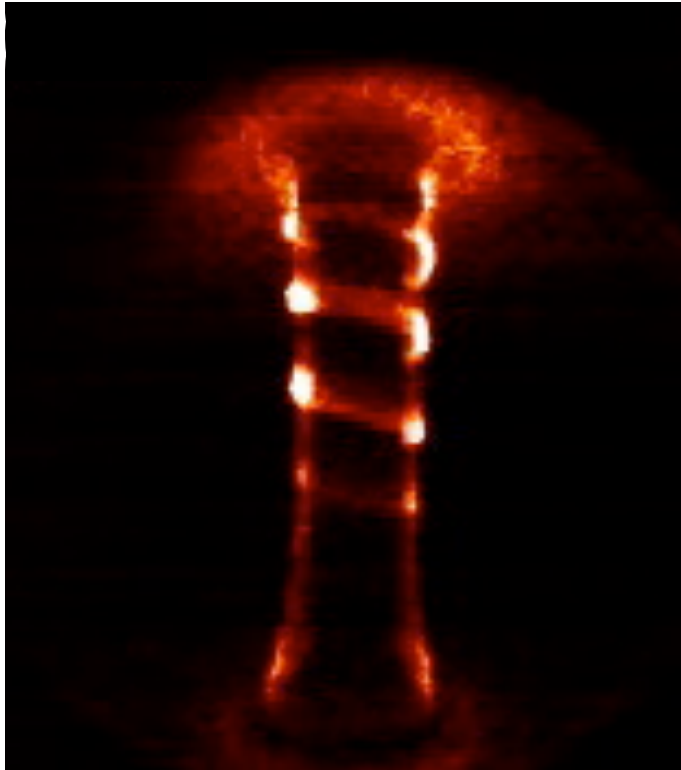
Major Radius	0.85m
Minor Radius	0.67m
Plasma Current	1.5MA
Toroidal Field	0.6T
Heating and Current Drive	
NBI (100keV)	7 MW
RF (30MHz)	6 MW

Outline



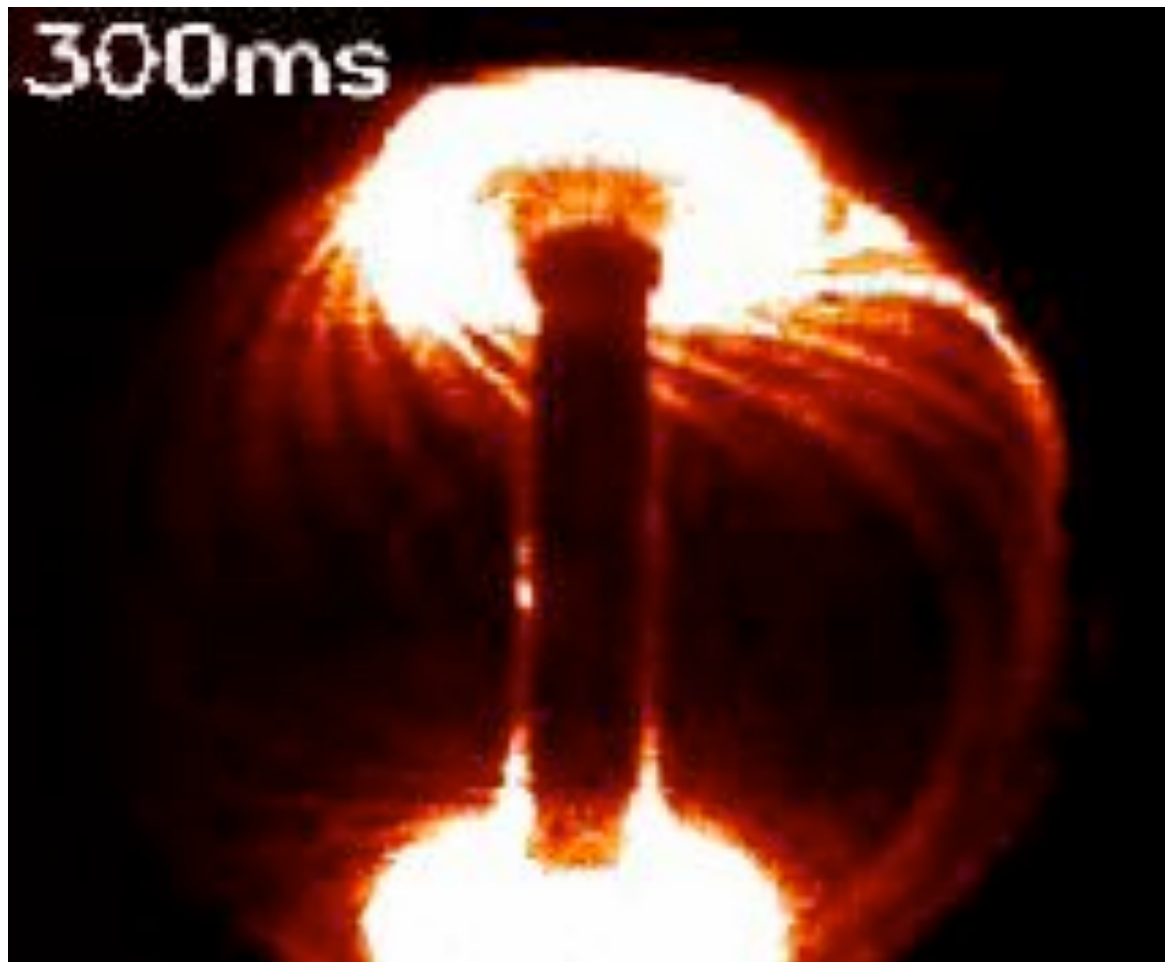
- Ohmic H-modes
 - E_r and plasma velocity changes 10-20 ms before L-H; agreement on several diagnostics
- Fish Eye View of Plasma - shows macro-dynamics
- GPI shows turbulence as fast moving blobs
- L-H mode transitions
- ELMs in Ohmic and NBI heated plasmas
 - GPI shows fast blobs move radially outward

Fish Eye View of Full Plasma - shows macro-dynamics

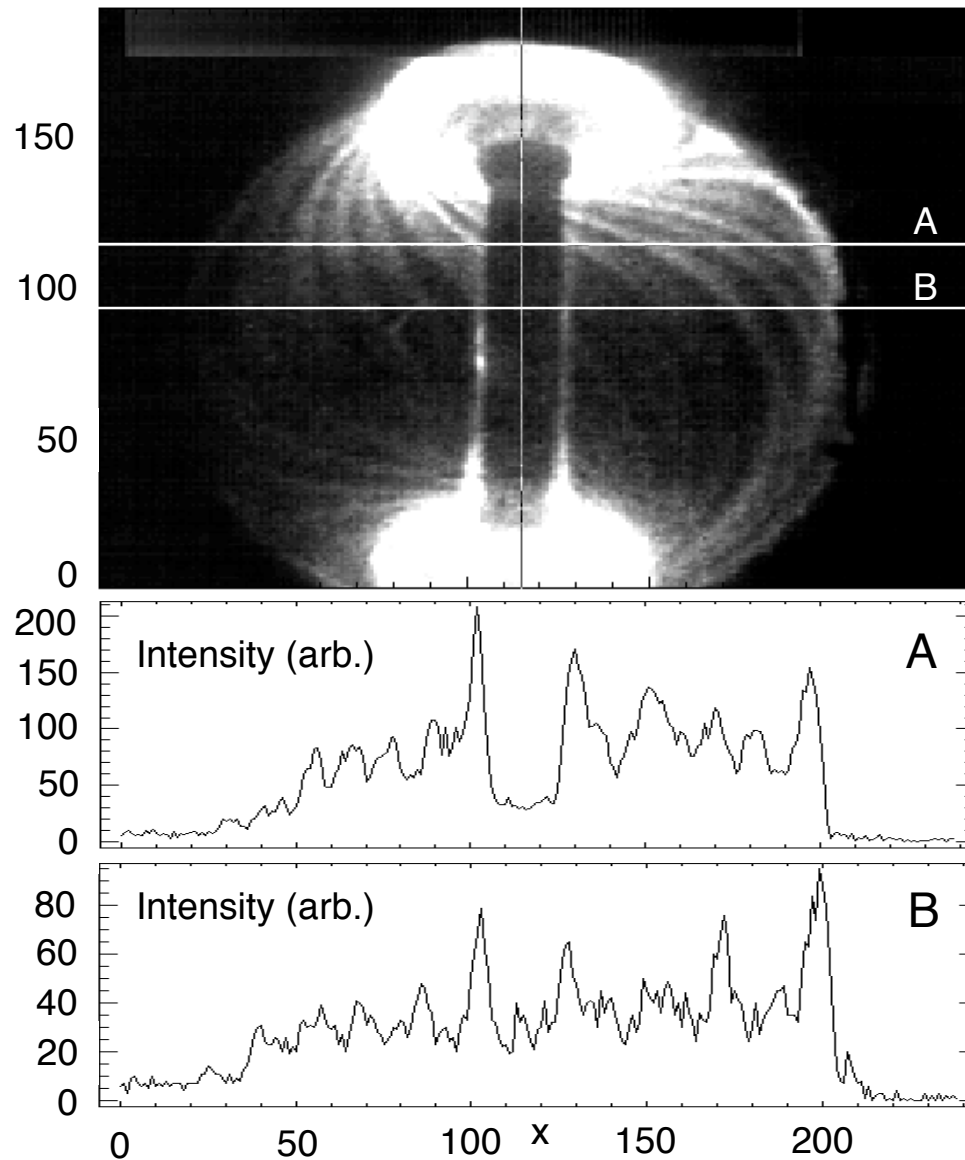


- **Fast Camera - Fisheye view showing activity near centerstack**
 - Normally run at 1000 frames/sec
- **Fisheye view inside NSTX with no plasma**

Plasma Showing Result of Interaction with Wall / Divertor during a Kink Mode



Perturbation Showing Tubes Swirling Down from Upper Divertor

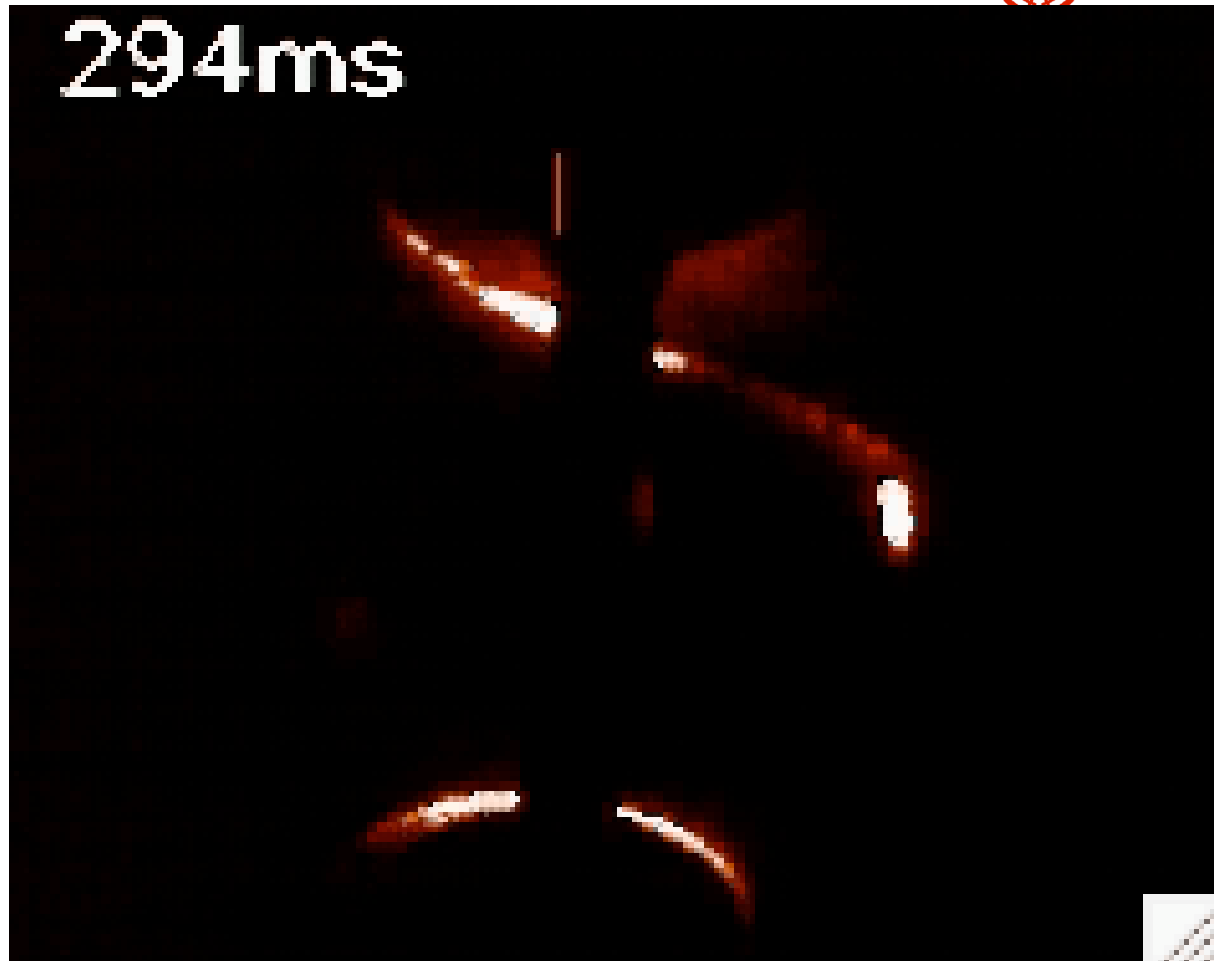


Fast Camera Image . Used CIII Filter for Viewing.

Frame Rate = 1000/sec

Relative Intensity vs Time.
Two Different Profiles A & B
Intensity Increases at each
Tube. Used CIII Filter for
Viewing.

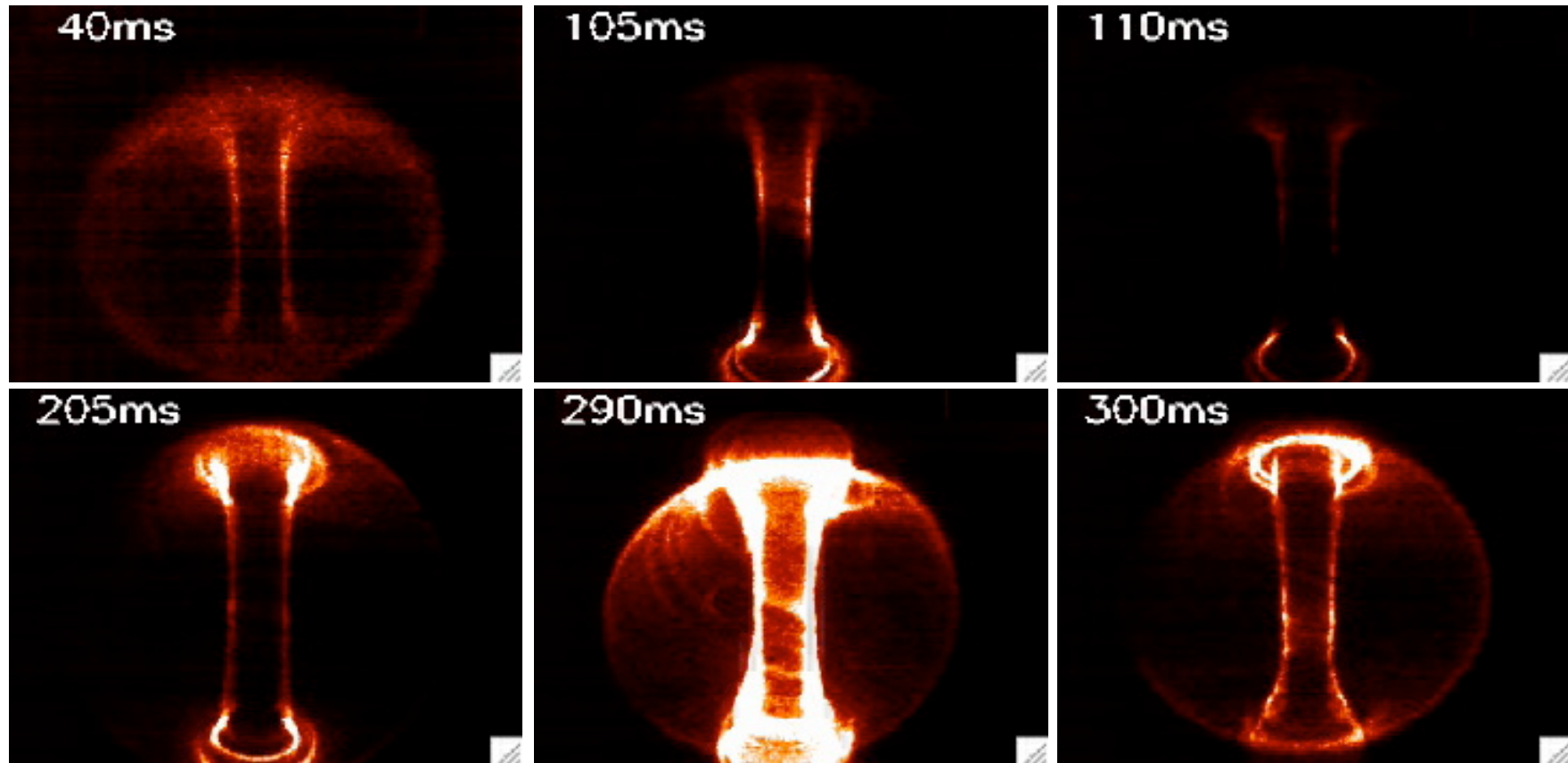
Lithium “flow” along field line after Li pellet ablation



H-mode Showing Early-time to L-H to Large ELM to Quiescent (1)



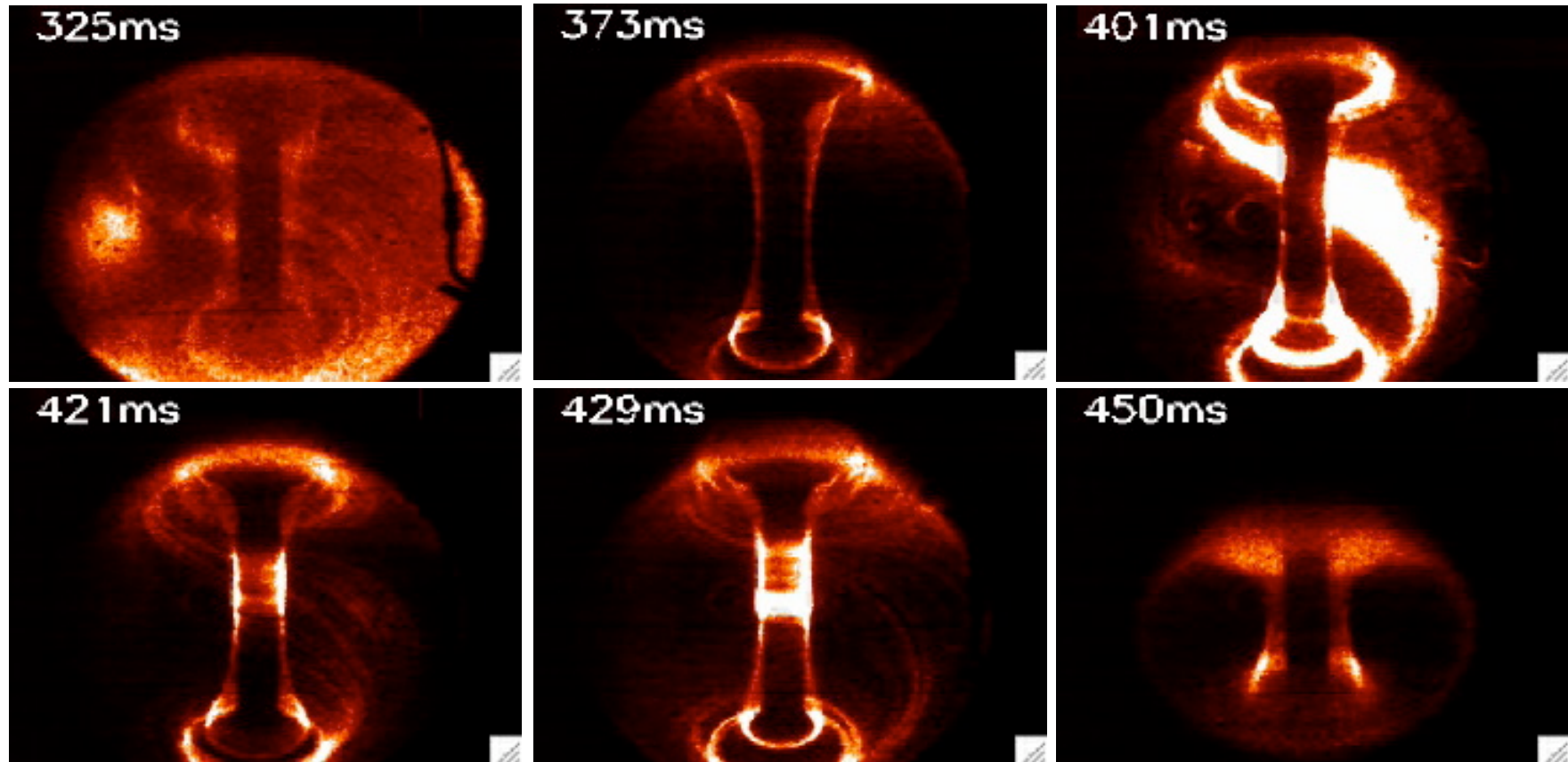
Shot 114151



H-mode Showing Quiescent → External Kink → Small Torus at EOS: (CIII filter)



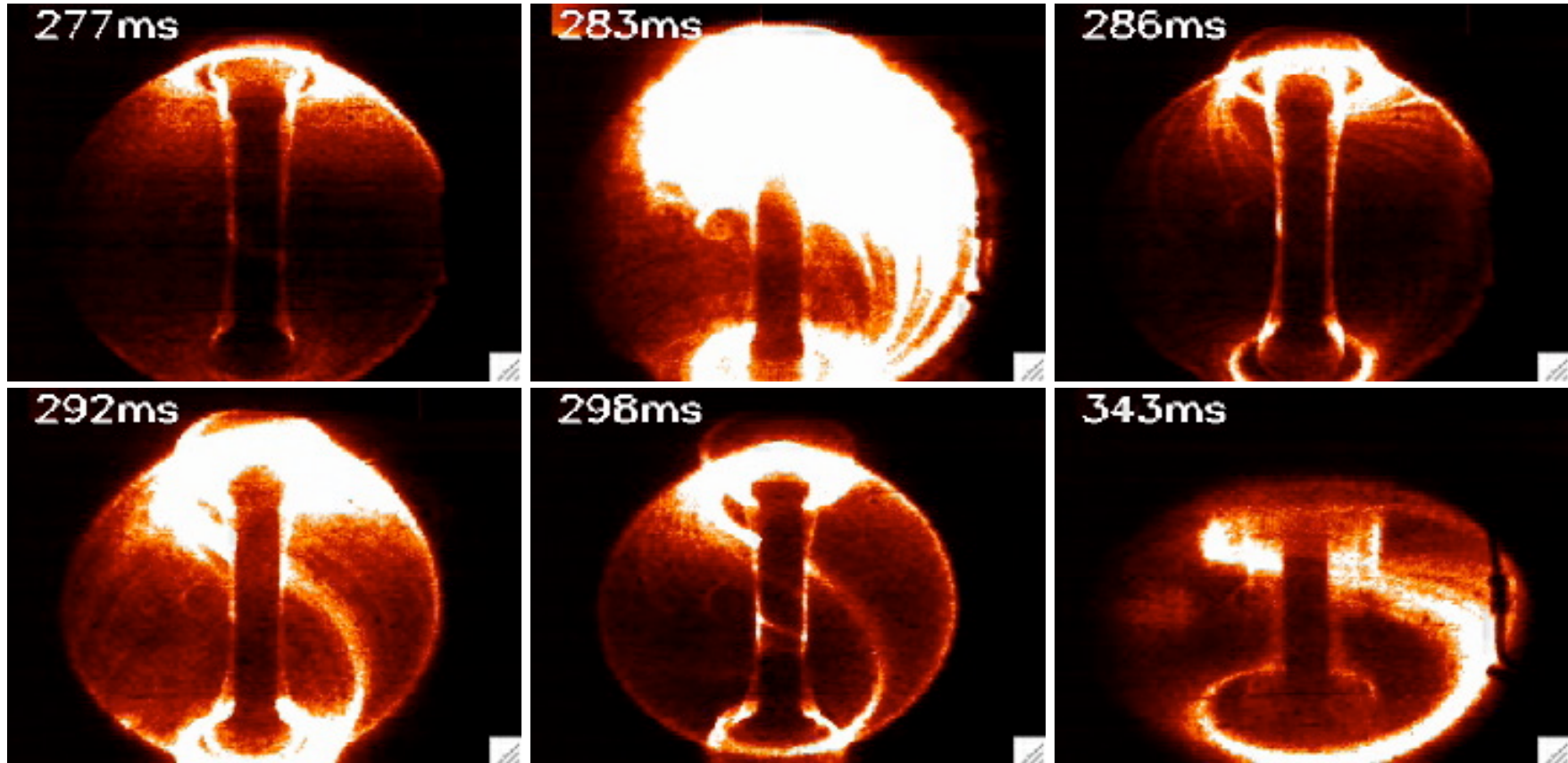
Shot 114151



Highest Normalized β ($\beta_N \sim 35\%$) Shot: Perturbed by an External Kink Mode



Shot 114463

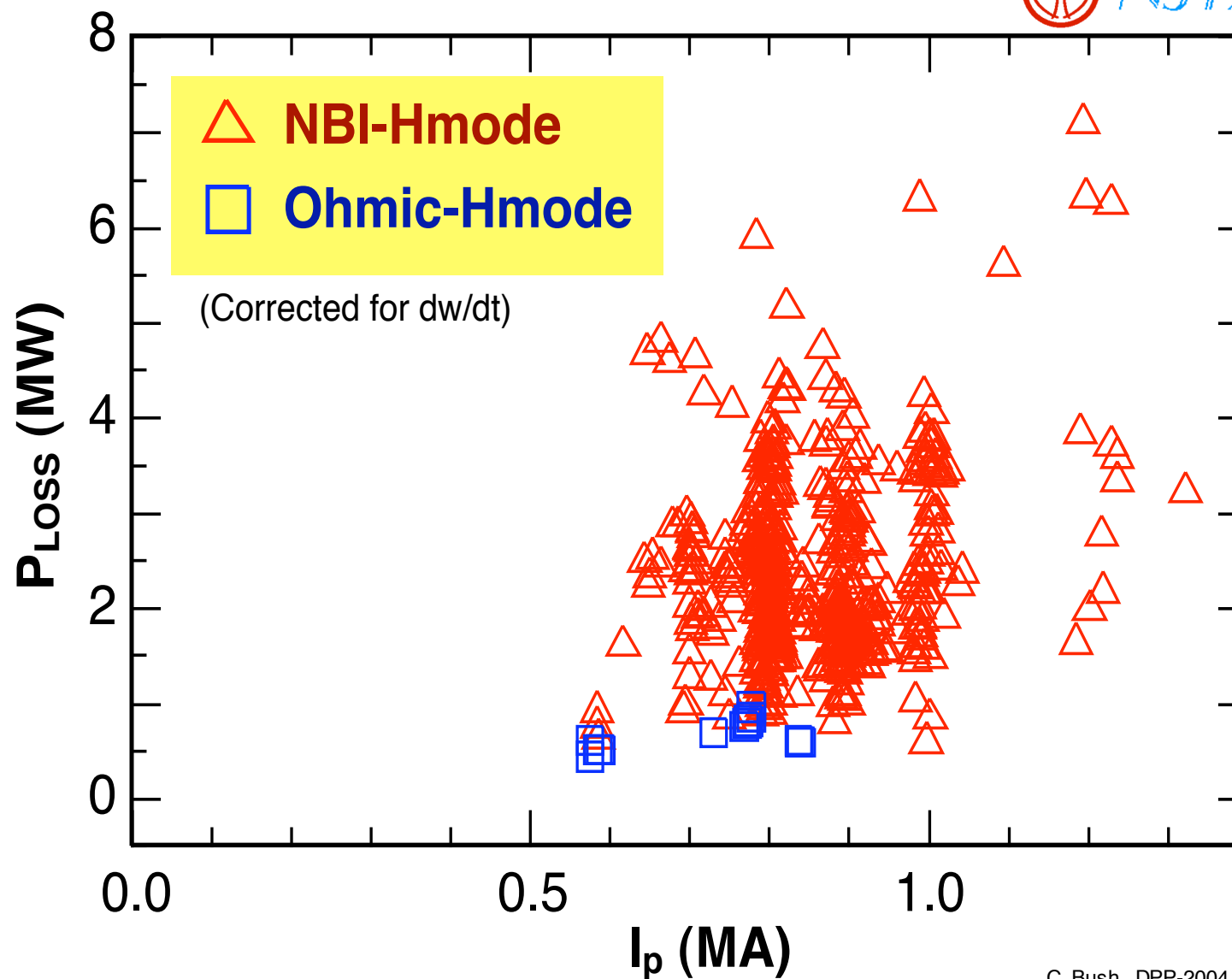


Results for Ohmic H-mode Scoping Study



- One-half run day – mini-scans in B_t and I_p
 - Some OH-H-modes randomly on other days
- H-modes at 600 to 900 kA, 3.0 to 4.5 kG TF
 - Short H-mode at $I_p = 600$ kA, $B_t = 3$ kG
- OH H-modes obtained for 1st time ever on NSTX last run
 - Most readily obtained after hot boronization
 - Alternating helium conditioning shots seem to help
 - Obtained both double null (DN) and lower single null (LSN) divertor
 - Most short duration, some with ELMs and some ELM-free
- Peaked Central n_e
 - ELMy: Small high frequency ELMs (?) keep ears from developing
 - ELM-free: have ears, but edge peak lower than central n_e
- No turbulence measurements made in core of OH H-mode
- Some edge reflectometer fluctuation data; Some GPI, no L-H

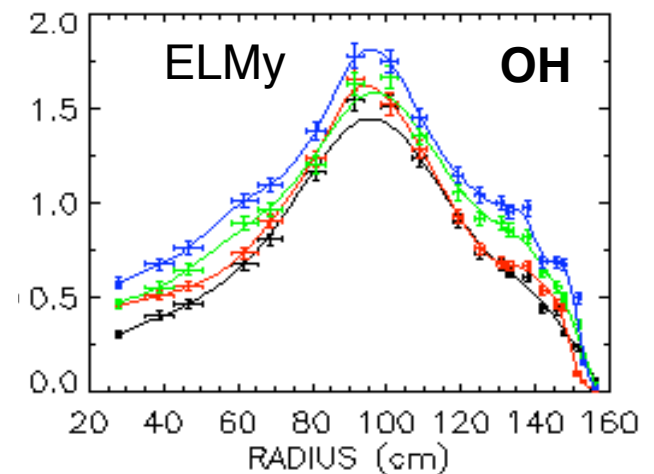
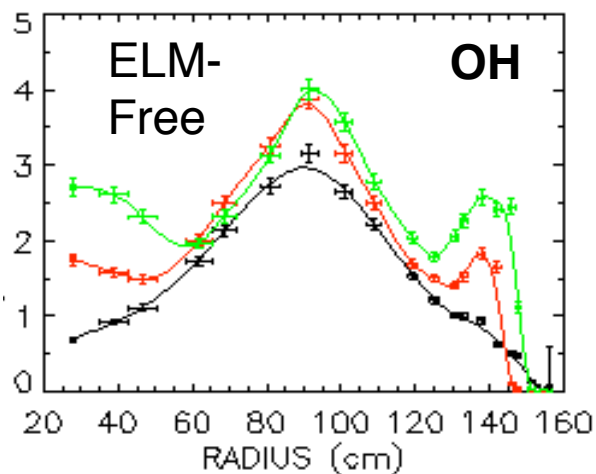
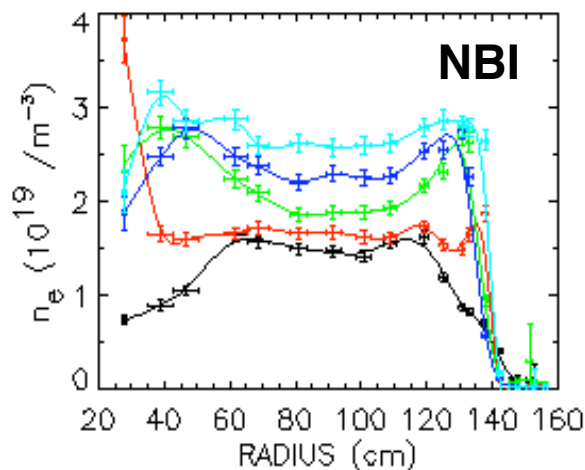
PLOSS for NBI and OH Hmodes



Comparison of Density Profiles of NBI and OH H-modes



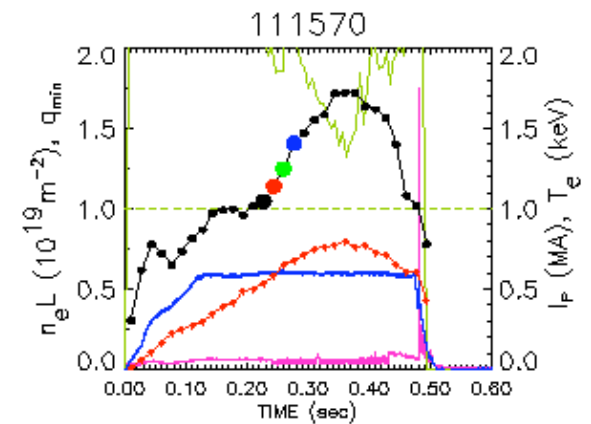
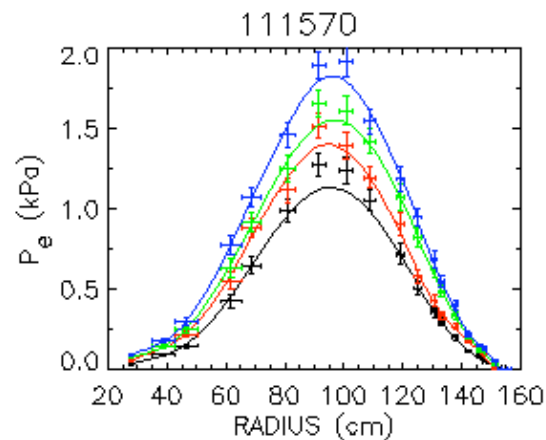
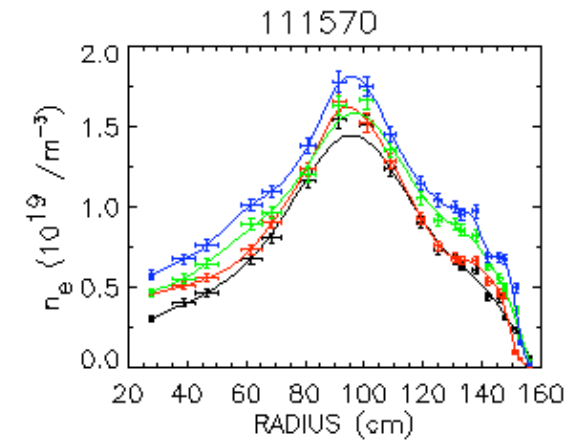
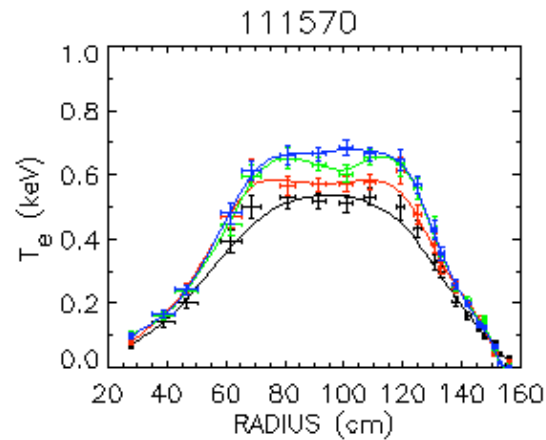
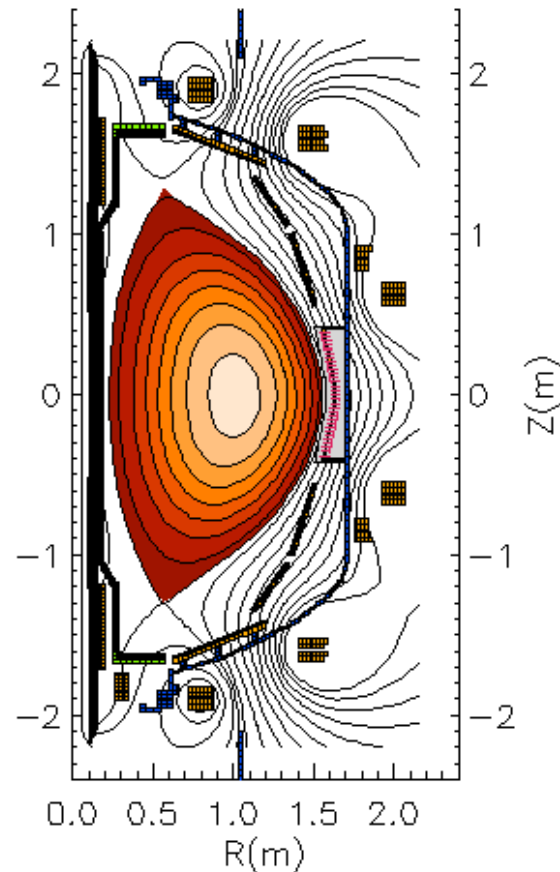
- Ohmic H-modes have low centrally peaked densities
 - Explore edge and core turbulence simultaneously
 - Target plasma for early NBI and combined ITB and ETB



OHH-mode with Dithers (DND)



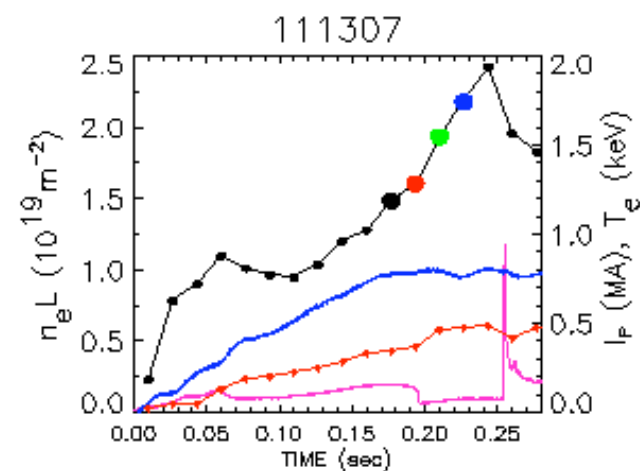
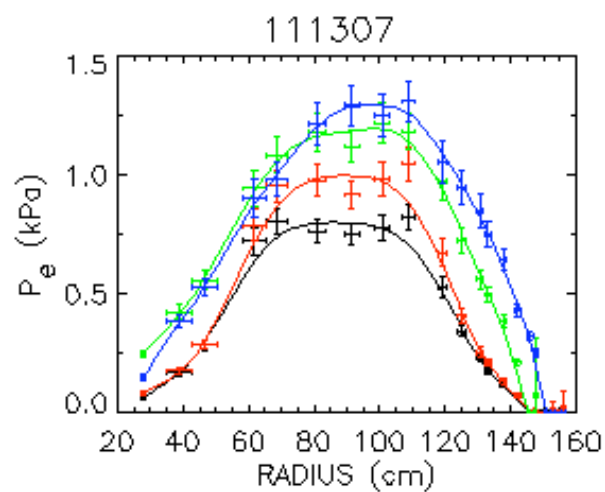
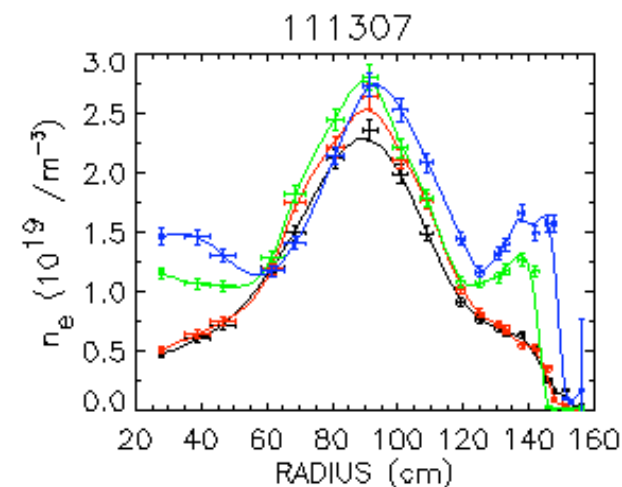
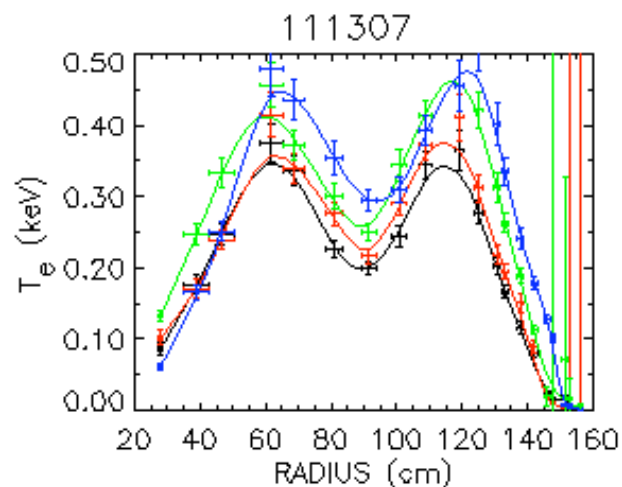
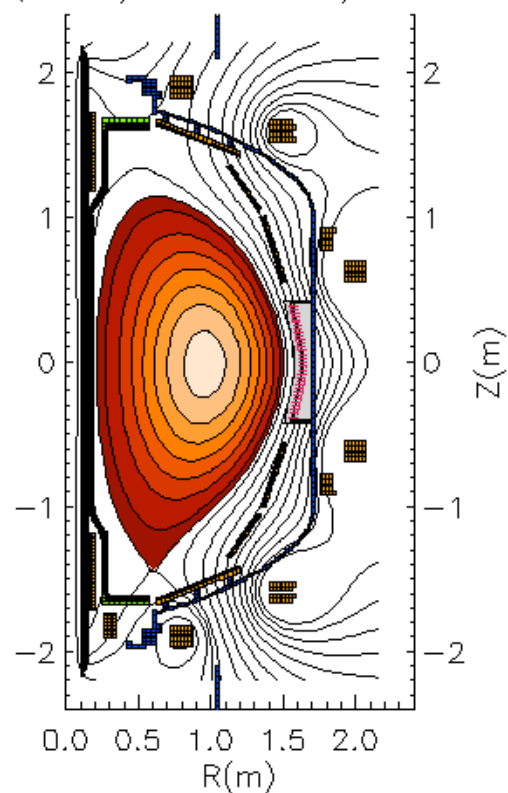
\EFIT02, Shot 111570, time=229ms



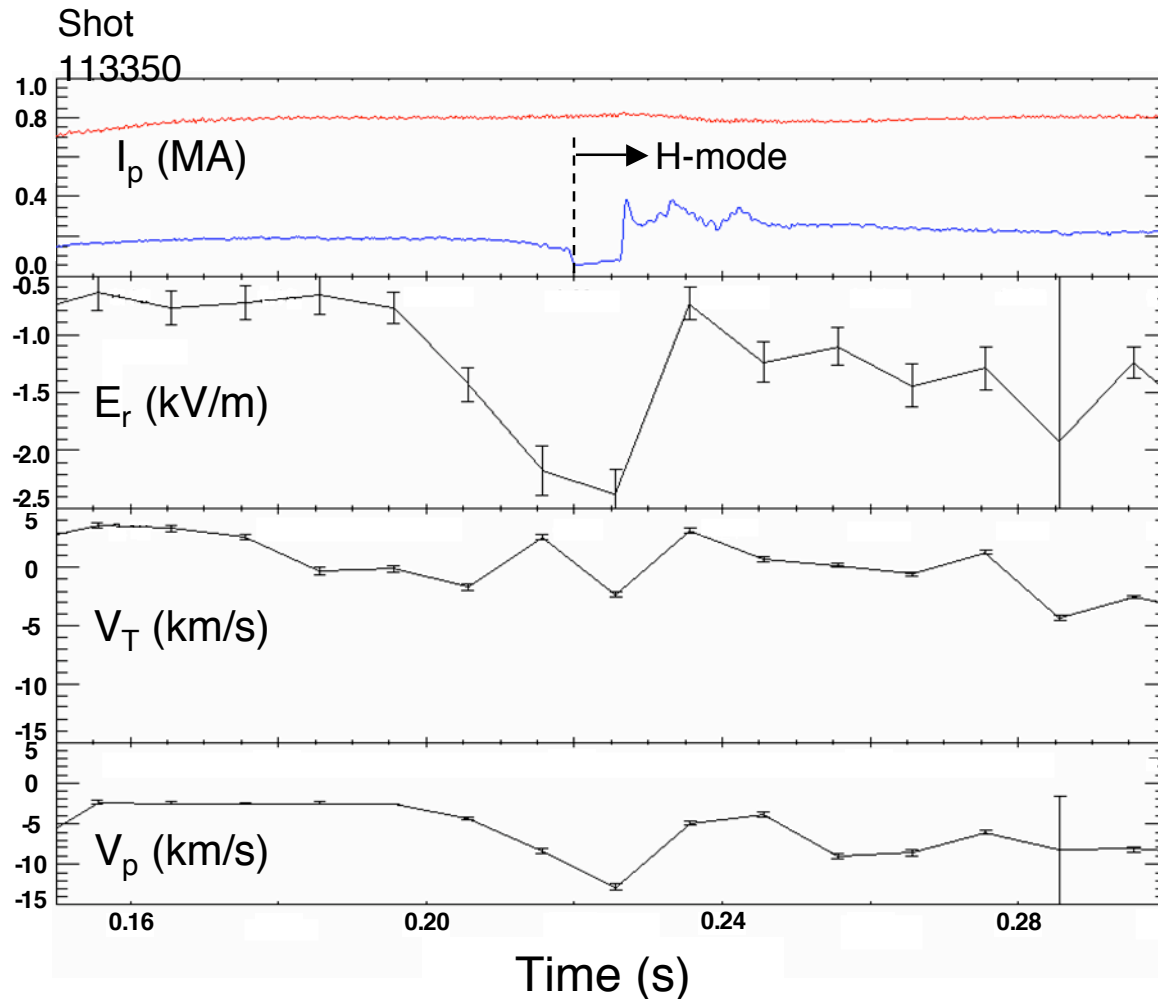
ELM-Free OHH-mode (LSN)



\EFIT01, Shot 111307, time=206ms

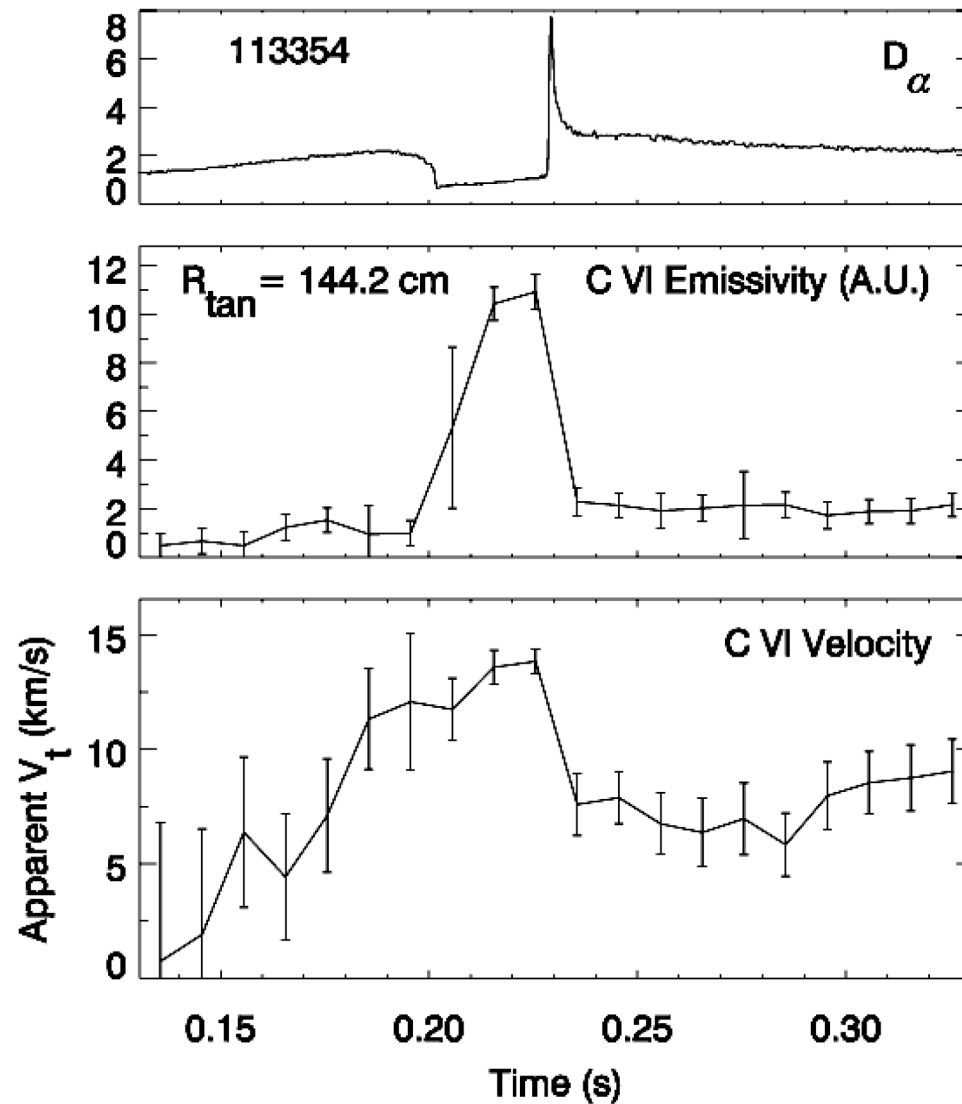


Edge measurements (ERD) in Ohmic H-modes show E_r and V_p change prior to L-H transition

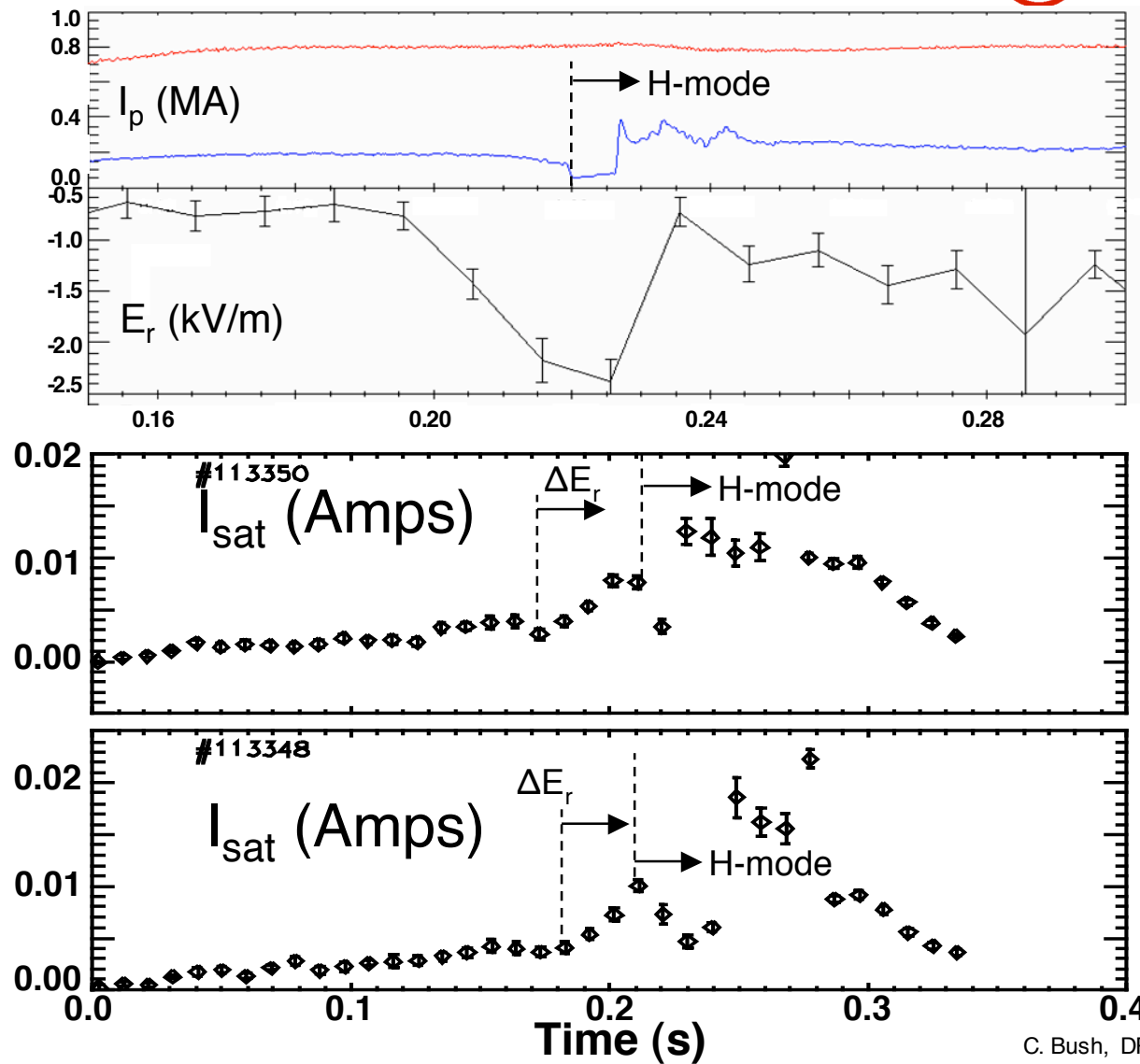


E_r and V_p begin to change 10 to 20 ms before L-H transition (here at $t \sim 0.220$ sec)

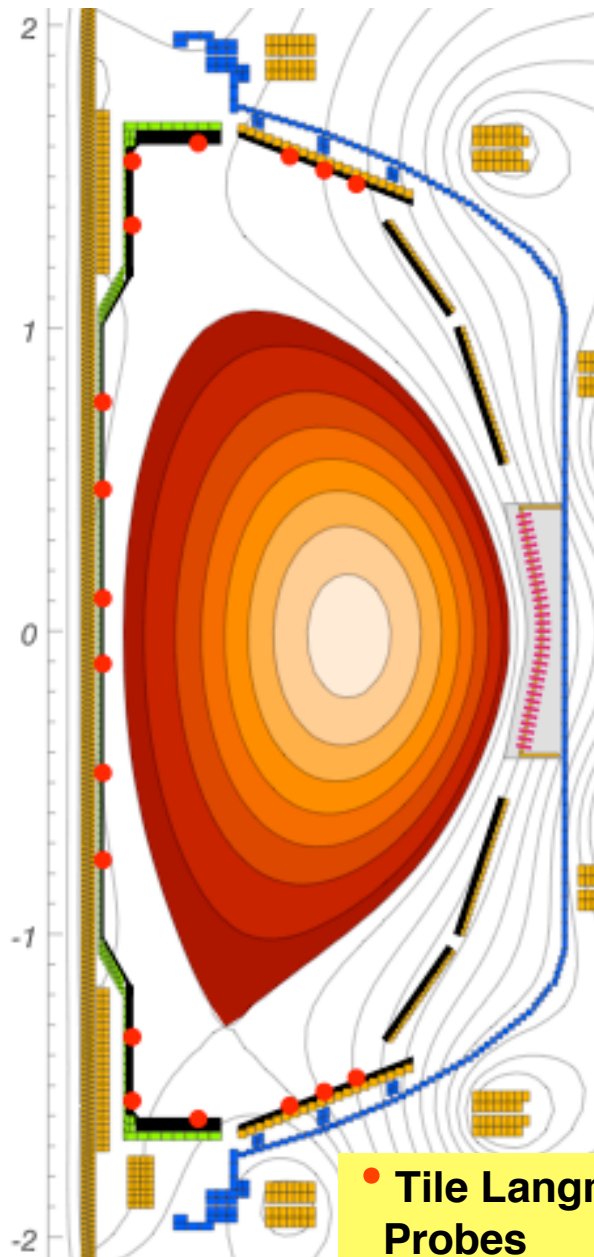
C VI Emissivity and Toroidal Velocity at Plasma Edge



Edge Er and Probe Ion Saturation Current vs. Time



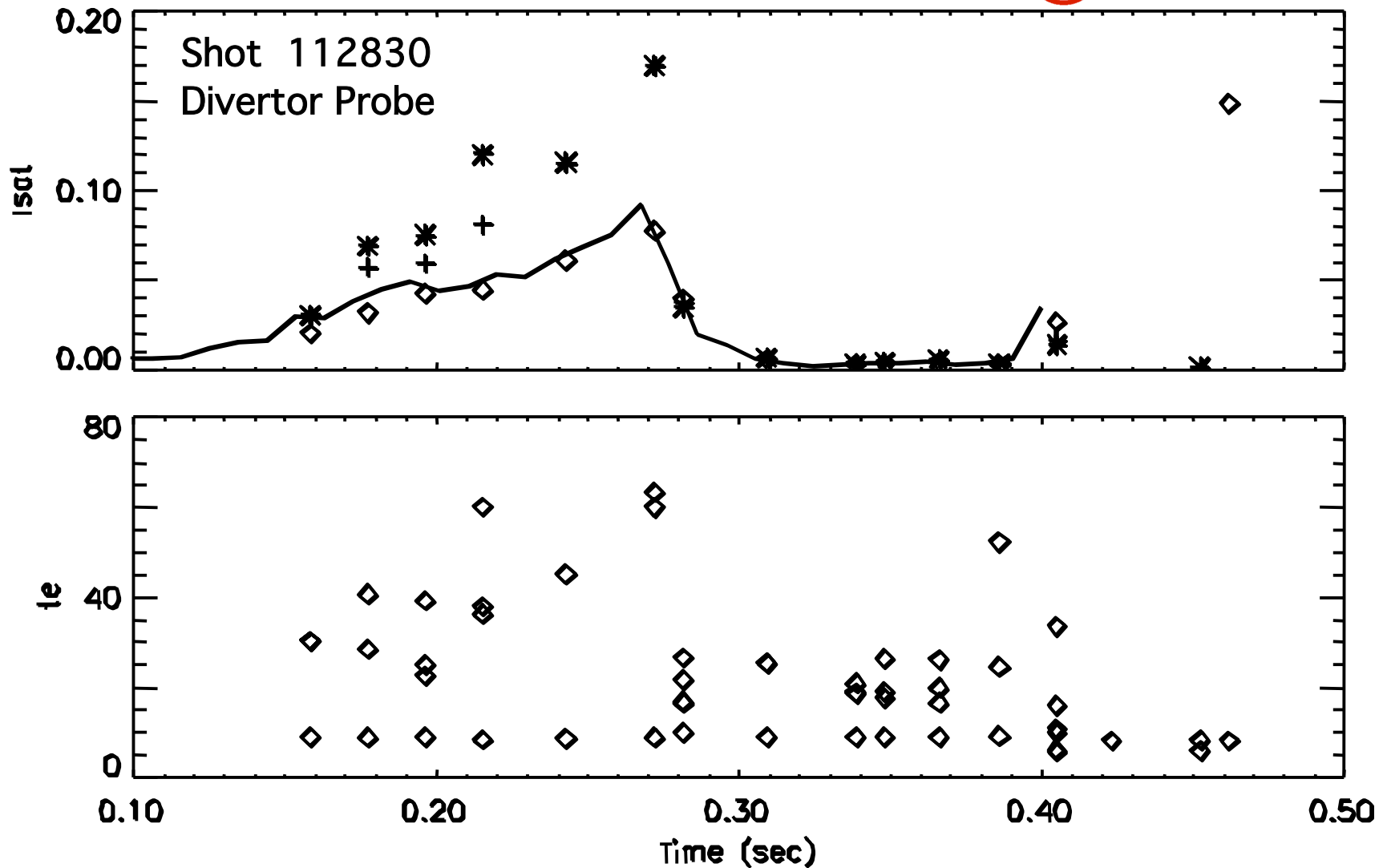
Langmuir Probes



• Tile Langmuir Probes

- Flush mounted single probes
- Total of 22 probes, 6 top and 6 bottom divertors
 - Remainder along centerstack
- Have data for vast majority of shots
- Virtually no signal from centerstack probes when plasma is diverted
- Some I_{sat} , T_e , n_e data in Tree

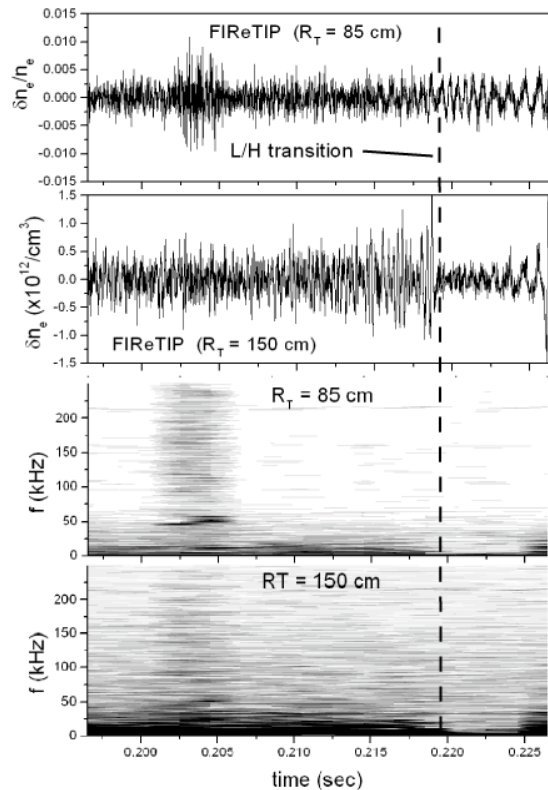
Determination of T_e from Probe Data



Electron Density Fluctuations from FReTIP Show Increased Intensity 10 to > 35 msec before L-H Transition



K.C. Lee & H. Park



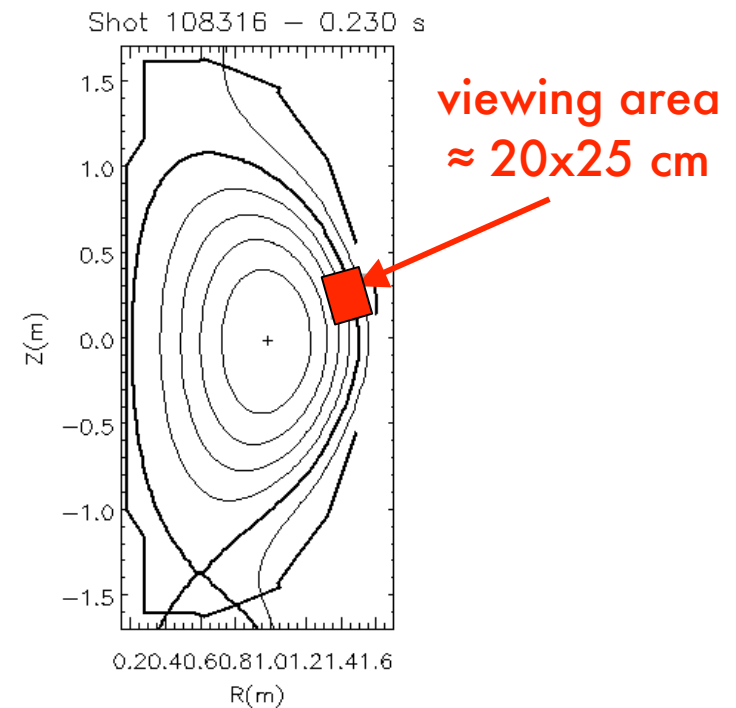
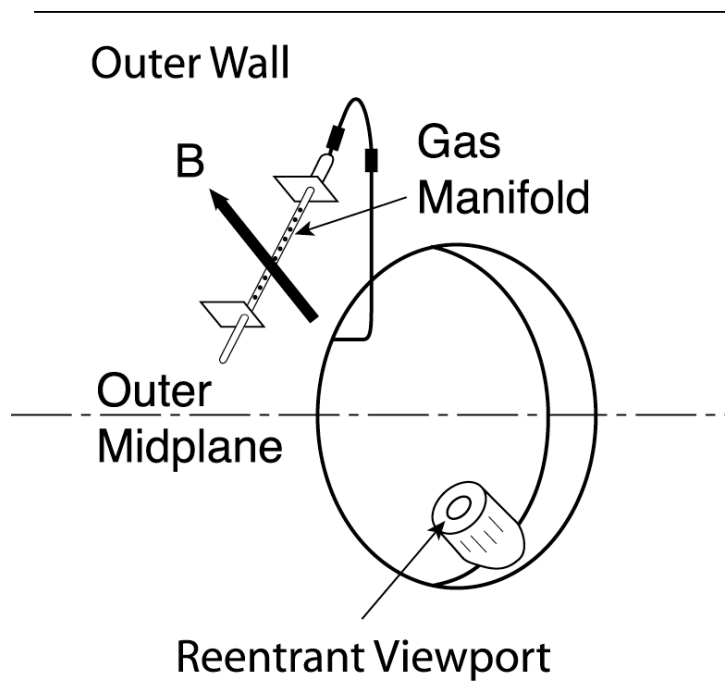
Shot number	L/H transition and data status	Start time of fluctuation increase (ahead of H transition)	Duration of fluctuation increase
111292	Clear	20 msec	10 msec
111307	Clear	25 msec	10 msec
111570	Clear	20 msec	8 msec
111571	Not clear		
111696	Not clear		
111697	Not clear		
111416	Clear	10 msec	10 msec
111821	Not clear		
111822	Not clear		
111832	Weak H-mode		
111834	Weak H-mode	30 msec	30 msec
111826	Weak H-mode		
113348	Weak H-mode		
113350*	Clear	18 msec	3 msec
113354	Clear	35 msec	1 msec
113356	Not clear		
113361	Clear	(1) 60 msec (2) 4 msec	(1) 10 msec (2) 1 msec

- The FReTIP electron density fluctuation and its spectrum at one of core channel ($R_t=85$ cm) and the edge channel ($R_t=150$ cm). There is a time period of fluctuation increase about 18 msec ahead of the H-mode transition which is within the time scale of radial electric field formation (Fig xx) starting point and it last about 3 msec.

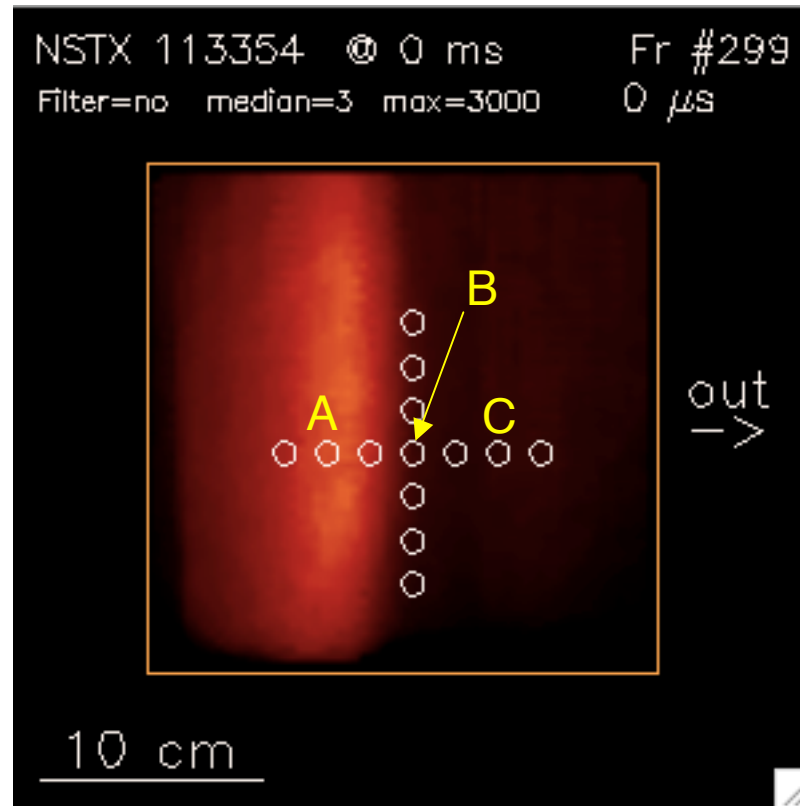
GPI Hardware and Orientation



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



GPI Fast Chords for OHH-mode Study



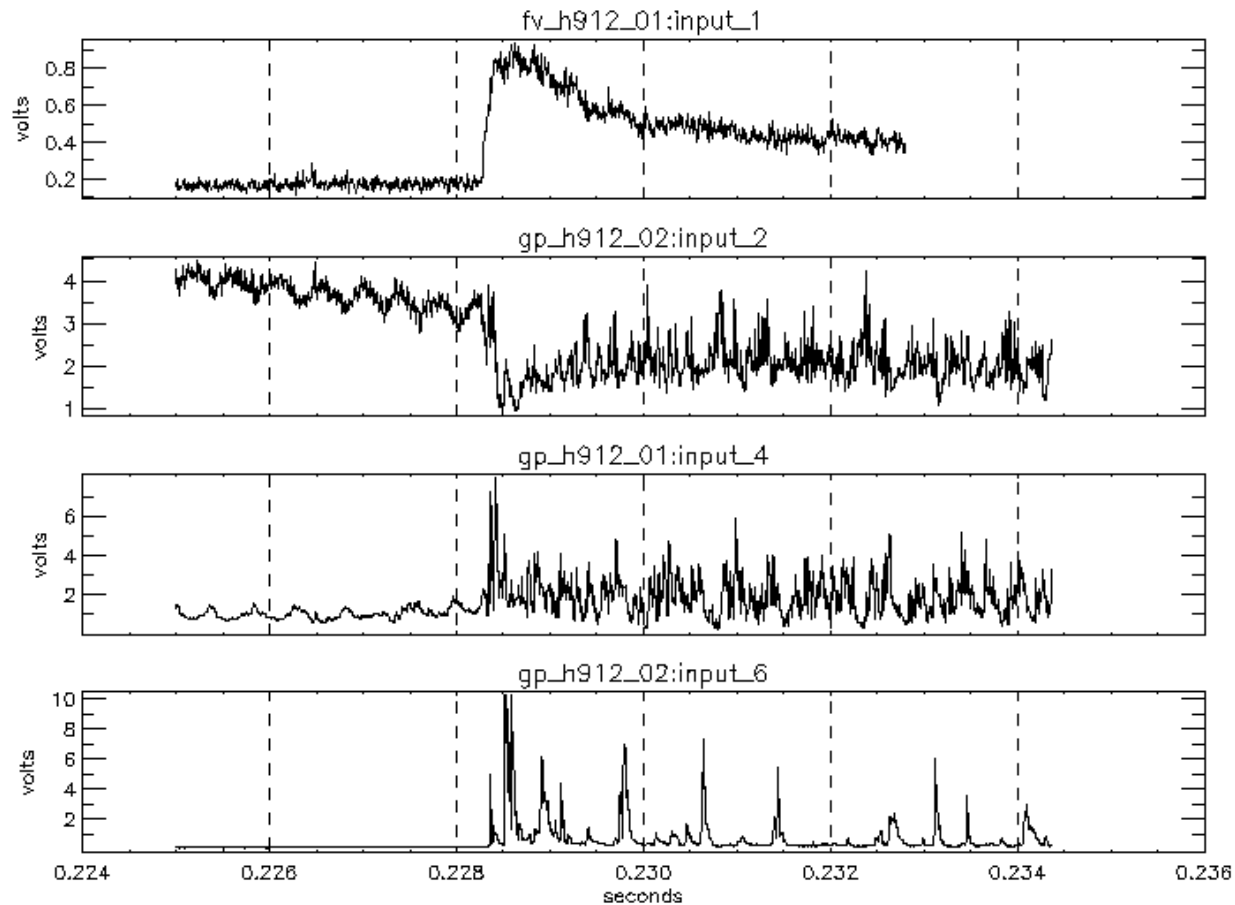
S. Zweben
And
R. Maqueda

Location of radial and poloidal views for
Fast chordal data

Fast Chord Data Showing Increased Turbulence at an H-L (back) Transition of an OHH-mode



Shots:
113354



fast D_{α}

Fast Chord A

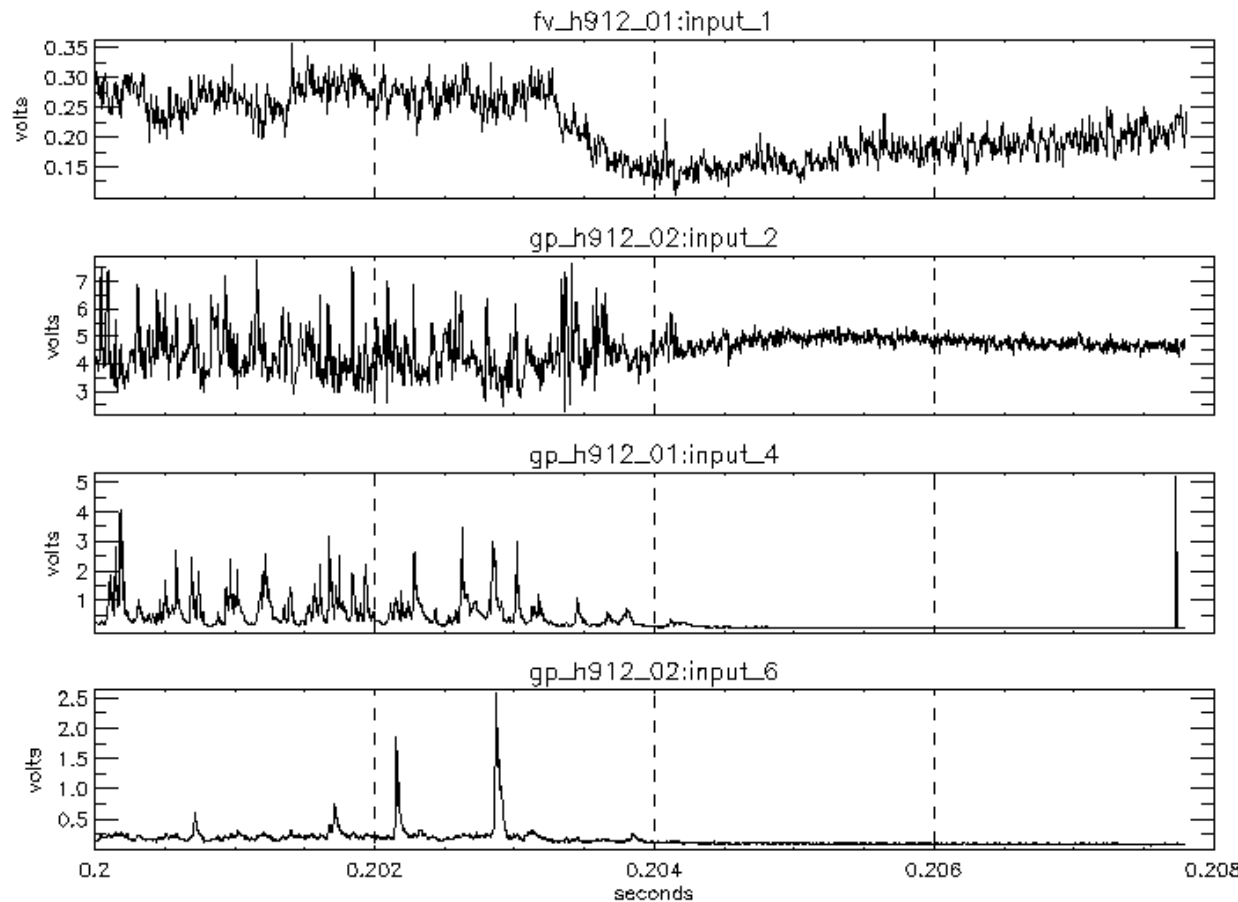
Fast Chord B

Fast Chord C

Fast Chord Data Showing decreased Turbulence at an L-H Transition of an OHH-mode



Shots:
113356



fast D_{α}

Fast Chord A

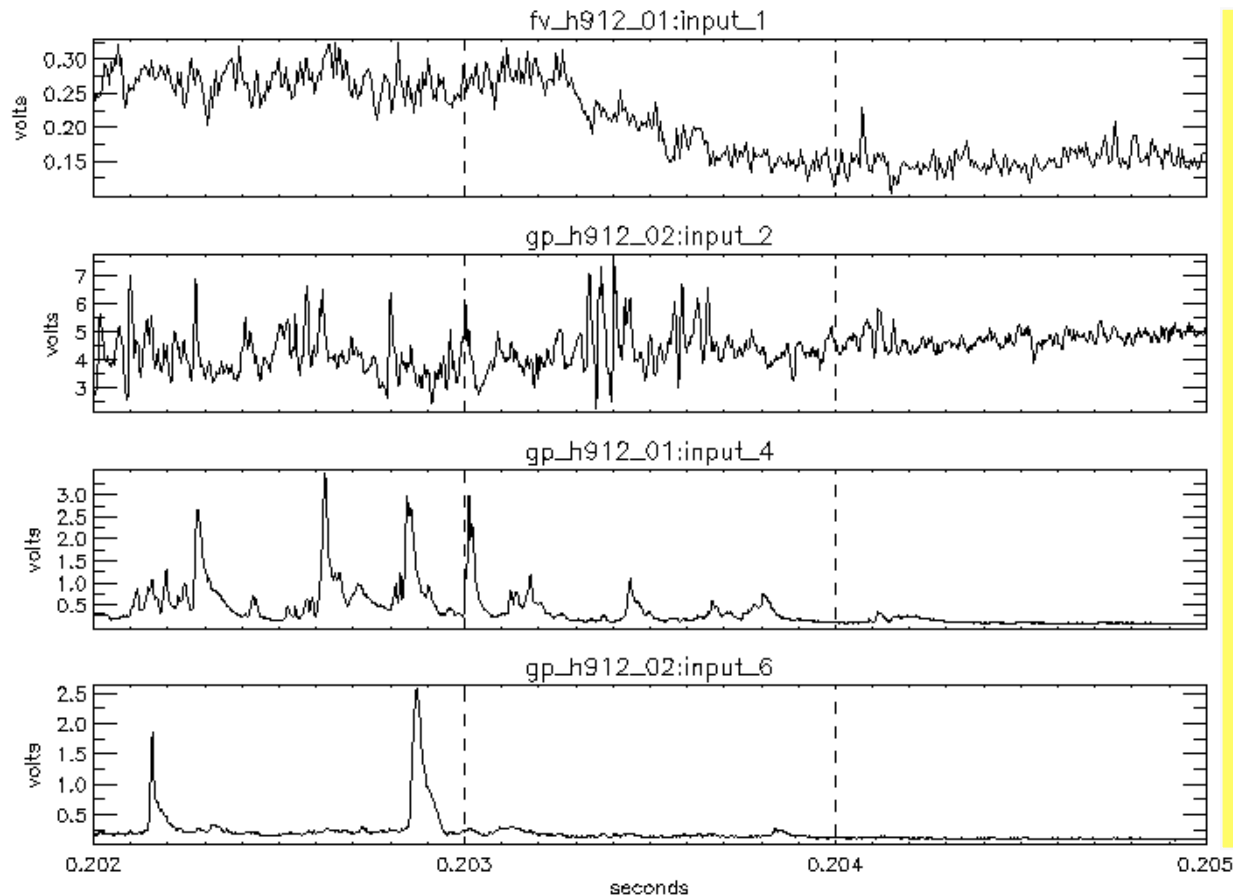
Fast Chord B

Fast Chord C

Fast Chord Data Showing decreased Turbulence at an L-H Transition of an OHH-mode



Shots:
113356



fast D_{α}

Fast Chord A

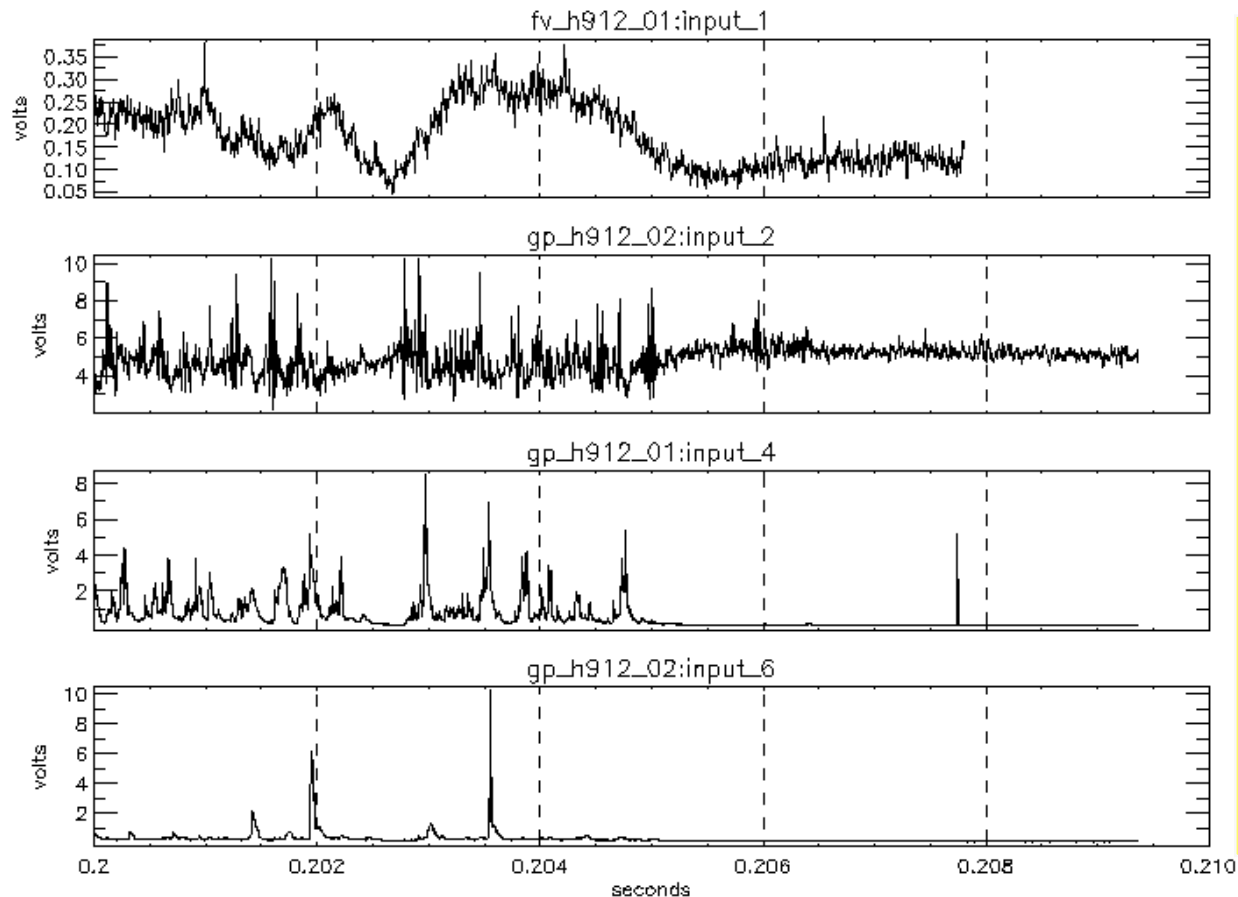
Fast Chord B

Fast Chord C

Fast Chord Data Showing decreased Turbulence at an L-H Transition of an OHH-mode



Shots:
113361



fast D_{α}

Fast Chord A

Fast Chord B

Fast Chord C

GPI Data

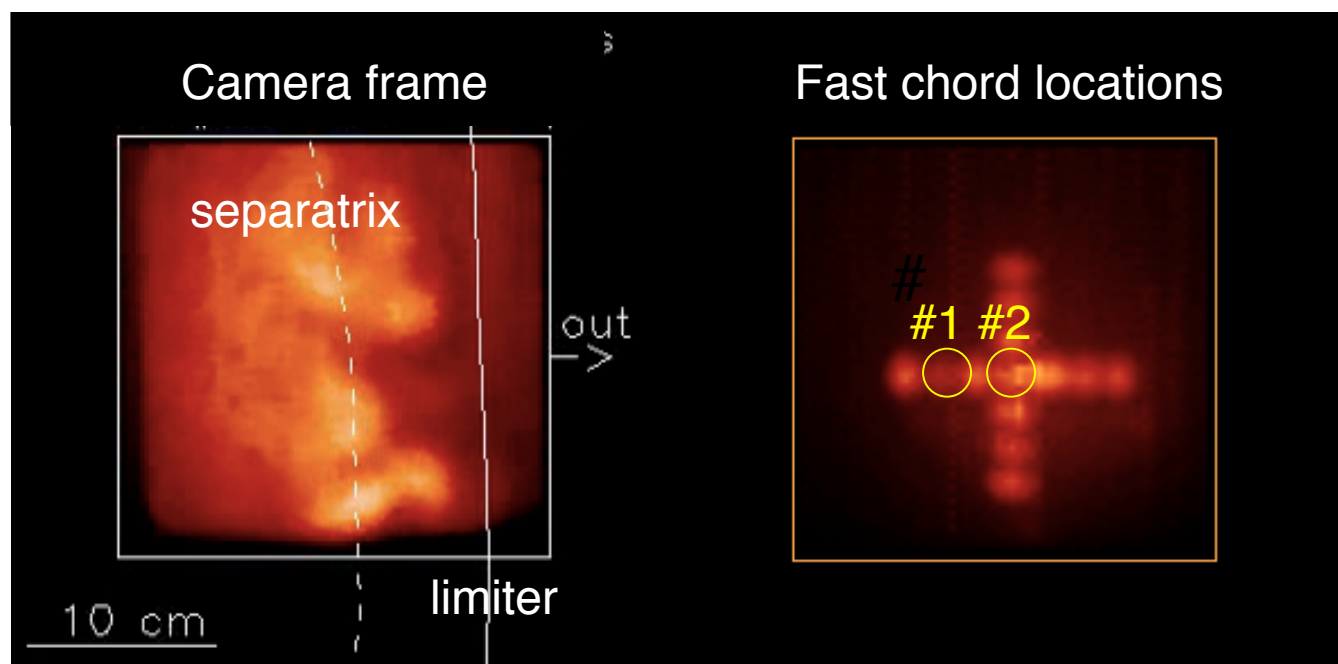


PSI-5 Camera (300 frames/shot):

- $\leq 250,000$ frames/sec with 64×64 pixels per frame

Fast Chords (13 channels/shot):

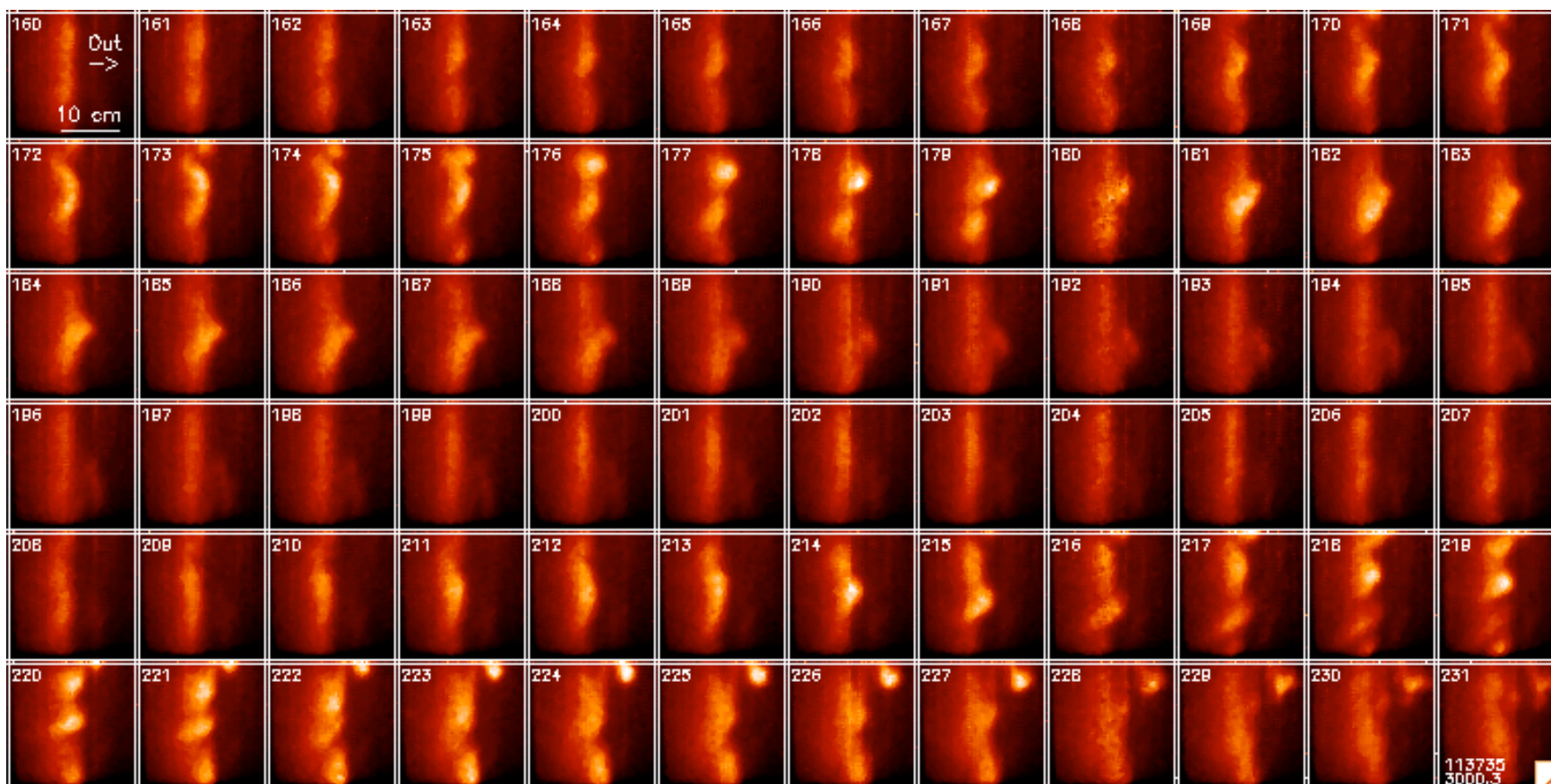
- 2 cm spots into PM tubes with 200 kHz bandwidth



Just Before L-H Transition Images



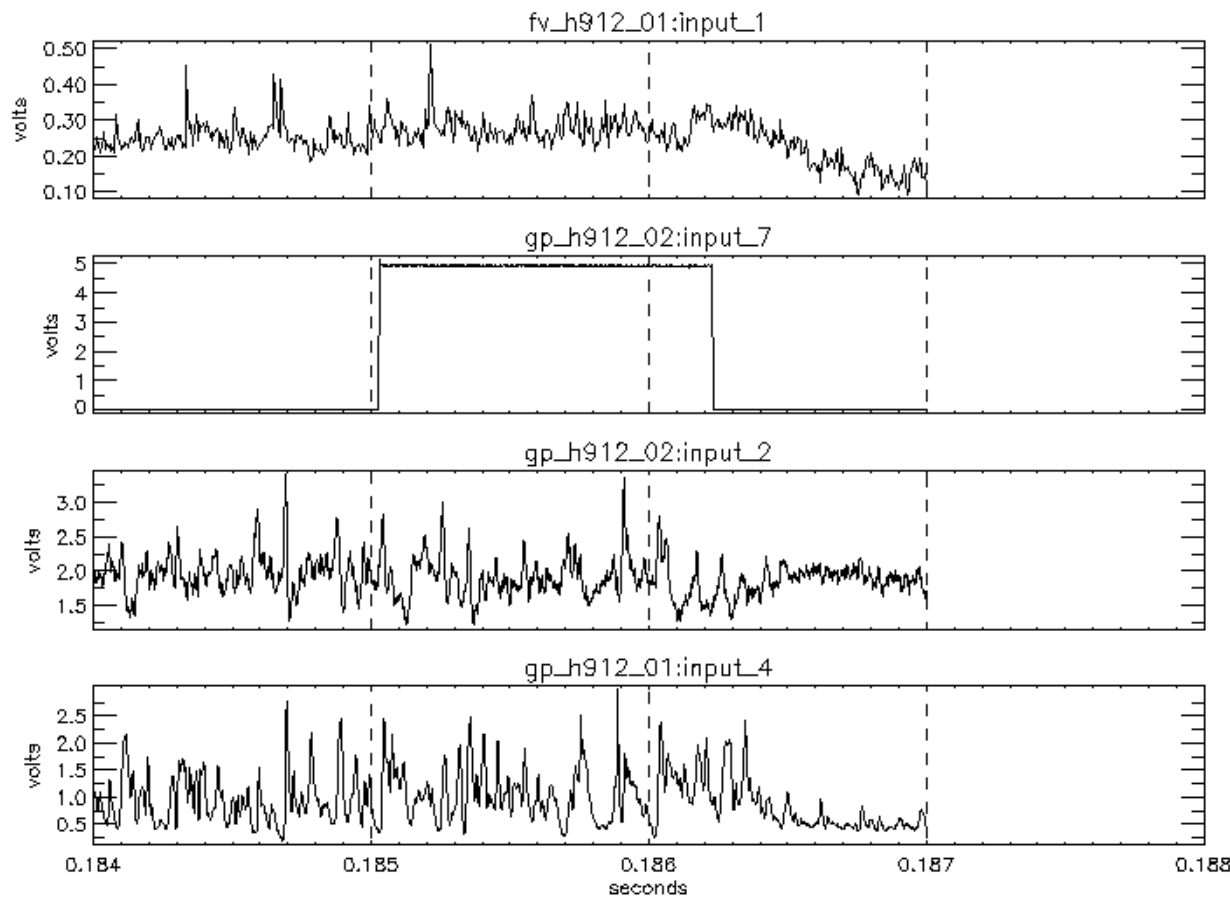
113735 @ 4 μ sec/frame (D_{α} light)



Just Before L-H Fast Chord Data



Shots:
113735



Divertor D_α

Camera gate

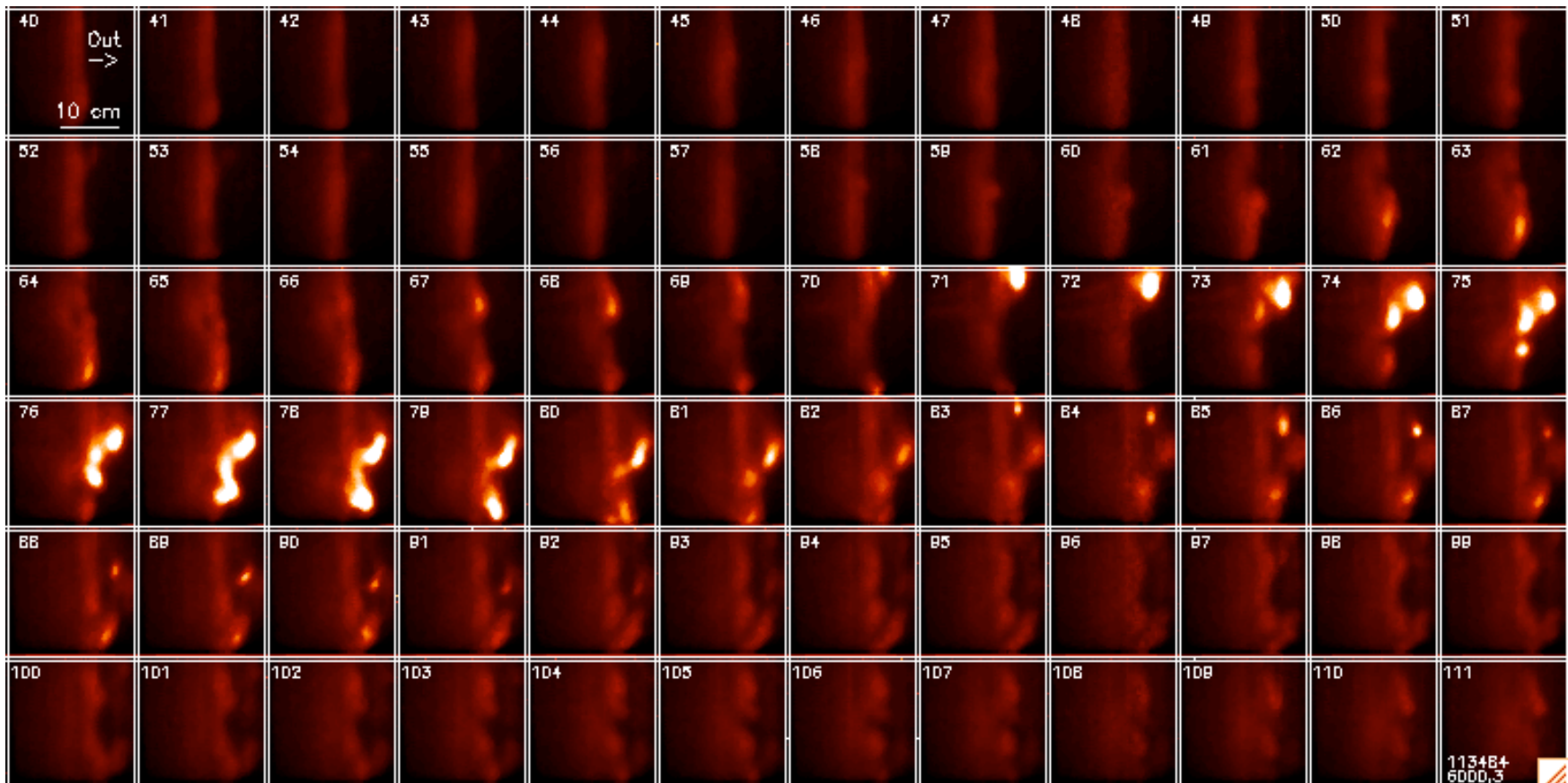
Fast chord #1

Fast chord #2

Medium ELM Images #2



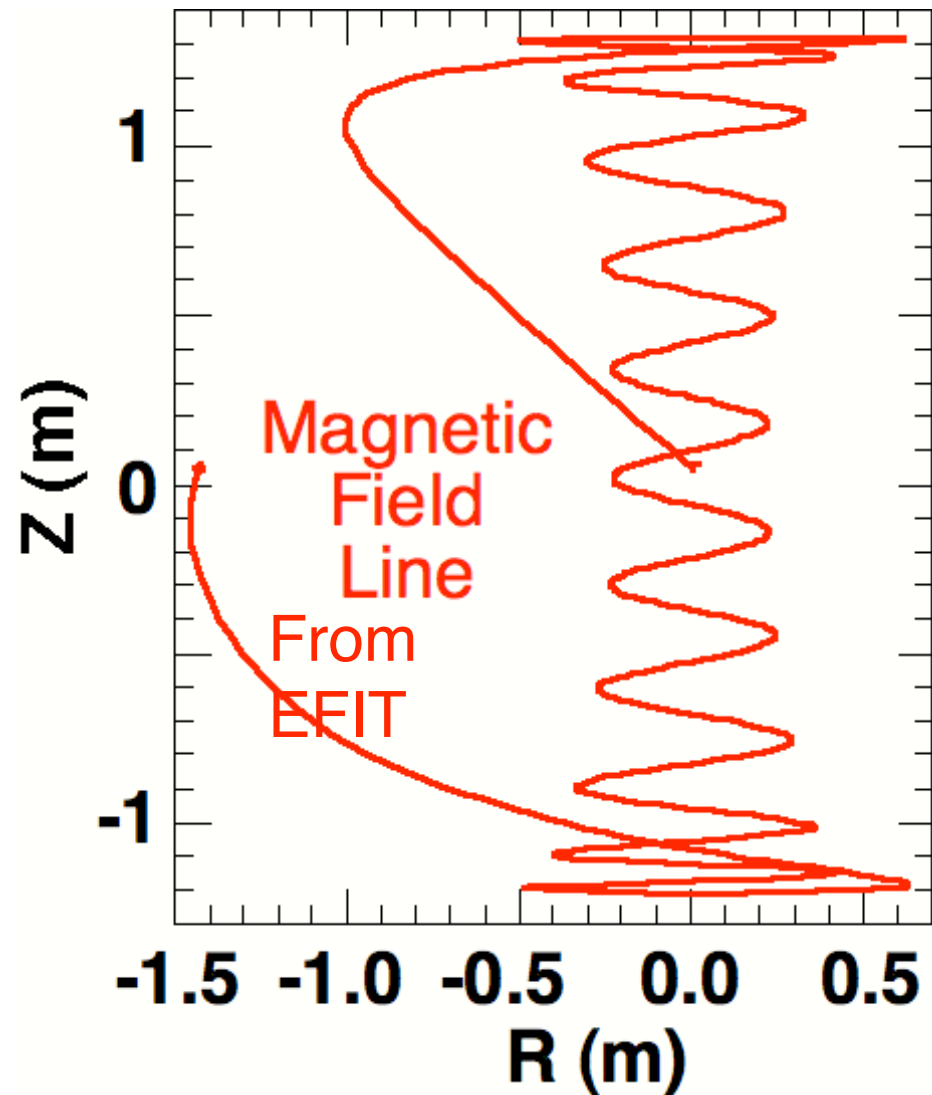
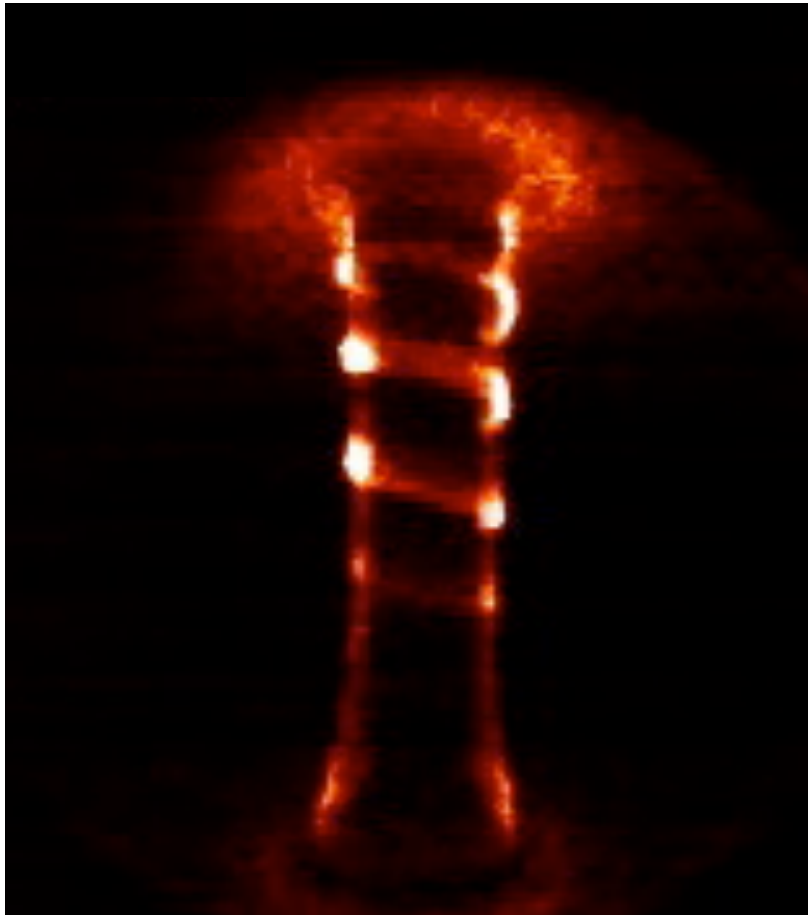
#113484 @ 4 μ sec/frame (D_{α} light)



Activity Near Inner Wall During an ELM (160 ms)



Shot 113862



C. Bush, DFP-2004

Summary of L-H Transition Data



- Transition from turbulent L-mode to quiescent H-mode usually occurs within $\leq 50 \mu\text{sec}$
- Apparently no new spatial structure or motion during the transition time - the edge turbulence just “turns-off”
- Often the main L-H transition is preceded by $\approx 1\text{-}5 \text{ msec}$ of intermittent quiescent (H-mode-like) periods
- The H-L transition usually looks like a high-m instability which evolves into a blob-like radial structure