H-mode Access and Characterization with Neutral Beam Injection on NSTX

C.E. Bush[a], R. Maingi[a], M.G. Bell[b], R.E. Bell[b], E.D. Fredrickson[b], D.A. Gates[b], D.W. Johnson[b], R. Kaita[b], S.M. Kaye[b], S. Kubota[c], H.W. Kugel[b], B.P. LeBlanc[b], R. Maqueda[d], S. Medley, J.E. Menard[b], D. Mueller[b], M. Ono[b], F. Paoletti[e], S. Paul[b], Y.-K.M. Peng[a], A.L. Roquemore[b], S.A. Sabbagh[e], V.A. Soukhanovskii[b], D. Stutman[f], E.J. Synakowski[b], G. Taylor[b], and S.J. Zweben[b]. *For the NSTX Team.*

[a]*Oak Ridge National Laboratory, Oak Ridge TN, 37831 USA*
[b]*Princeton Plasma Physics Laboratory, PO Box 451, Princeton, NJ, 08543 USA*
[c]*University of California at Los Angeles, Los Angeles, CA 90095 USA*
[d]*Los Alamos National Laboratory, Los Alamos, NM, 87545 USA*
[e]*Columbia University, New York, NY, USA*
[f]*Johns Hopkins University, Baltimore, MD, 87545 USA*

NSTX Results Review
Princeton Plasma Physics Laboratory -- Princeton, New Jersey
September 18-21, 2001

Outline and Motivation

- H-modes with high τ_E and dW/dt obtained.

  -- limited by duration of ELM free H-mode (need for high β).

- Well defined edge transport barrier as evidenced by steep n_e gradient from both TS and reflectometry.

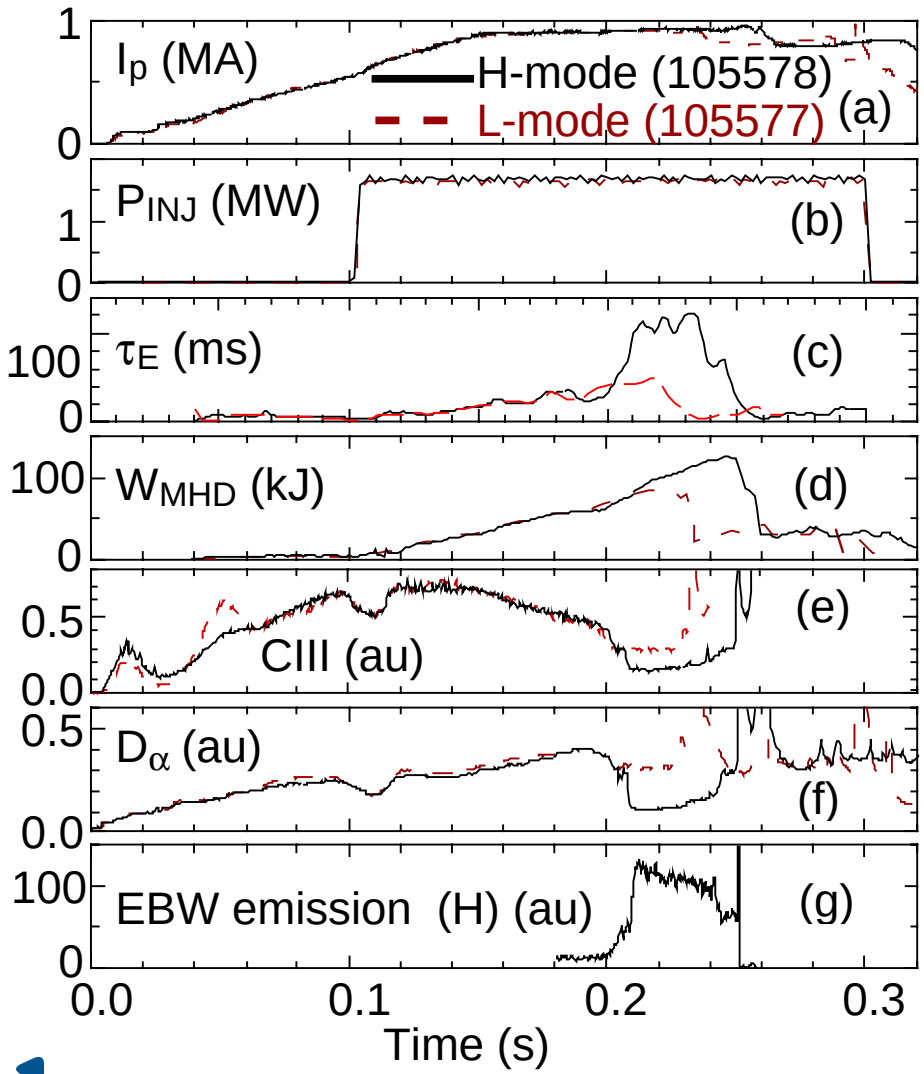
  -- supported by EBW and GPI diagnostics.

- Evidence for turbulence suppression (increase) at L-H (H-L) transition and during H-mode (Mirnov coils, GPI, reflectometry).
- Able to get ELMy H-modes on demand: Need more control.
- Power threshold determined for a set I_p,B_t,n_e:

  -- Proper scaling for P_{th}?

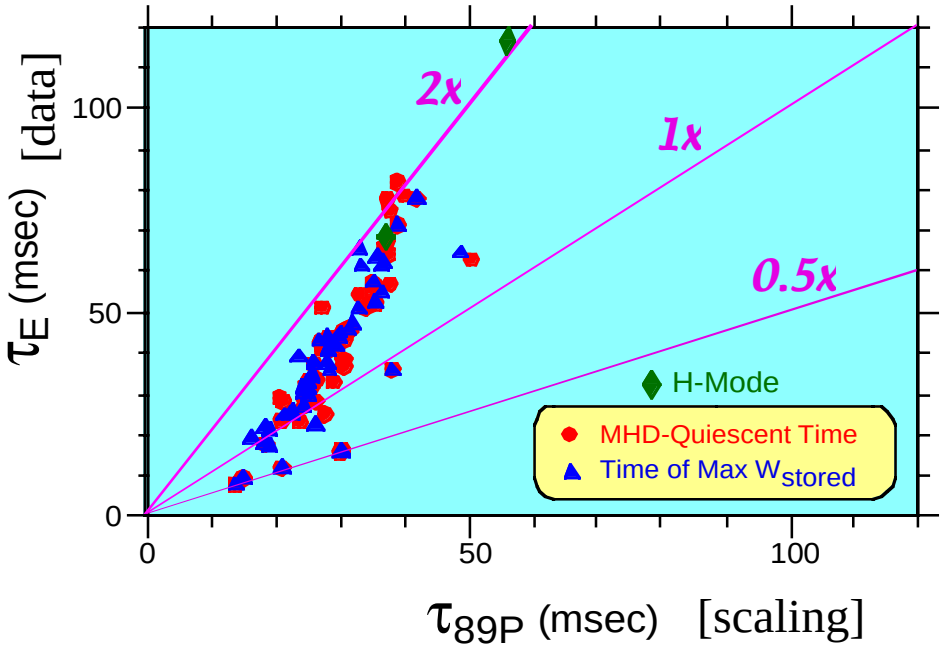
- Evidence for poloidal plasma rotation.
- Summary and Conclusions.

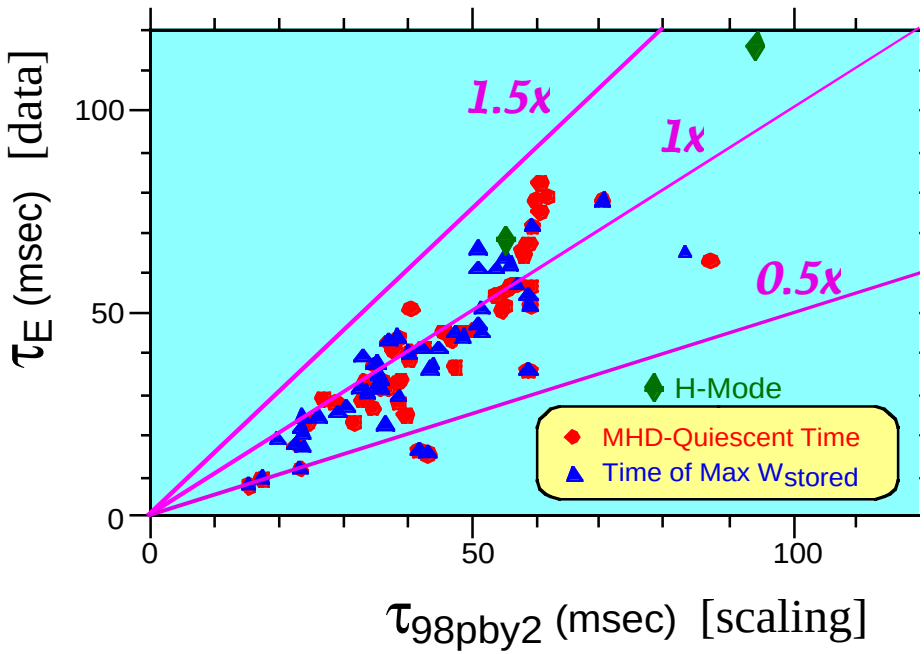
ELM-free H-modes with τ_E ~ 120 ms Have Been Obtained. -- Lower Single Null Divertor (LSND), P_b = .83 - 2.4 MW



- Same I_p, B_t, n_e
- Same P_b pulse
- τ_E improves
- Stored energy increases
- Central P_{rad} increased during H-mode
- D_α drop $\Rightarrow$ H-mode
- Emission from EBW increases 3 fold.
  $\Rightarrow$ steeper edge n_e gradient. (G. Taylor)
- Ti(0) increases. (from NPA) (S. Medley)

Confinement In NSTX Is H-mode Magnitude, with or without H-mode Signatures

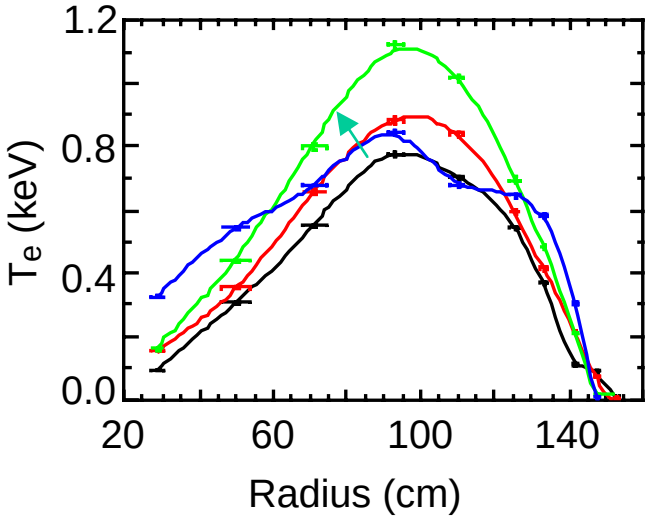


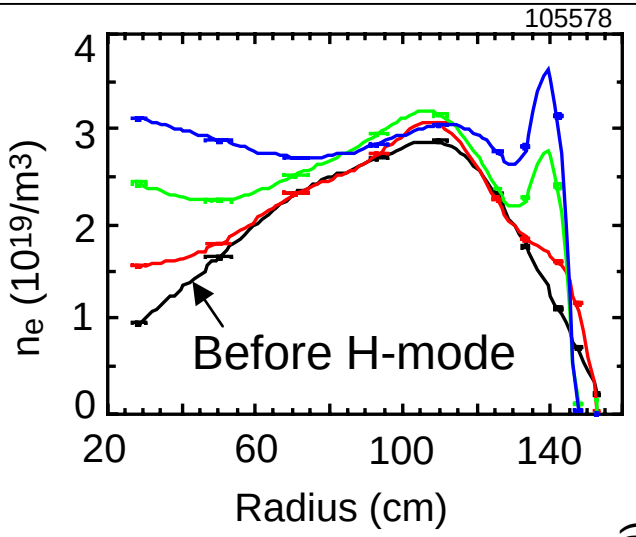


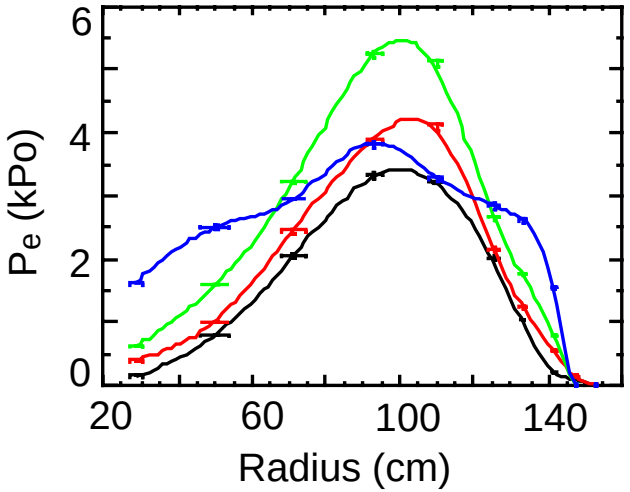
- dW/dt ~ 0 for most data except H-mode points, which have large dW/dt

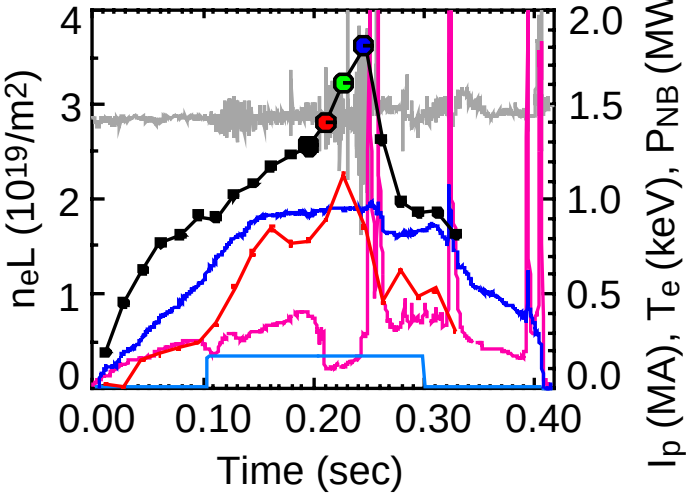
S. Kaye

The Edge Transport Barrier is Evidenced by the steep edge n_e gradient ("ear-like" features)





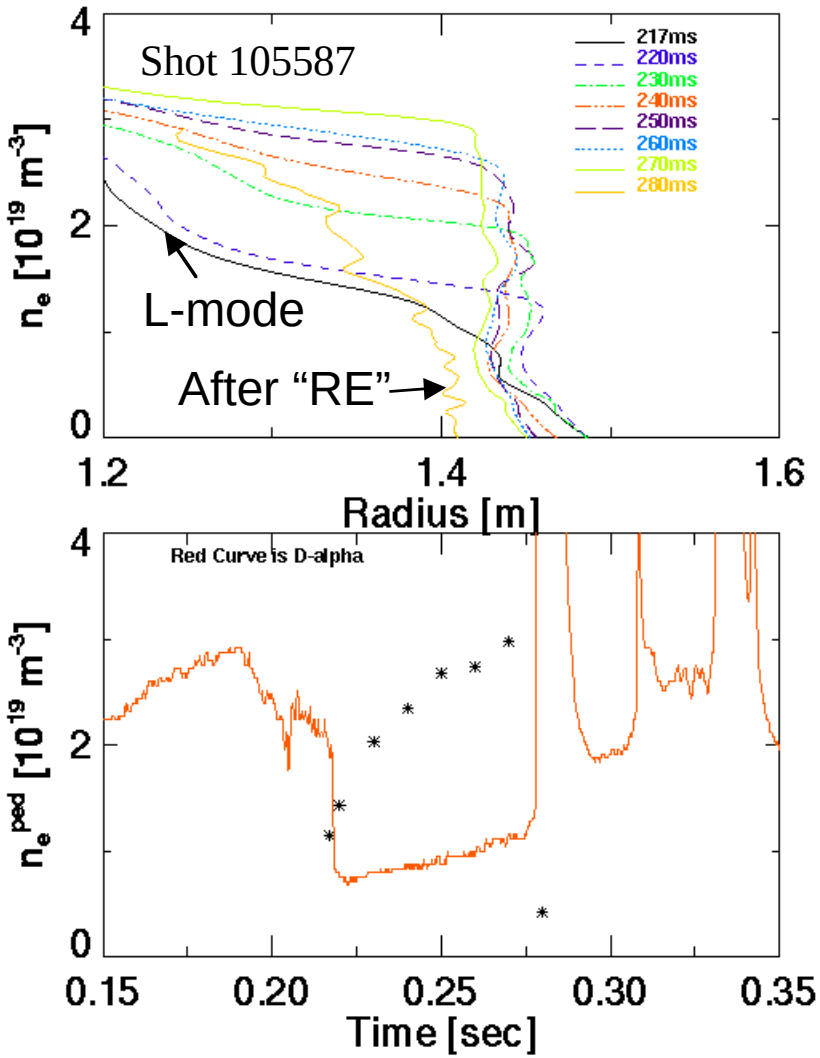




- From Thomson Scattering

B. Le Blanc
R. Bell
D. Johnson
D. Hoffman

Edge n_e pedestal height increases during H-mode.



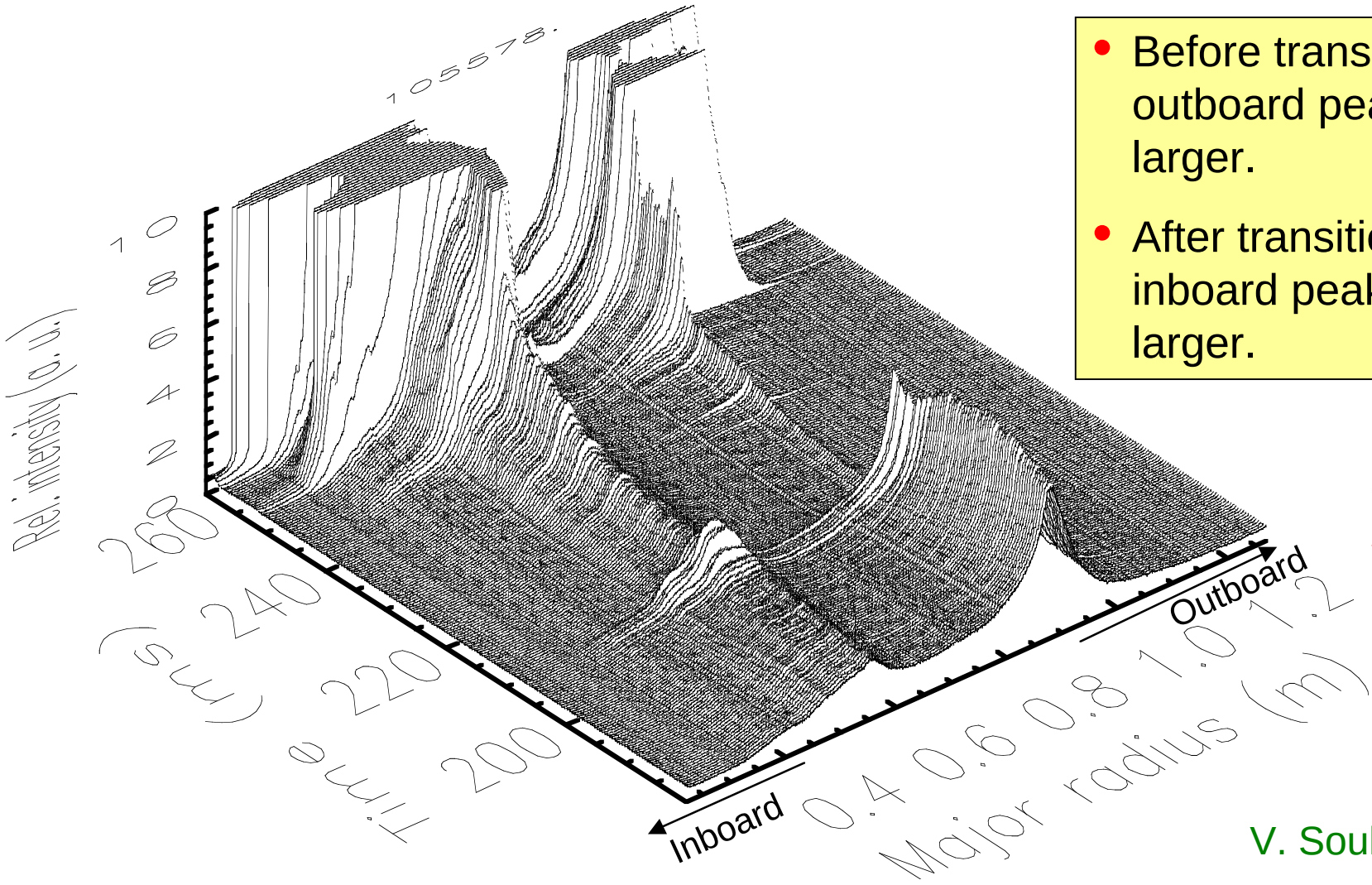
n_e from edge scanning reflectometer, just before and during H-mode.

(reflectometry cannot see dip, thus no "ear-like" feature)

Time evolution of D_α and "pedestal" n_e.

S. Kubota, T. Peebles

Reduced D_α Emission is Observed at the Divertor Strike Points at the L-H Transition

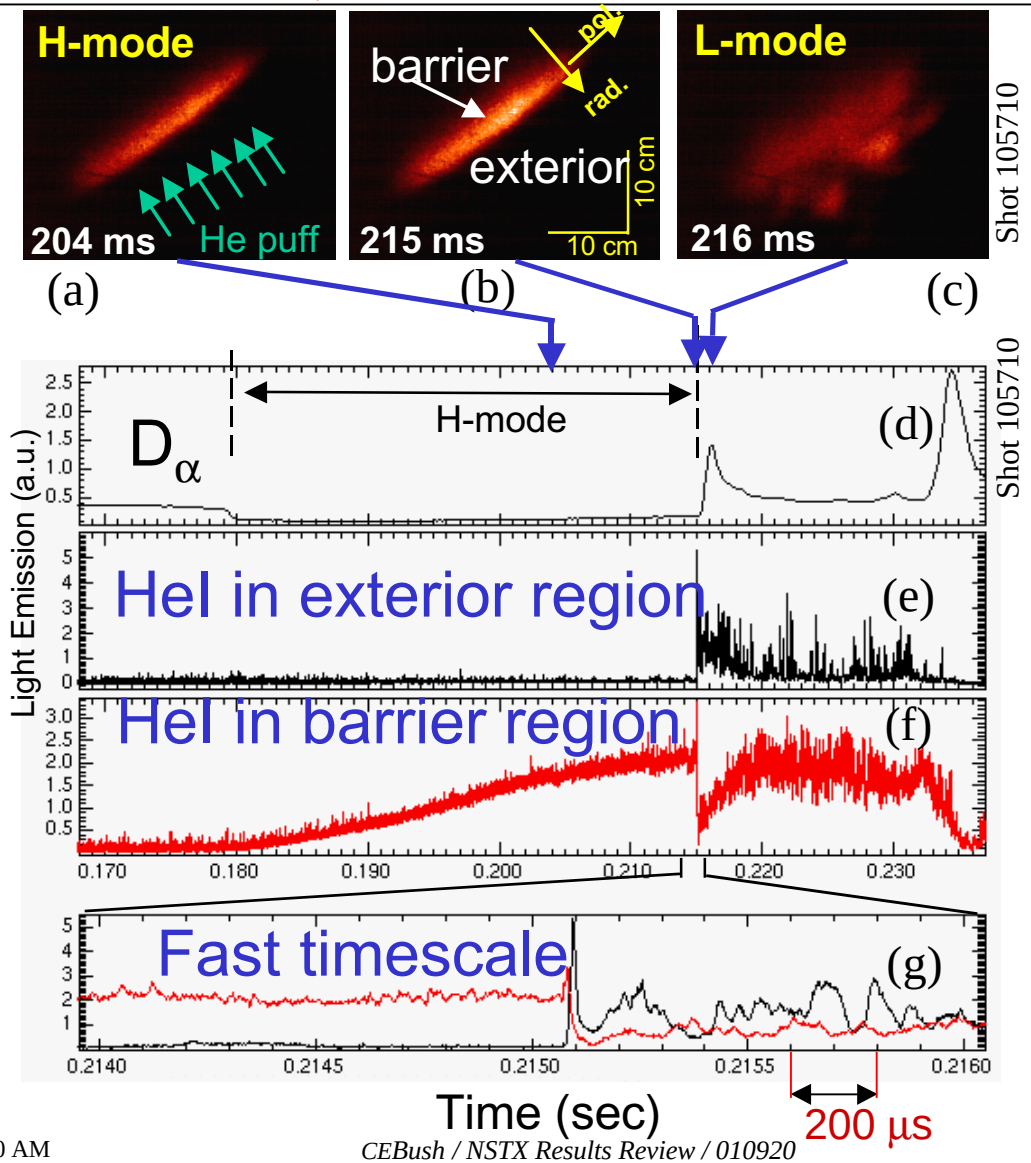


- Before transition, outboard peak is larger.
- After transition, inboard peak is larger.

- Peaks in emission at strike points

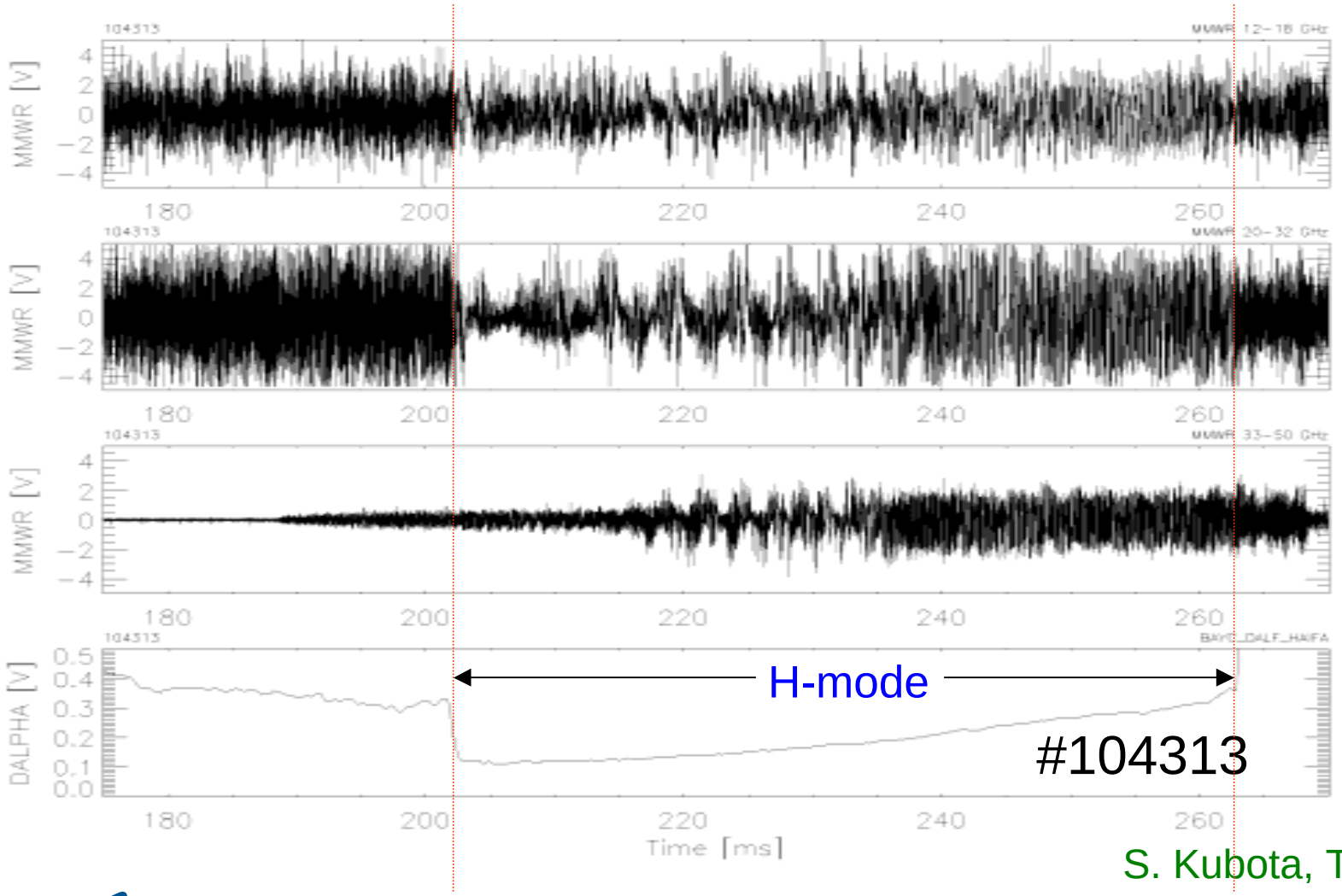
V. Soukhanovskii

GPI Shows Edge Transport Barrier Goes Away within 30 μs at H-L Transition



R. Maqueda
S. Zweben

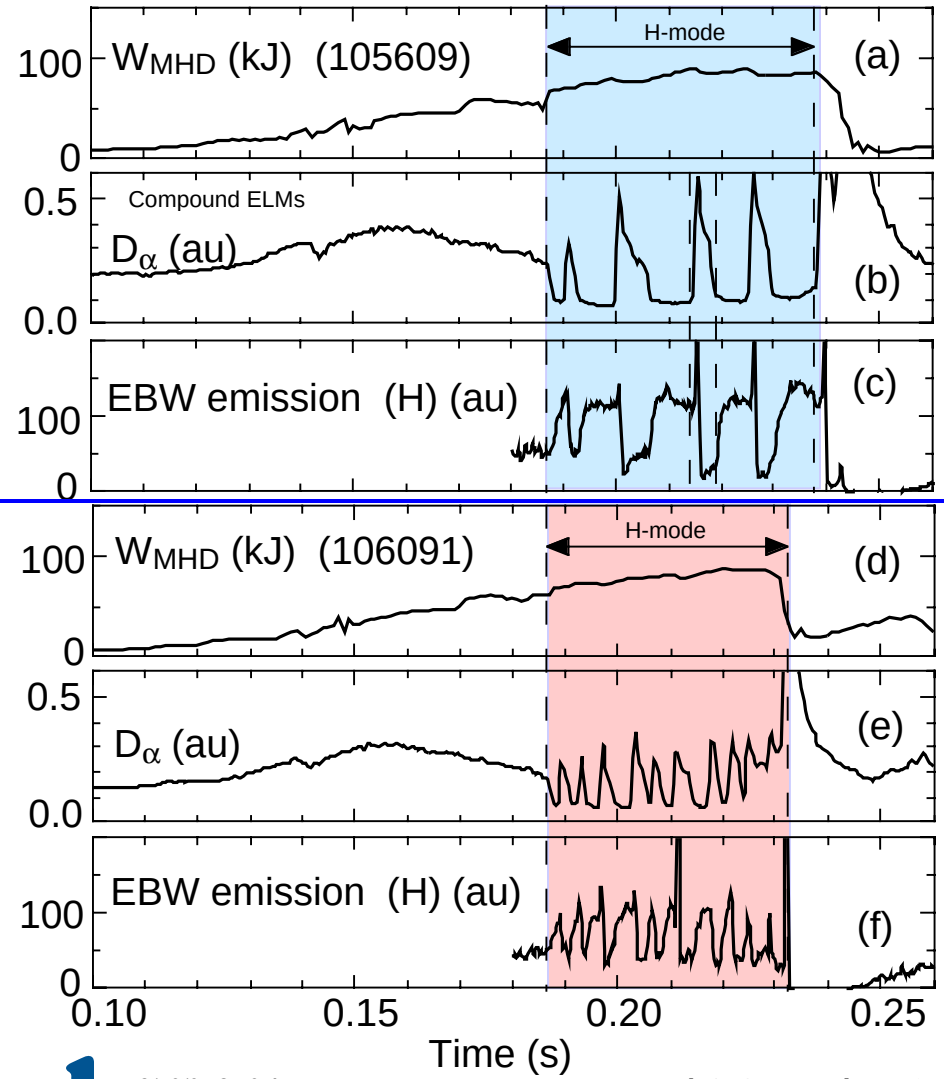
Edge Fluctuations Reduced During H-mode Phase (Scrape-Off Layer and Core Are Unaffected)



- SOL
- EDGE
- CORE
- D_α

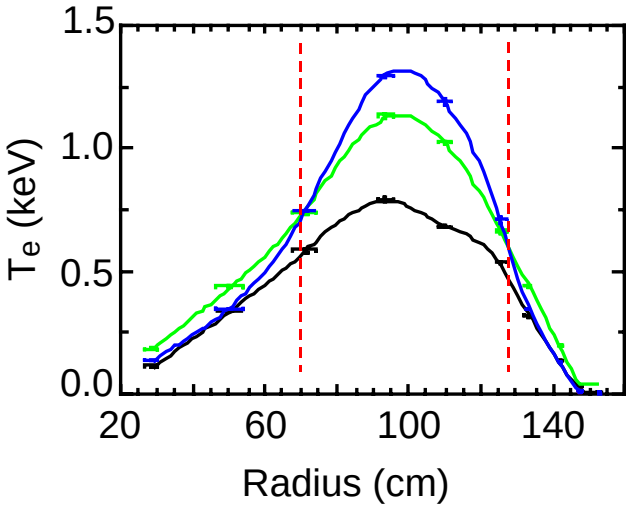
S. Kubota, T. Peebles

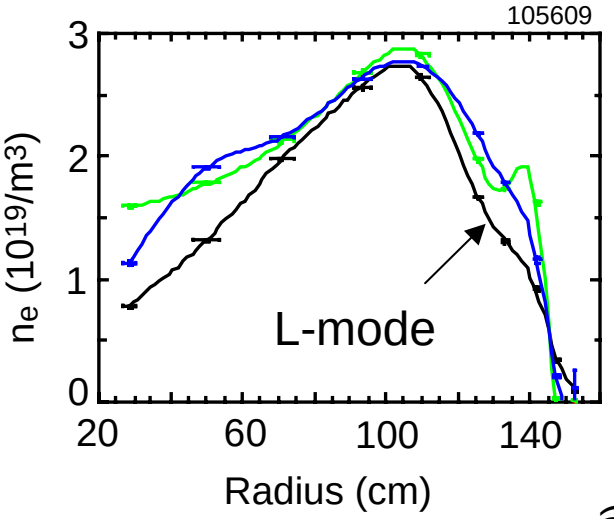
ELMing H-modes Obtained in NSTX Are Similar to Those in Conventional Aspect Ratio Tokamaks



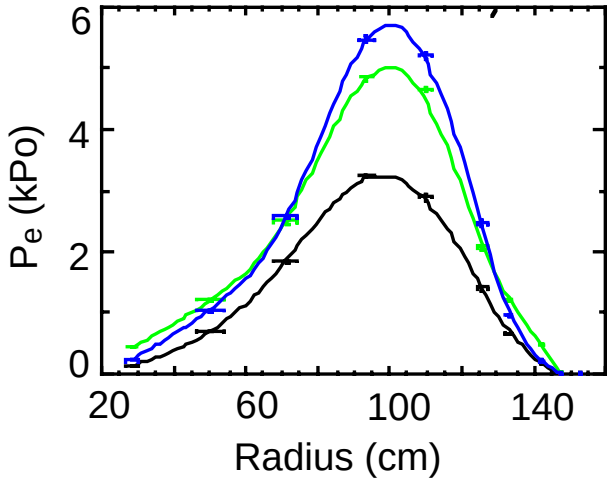
- Large compound ELMs with early divertor
- EBW emission is reduced at each ELM. Recovers between ELMs.
- Smaller high frequency ELMs at $P_{tot} > P_{th}$
  ELMs ⇒ dithers near threshold

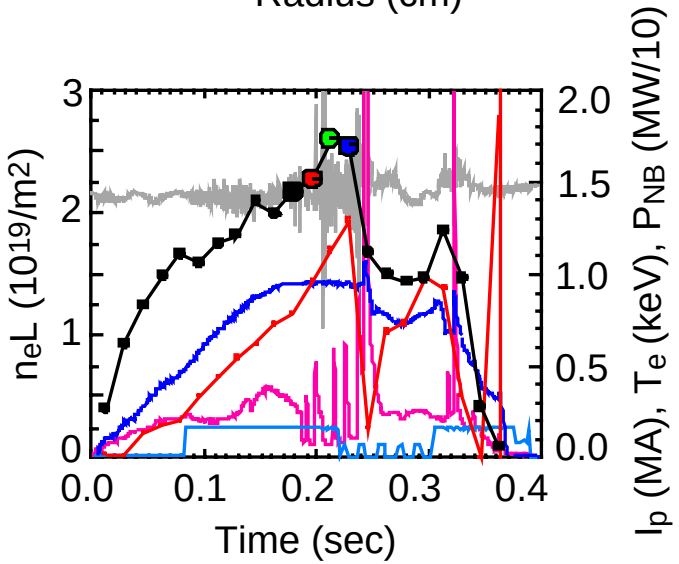
The Edge n_e Peak goes away at ELM, but returns Between ELMs. Large ELMs Reach Deep Inside Plasma.



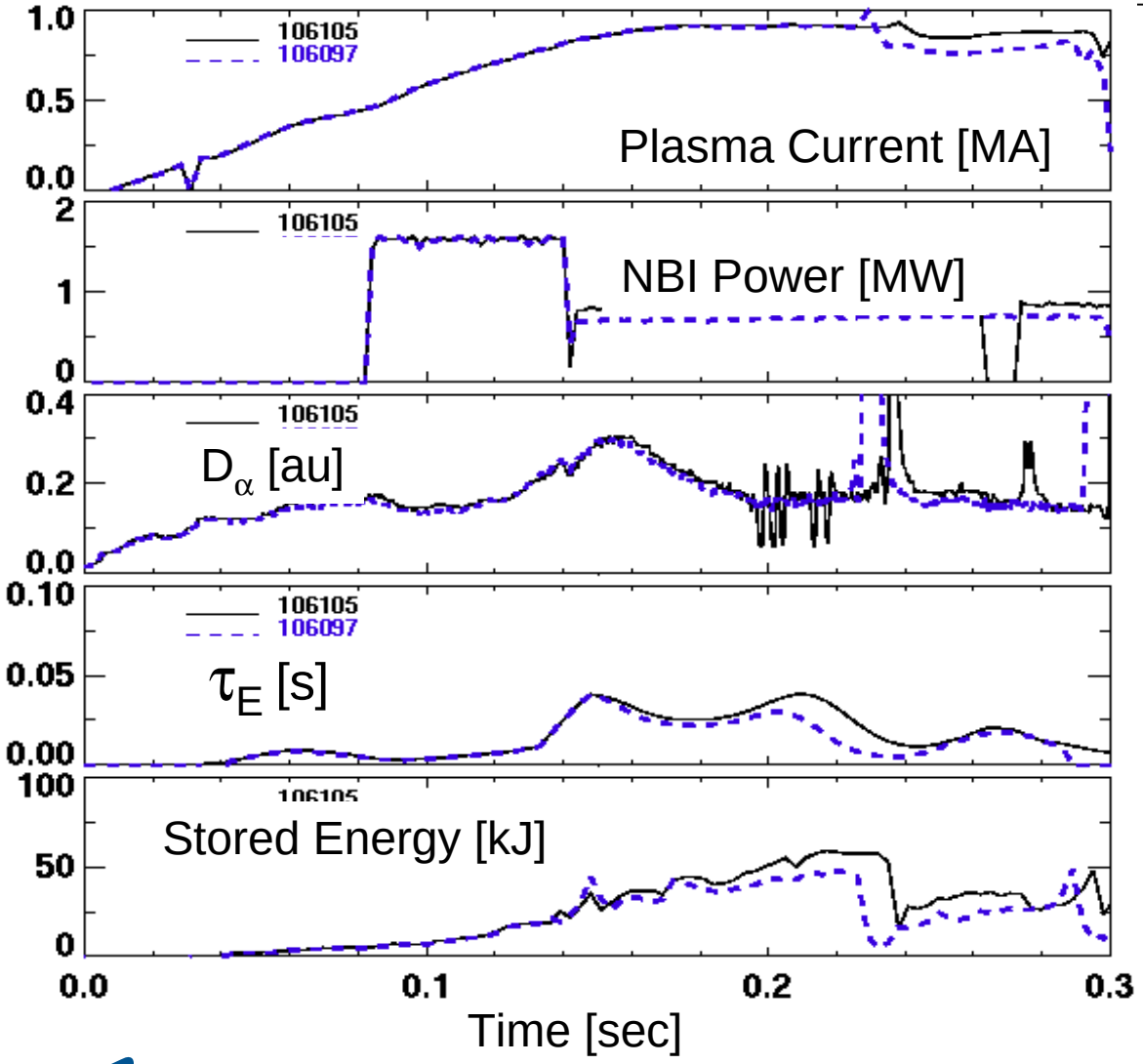


B. Le Blanc
R. E. Bell
D. Johnson
D. Hoffman





H-mode 'Dithers' Appear When NBI Power Approaches L-H Threshold Power



- Same plasma current. B_t = 0.45T, n_e
- NBI power near P_{L-H}
- Dithers show up in D_α
- τ_E improves slightly
- Stored energy increases slightly

The Proper Power Threshold Scalings for ST's Have Yet to be Determined

- Comparison to the International H-mode database scaling: Global Parameters

$P_{th} = 0.65\ n_e^{0.93} B_t^{0.86} R^{2.15}$ (MW, $10^{20}/m^3$,T,m)

$= 50 - 60$ kW = 0.06 MW for NSTX

P_b (threshold) = 0.83 MW, from threshold experiment

$P_{th} = P_{tot} = P_{OH} + P_b = 2$ MW $\Rightarrow$ 2 MW / 0.06 MW ~33 times

or

Using P_{Loss}

$\dot{P} = \dot{w}_b + \dot{w}_p = 470$ kW +450 kW = 920 kW

$P_{th} = P_{tot} - \dot{P} = 1.1$ MW $\Rightarrow$ 1.1/ 0.06 MW ~ 18 times

- Compare with Canonical Profiles Transport Model: Local Parameters

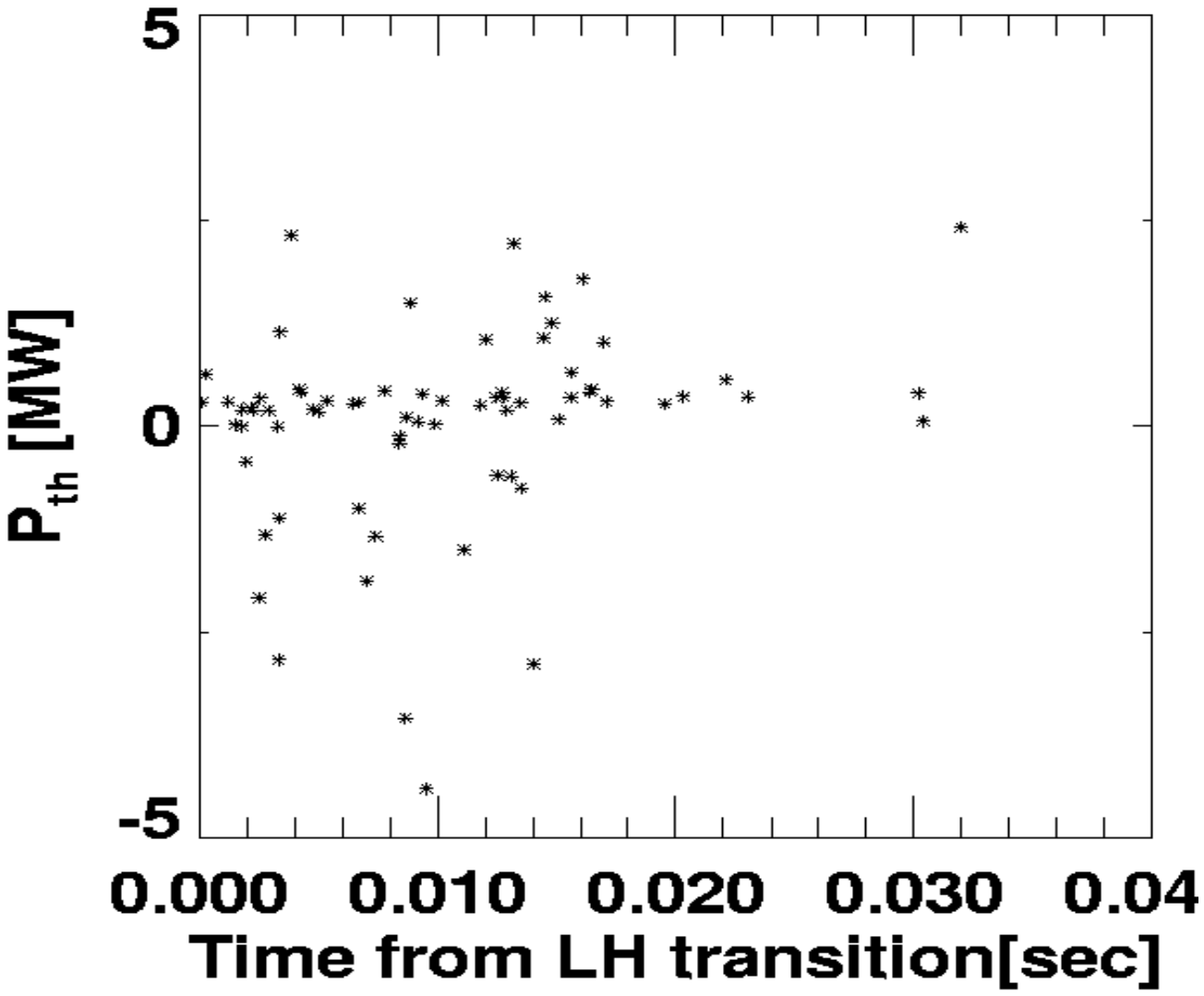
P_{th} (MW) = 0.13 $(Z_0 + Z_q - Z_n)\ RT_e(a)K$

Where $P_{tot} = P^{con} - P^{rad} > P_{th}$, $K = nX = a^2 n / 2\tau_E$, $Z_q = 3(1-1/q_a)$

$Z_q = 3\ (1 - 1/q_n) \sim 2 - 2.5$, $Z_n = - an'_a/n_a$

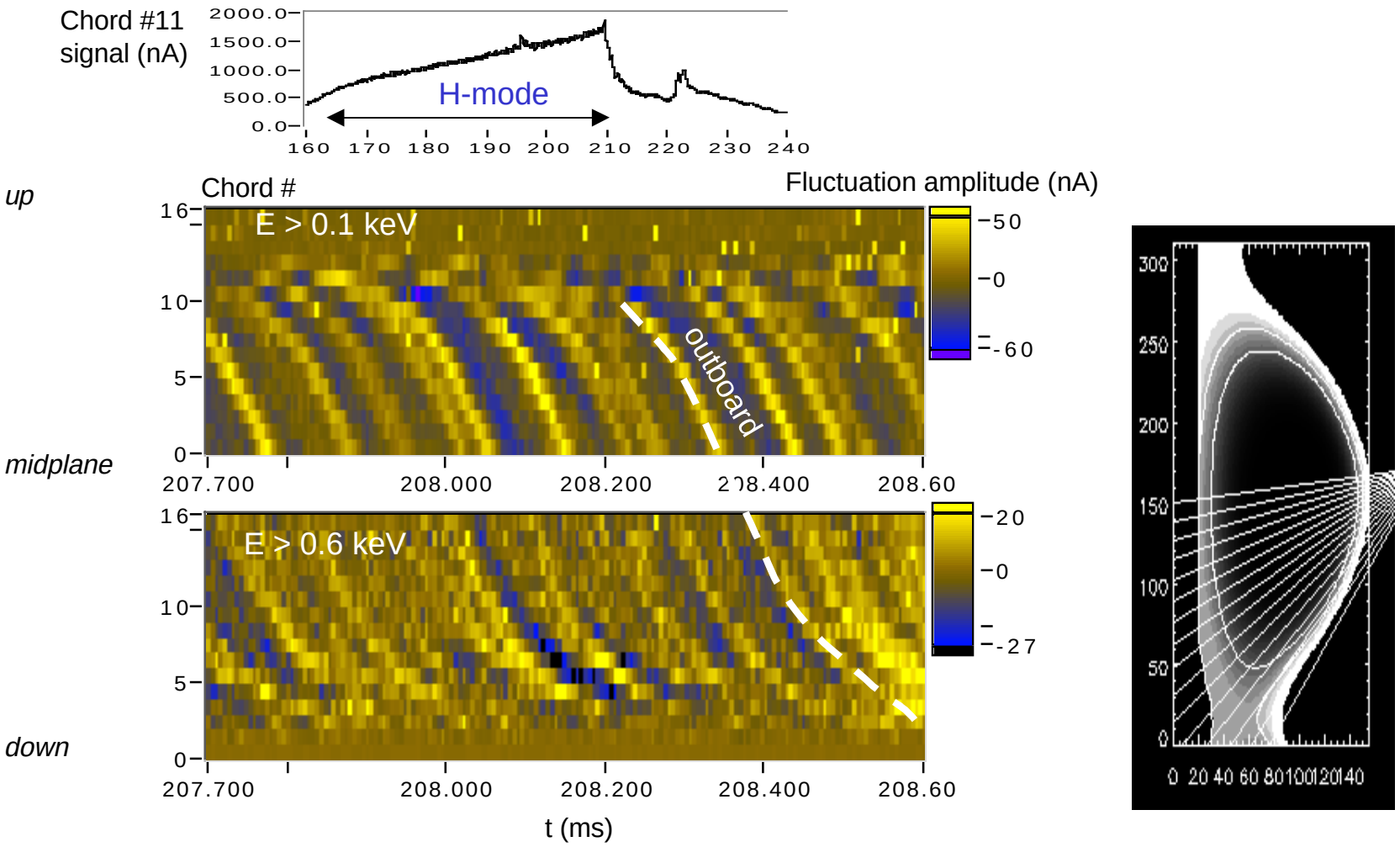
$\Rightarrow P_{th} = 100$ kW to > 2 MW for NSTX (Dnestrovskij - Proc, 26th EPS Conf.)

The NSTX H-mode Database Shows Values of P_{CPTM} Significantly and Consistently Above $P_{international}$.



- Comparisons with the Canonical Profiles Transport Model (CPTM) are just beginning.
- P_{CPTM} values mostly ~ 400 - 500 kW.

USXR Arrays Show Filaments Rotating in the Outboard Plasma Periphery



D. Stutman

Summary and Conclusions

- **ELM-free and ELMy H-modes obtained on NSTX using NBI.**
  - only obtained in Lower Single Null Divertor (LSND).
  - obtained with a variety of heating; NBI, RF (HHFW), NBI + RF
- **Best H-mode confinement: τ_E ~ 120 ms, $\leq$ 1.3 times ITER98pby2 scaling.**
- **Turbulence suppression is observed at L-H transition.**
  - scanning edge reflectometer, Gas Puff Imaging, center stack Mirnov
- **NSTX H-mode has well defined edge transport barrier; large edge n_e gradient.**
  - edge n_e profiles from Thomson scattering and edge scanning reflectometer.
  - signal due to EBW, GPI.
- **Power threshold determined, with P_b < 840 kW at 0.9 MA.**
  - P_{th}(NSTX) >> P_{th}(International H-mode Database): Global parameters.
  - Beginning to compare P_{th}(NSTX) with local models such as the CPTM.