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ELM and L-H Transition Dynamics in NSTX

Rajesh Maingi
Oak Ridge National Laboratory

C.E. Bush 1), E.D. Fredrickson 2), J.E. Menard 2), N. Nishino 3), A. L. Roquemore 2), K. Tritz 8), S.J. Zweben 2), M.G. Bell 2), R.E. Bell 2), J. Boedo 4), D.A. Gates 2), D.W. Johnson 2), R. Kaita 2), S.M. Kaye 2), H.W. Kugel 2), B.P. LeBlanc 2), R.J. Maqueda 6), D. Mueller 2), S.A. Sabbagh 7), V.A. Soukhanovskii 5), D. Stutman 8)

1) Oak Ridge National Laboratory
2) Princeton Plasma Physics Laboratory
3) Hiroshima University, Japan
4) Univ. California - San Diego
5) Lawrence Livermore National Laboratory
6) Fusion Physics and Technology
7) Columbia University
8) Johns Hopkins University

IAEA Fusion Energy Conference
Vilamoura, Portugal
Nov. 2, 2004

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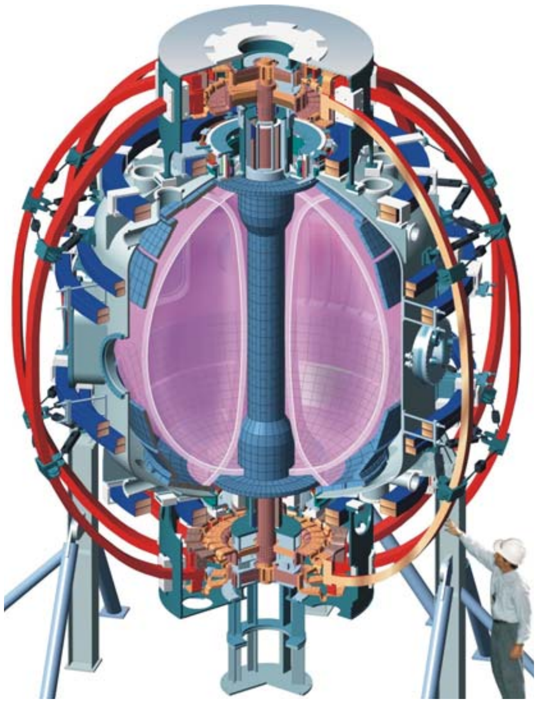
High Performance, Small ELM regime Observed in NSTX

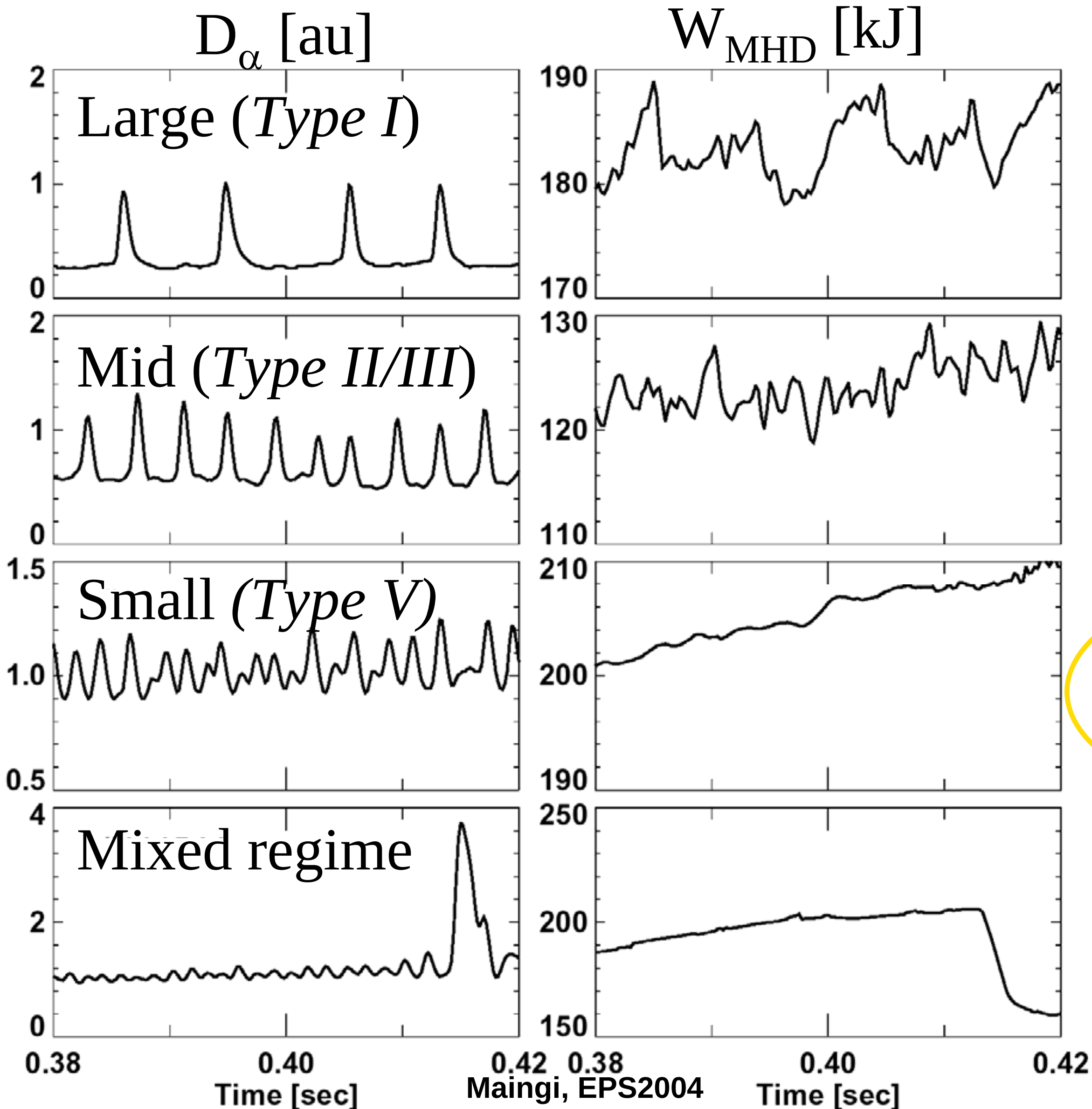


Outline

- Overview of ELM regimes
- Small ELM signatures
  - Visible cameras at several poloidal locations
  - Magnetics and soft X-rays
- Turbulence imaging during L-H transition

Parameters	Value
Major Radius	0.85m
Minor Radius	0.67m
Plasma Current	1.5 MA
Toroidal Field	0.45T
NBI/RF Heating	7.4/6 MW

Many Different ELM types Observed in NSTX



Maingi, EPS2004

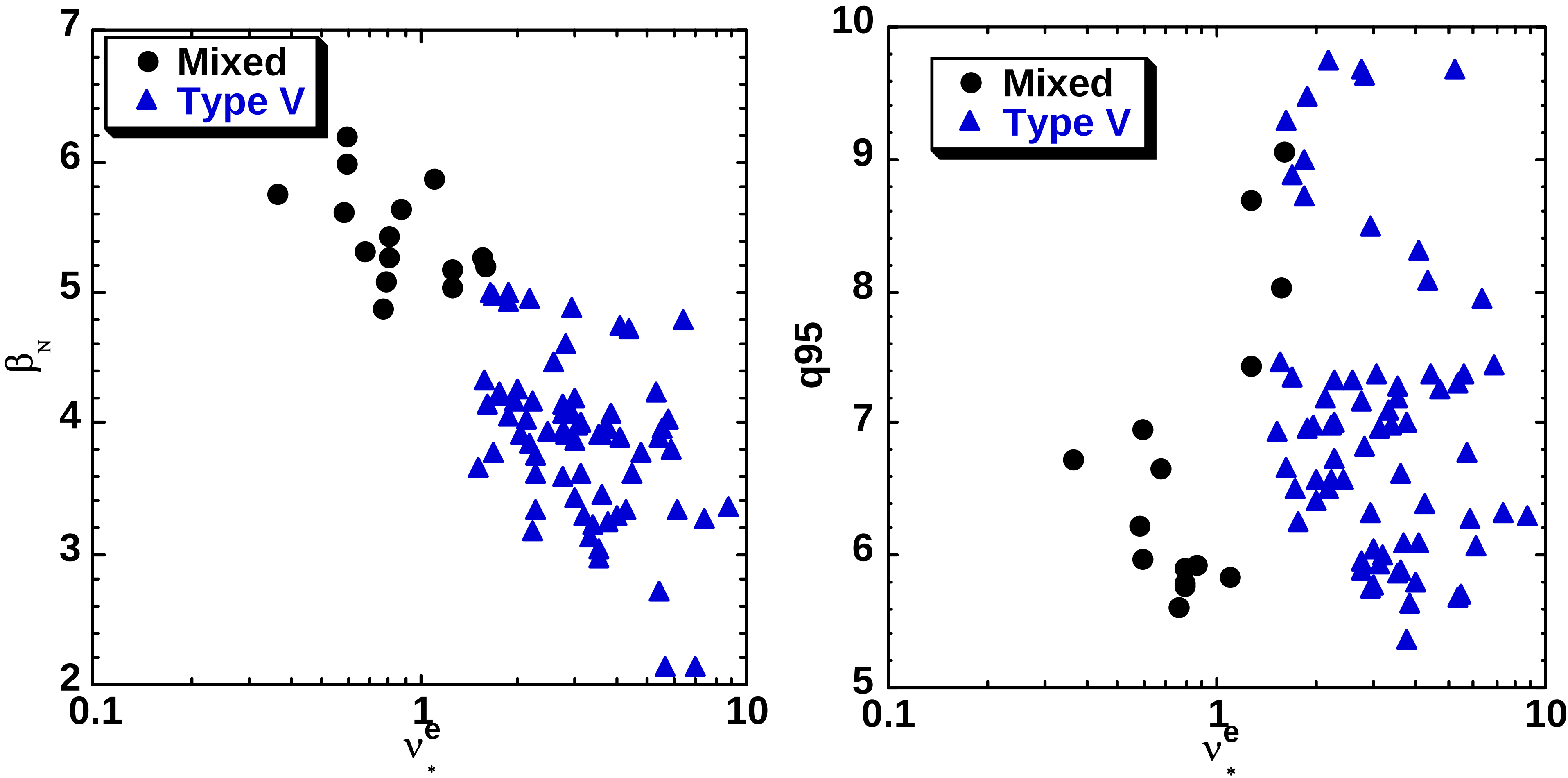
$\Delta W_{MHD}/W_{MHD} \sim$ 3-15%
$P_{heat} >> P_{L\text{-}H}$

$\Delta W_{MHD}/W_{MHD} \sim$ 1-5%
$P_{heat} \geq P_{L\text{-}H}$

$\Delta W_{MHD}/W_{MHD} \leq$ 1%
Wide P_{heat} range

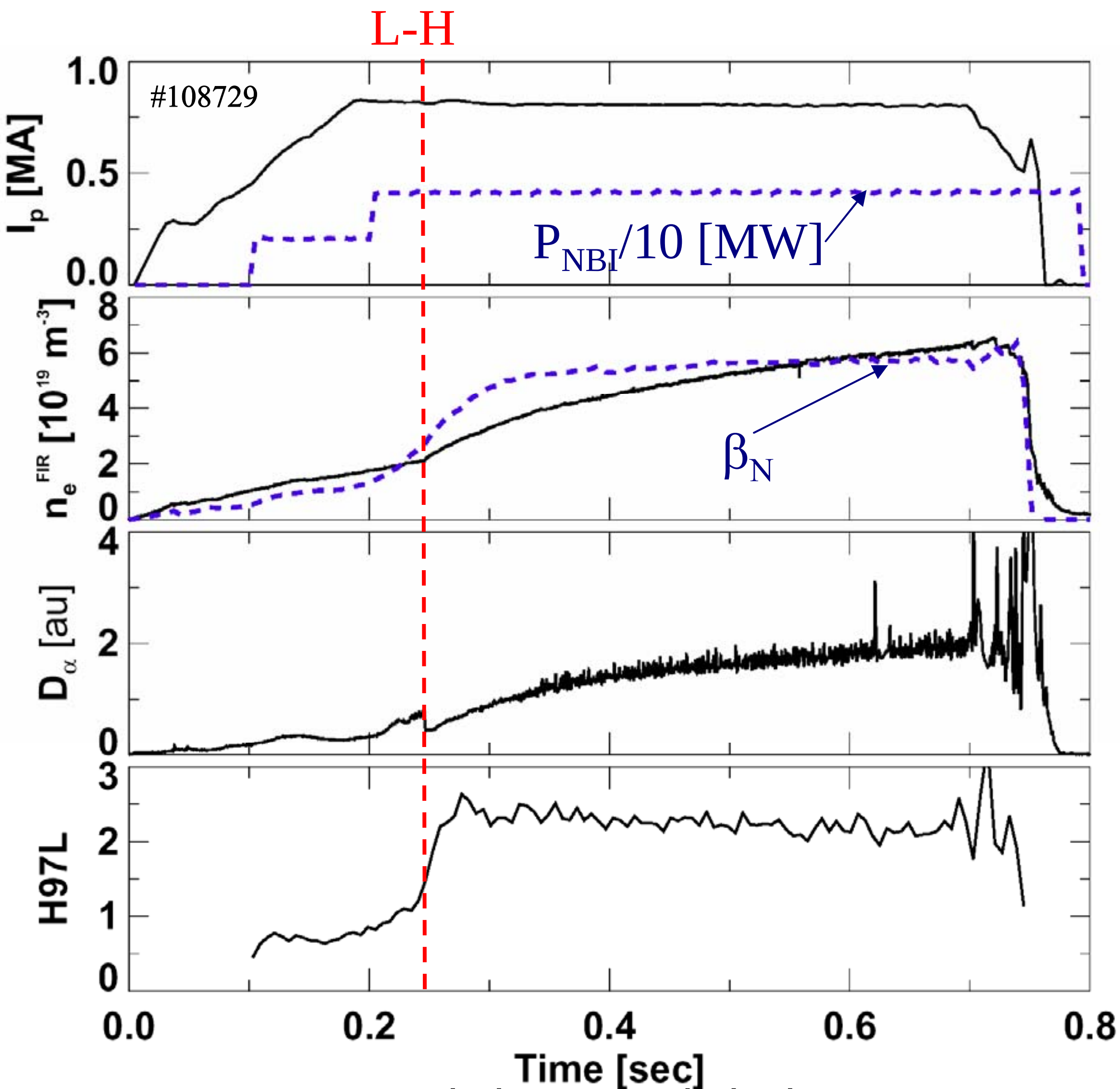
$\Delta W_{MHD}/W_{MHD} \leq$ 30%
High P_{heat}, β_N

Pedestal $\nu_*^e \approx 1$ Divides Type V and Mixed ELM regimes



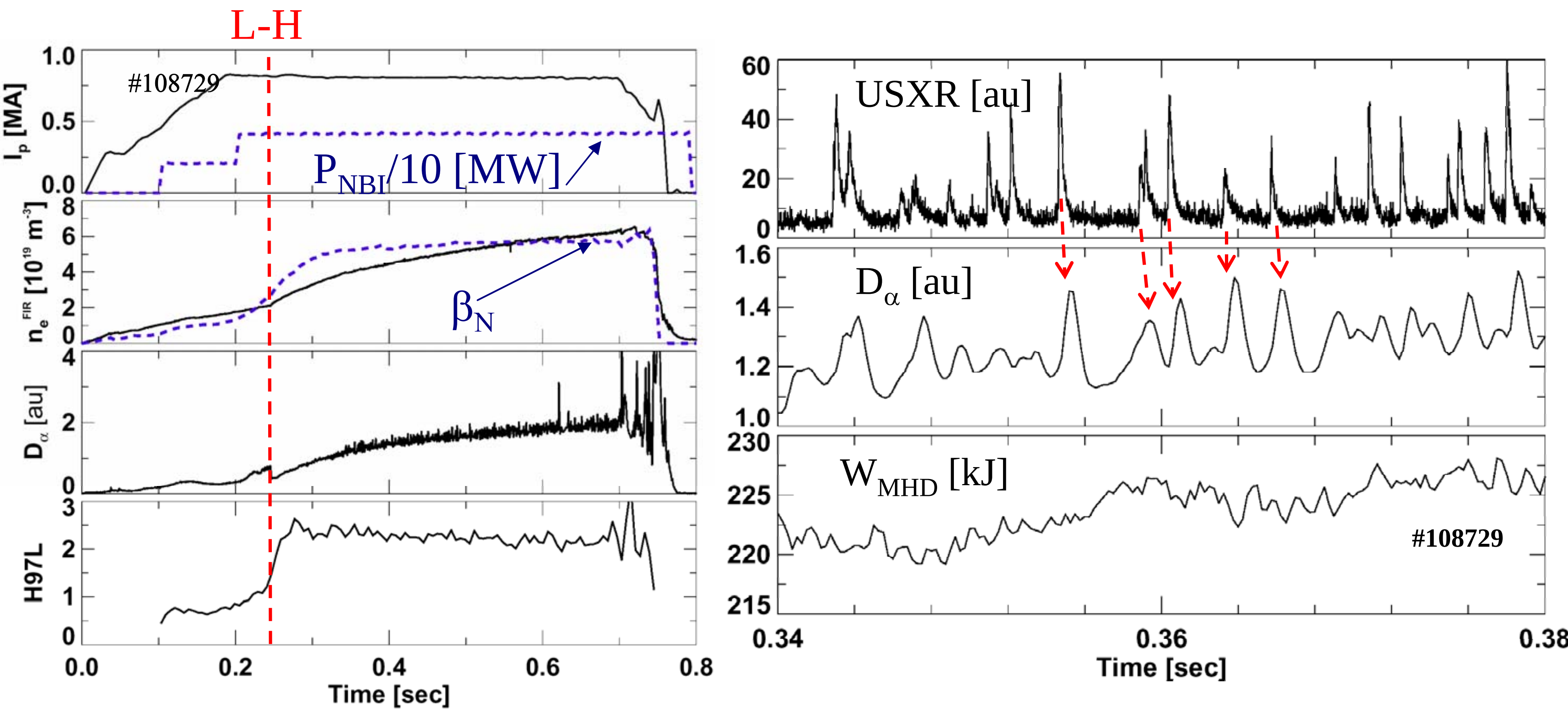
I_p: 0.6-0.9 MA, B_t=0.45 T, P_{NBI}: 2-6 MW, LSN, κ=2.0, δ=0.4

Small ELMs (*Type V*) are an important ingredient of long pulse, high performance discharges



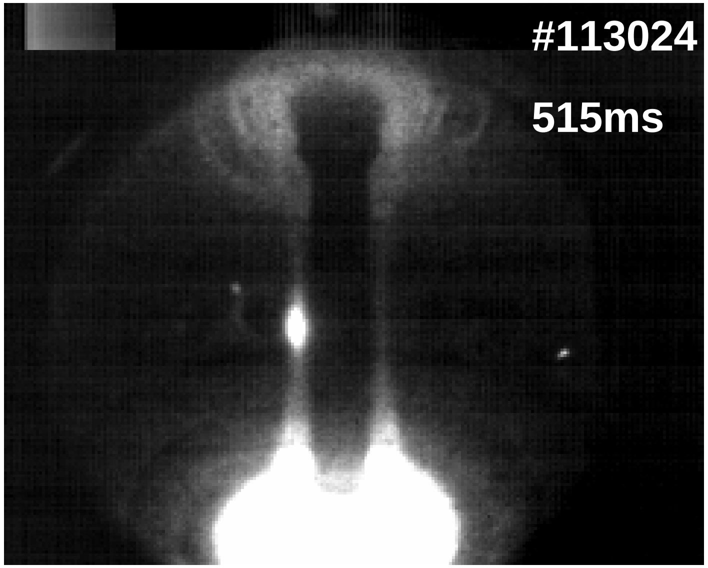
Maingi, NF 2004 submitted

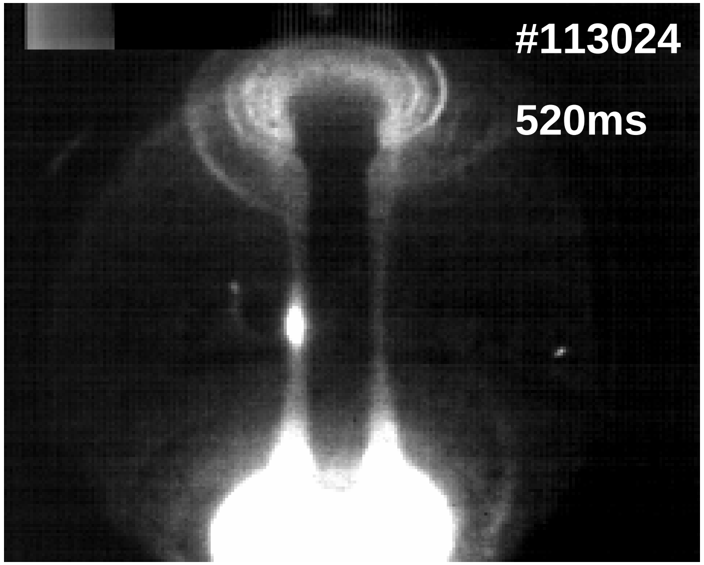
Small ELMs are distinct, individual perturbations with signatures on D_α and Ultra-Soft X-Rays



Maingi, NF 2004 submitted

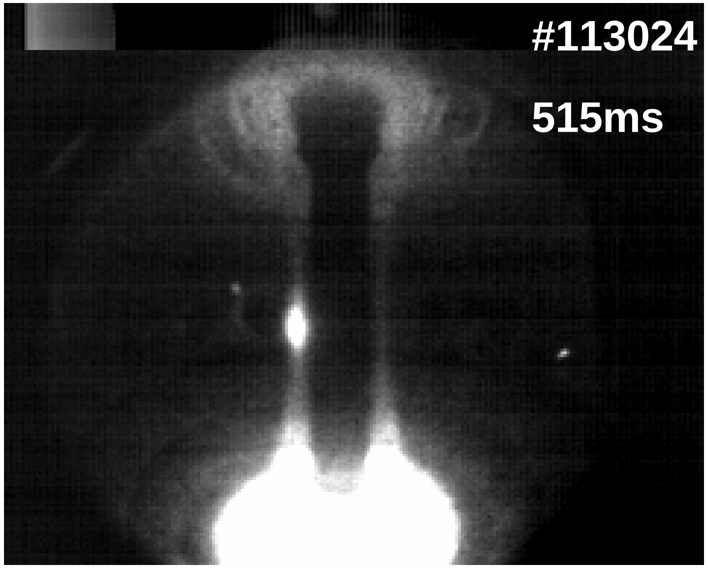
Plasma Fisheye TV Shows Localized Perturbation for Small ELM crash

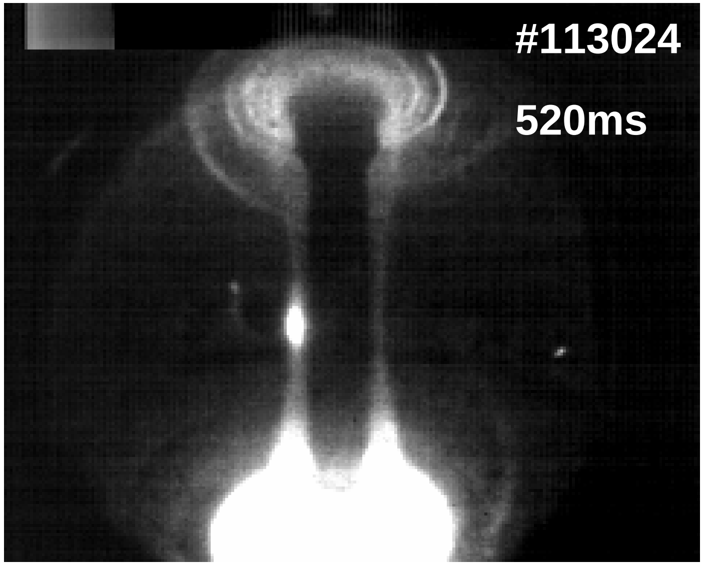




Bush (ORNL)

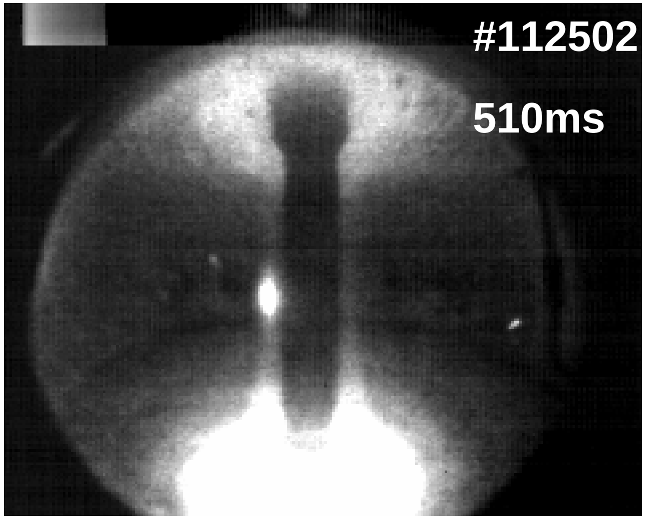
Plasma Fisheye TV Shows Localized Perturbation for Small ELM crash

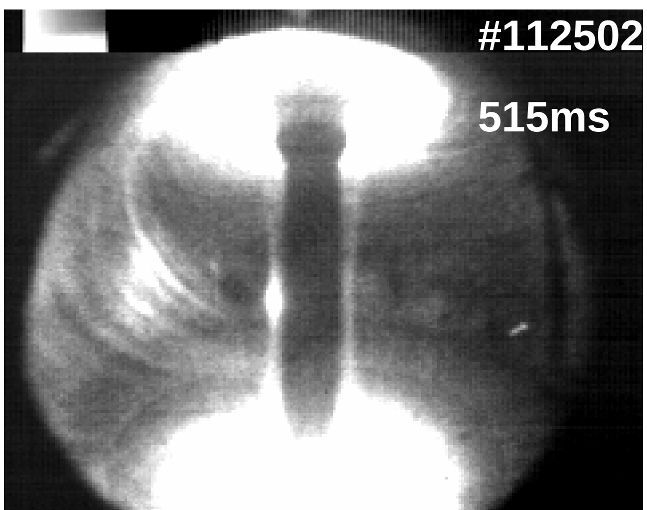


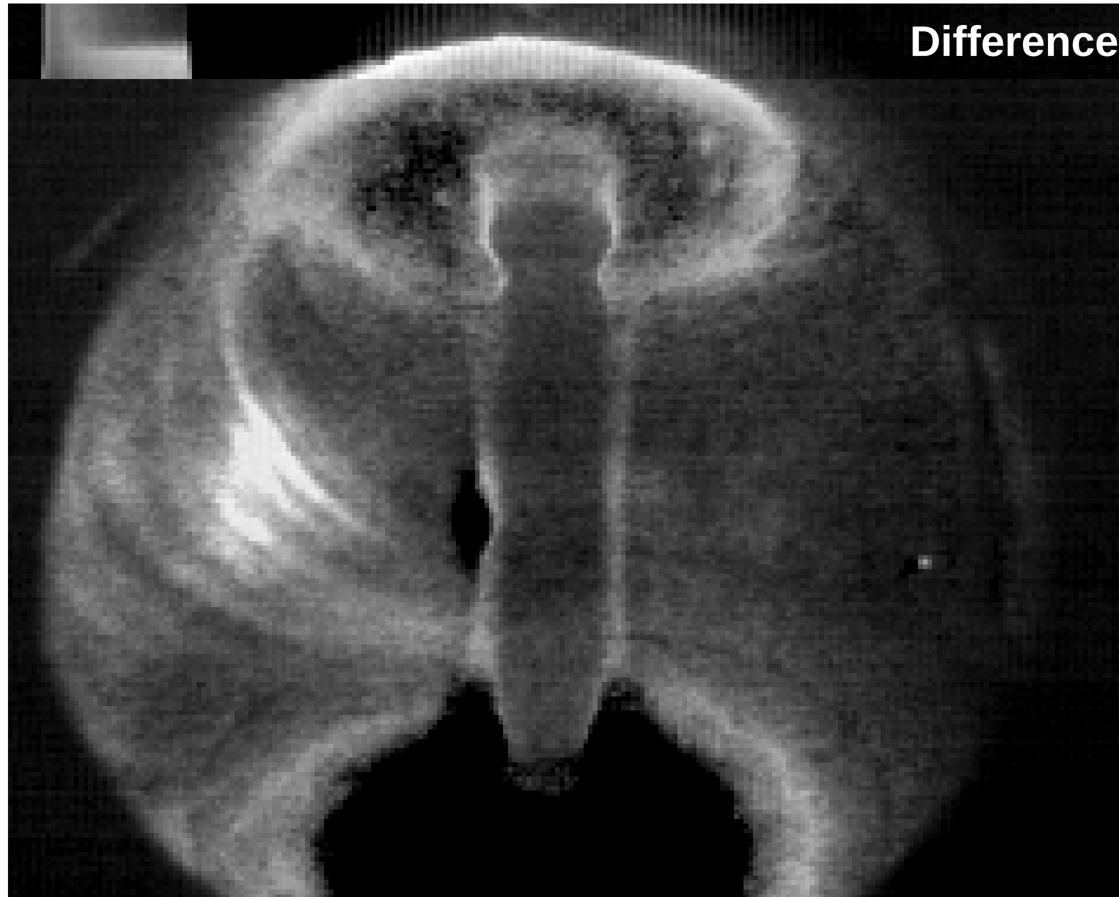


Bush (ORNL)

Plasma Fisheye TV Suggests low-n Perturbation for Large (*Type I*) ELM



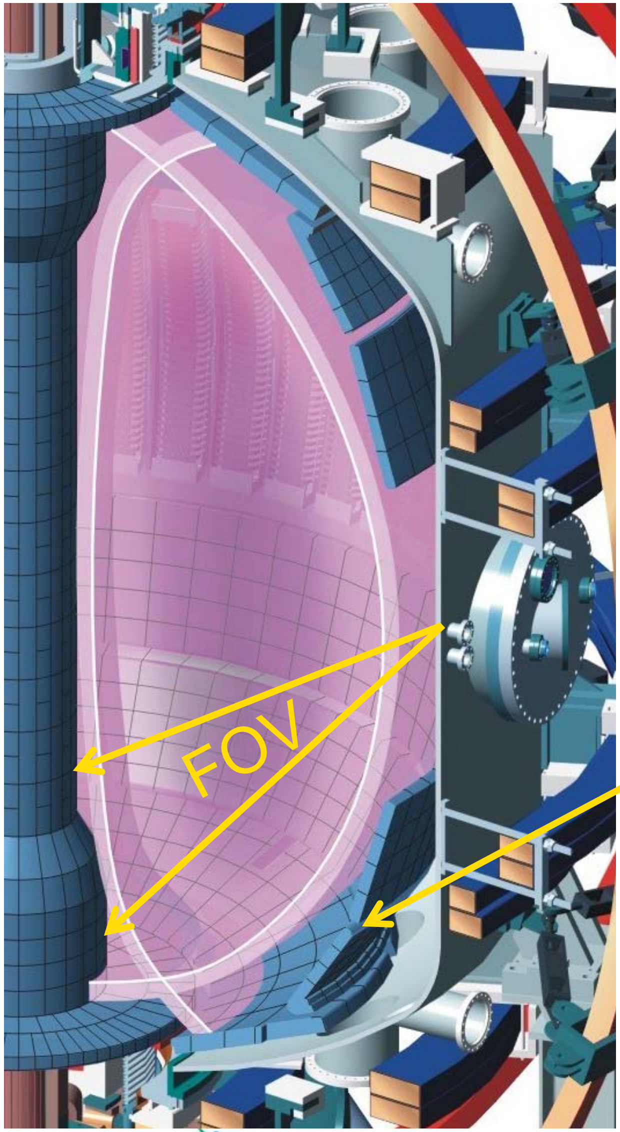


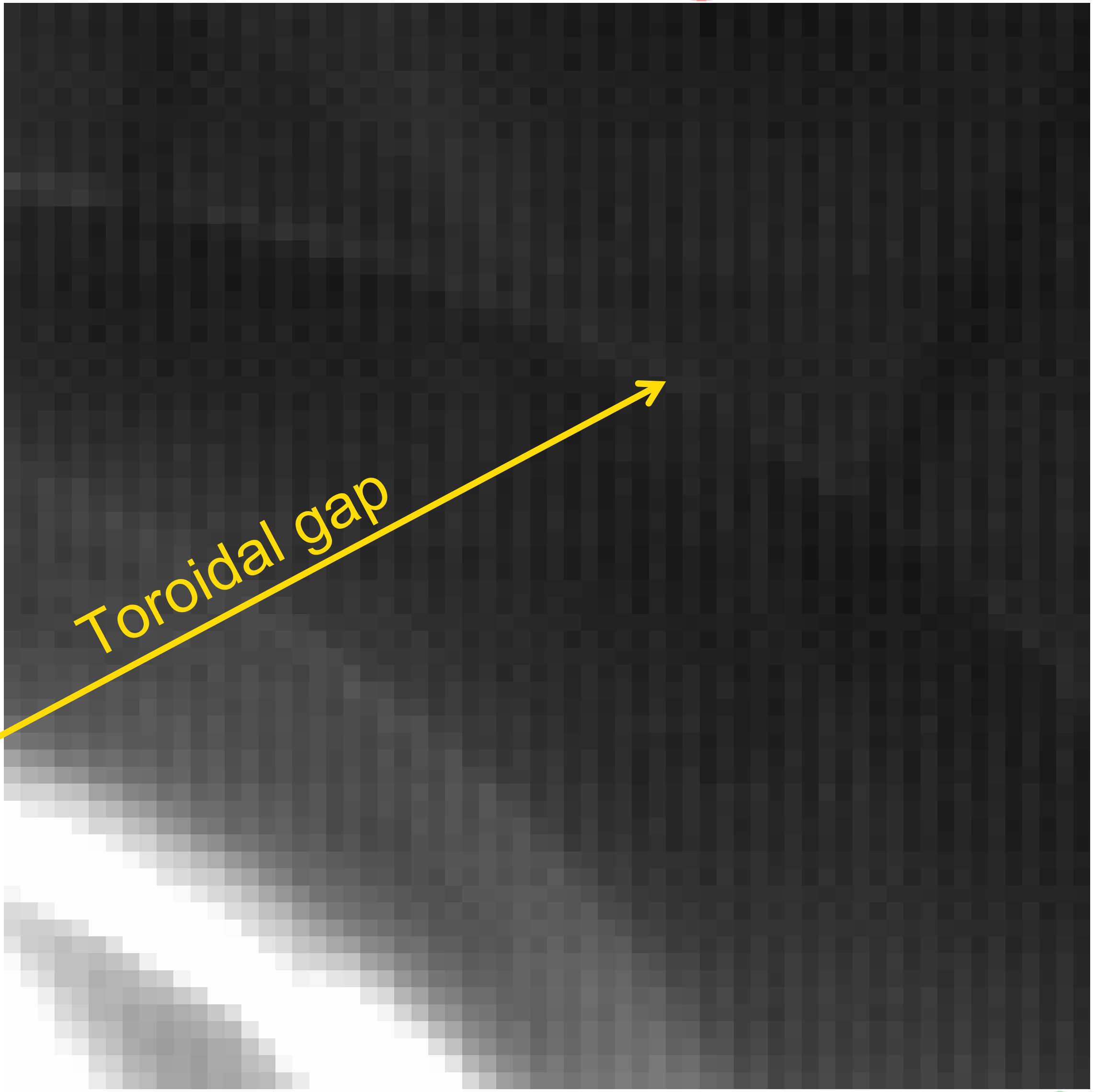


#112502, 510ms, 515ms, Difference (515ms - 510ms)

Bush (ORNL)

Small ELMs have different spatial and temporal characteristics from turbulent filaments





HIROSHIMA UNIVERSITY

Nishino (U. Hiroshima), Roquemore

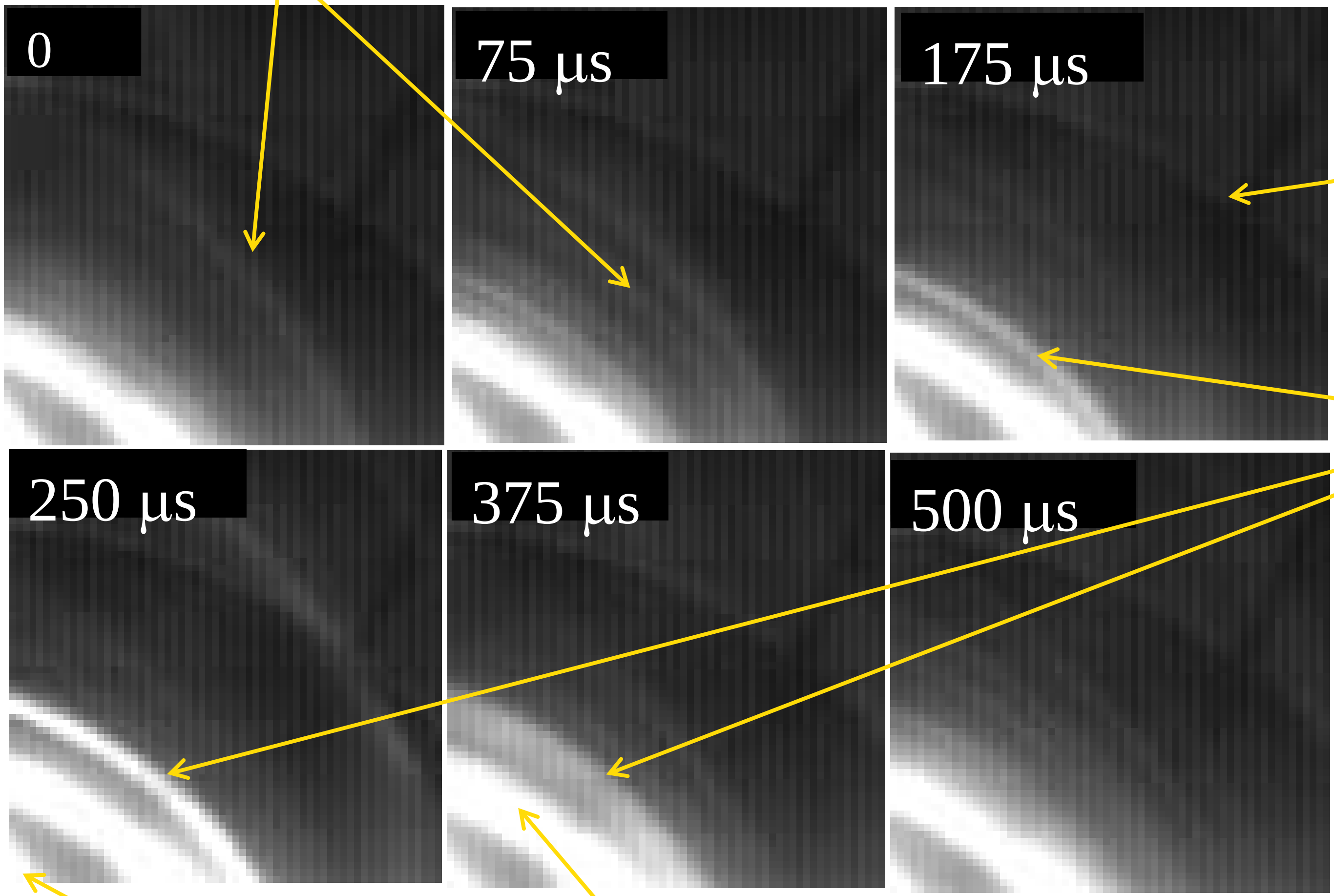
#109063: 0.593-0.605s

Small ELM lifetime much longer than filament auto-correlation time ~ 30μs

NSTX

- Midplane view of Small ELM

Filaments



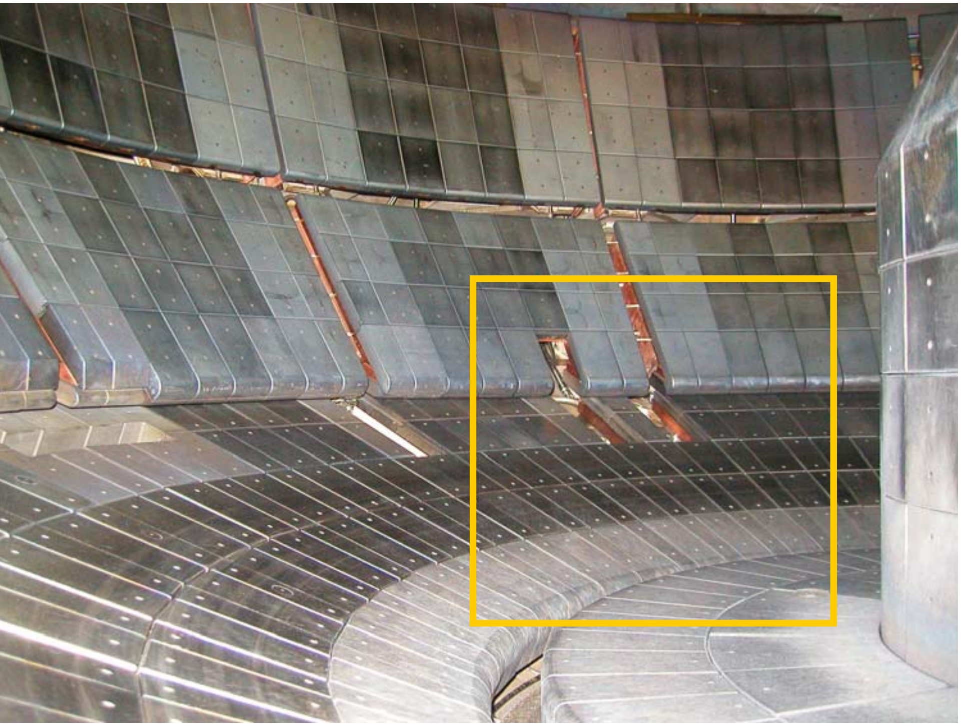
Toroidal gap

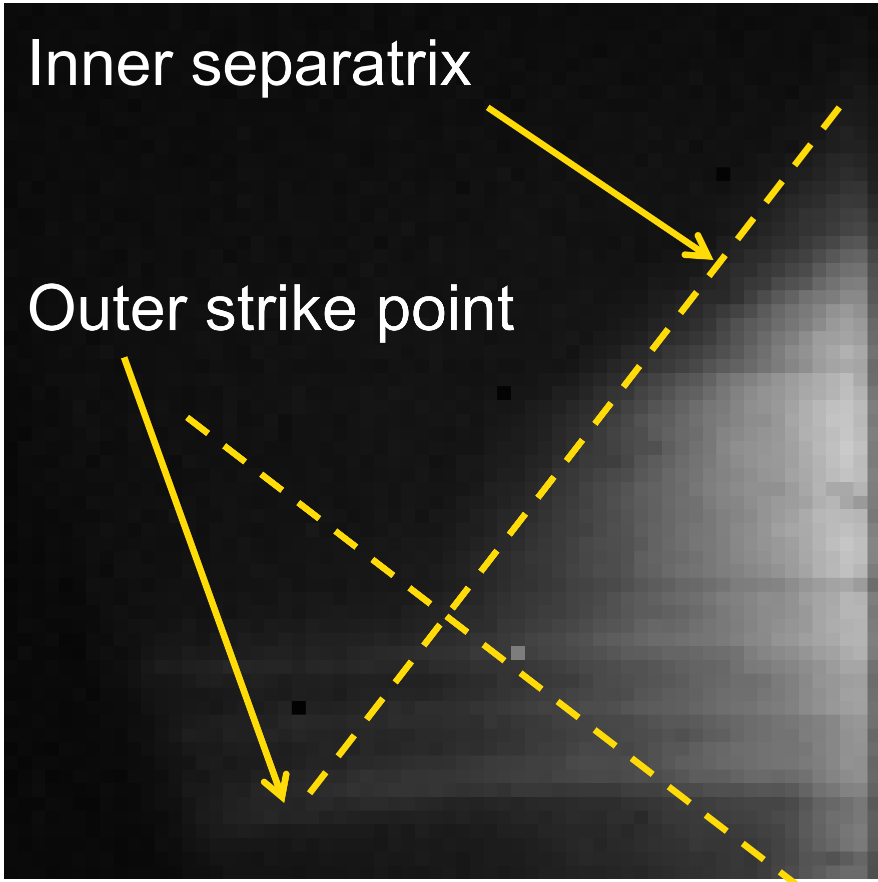
ELM Growth/ decay

Inner Strike Point *Outer Strike point*

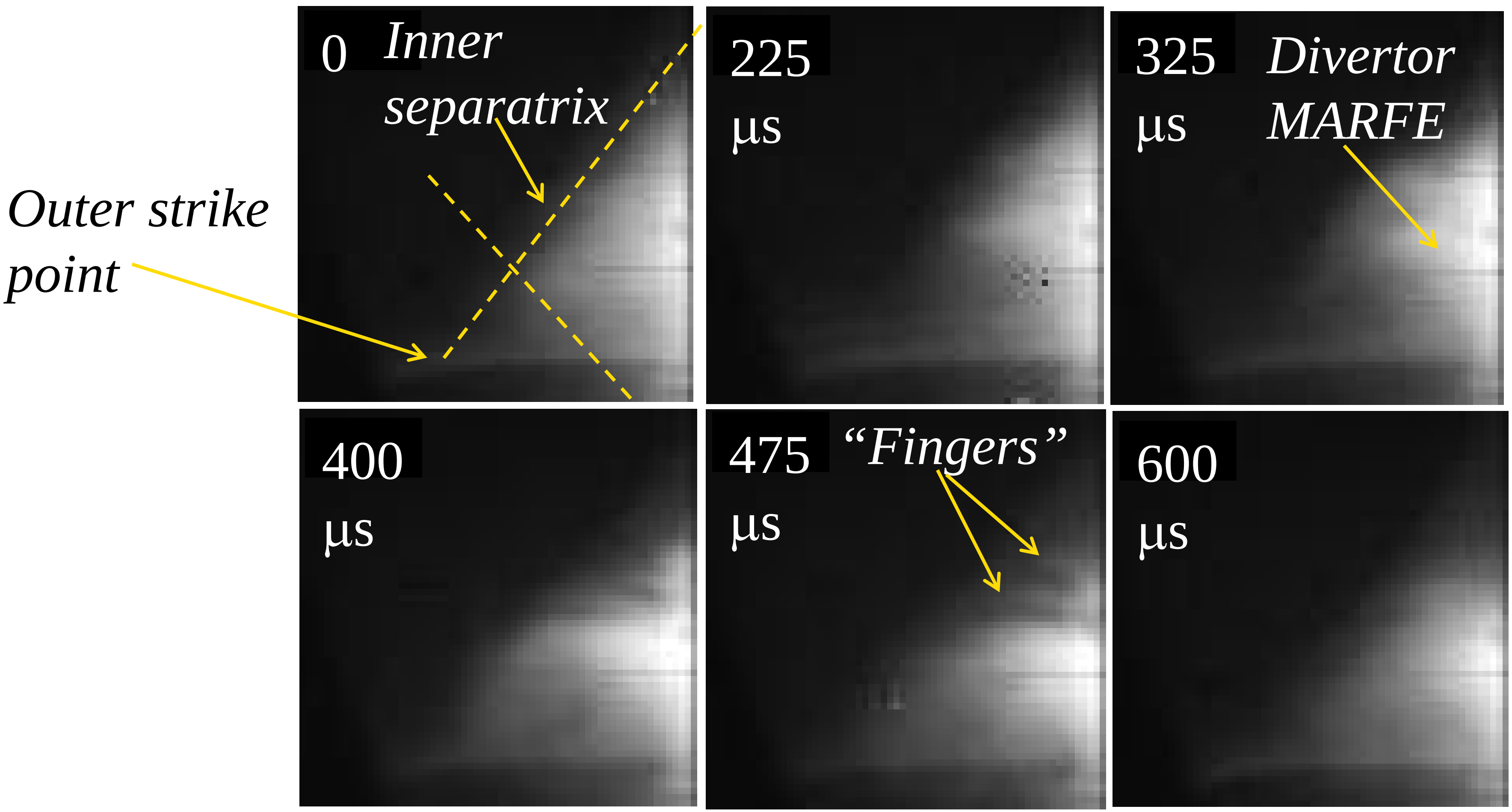
Divertor visible camera shows Large (Small) ELMs do (not) burn-through inner divertor MARFE

- Recycling light bands appear at larger major radius than outer strike point during small ELM



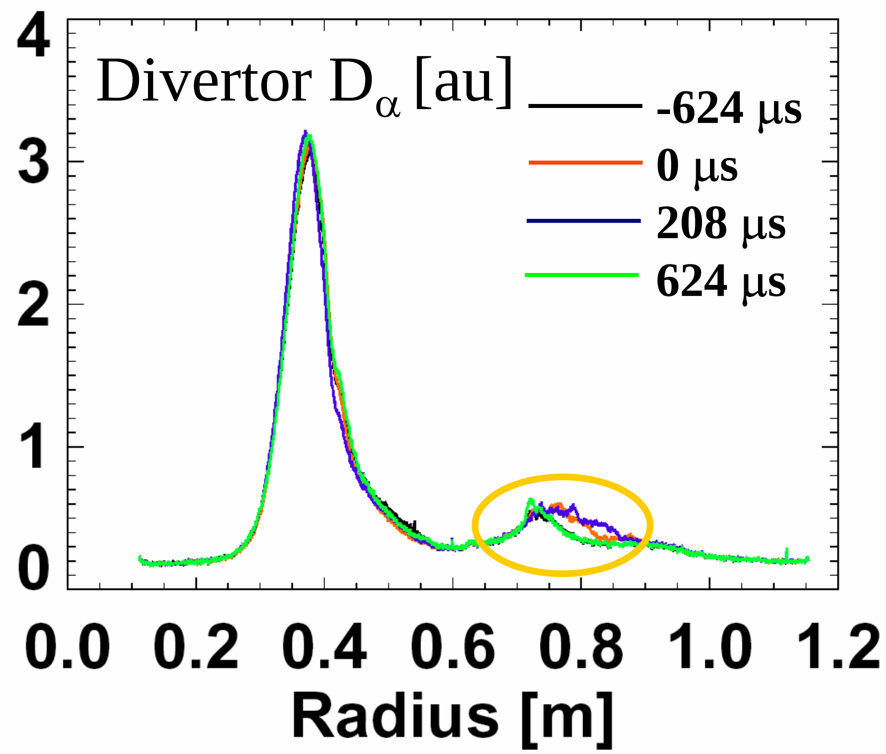


Large, dynamic structures observed in emitted light near X-point during small ELMs



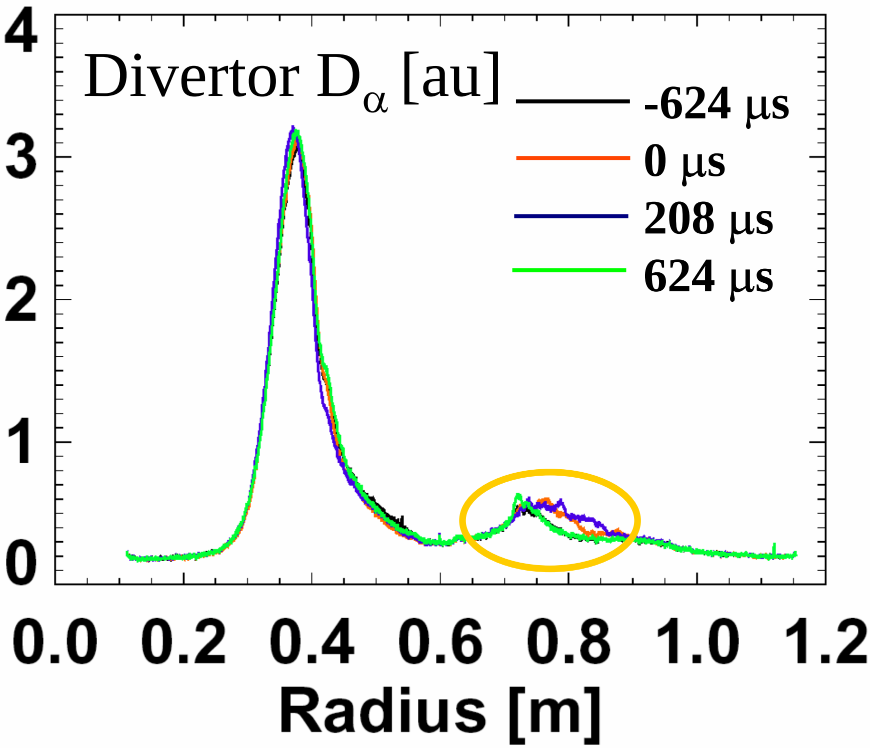
- Delay between in and out perturbations ~ 250-400 μs during small ELMs, and 100-200 μs during large ones

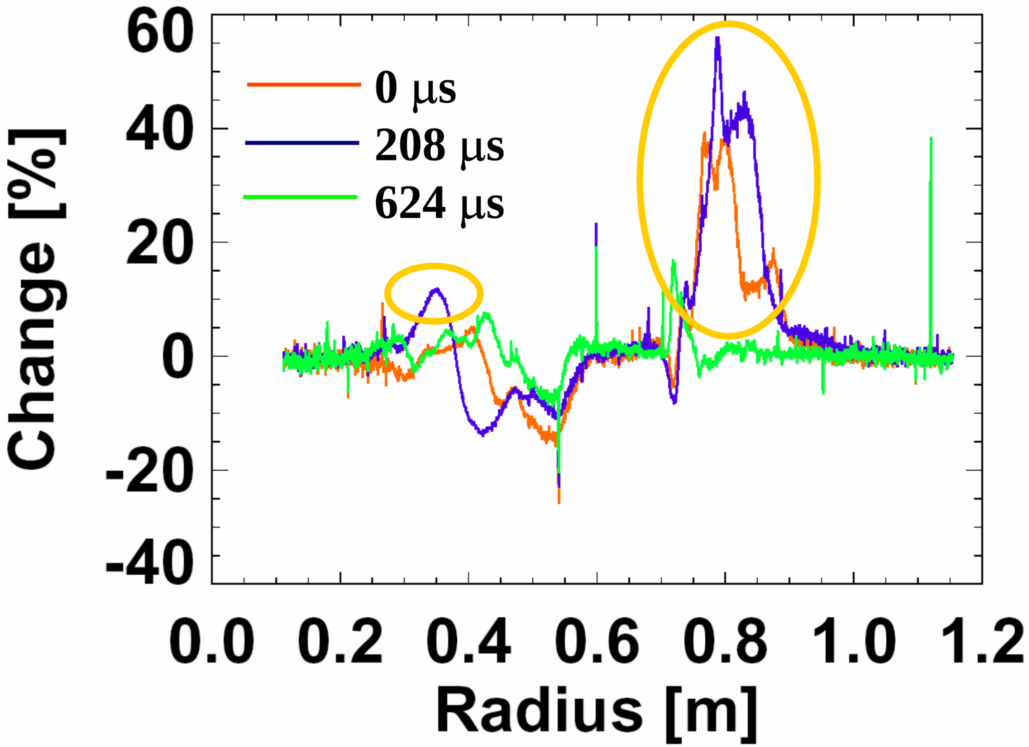
Outer divertor perturbation relatively larger during small ELM



Soukhanovskii, LLNL
R. Maingi, IAEA 2004 talk
#112503-frames 1375-81

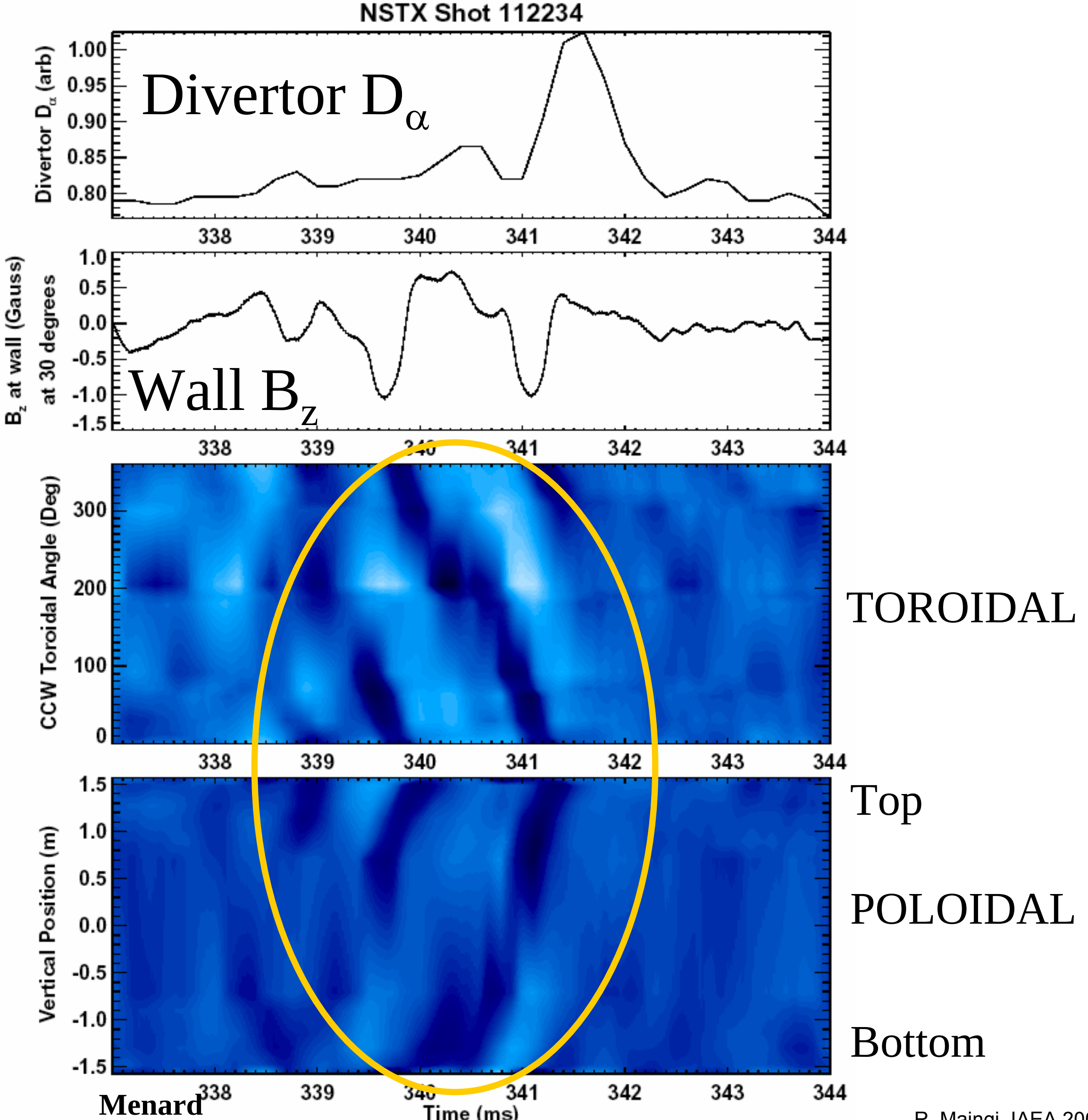
Outer divertor perturbation relatively larger during small ELM and occurs 1-2 frames (200-400 μs) before inner divertor



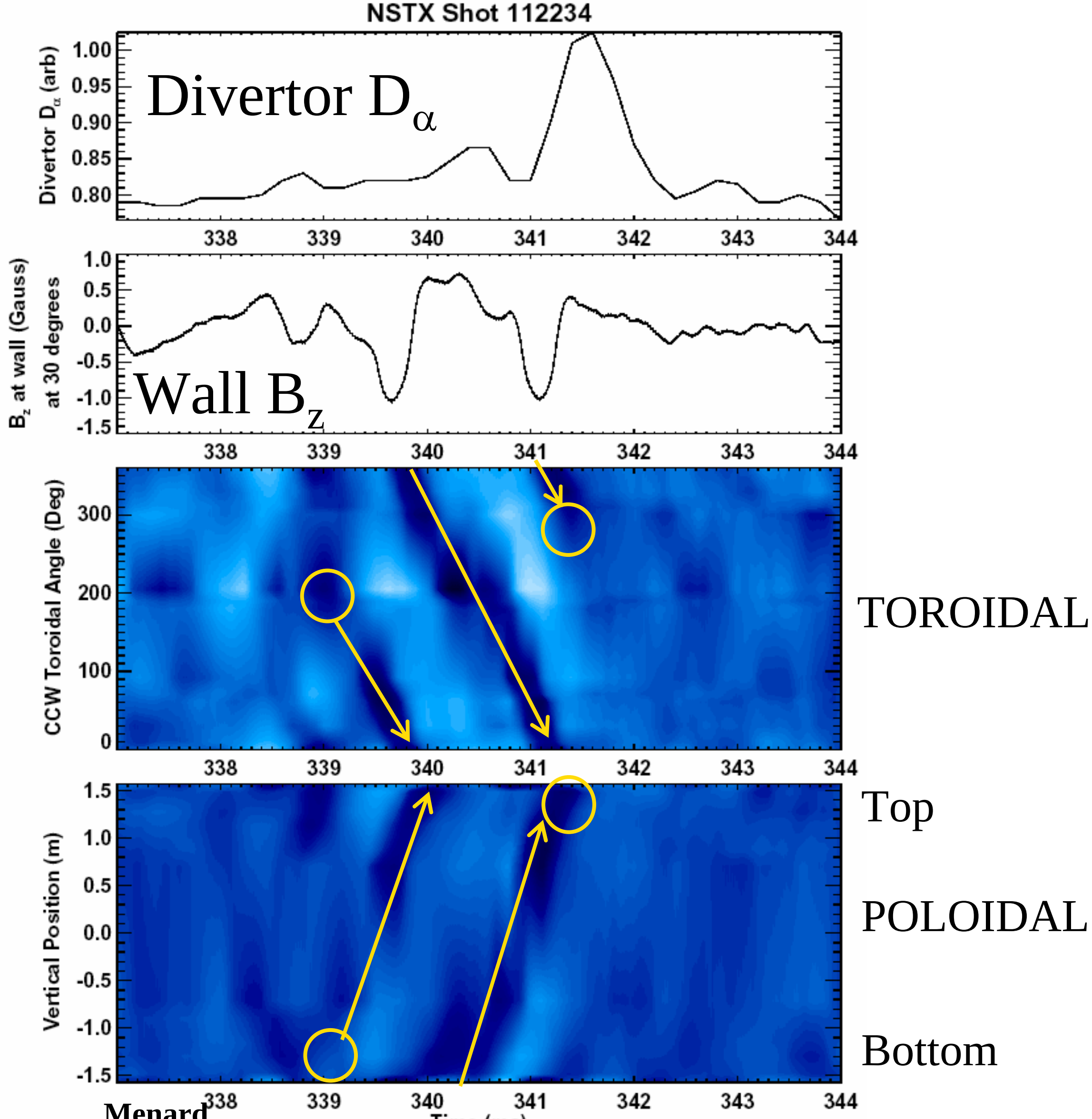


- Delay suggests leakage of ELM flux on outboard side near the X-point and convective transport to target ($l_{||}$ = 40 m, T_i^{ped}=200 eV)

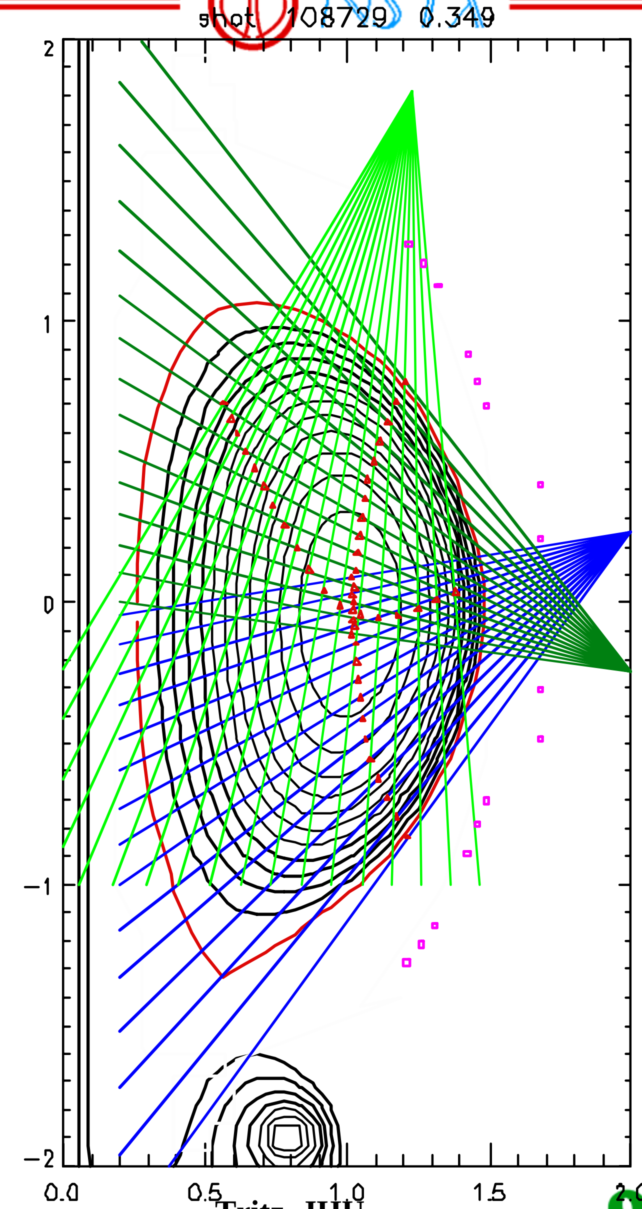
n=1 pre-cursor to small ELMs propagates toroidally counter to I_p and poloidally away from X-point



n=1 pre-cursor to small ELMs propagates toroidally counter to I_p and poloidally away from X-point

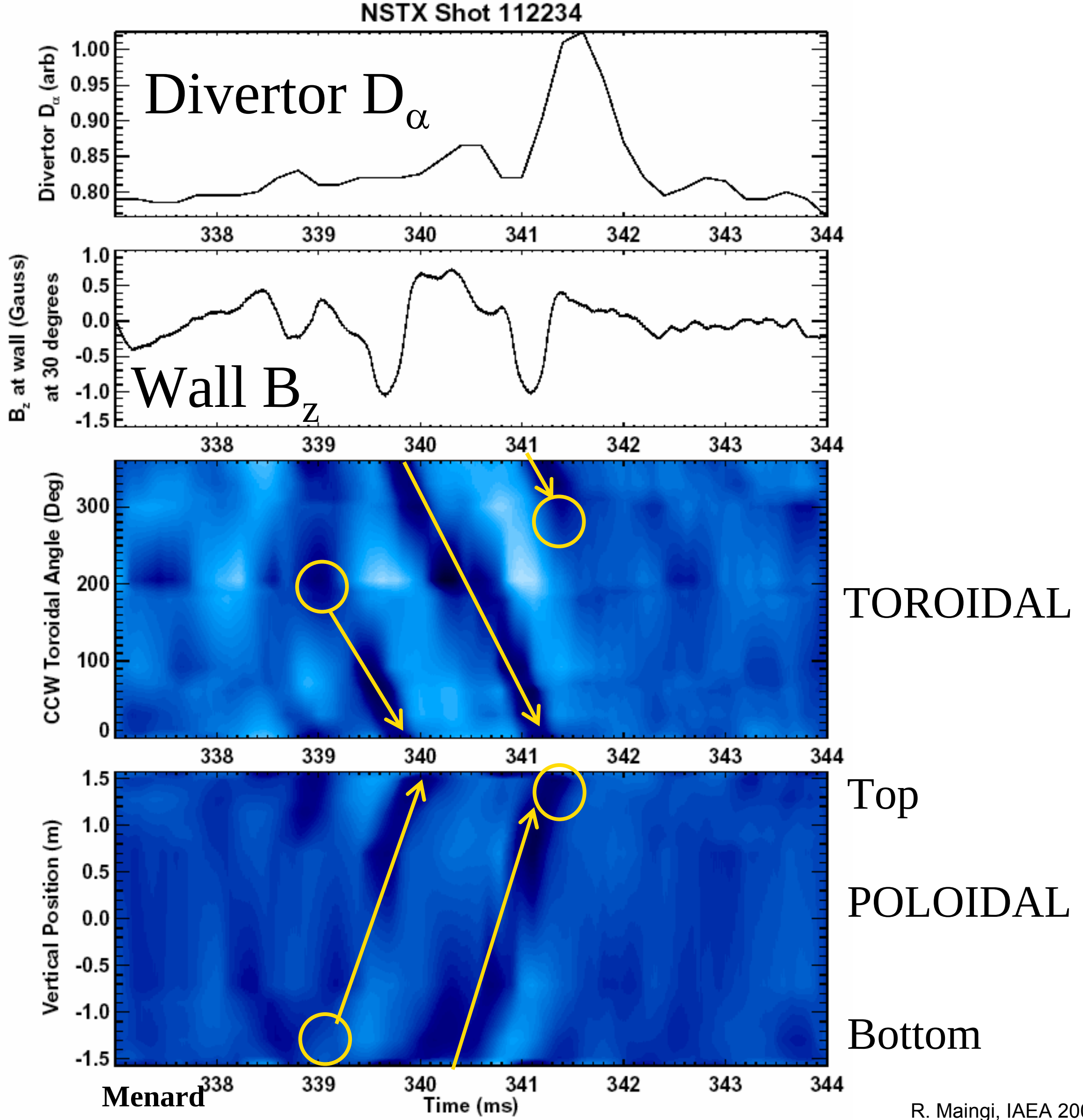


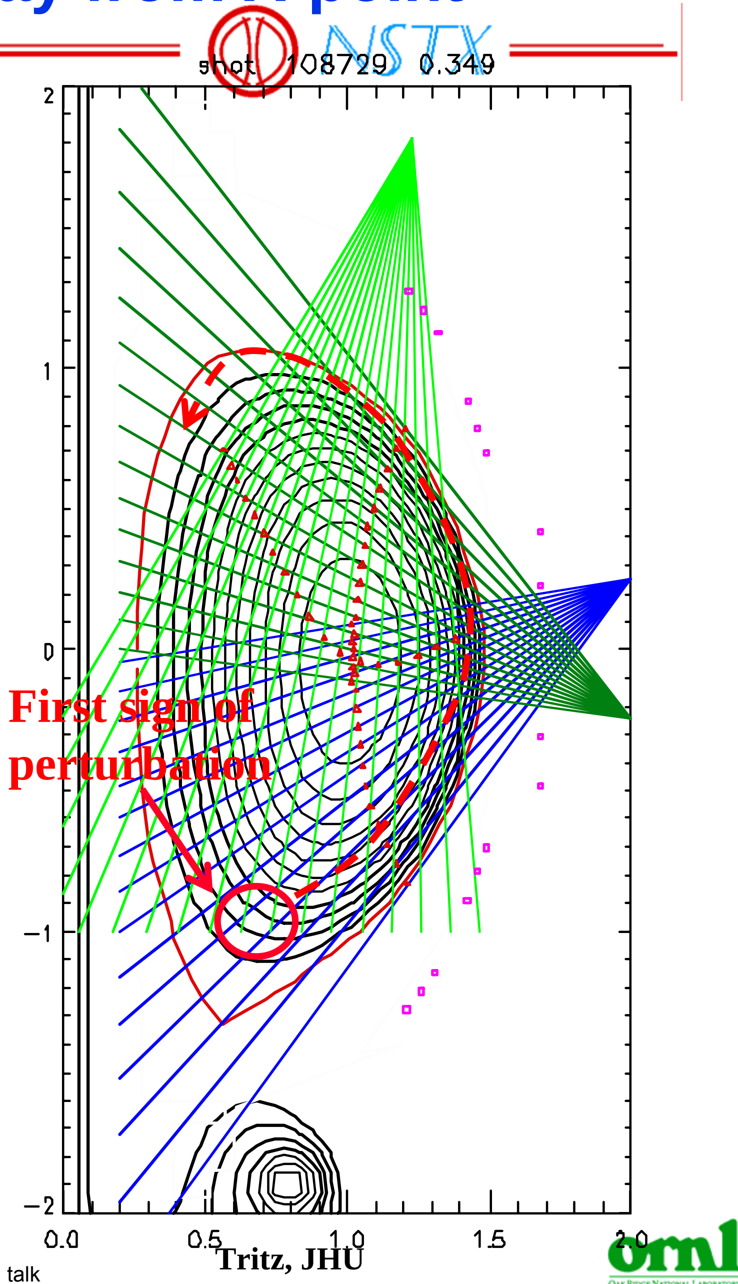
Menard



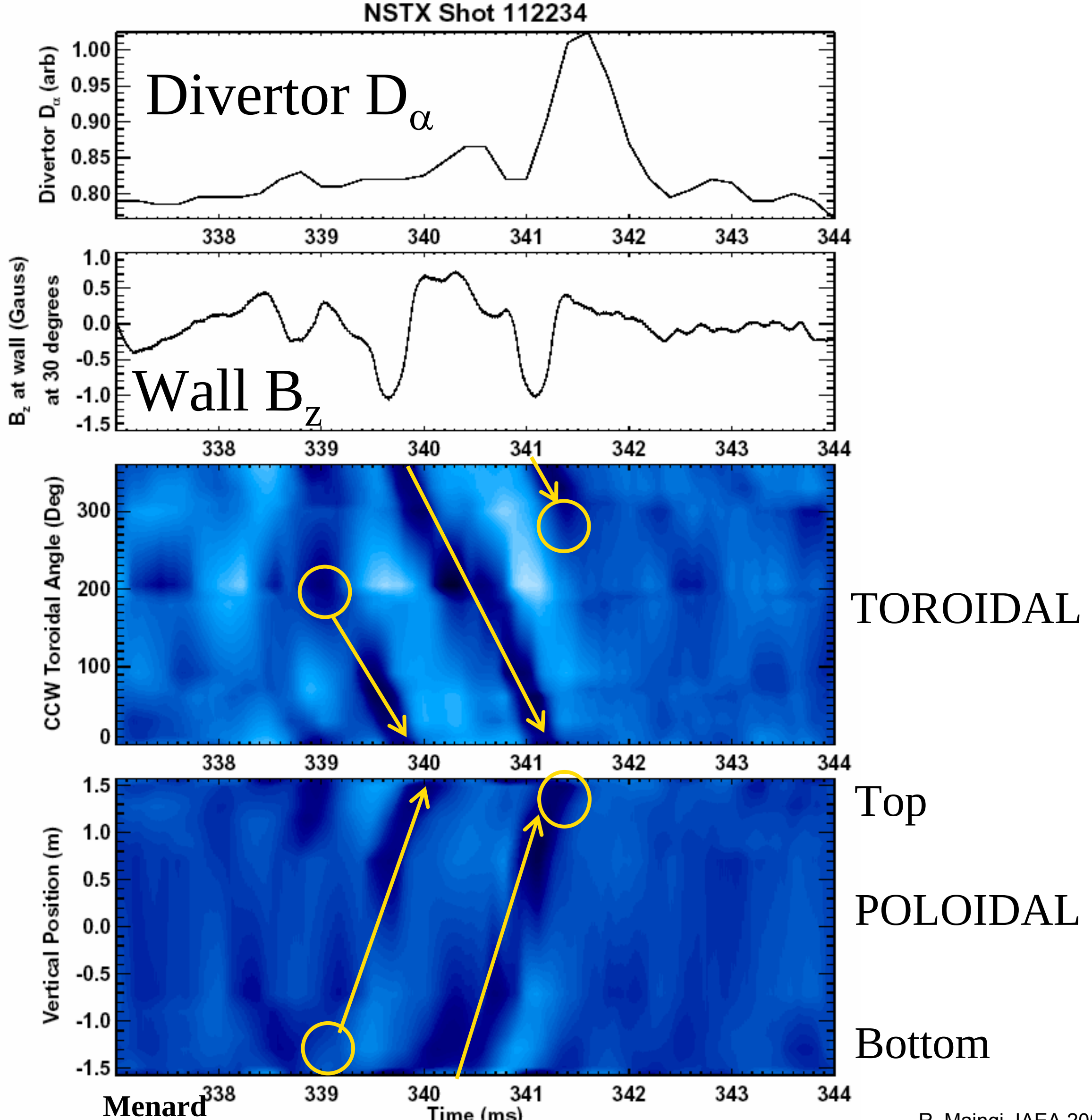
Tritz, JHU

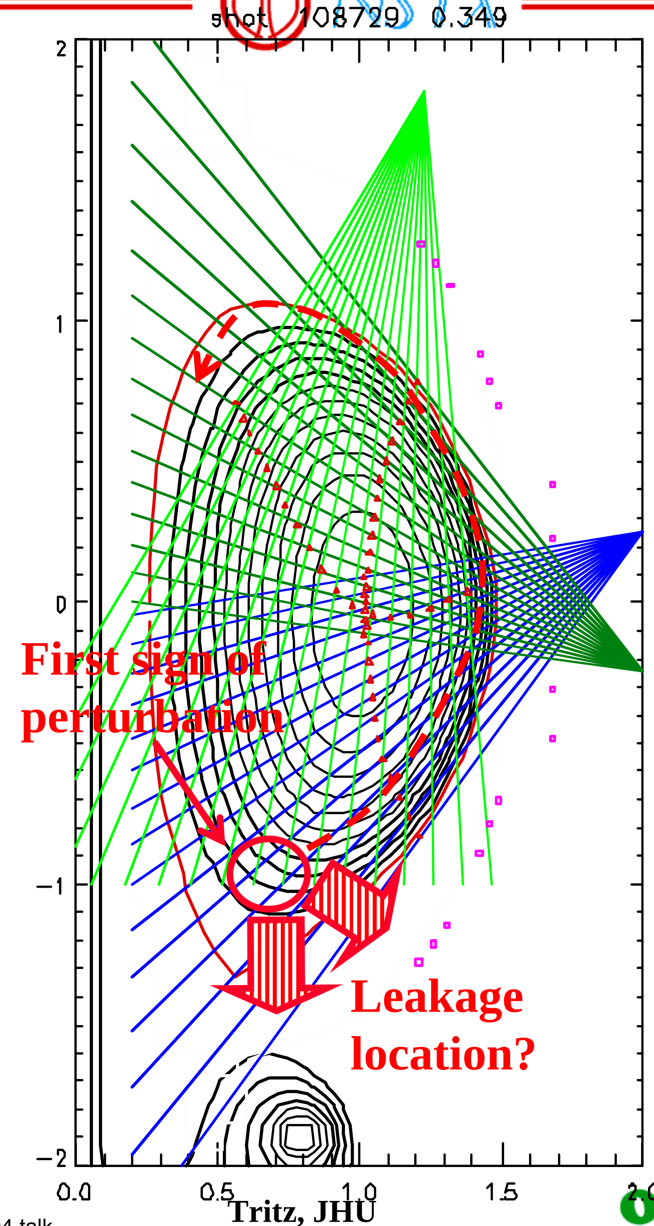
n=1 pre-cursor to small ELMs propagates toroidally counter to I_p and poloidally away from X-point





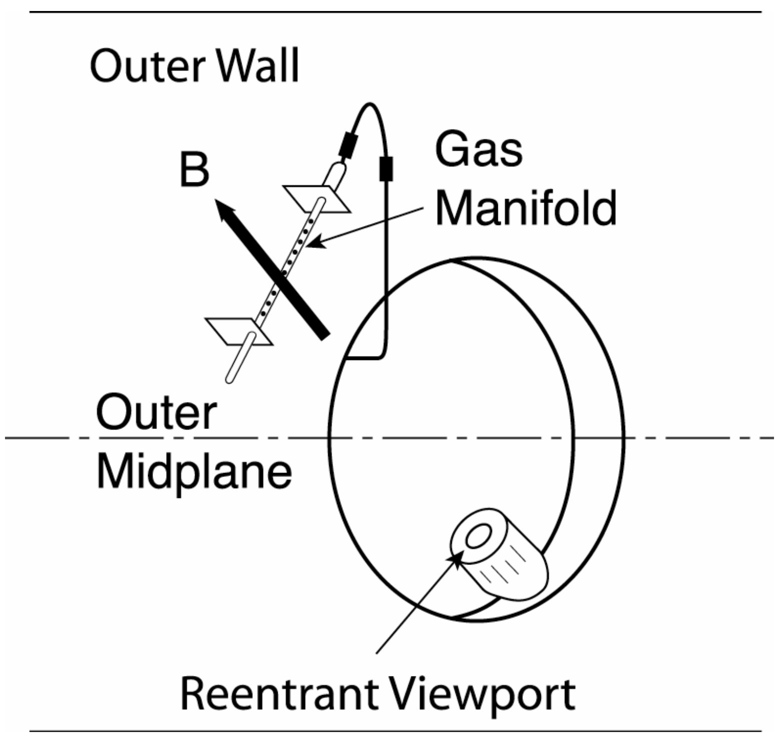
n=1 pre-cursor to small ELMs propagates toroidally counter to I_p and poloidally away from X-point

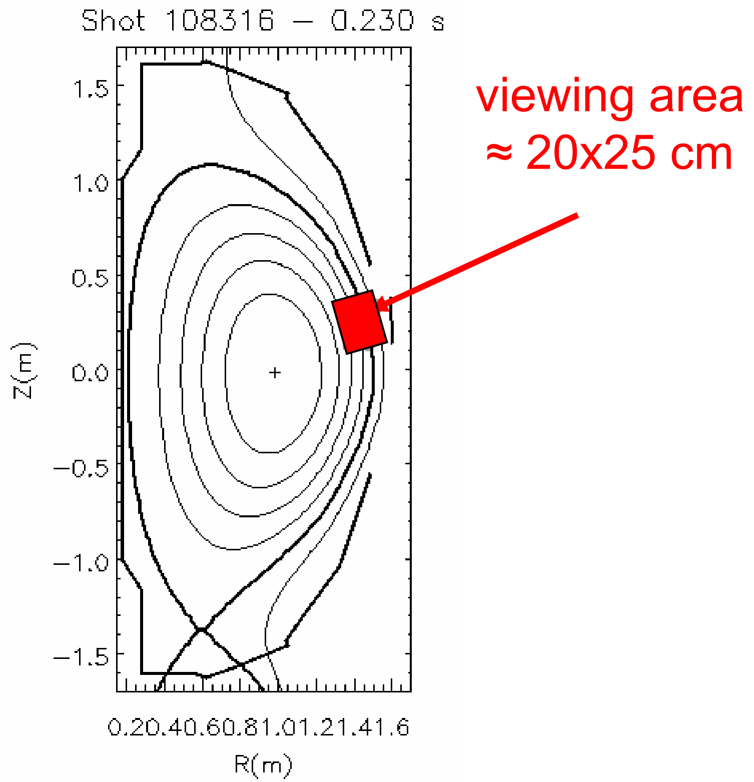




Gas Puff Imaging Used for L-H transition Study

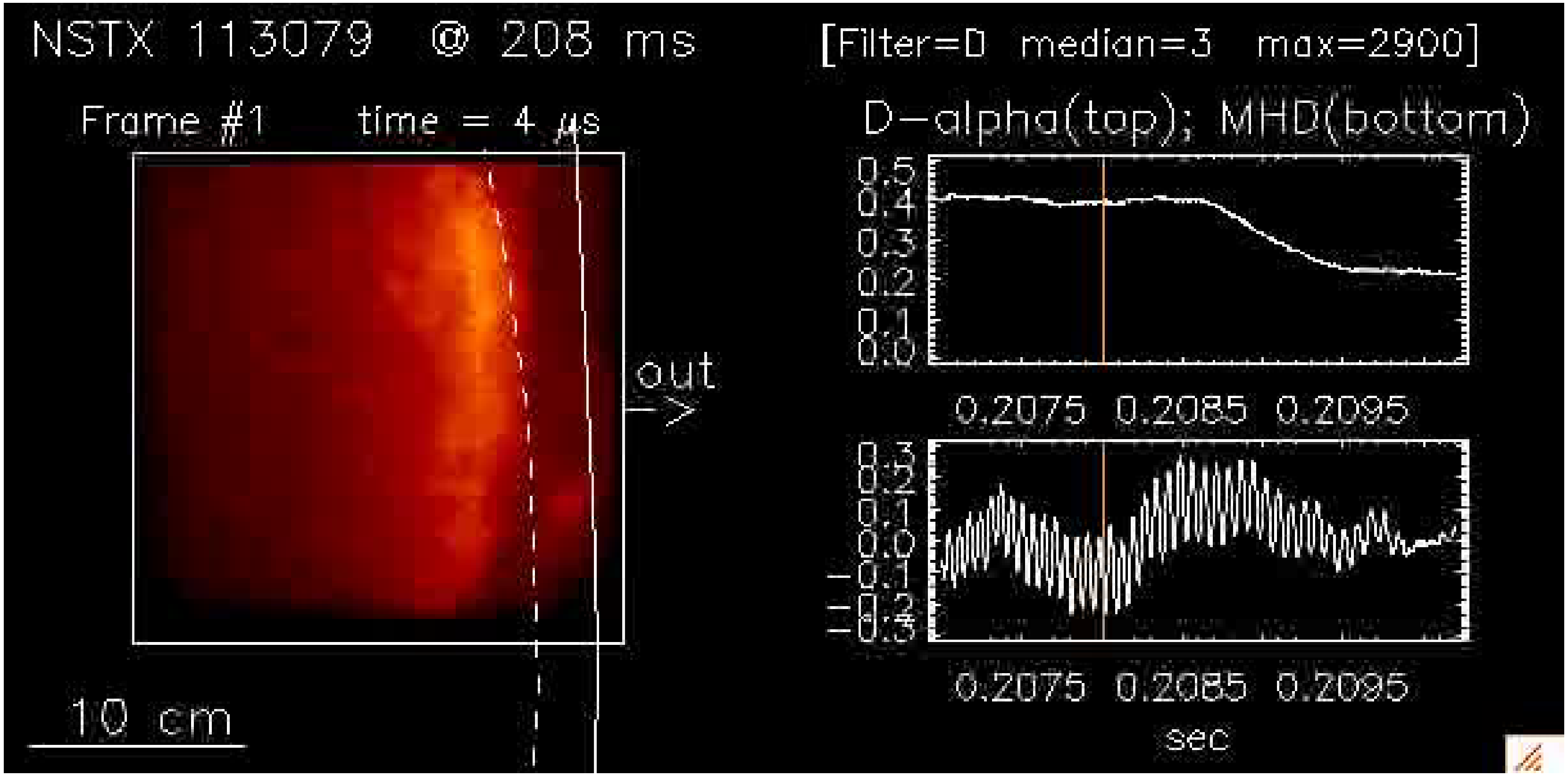
- Looks at D_α or HeI light from gas puff $I \propto n_o n_e f(n_e,T_e)$
- View ≈ along B field line to see 2-D structure ⊥ B
- Image coupled to camera with 800 x 1000 fiber bundle





Zweben, Munsat, Bush (ORNL)

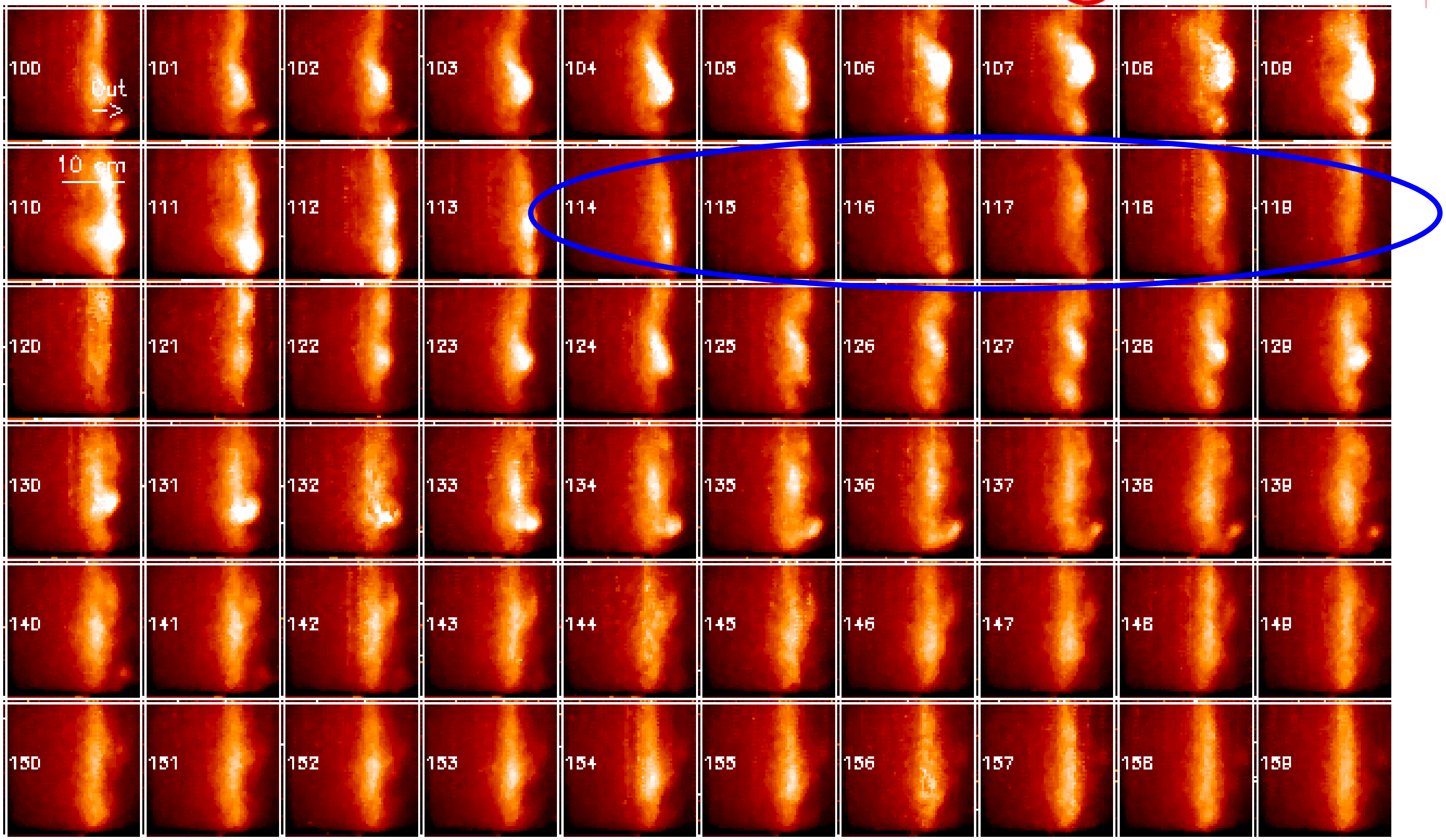
Turbulence quench time ≤ 100 μsec during L-H transition (gas puff imaging)



- **No obvious change in edge flow pattern before L-H**

Zweben, Munsat, Bush (ORNL)

Quiescent periods sometimes precede full L-H



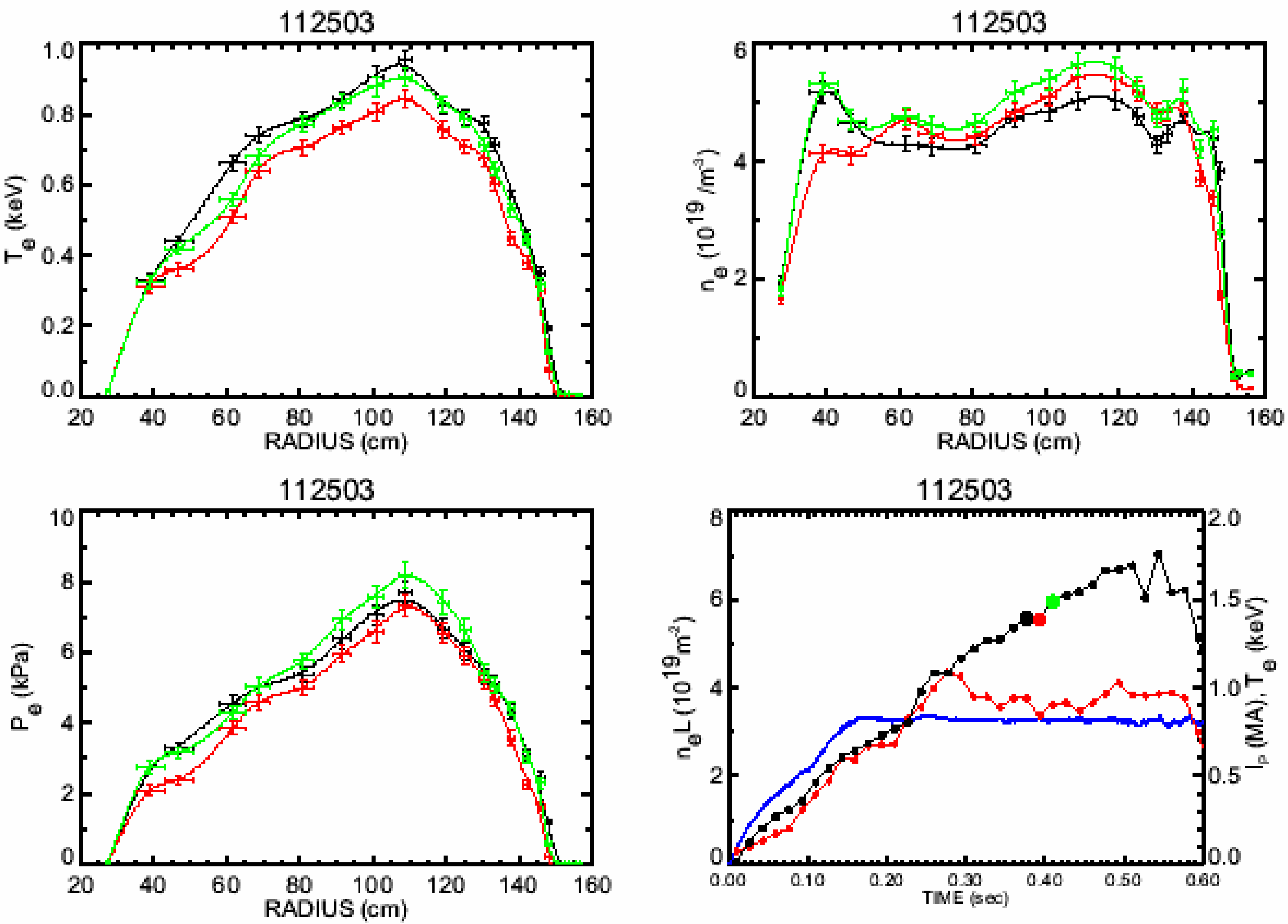
Zweben, Munsat, Bush (ORNL)

Summary and Conclusions

- Small ELMs, *Type V*, compatible with high performance
  - No measurable impact on stored energy per ELM
  - Lots of structure near X-point - "fingers"
  - Delay of inboard signature relative to outboard longer than large ELM
    - Possible ELM leakage onto open field lines near X-point
  - Extrapolable to lower ν_*^e ?
- Edge turbulence quenched in 100 μsec before L-H transition
  - No clear change in edge flow patterns
  - Quiescent periods often precede L-H transition

Backup

Type I "ELM" can cause drop in edge n_e and global T_e perturbation



- **Propagation from edge into core via USXR imaging in ≤ 1 msec**

Gas Puff Imaging system shows Type I ELM structure near outer midplane

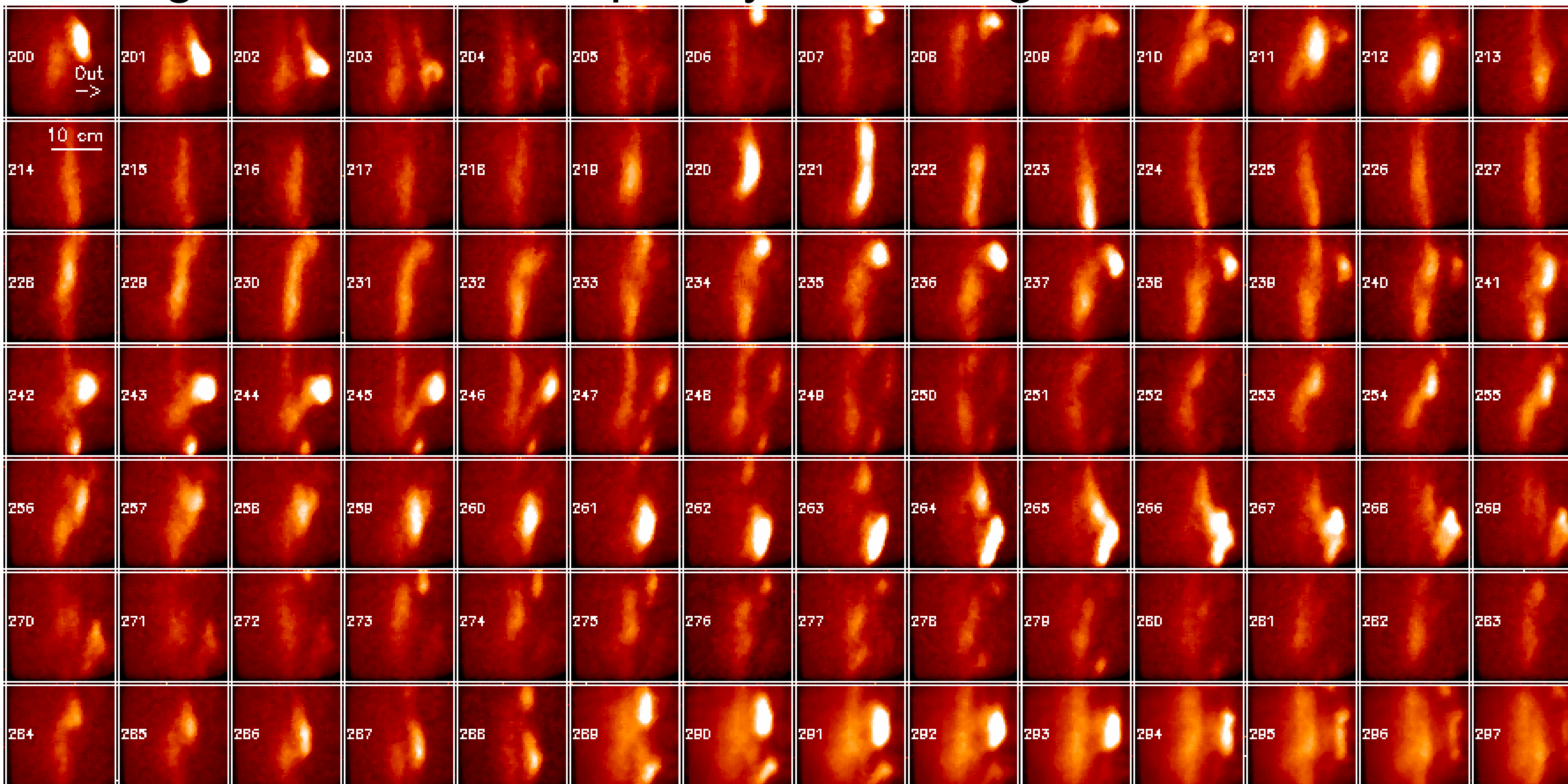
- Large Type I ELM near t=0.3504 sec looks like L-mode images with ‘blob’ frequency increasing > 100%

Zweben, Munsat, Bush (ORNL)

Gas Puff Imaging system shows Type I ELM structure near outer midplane

NSTX

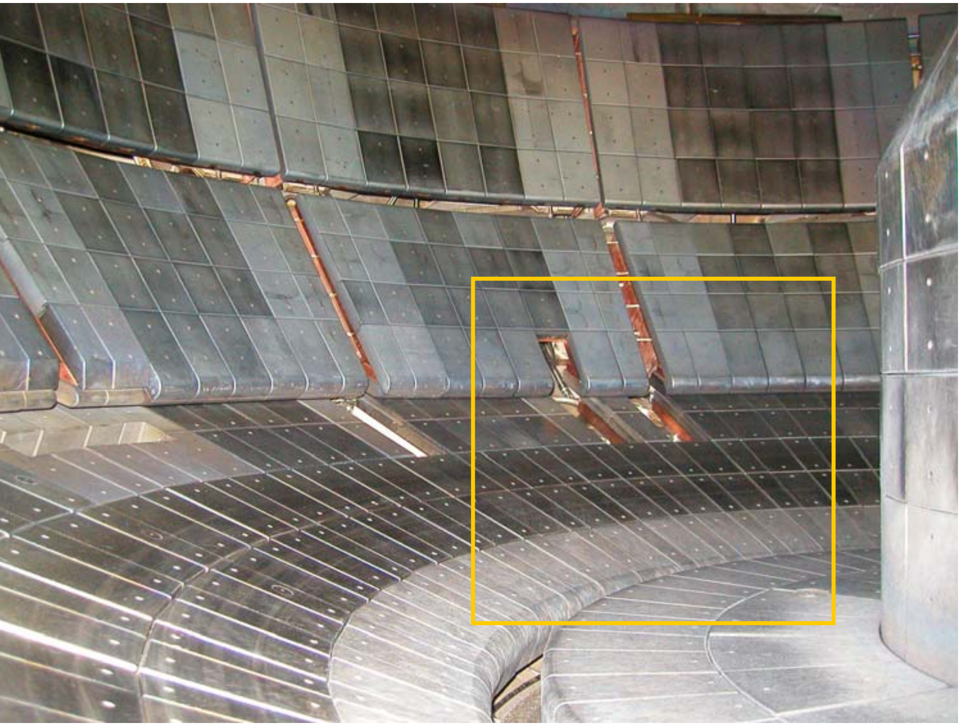
- Large Type I ELM near t=0.3504 sec looks like L-mode images with ‘blob’ frequency increasing > 100%

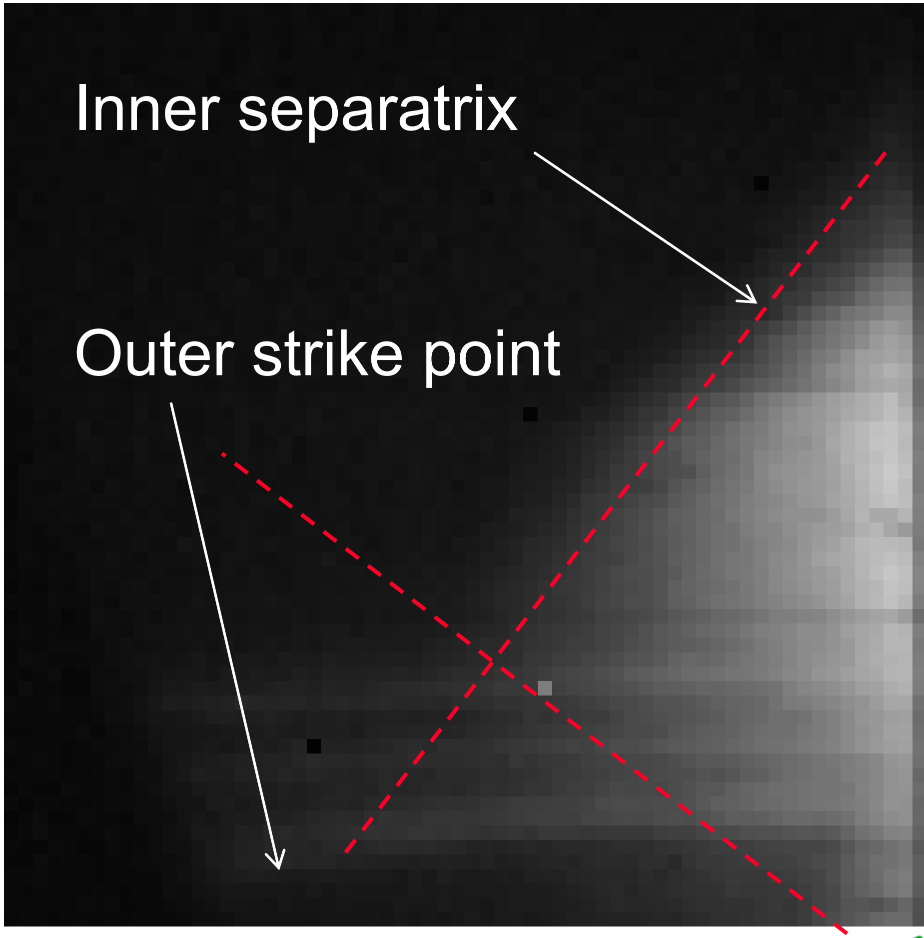


Zweben, Munsat, Bush (ORNL)

Divertor visible camera shows Type I ELM burning through inner divertor MARFE-like region

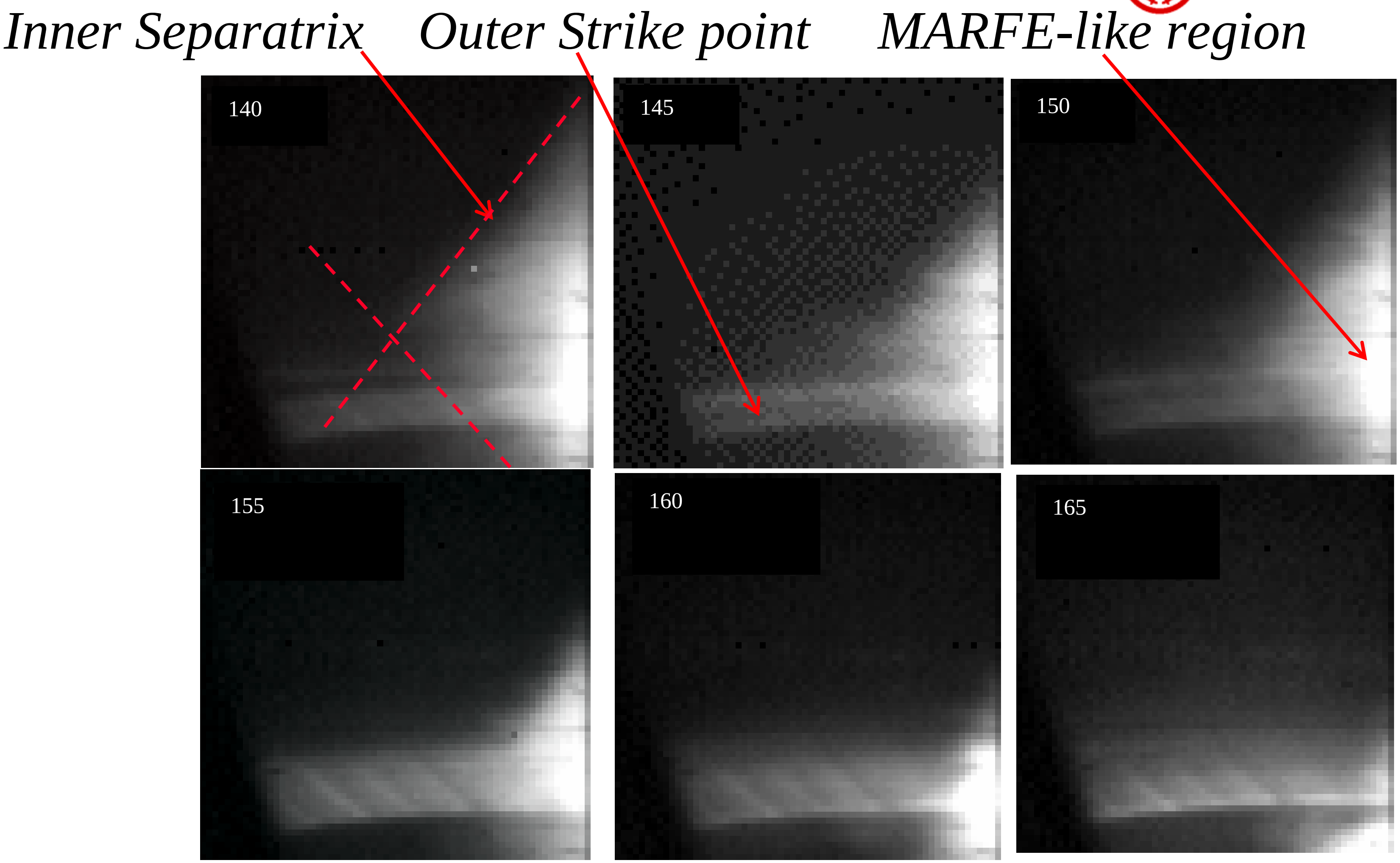
- Approximate camera field of view in LHS yellow box





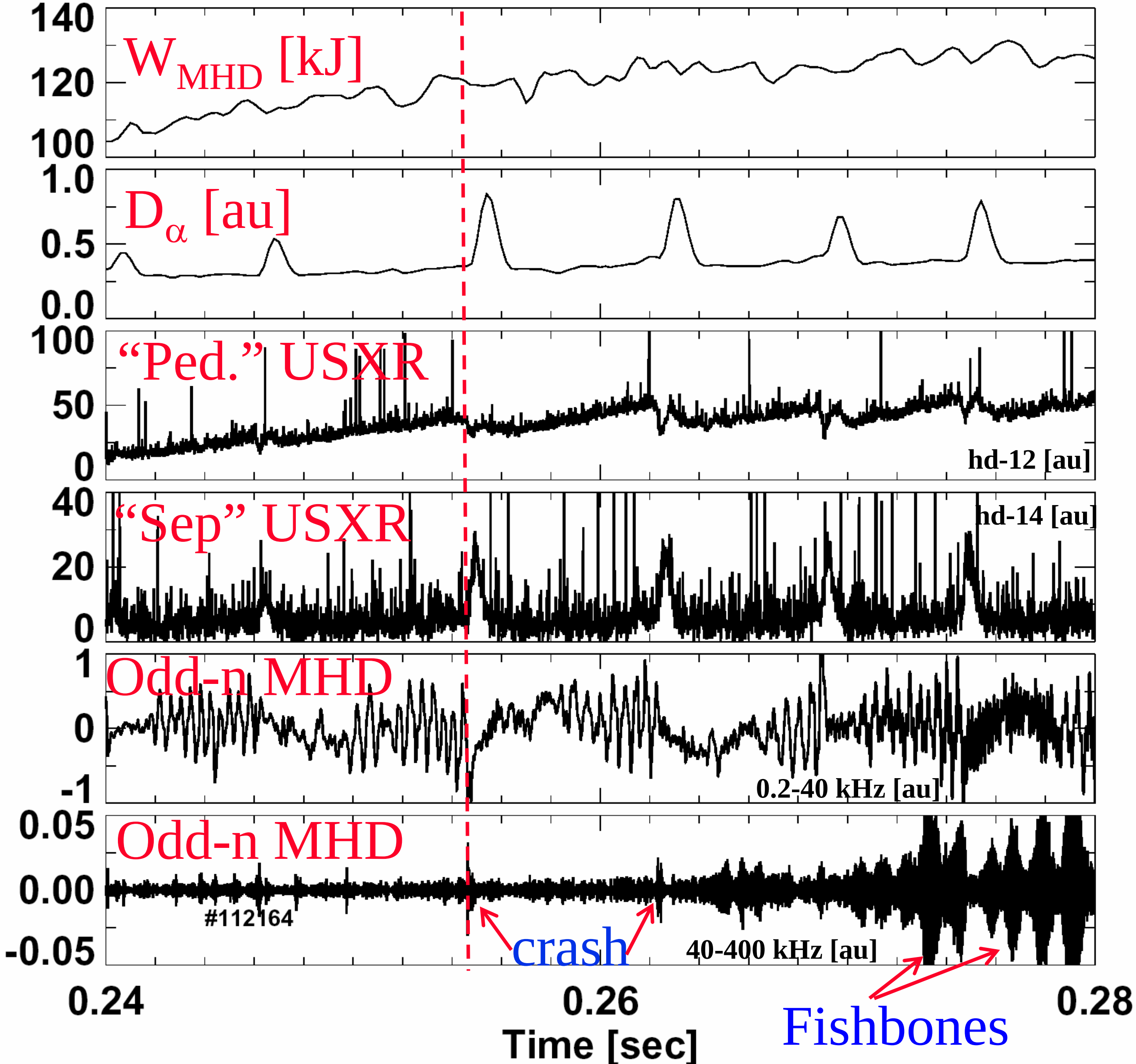
Nishino (U. Hiroshima), Roquemore, Maingi (ORNL) [#112503]

Type I ELMs burn through MARFE-like region near inner X-point



• All data with 24.7μs time between frames; relative frames numbers indicated

Characteristics of Type II/III ELMs



Little impact per each ELM

Outflux from pedestal

Influx to SOL Or separatrix

Low frequency 2 kHz pre-cursor

High frequency crash

Gas Puff Imaging system shows Type III ELM structure near outer midplane

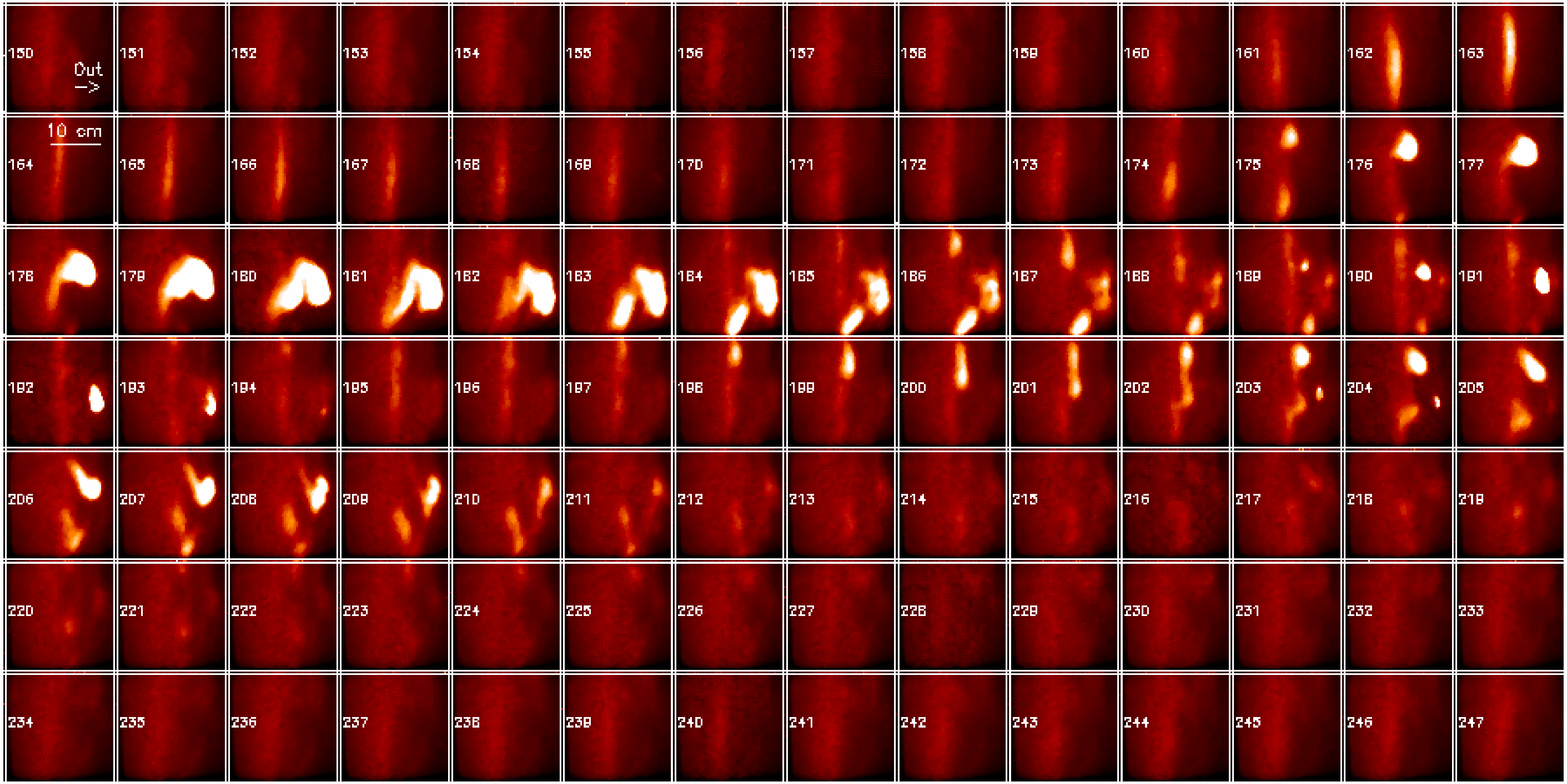
- Smaller events (blobs, but not Type V ELMs) precede Type III ELM near t=0.4515 sec #113409

Zweben, Munsat, Bush (ORNL)

Gas Puff Imaging system shows Type III ELM structure near outer midplane

NSTX

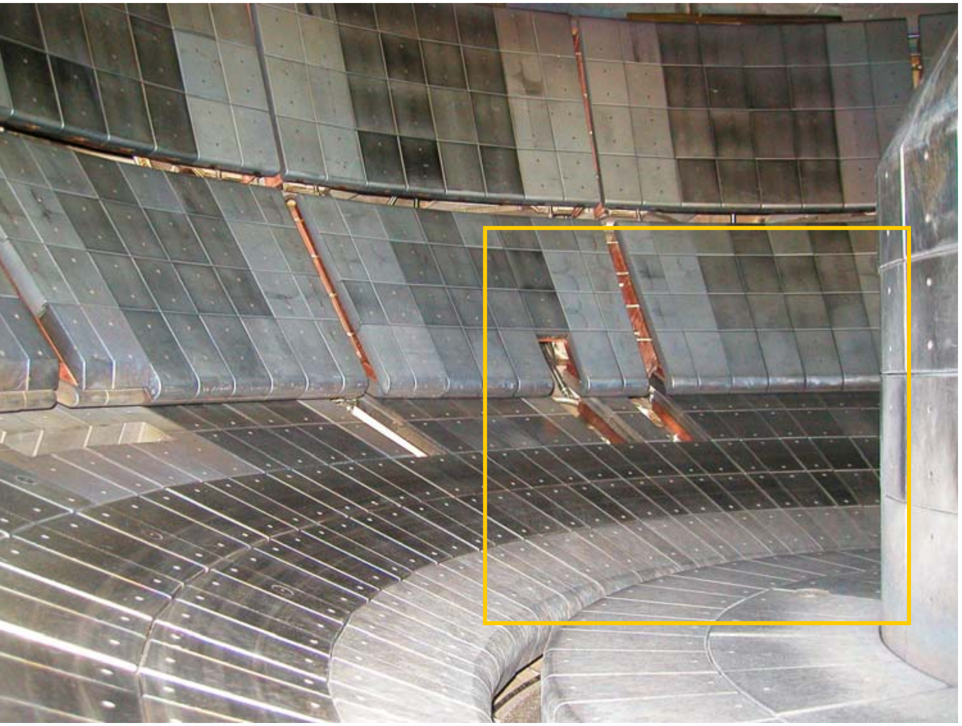
- Smaller events (blobs, but not Type V ELMs) precede Type III ELM near t=0.4515 sec #113409

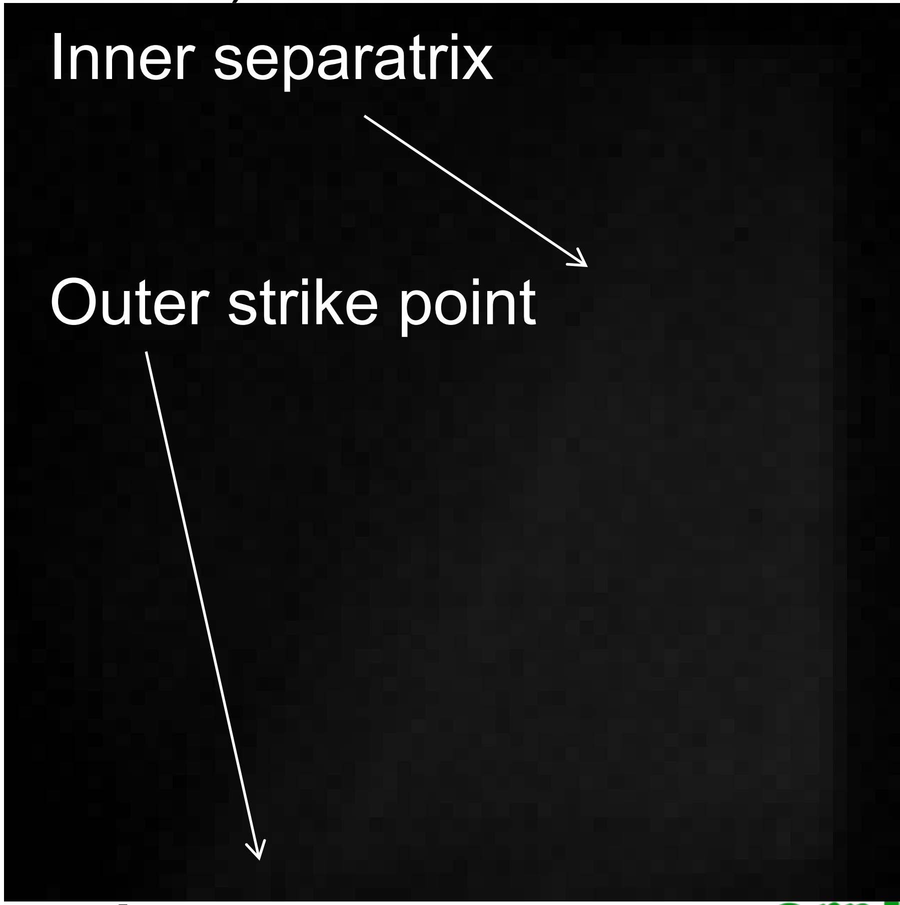


Zweben, Munsat, Bush (ORNL)

Divertor visible camera shows periodic Type II/III ELM phenomenology

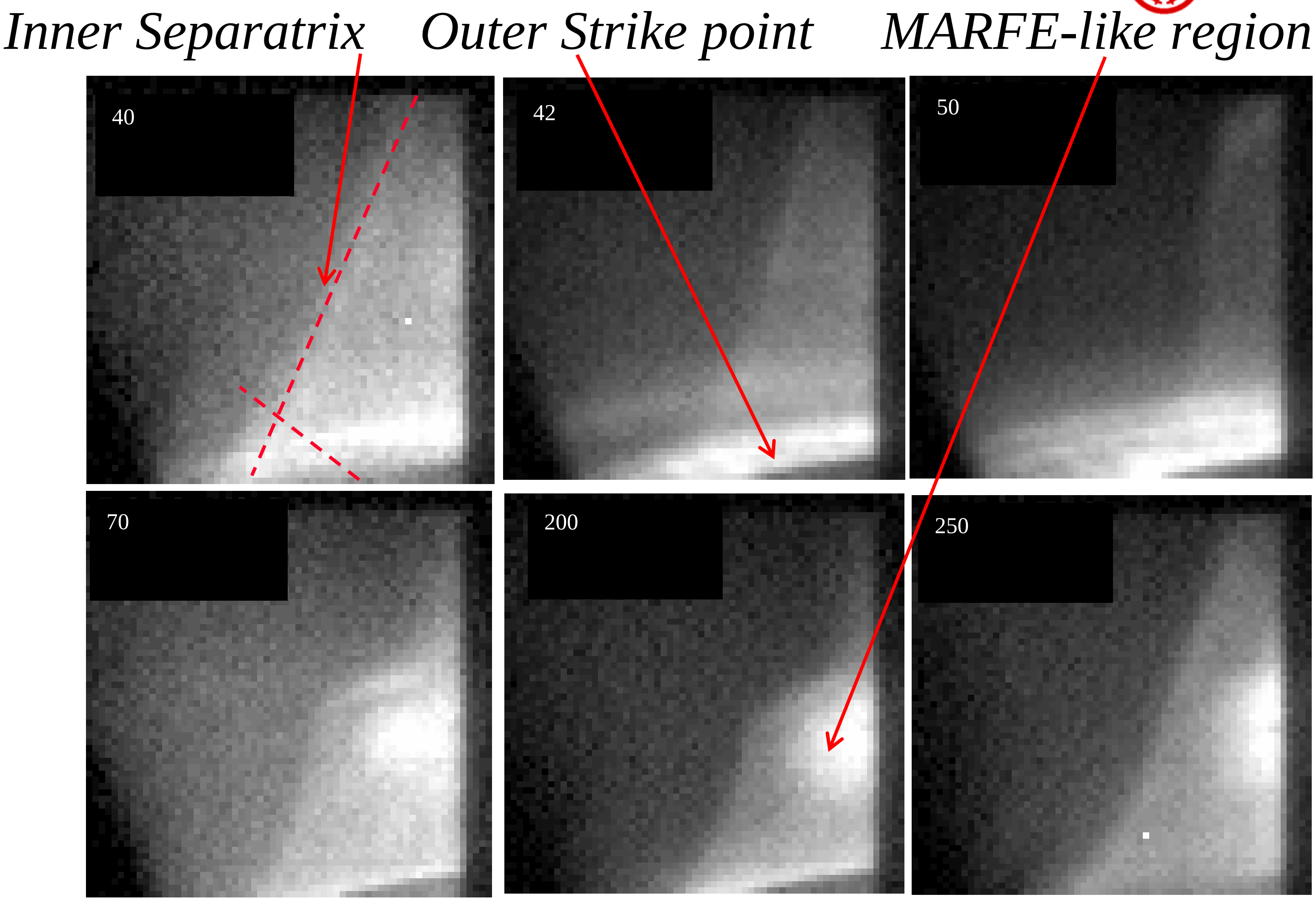
- Magnetic outboard strike point perturbation preceded MARFE like structure formation on inner leg (approximate camera field of view in LHS yellow box)





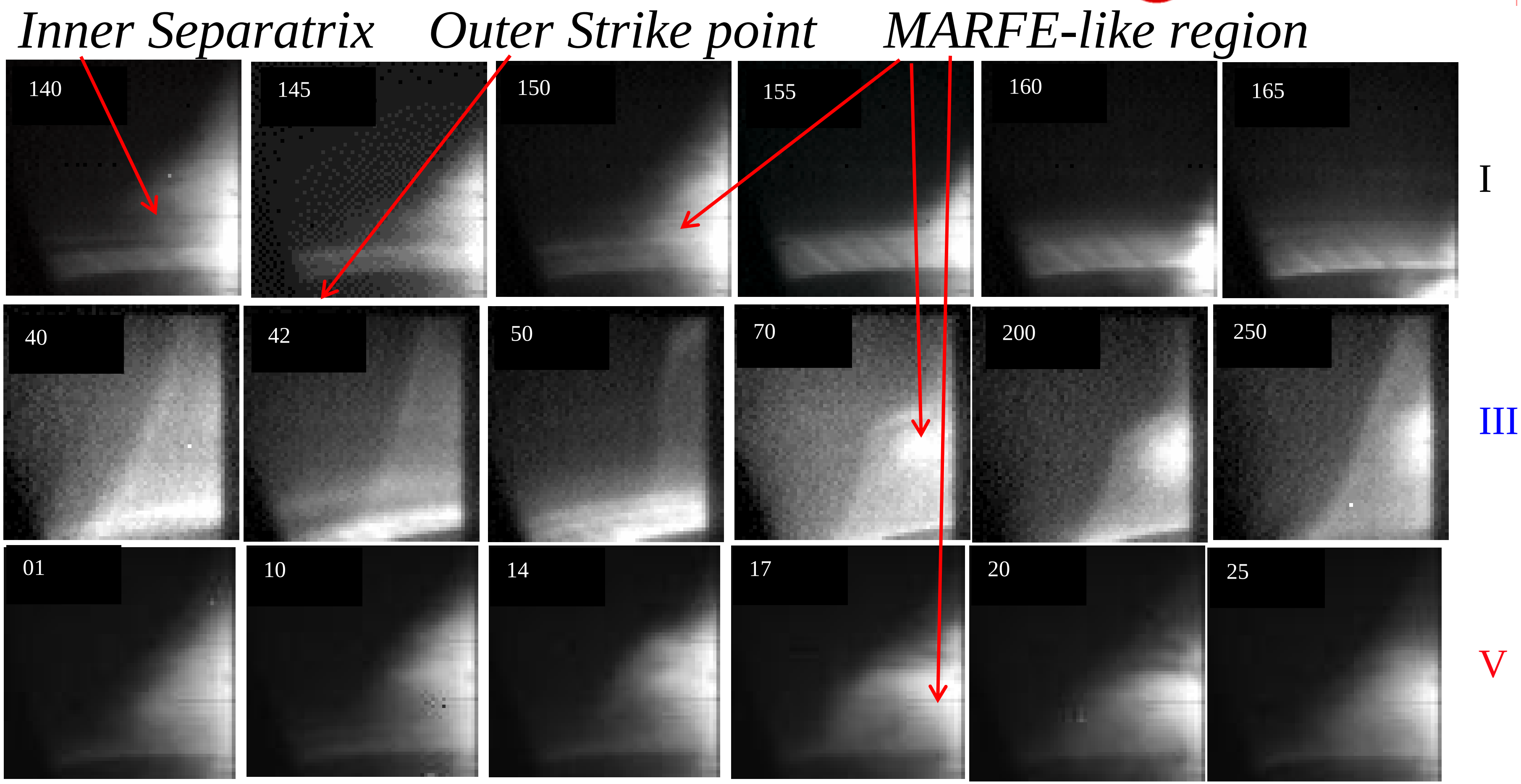
Nishino (U. Hiroshima), Roquemore, Maingi (ORNL) [#112165]

Type III ELMs do not burn through MARFE-like region near inner X-point



- All data with 24.7μs time between frames; relative frames numbers indicated

Type I (III, V) ELMs do (not) burn through MARFE-like region near inner X-point



- All data with 24.7μs time between frames; relative frames numbers indicated
- ELMS from different shots or different time range within a shot

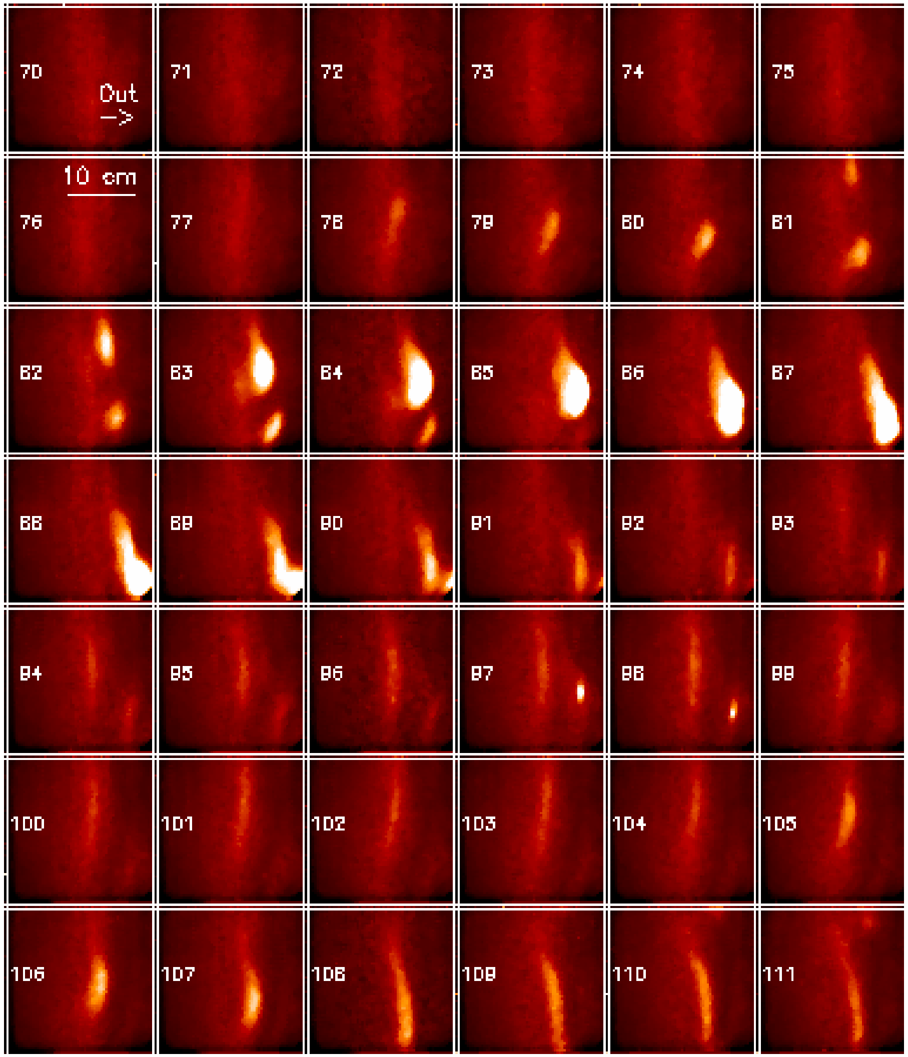
Gas Puff Imaging system shows Type V ELM structure near outer midplane

- Smaller events (blobs, but not Type V ELMs) occur between two type V ELMs in video clip #113411

Zweben, Munsat, Bush (ORNL)

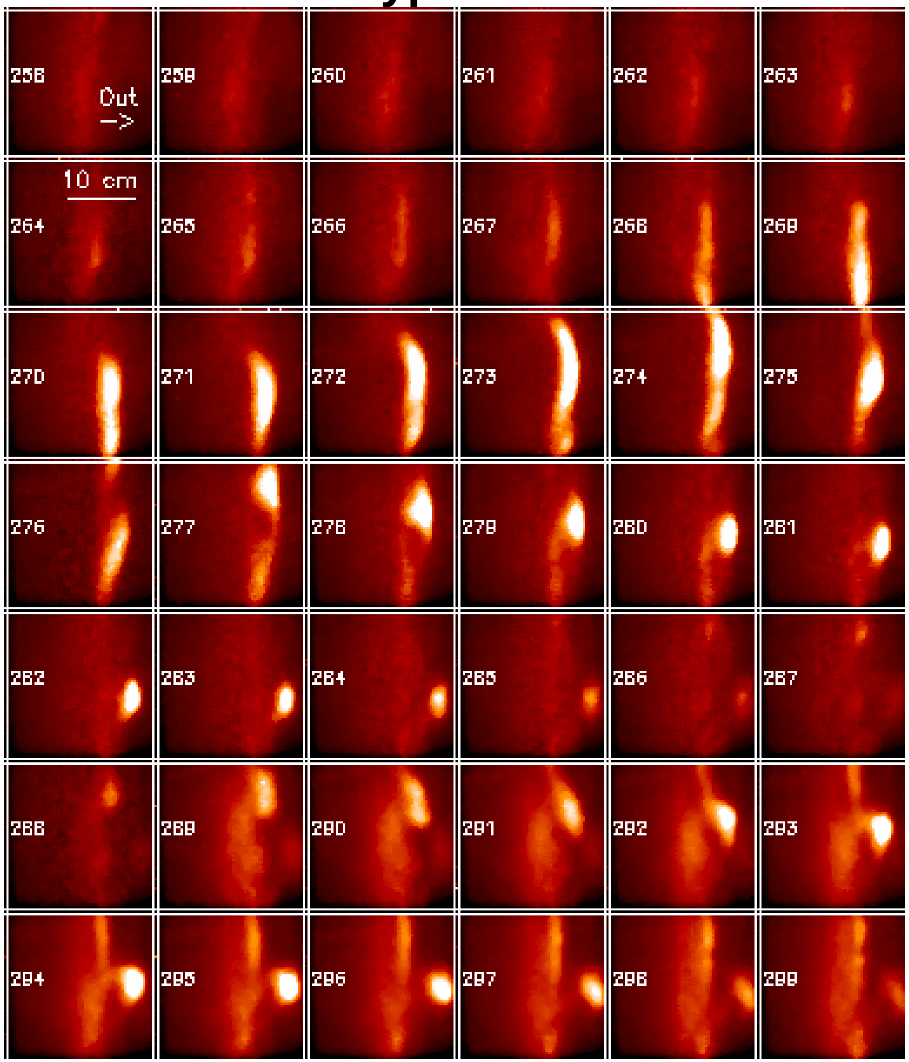
Gas Puff Imaging system shows Type V ELM structure near outer midplane

First Type V ELM



#113409, t=0.4507-0.45111 s, 10μs/frame

Second Type V ELM



#113409, t=0.45259-0.453 s, 10μs/frame

Zweben, Munsat, Bush (ORNL)

L-H Transition Physics Summary

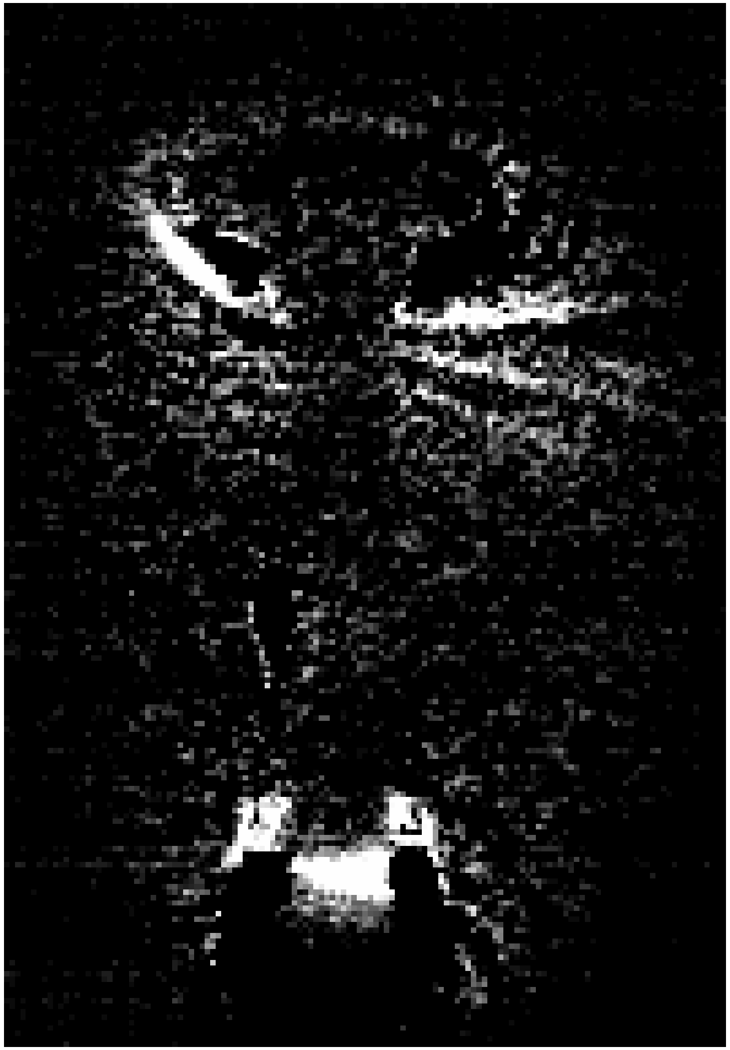
- H-mode theories can separate well developed H-mode and L-modes
  - ✱ No predictive capability in going from L-H
- Edge turbulence quenched in 100 μsec before L-H transition
  - ✱ No clear change in edge flow patterns
  - ✱ Quiescent periods often precede L-H transition
- Other results: fueling from center stack facilitates H-mode access
  - ✱ Sometimes translates into lower power threshold
  - ✱ Role of neutrals/charge exchange loss unclear

ELM Research Areas

- ELM stability
  - Obtain complete dataset (MSE, Thomson, edge probe, plasma fisheye TV, …) on which to test edge stability calculations before and after different ELM types
  - Identify pre-cursor mode #s
  - Relationship to pedestal pressure/gradient limits?

- Type II/III and V ELM dynamics and dependencies
  - Importance of MARFE
  - Dependence on shape and collisionality
  - Origin of structures/fingers in divertor light patterns?

Plasma Fisheye TV Suggests n>1 Perturbation for Medium-sized *(Type II/III)* ELM?

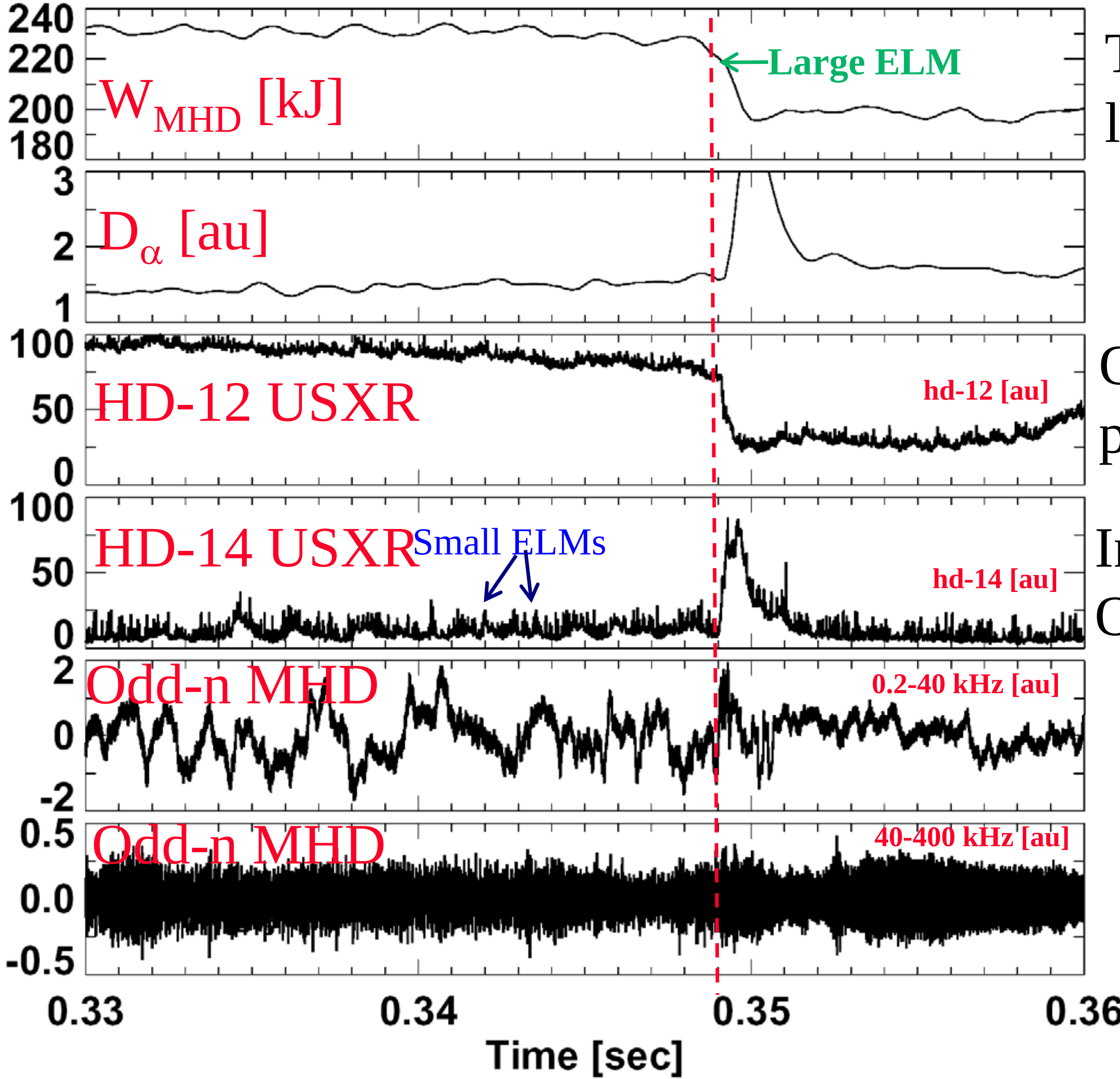


#113380, Difference (460ms - 455ms)

#113409, Difference (390ms - 385ms)

Bush (ORNL)

Title? Characteristics of Mixed Small + Large "ELM" Discharge



Type I ELM
large ΔW_{MHD}

Outflux from
pedestal

Influx to SOL
Or separatrix