ET5: BOUNDARY PHYSICS
CY 2000 RESULTS ASSESSMENT

NSTX

Presented

by

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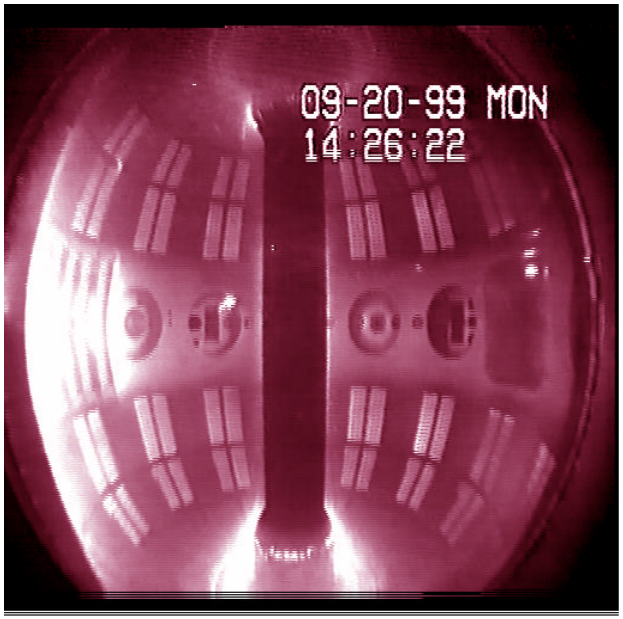
Oak Ridge National Lab

In collaboration with the NSTX team

NSTX Research Forum

Princeton, New Jersey: Jan. 15-18, 2001



Columbia U.

WALL CONDITIONING PROGRAM EMPLOYS MANY TECHNIQUES

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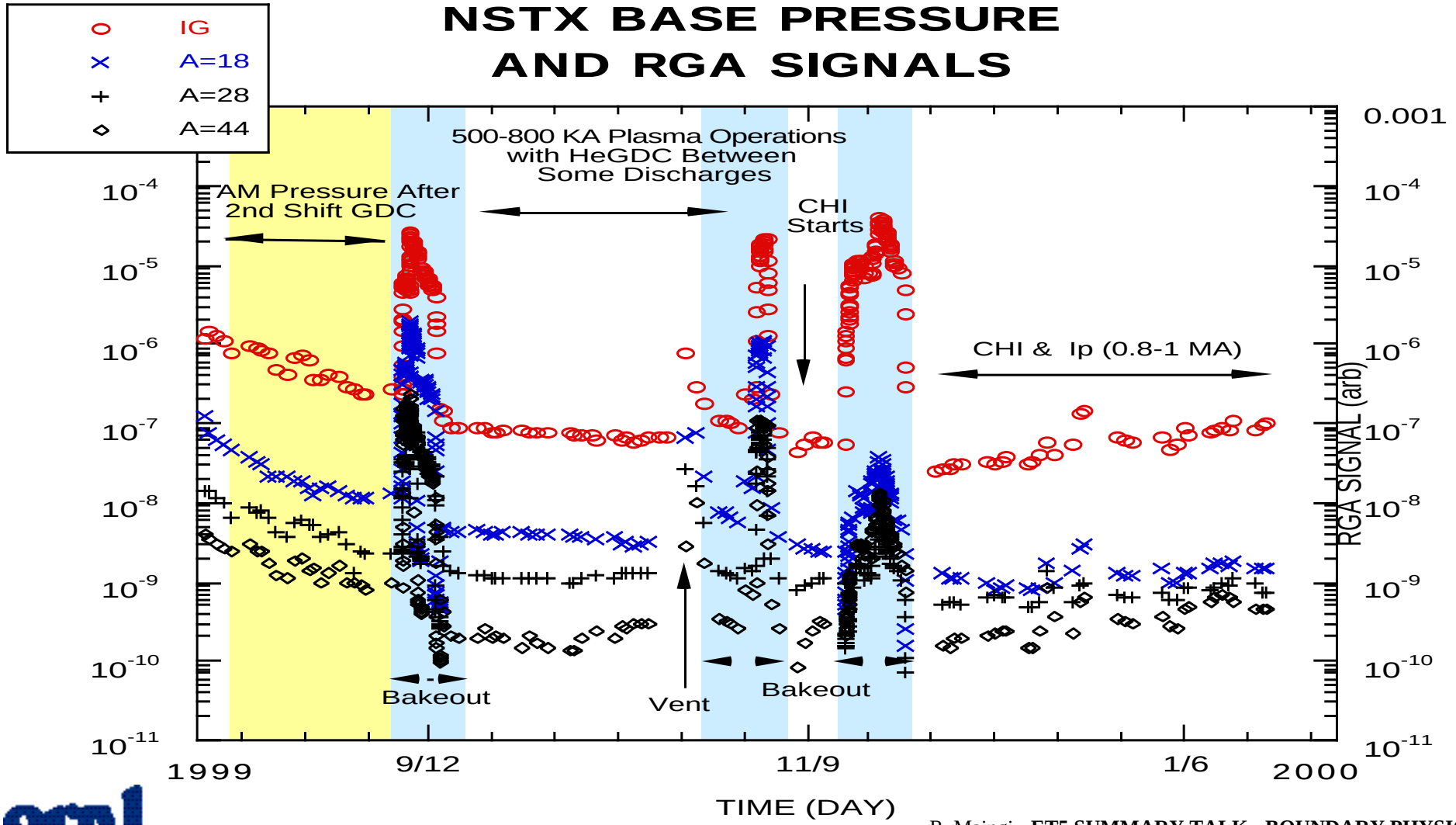
- Center stack resistive bakeout to 300 deg. C, passive plates plates to 160 deg. C
- Helium Glow Discharge Cleaning (HeGDC) to remove impurities and deuterium
- Boronization with Deuterated Trimethyl Boron (TMB); gas bled in during HeGDC, followed by 2 hours of pure HeGDC (remove deuterium in boron film)
- Inter-shot HeGDC of 5 minutes as required during NBI operations for reproducibility and deuterium removal
- Helium discharges for further depletion of wall deuterium (lowest deuterium recycling cases)

NSTX 1 MA DISCHARGES PRECEDED BY BAKE-OUT, D_2GDC AND HEGDC



BORONIZATION REDUCED EDGE IMPURITY EMISSION

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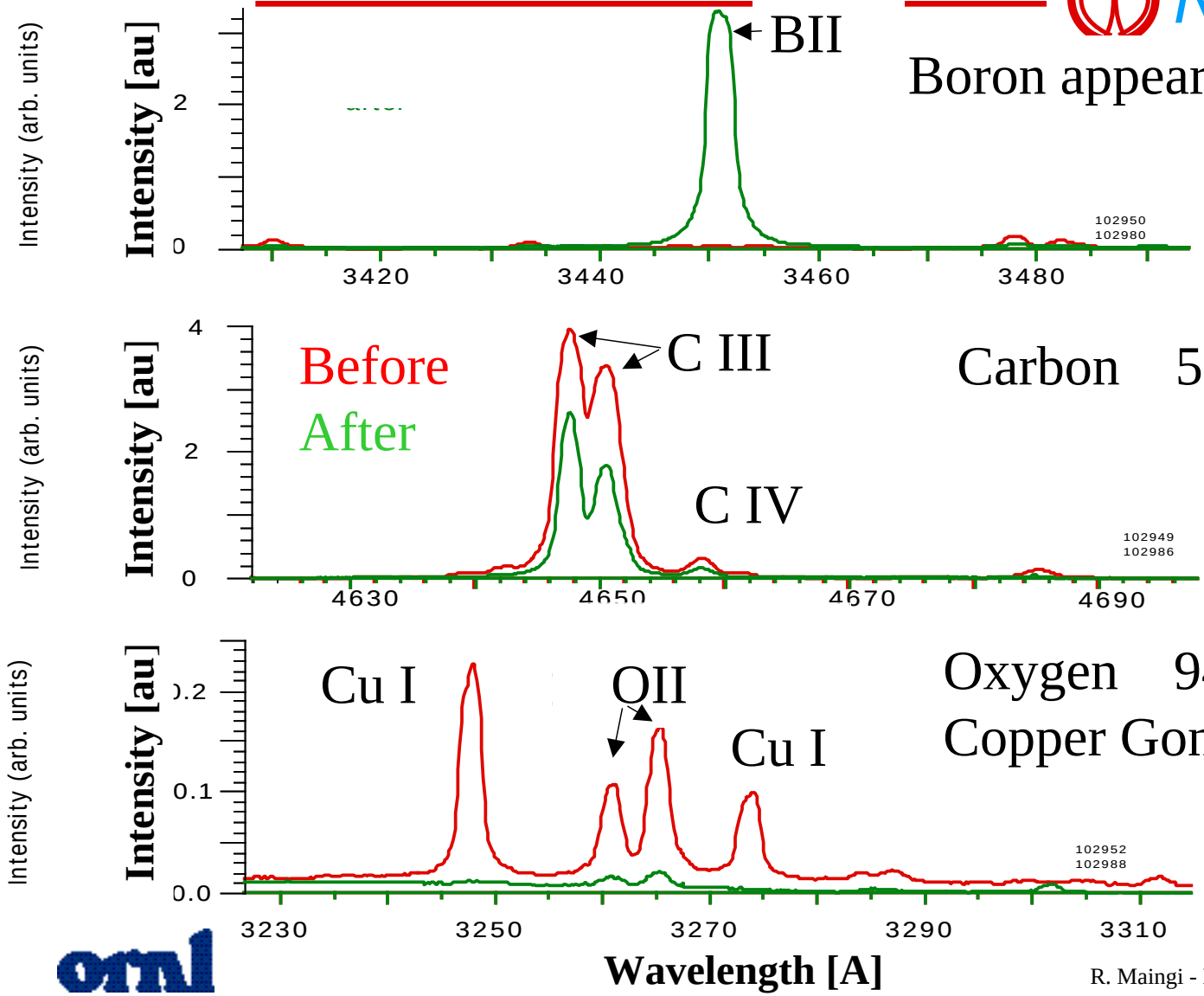

ALSO:

D_α 100%

VB 67%

V_{loop} 33%

τ_E 33%

BORONIZATION ENABLED LONGER PULSE, 'CLEANER' DISCHARGES

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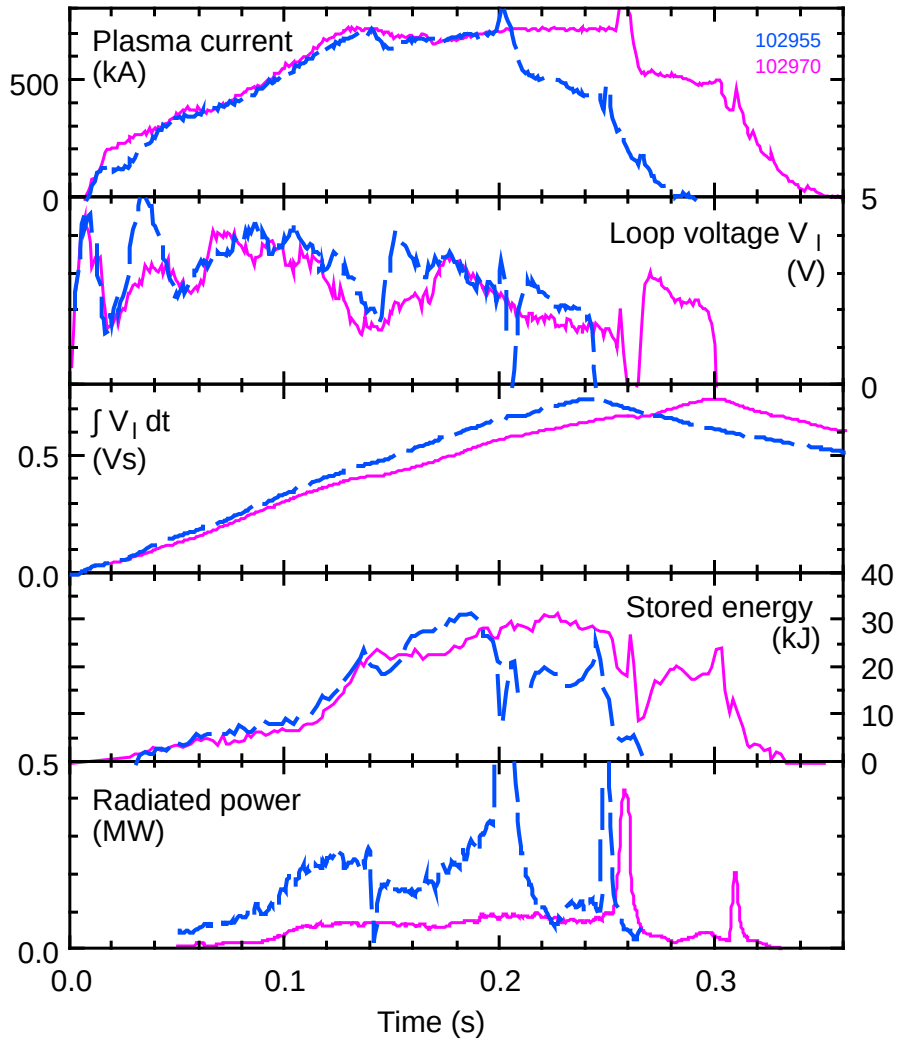

- Ip flattop increased
- Loop voltage decreased marginally
- Volt-second consumption reduced
- Stored Energy unchanged
- Radiated power decreased

BORONIZATION ENABLED ACCESS TO HIGHER DENSITY, CONFINEMENT

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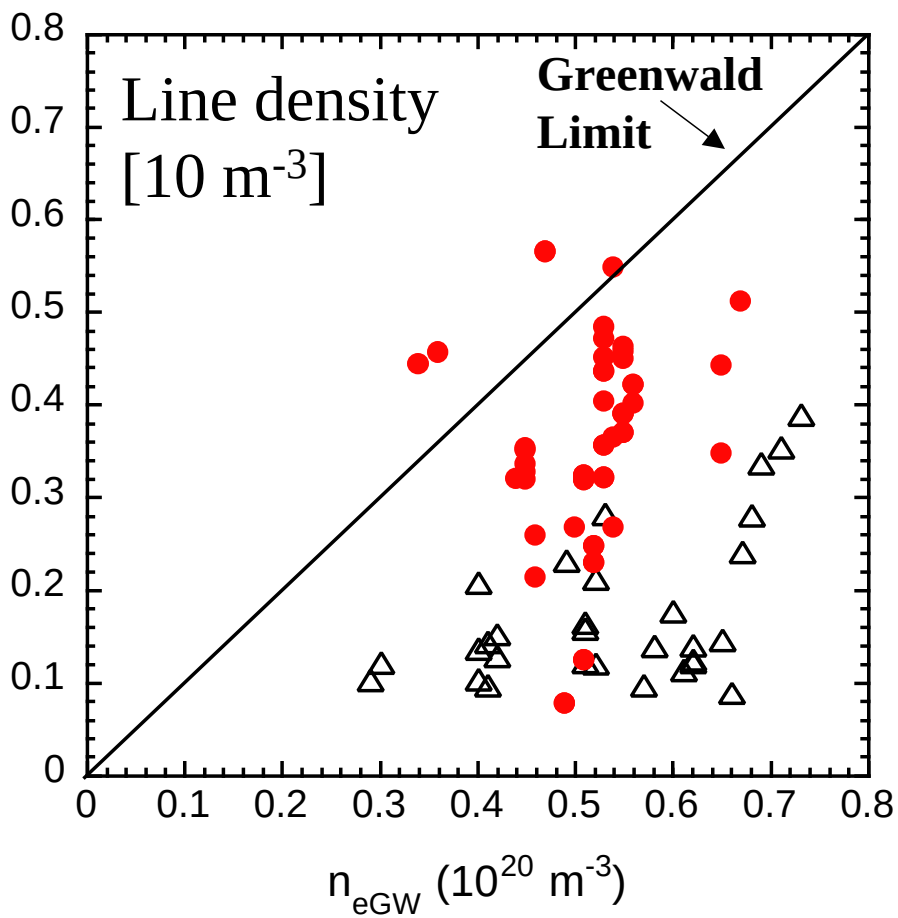
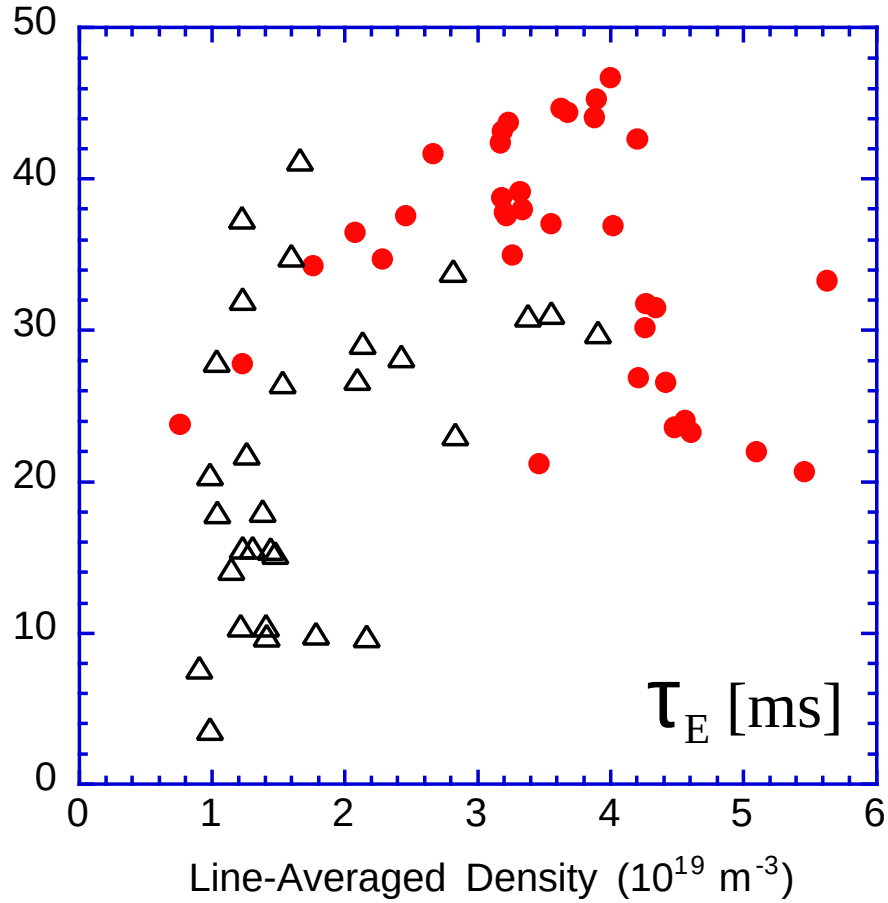
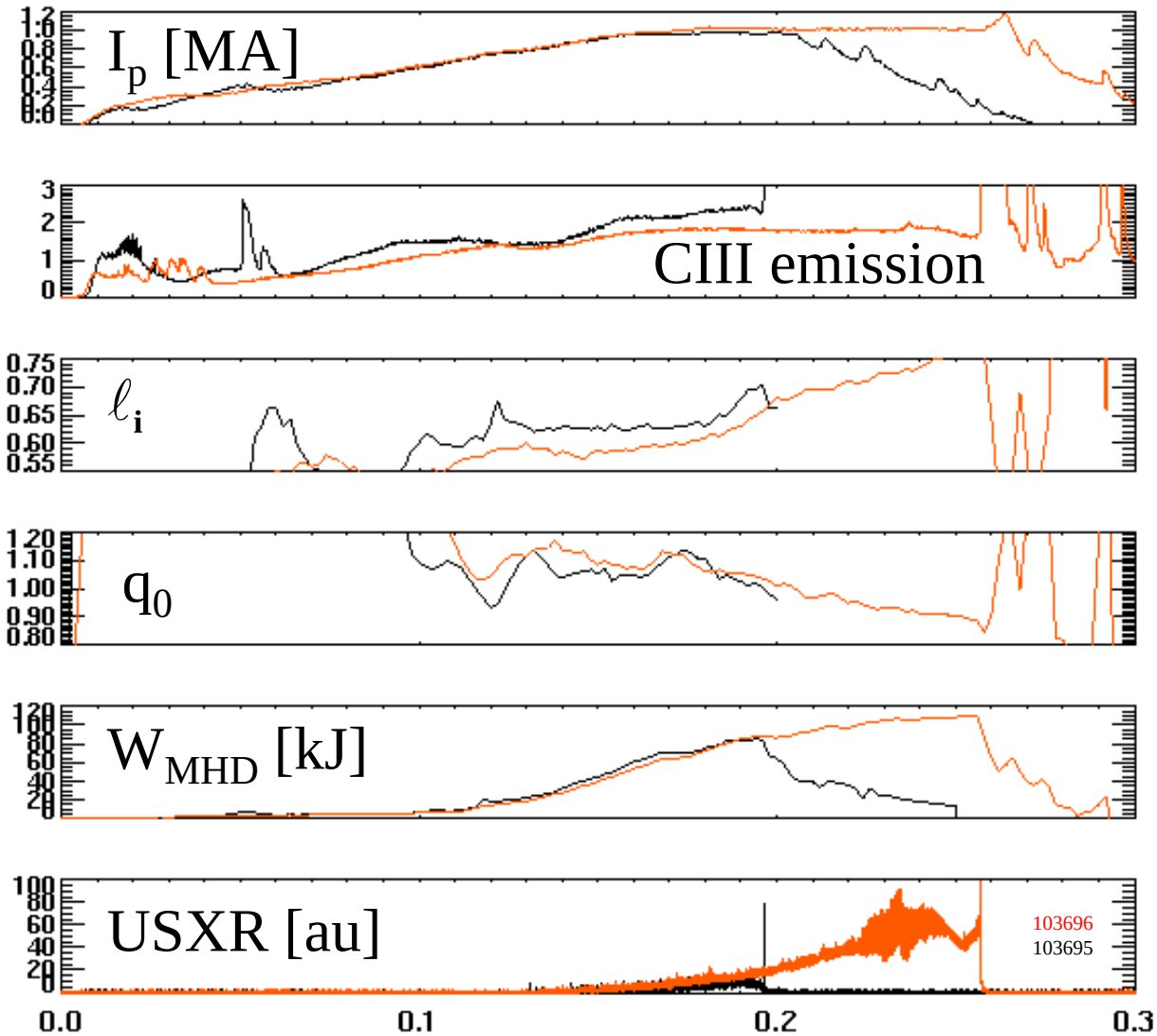
Before TMB **After TMB**





HeGDC IS AN INGREDIENT TO HIGH PERFORMANCE, NBI DISCHARGES



- I_p flattop increased
- Carbon reduced
- ℓ_i reduced
- q_0 increased
- Stored energy increased
- MHD termination delayed

HELIUM DISCHARGES USEFUL FOR REDUCING RECYCLING AND IMPURITIES

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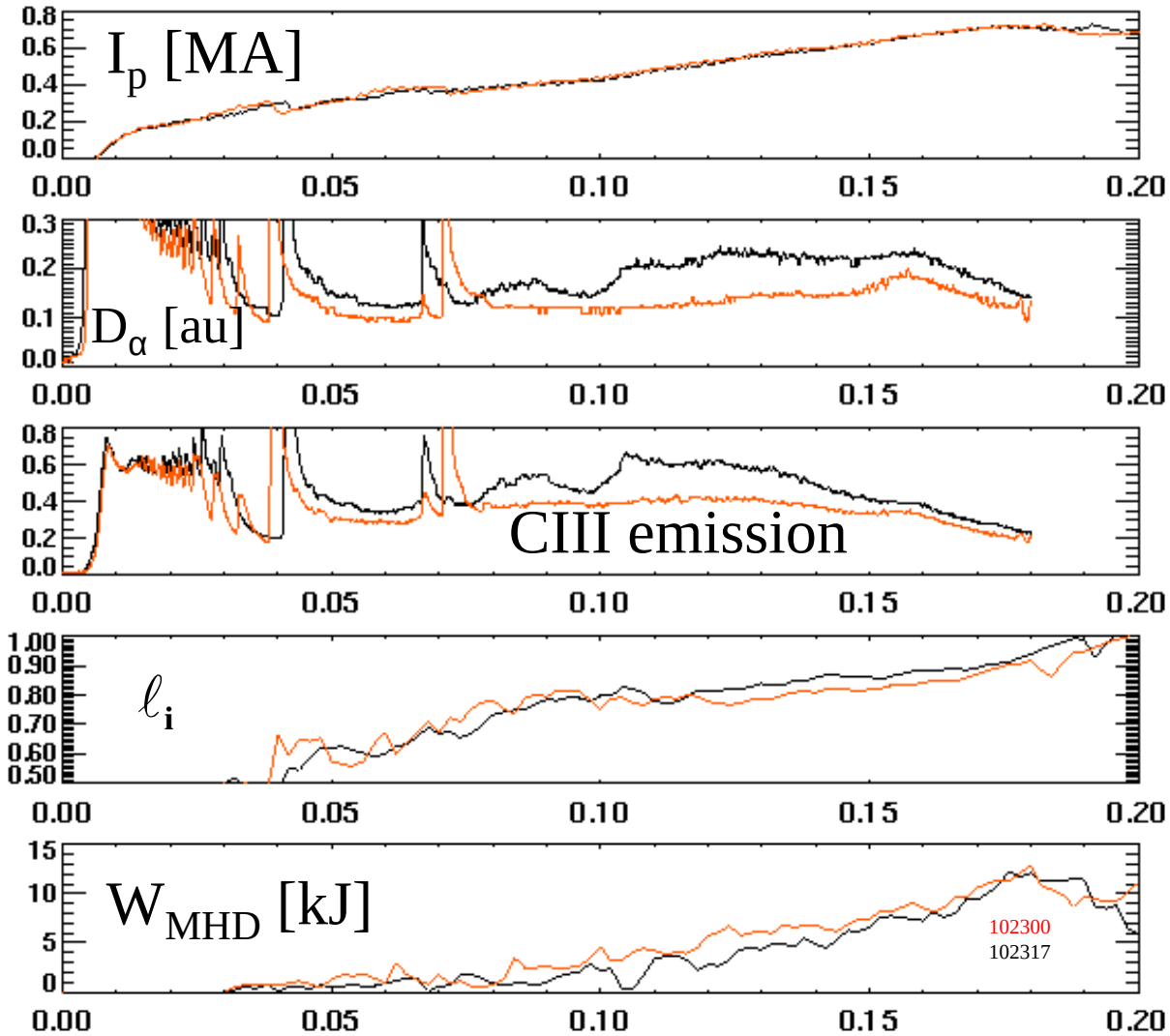
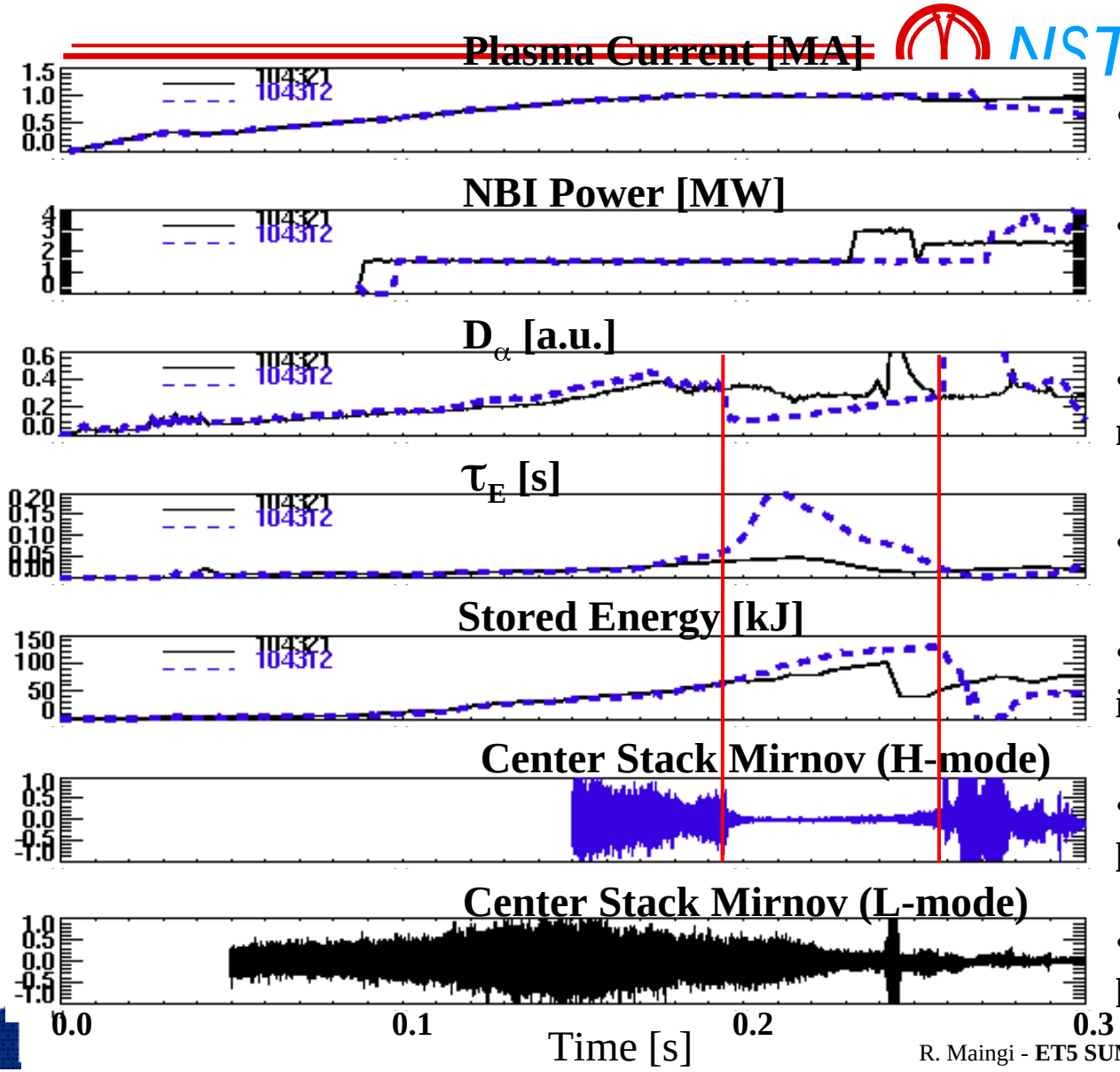


- Deuterium reference discharges(12 Helium discharges between)
- D_α reduced
- Carbon reduced
- ℓ_i slightly reduced
- Stored energy unchanged

H-MODE TRANSITIONS AND IMPROVED CONFINEMENT OBSERVED



- Same Ip
- Early NBI
- D_α drop in H mode
- τ_E improves
- Stored energy increases 25%
- Mirnov oscillations reduced
- Mirnov oscillations reference

H-MODE EDGE DENSITY PROFILE DEVELOPS 'EARS' DURING ELM-FREE OPERATION

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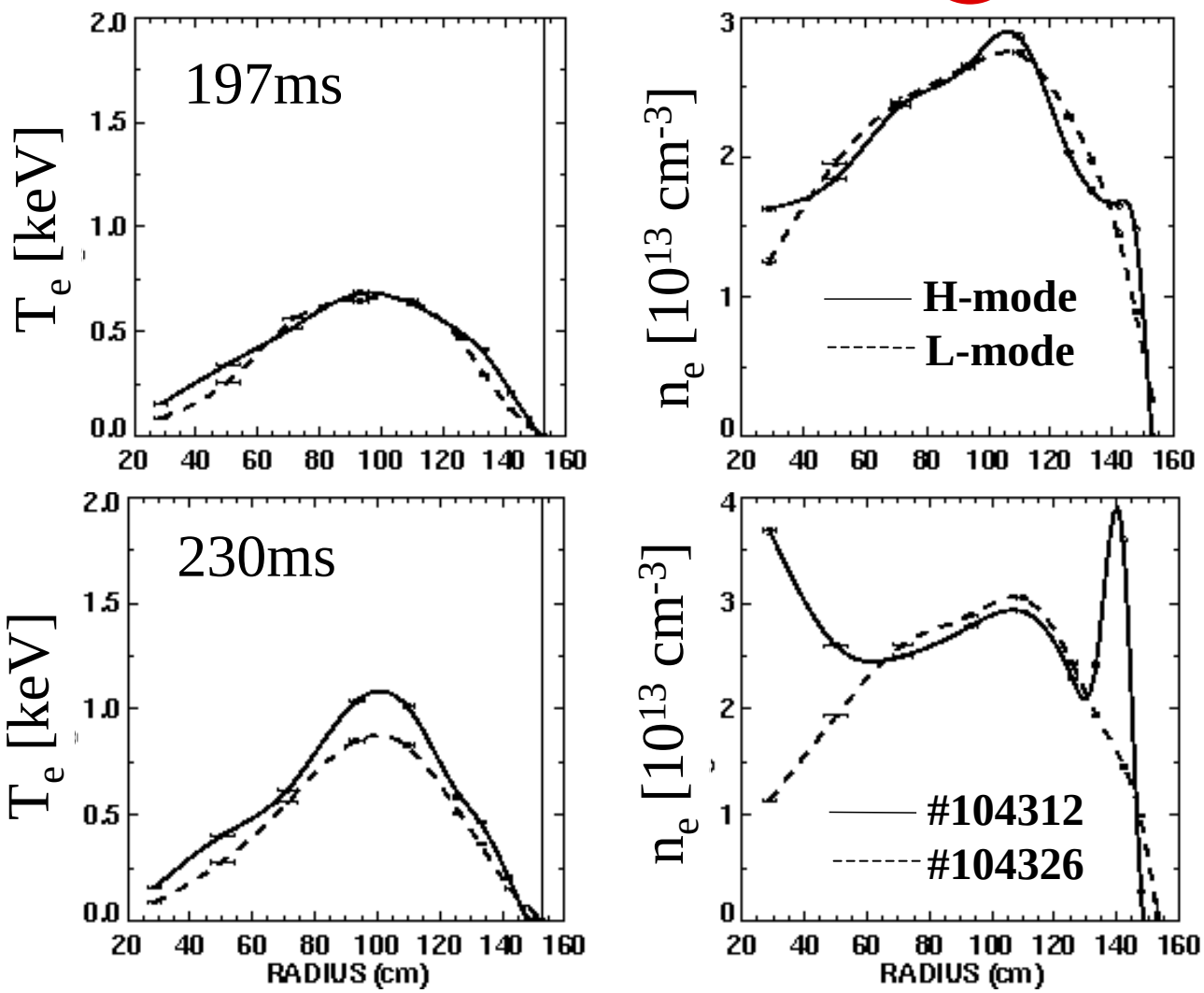

- Profiles just after the H-mode transition are fairly close in H-mode and non H-mode shots
- T_e increases and n_e profile has sharp gradient and 'ears', like MAST

WALL COUPONS WERE INSTALLED IN NSTX TO MEASURE EROSION/DEPOSITION AT WALL

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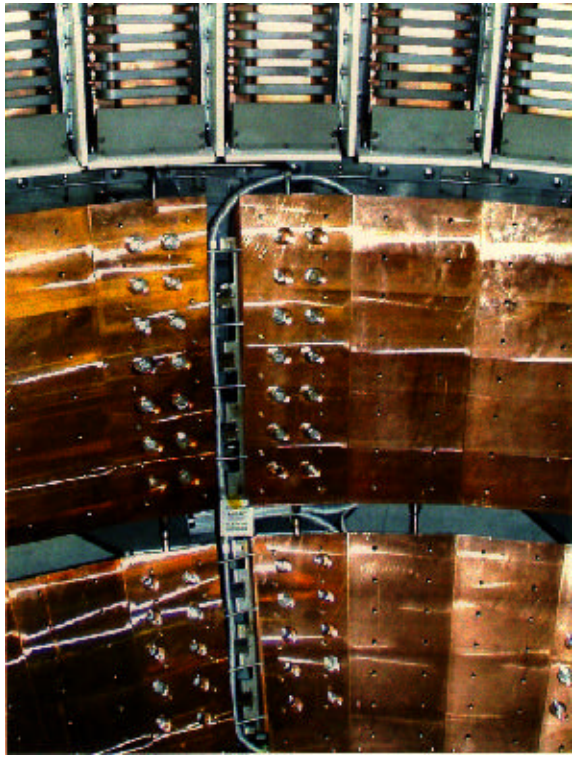
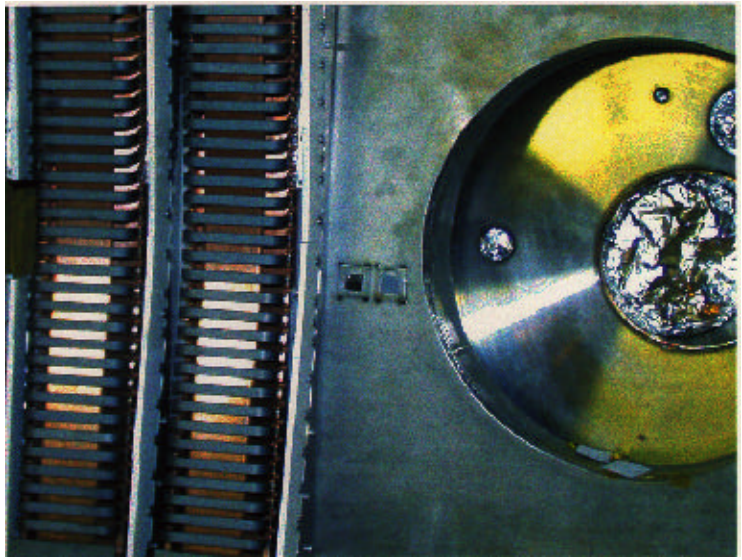
- SS coupons were coated with 0.4μm carbon film. Change in carbon thickness, (measured by 1.5 MeV proton backscattering before & after plasma exposure) shows net carbon removal at the wall.



Poloidal coupon array in passive plates Bay C

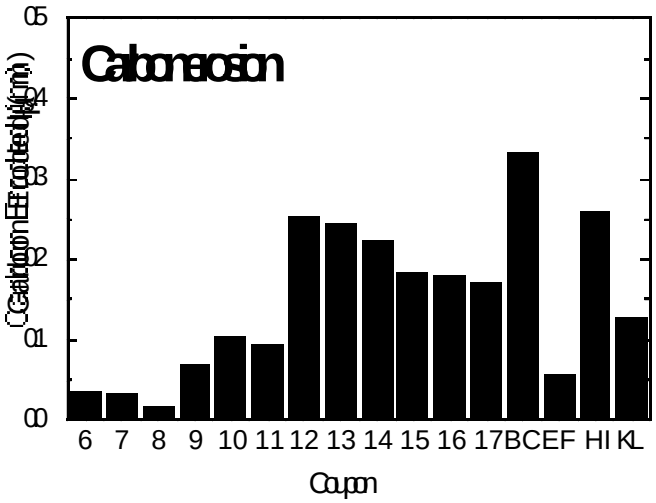
Courtesy of W. Wampler



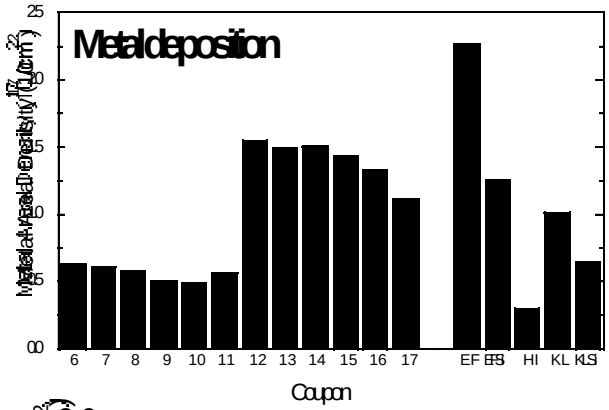
Midplane Toroidal coupons Bays BC, EF, HI & LK

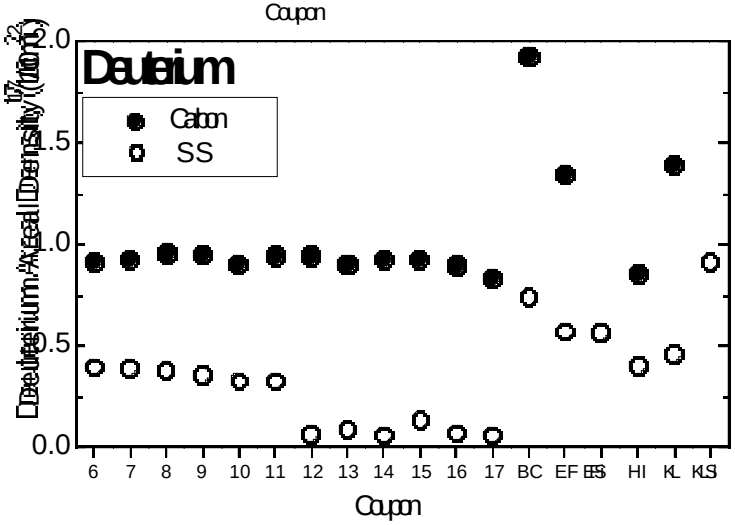
Results from analysis of Wall Coupons

NSTX



Poloidal array: Upper PP, Lower PP | Toroidal array





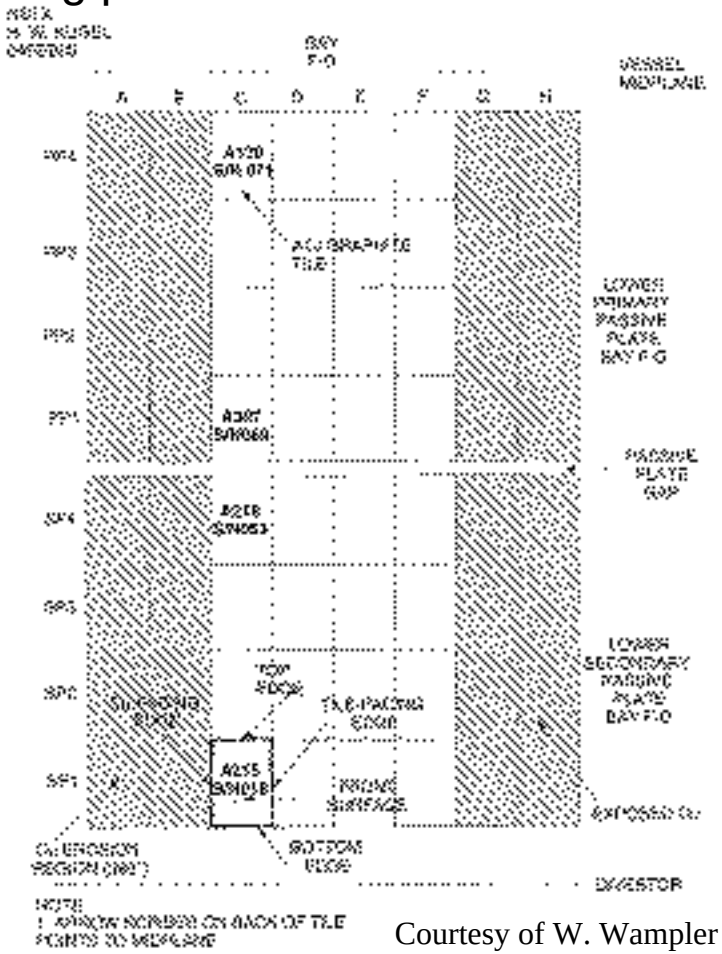
Conclusions from coupon experiment:

- Net carbon erosion on all coupons, more C erosion on lower PP than on upper PP.
- Non-uniform C erosion, probably not from GDC.
- Metal deposition on all coupons, more metal on lower PP than on upper PP.
- Deuterium in carbon consistent with saturation by few hundred eV.

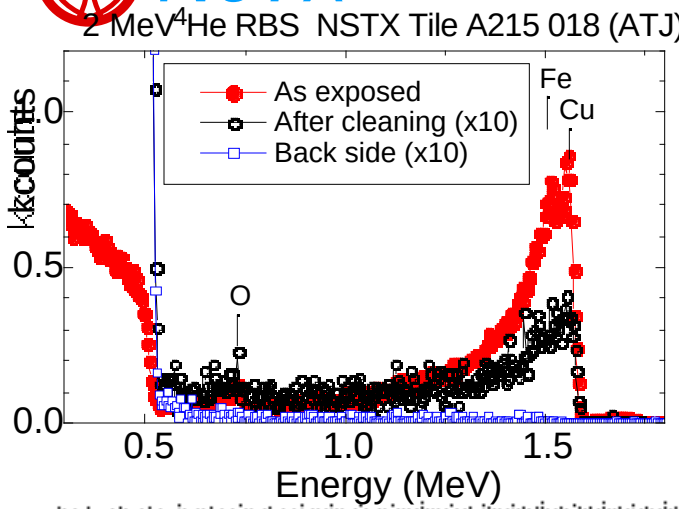
Courtesy of W. Wampler

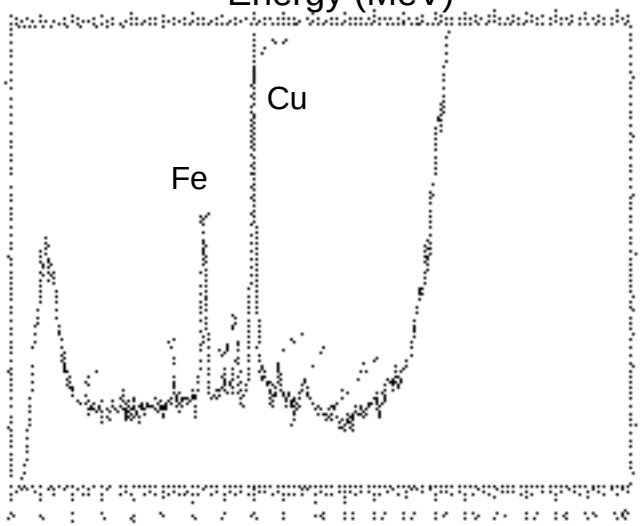
Metal coverage measured by RBS on four NSTX Passive plate graphite tiles

- Cu & Fe ~ $2x10^{17}/cm^2$ on plasma-facing surfaces, similar to lower PP coupons.
- Cleaning procedure removed 95% of metals.



Courtesy of W. Wampler

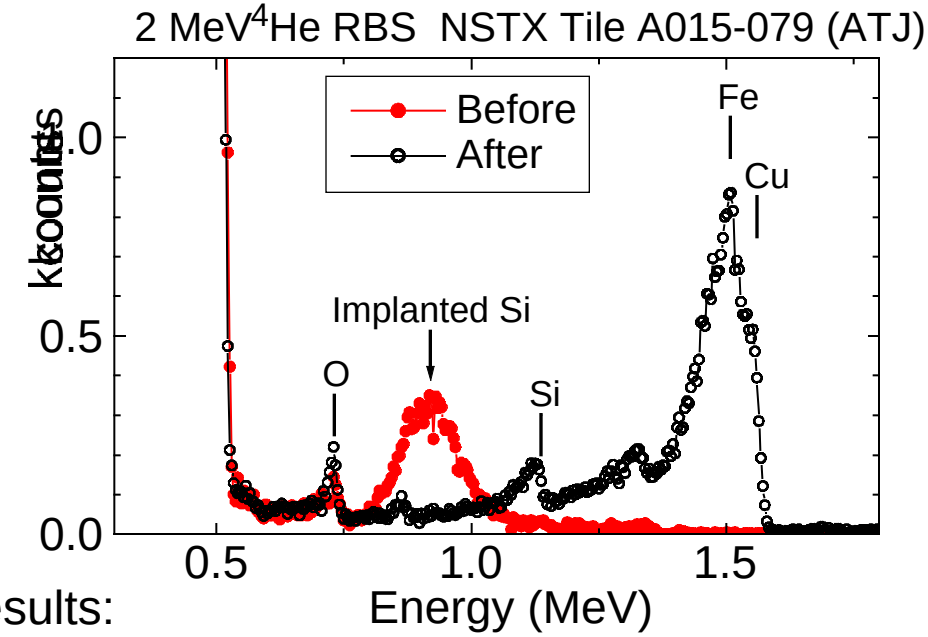




X-ray Fluorescence spectrum tile 53

NSTX center column tiles analysis

Two center column tiles were implanted with 300 keV Si.
Depth of Si (initially 0.34μm) measured by IBA before & after plasma exposure indicates net erosion/deposition of C.



Results:
Si marker gone - net erosion > 0.4 μm.
Metal coverage: $0.13 \times 10^{17}/cm^2$ Tile A015-079 (ATJ)
$0.48 \times 10^{17}/cm^2$ Tile A043-020 (CFC)
~10x less metal than outer wall

Courtesy of W. Wampler

DIAGNOSTICS REQUIRED FOR EDGE FUEL AND IMPURITY STUDIES BECOMING OPERATIONAL

NSTX

DIAGNOSTIC	STATUS
Visible spectrometer	Working: used for boronization study
Ultra-soft X-ray Array	Working: 4 cm edge resolution
Filtered visible fibers	Working: D_α, Carbon, Boron, Oxygen
50-300 Å spec. GRITS	Working: used in impurity transport
2nd Visible spectrometer	Debugging: 3 new sight lines
300-1000 Å spec. SPRED	Debugging: first data obtained
Divertor 1-D CCD camera	Debugging: D_α filter, 2048 channels
Thomson Scattering	Working: few edge chans, more soon
Edge reflectometers (2)	Working: good edge resolution
IR camera	Debugging: magnetic shield added
ChERS system	Preliminary system working; final system planned with many edge chan.
Mid. Reciprocating probe	To be installed next vent, CY 2001
Divertor Langmuir probes	Coarse array in tiles: being tested with some borrowed control hardware

BOUNDARY PHYSICS PROGRAM FACILITATES NSTX ACHIEVEMENT OF PERFORMANCE GOALS

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"Operations" role

- Bakeout, boronization, helium glow discharge cleaning, and helium plasma discharges used for conditioning
- Boronization allows cleaner, better performance plasmas
- HeGDC between discharges (5 minutes) necessary for reproducible, highest performance NBI discharges
- HeGDC lowers edge recycling and impurity content, allowing slower ℓ_i evolution and longer time before q0 ≤ 1

"Science Focus" Role

- H-mode and edge turbulence studies begun
- Diagnostics coming online for more detailed studies

EXISTING EXPERIMENTAL IDEAS

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- **Edge heat flux scaling in NSTX - milestone in FY 2003**
- **Edge turbulence studies with imaging camera**
- **Pre-bake characterization/fiducial shots**
- **Routine fiducial shots**
- **Cross field transport + turbulence with reciprocating probe**
- **Plasma boronization**
- **Particle balance in ohmic and auxiliary heated plasmas**
- **HeGDC in a "clean" (low metals) vessel**
- **Heat flux reduction scenarios**
- **Short term wall condition changes with coupons**
- **Boronization probe as materials erosion probe**
- **Support/continue H-mode studies (mainly T & T)**

DIAGNOSTICS REQUIRED FOR EDGE FUEL AND IMPURITY STUDIES BECOMING OPERATIONAL

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- Visible survey spectrometer (VIPS) - boronization study
- New VIPS(2) - operational, different sight-line from VIPS
- UV spectrometers (GRITS,SPRED) - first data end CY 2000
- Filtered visible spectroscopy - D_α, Carbon, Oxygen, Boron
- Ultra soft-Xray array - operational, with edge chords
- Thomson Scattering - few channels in edge, more coming
- Edge reflectometers - operational
- IR camera - installed and tested, shielding added after run
- Reciprocating probe - to be installed next vent (CY 2001)
- Divertor 1D CCD camera - data obtained, in debugging
- Fixed divertor Langmuir probes - installed in tiles but no permanent external control hardware

SHORT H-MODE PHASES OBSERVED IN NSTX

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- Obtained in lower-single null divertor only
  - Inner wall gap > 1-2 cm
  - P_{NBI} > 850 kW {B_t=0.45 T, 0.7<I_p<1 MA}
- Diagnostic Signatures
  - Edge visible light drops (D_α, CIII, BII, OII)
  - Center stack Mirnov oscillations diminish
  - Edge density gradients increase (MPTS)
  - EBW emission triples -> steeper edge n_e gradient
  - SXR emission profile develops sharp edge gradient
- Effects on confinement
  - Stored energy increased by 20-30%
  - Peak dW/dt and dN_e/dt both double
- Termination and Reproducibility
  - Duration 500 μs - 65ms
  - Terminated by MHD onset, some ELM-like and some cold-island driven
  - Terminated also when inner wall gap < 1 cm
  - HeGDC between shots probably needed
  - Easier to obtain early in run day

EDGE VISIBLE LIGHT REDUCED DURING H-MODE PHASES

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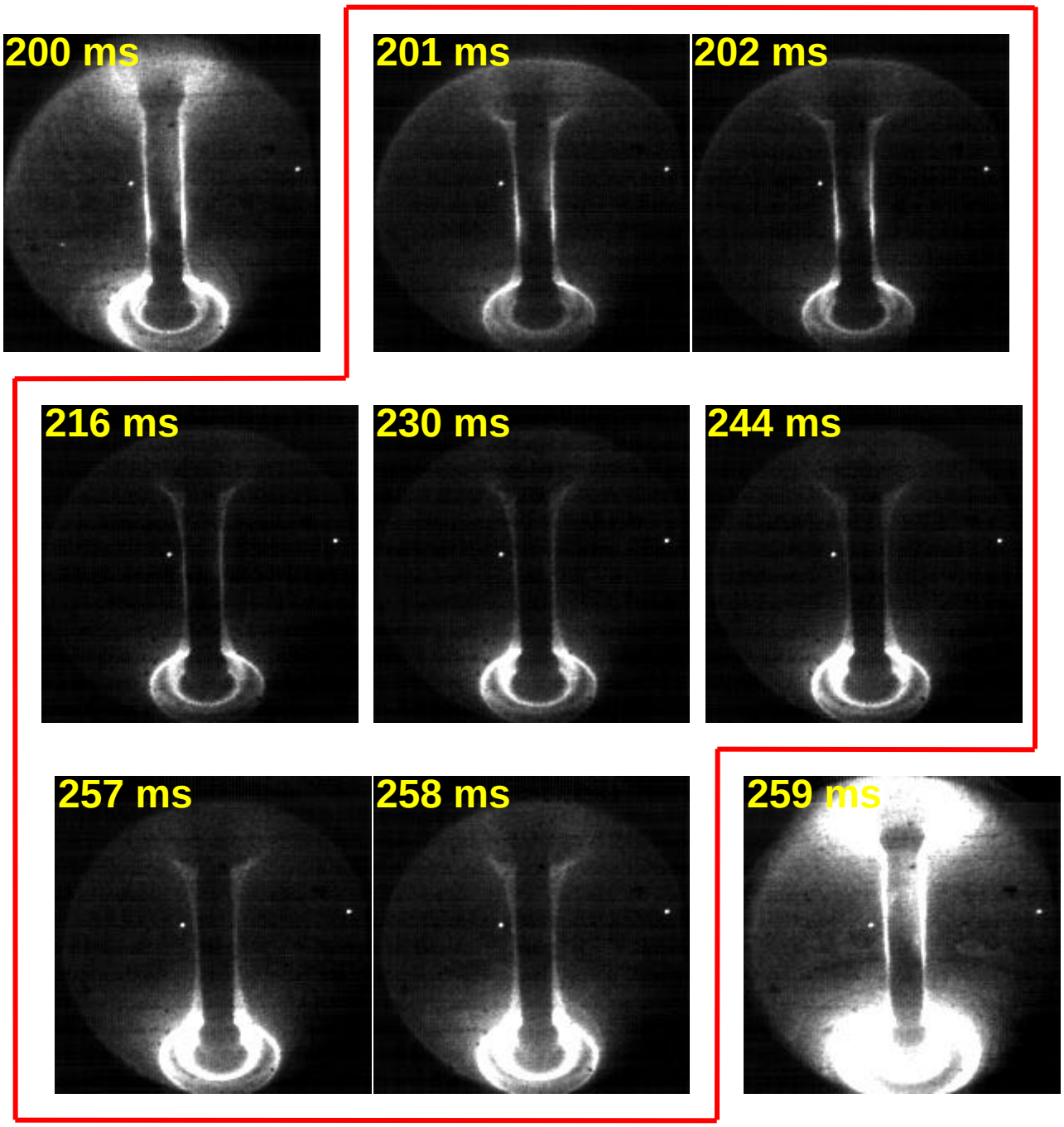
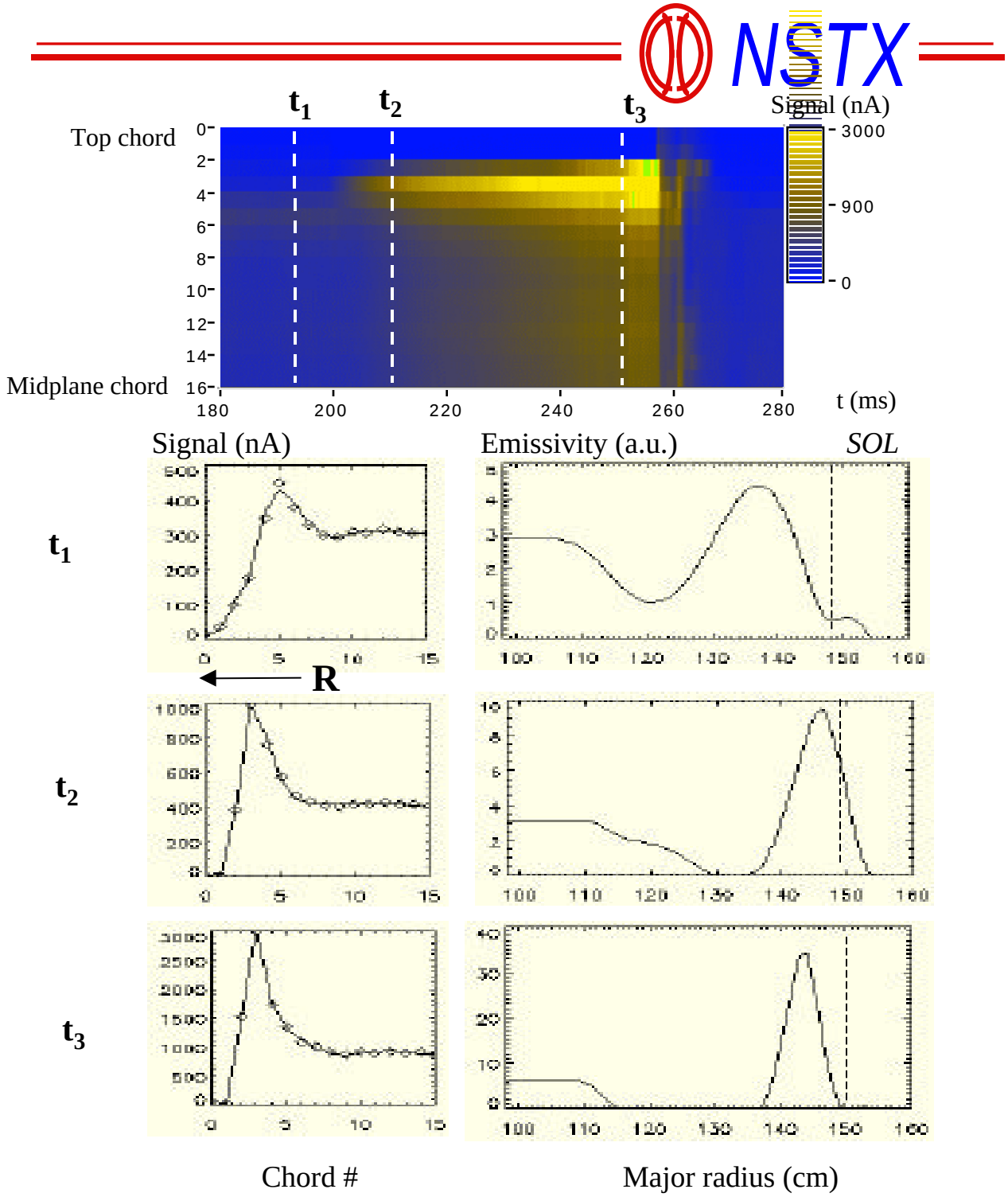


Shot 104316

Los Alamos NATIONAL LABORATORY

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Evolution of USXR (CV+CVI) profiles during H-mode (#104316)



- **Profiles sharpen, SOL emission vanishes**
- **Strong increase in C edge emission**
- **MIST simulations suggest impurity accumulation at the periphery and decrease in transport**

PPPL PRINCETON PLASMA PHYSICS LABORATORY

MHD activity at H-mode termination
(E > 0.6 keV emission, 0.5-100 kHz band)

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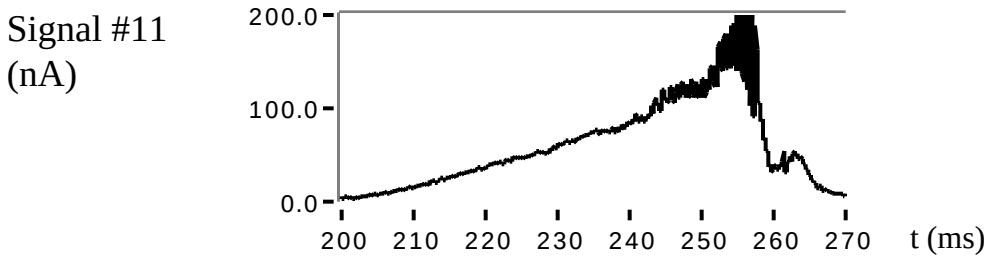

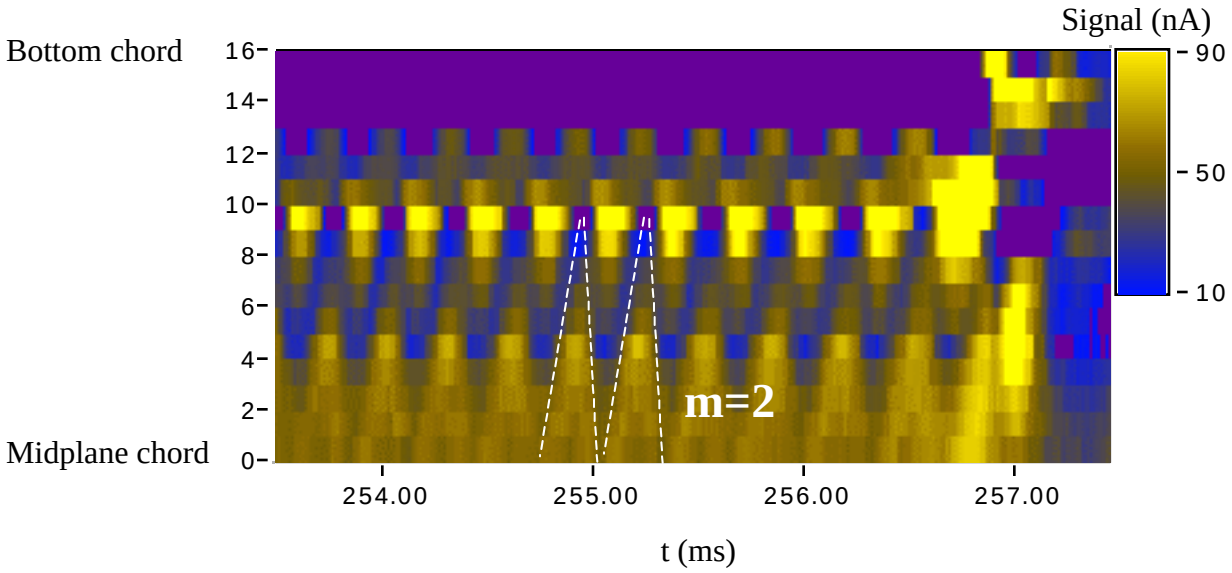

- **H-mode terminated by magnetic reconnection at the periphery**
- **Main precursor is cold m=2 island (darker), coupled to outer, probably higher m mode**
- **The picture suggested by the USXR data:**
  Improved edge confinement -> impurity accumulation (stronger in island(s)) -> magnetic reconnection
- **Inducing ELMs may avoid the H-mode termination**

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