Diagnostic Development for NSTX

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for the NSTX National Team

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Topics

- Diagnostic status and advances in the last 2 years
- Current diagnostic data for confinement and stability
- Diagnostics for boundary physics and wall interactions
- Planned diagnostic upgrades and development
- Development of plasma control

Diagnostics Installed Aug 2001

* Diagnostics in operation

• Diagnostics in commissioning phase

Confinement Studies

* **Magnetics for equilibrium reconstruction**
* Diamagnetic flux measurement
* **Thomson scattering (10 ch., 60Hz)**
* 2 mm interferometer (single chord)
* VB detector (single chord)
* Bolometer array (midplane tangential)
* X-ray crystal spectrometer ($T_i(0)$, $T_e(0)$)
* X-ray pulse height analyzer
* **Charge Exchange Recombination Spectroscopy** (CHERS): T_i & v_ϕ (18 ch.)
* **Neutral particle analyzer** (central chord)
- **Electron Bernstein wave radiometer**
- FIReTIP 119μm interf'r/polarim'r (2 ch) [UCD]

MHD/Fluctuations

* **High-n and high-frequency Mirnov arrays**
* **Soft x-ray arrays** (3) [JHU]
* **Edge reflectometer** [UCLA]
* **Edge fluctuation imaging** [LANL]
* Fast ion loss probe

Plasma Monitoring

* Fast visible camera [LANL]
* VIPS-1: Visible spectrometer (reticon)
* VIPS-2: Visible spectrometer (CCD)
* SPRED: UV spectrometer (CCD)
* GRITS: VUV spectrometer [JHU]
* Fission chamber neutron measurement
* Fast neutron measurement
* **1-D CCD H_α camera** [ORNL]
* Visible filterscopes (H_α, OII, CII) [ORNL]
* Scrape-off layer reflectometer [ORNL]
- Locked mode coils
- IR camera

Diagnostics in bold will be highlighted in this talk

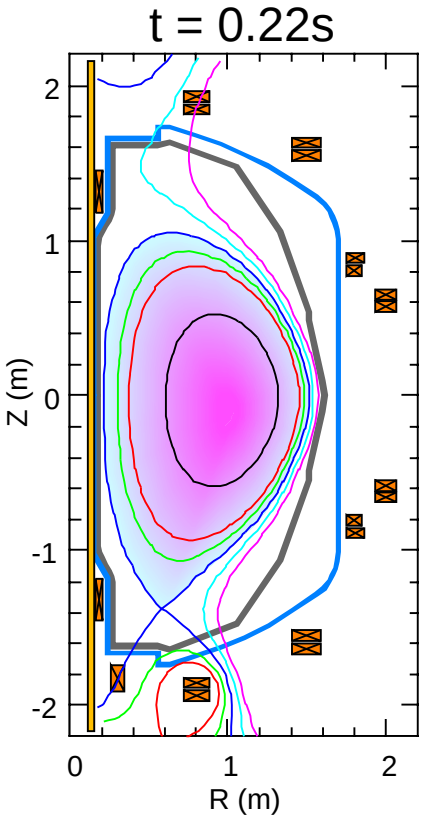
Comprehensive Magnetic Diagnostics for EFIT Analysis

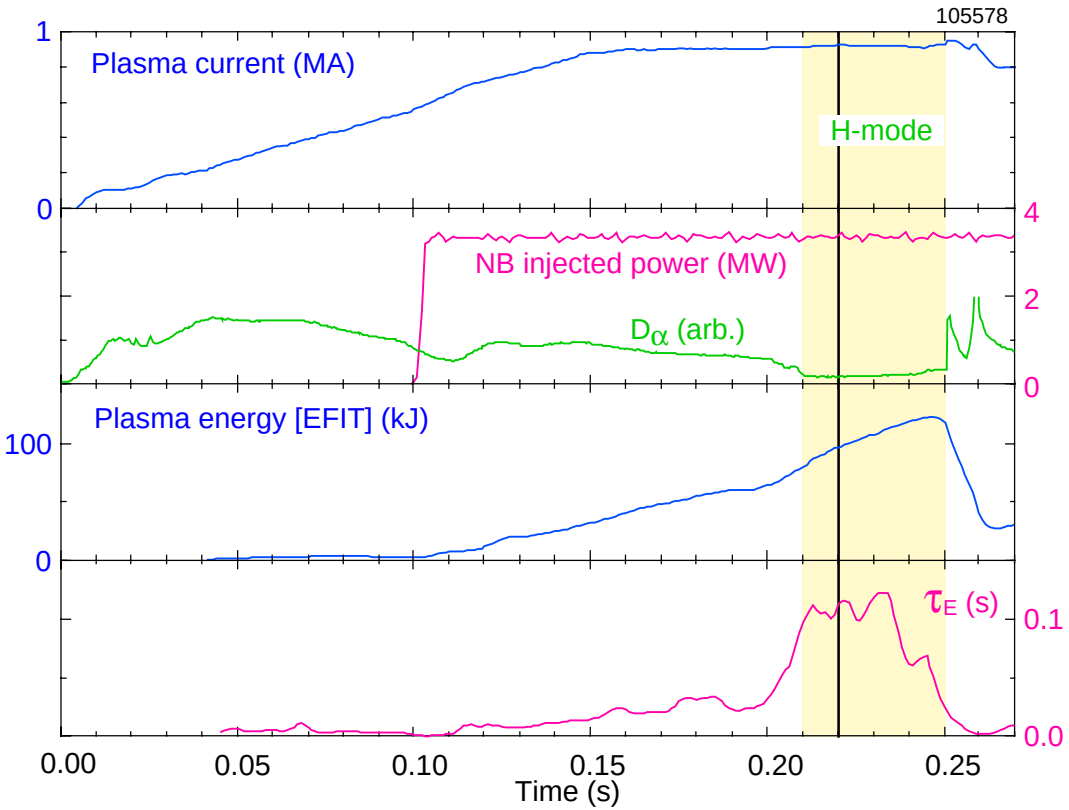
- B-field coils, flux loops and coil currents provide data for EFIT analysis

  ⇒ full configuration and global plasma parameters as functions of time

  - time resolution to 1ms for transient events

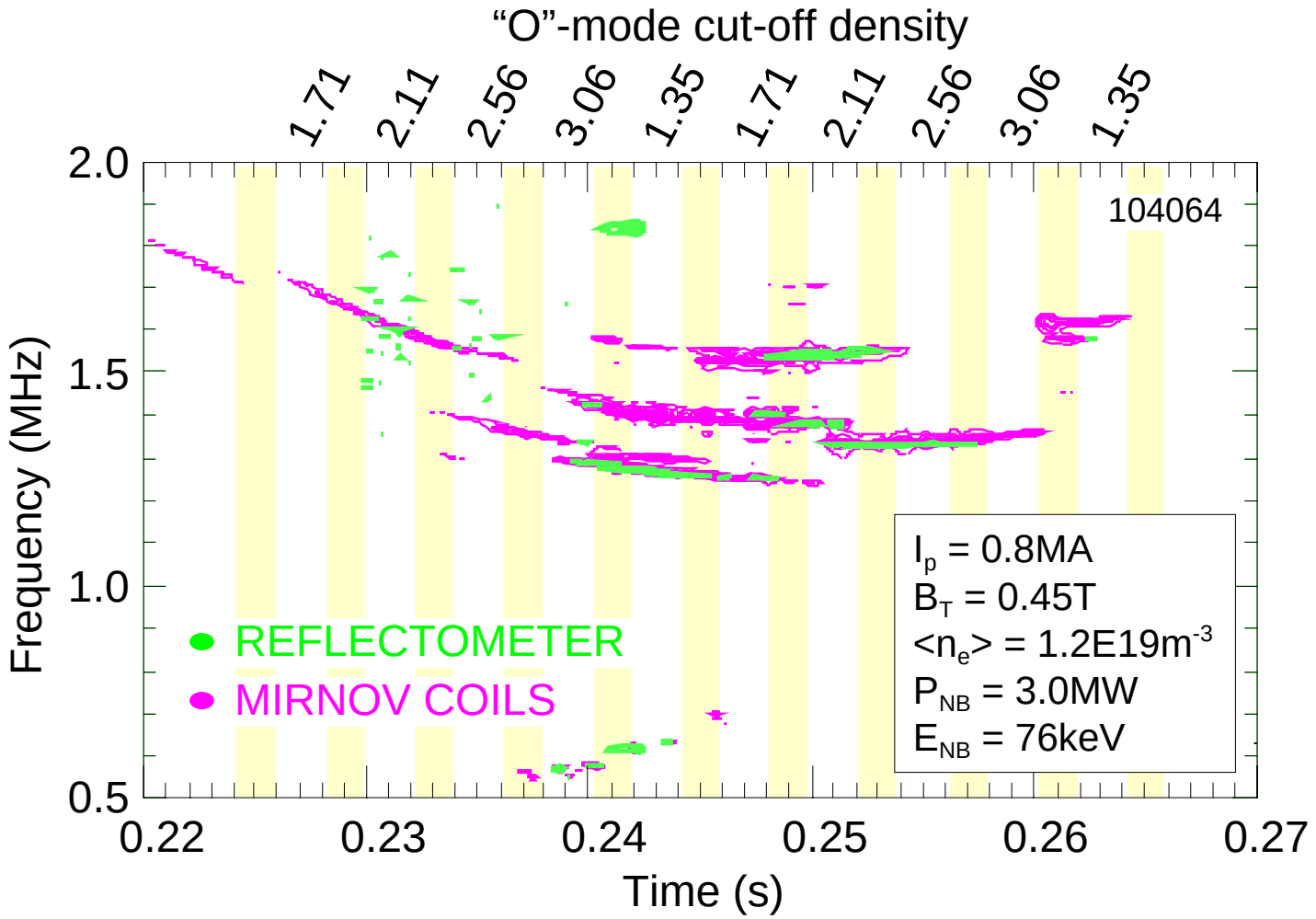
  - Now working to incorporate kinetic profiles in analysis





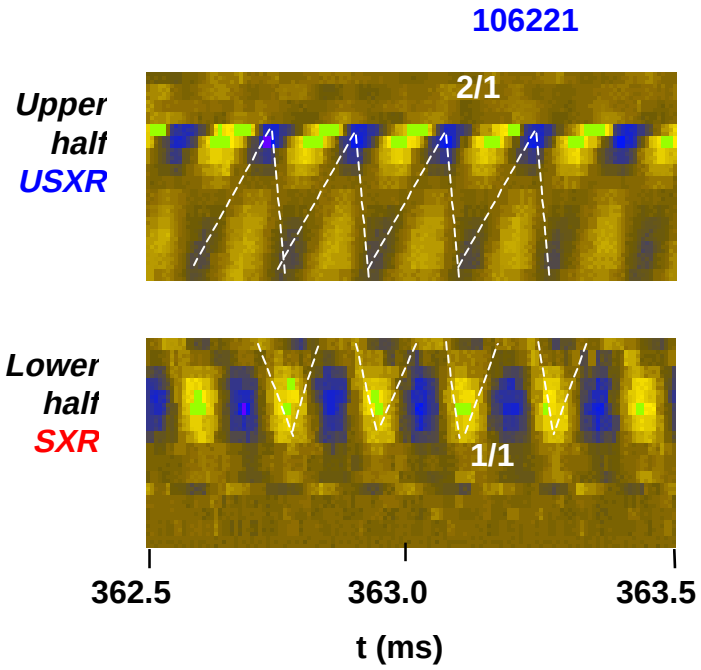
Magnetic Sensors Also Used for Fluctuation Studies

- Outboard Mirnov coils and Scanning Edge Reflectometer *[UCLA]* detect fluctuations in the Alfvén frequency range excited during NBI

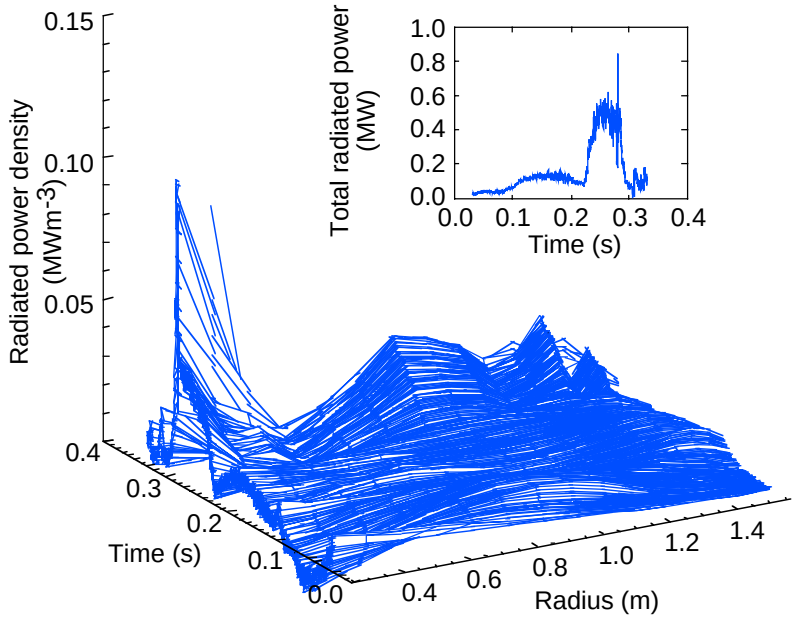


Arrays of Ultra-soft X-ray Detectors Reveal MHD Mode Structure and Measure Radiated Power

- USXR/SXR capability enables simultaneous observation of peripheral (2/1) and core (1/1) MHD modes



- Inversion of data from tangential array of detectors reveals central peaking of radiated power during ELM-free H-mode



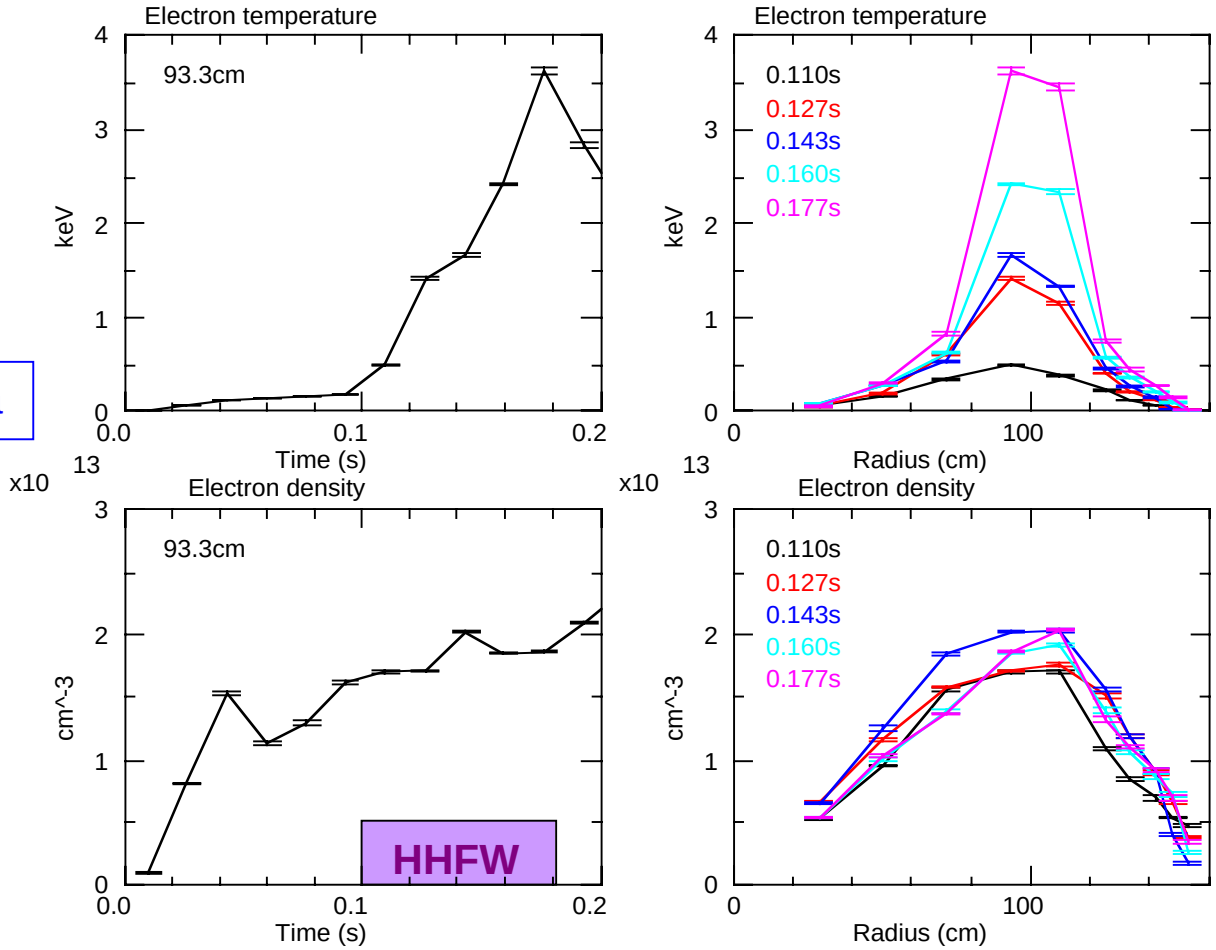
Multi-Point Thomson Scattering Provides Basic Profiles for Confinement and MHD Stability Studies

- 10 spatial channels with 2 independently timed lasers at 30Hz
  - Pulse separation as small as 0.4ms for
    - diagnosis of reproducible transient phenomena
    - measurement of rates of change
- Calibrated by Rayleigh scattering for absolute density measurement
  - Checked against 2mm and FIR interferometers in quiescent plasmas
- High throughput collection optics and fiber-optic relay for good S/N
- High dynamic ranges in both density and temperature
- Investigating using background light measured between laser pulses to provide radial profile of VB emission for $Z_{eff}(R)$ measurement

B. LeBlanc, R. Bell, D. Johnson, D. Hoffman

High Electron Temperatures during HHFW Heating

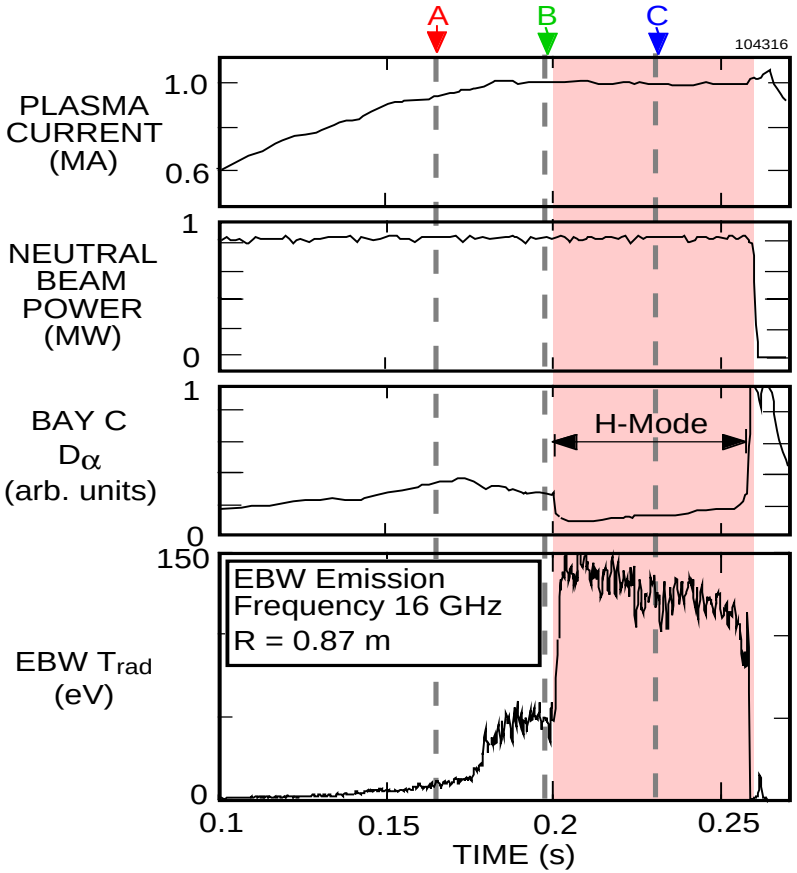
MPTS data

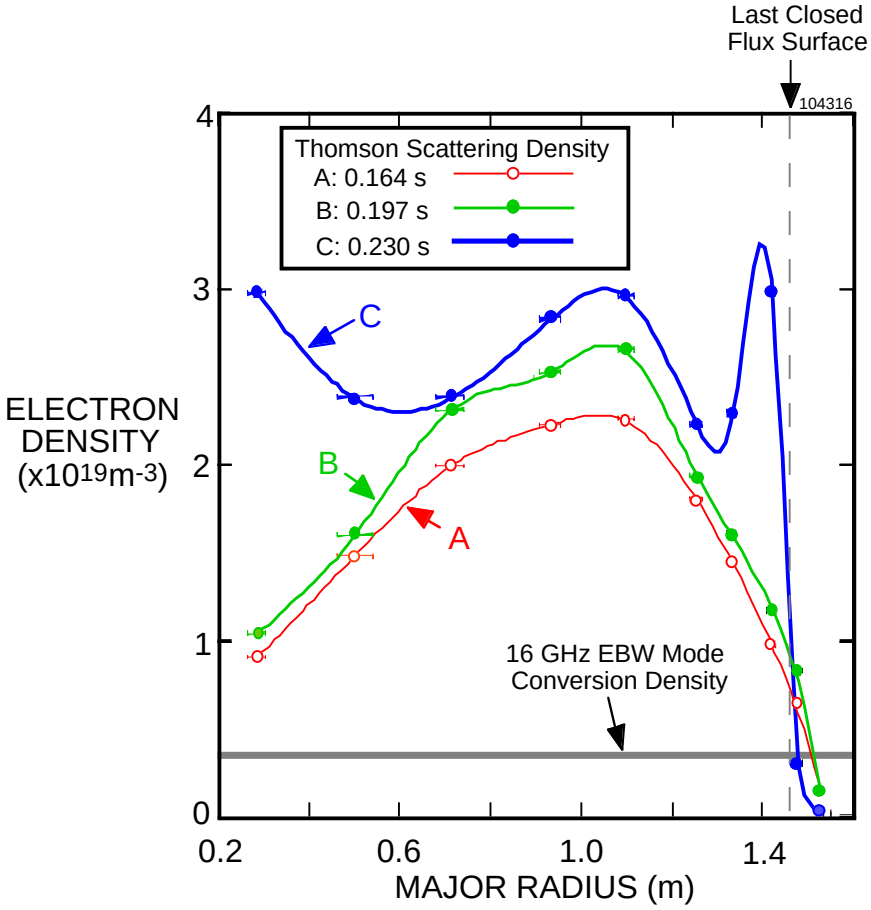


- Have confirmed T_e by soft x-ray spectra (PHA, T_e in 1 - 3 keV range) and x-ray line ratio (crystal spectrometer, T_e in 1 - 2 keV range)

EBW Radiometer Shows Potential for T_e Diagnostic

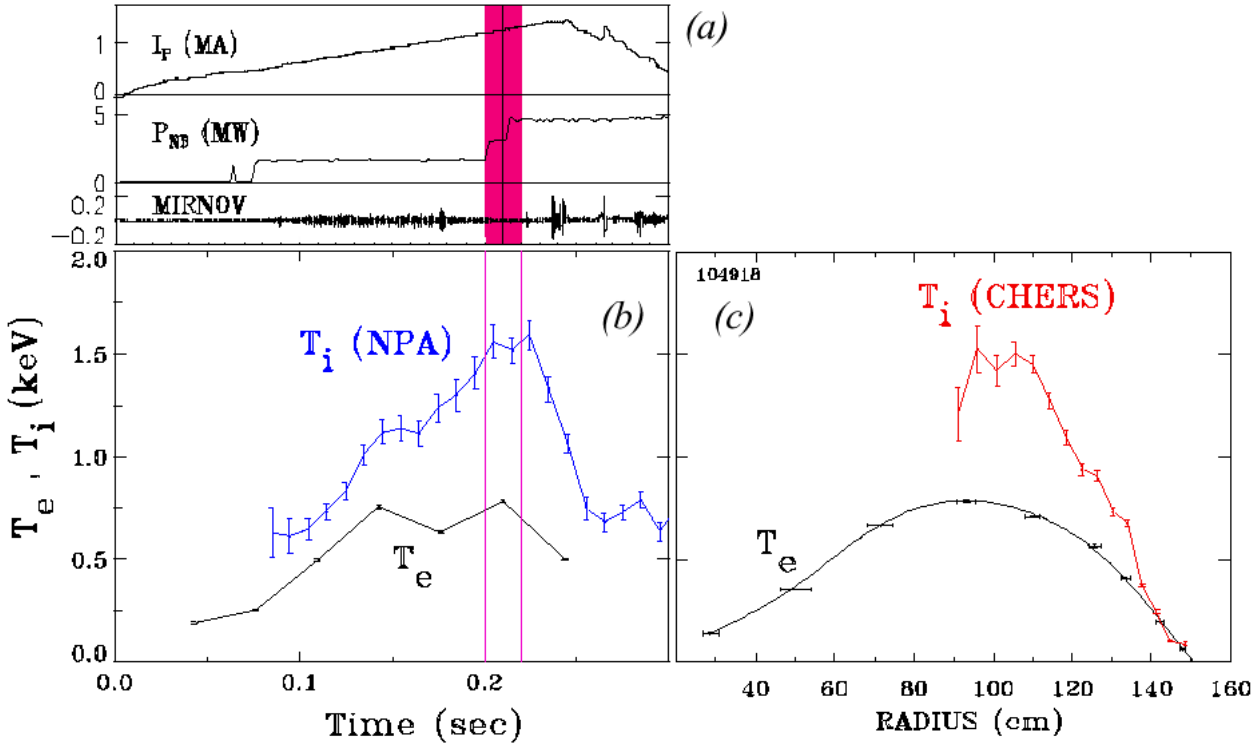
- Fundamental thermal EBW from core can convert to X-mode emission
  - efficiency depends on density scale length at UHR in plasma edge
  - emission increases as edge density profile steepens during H-Mode





Ion Temperature from CHERS and NPA

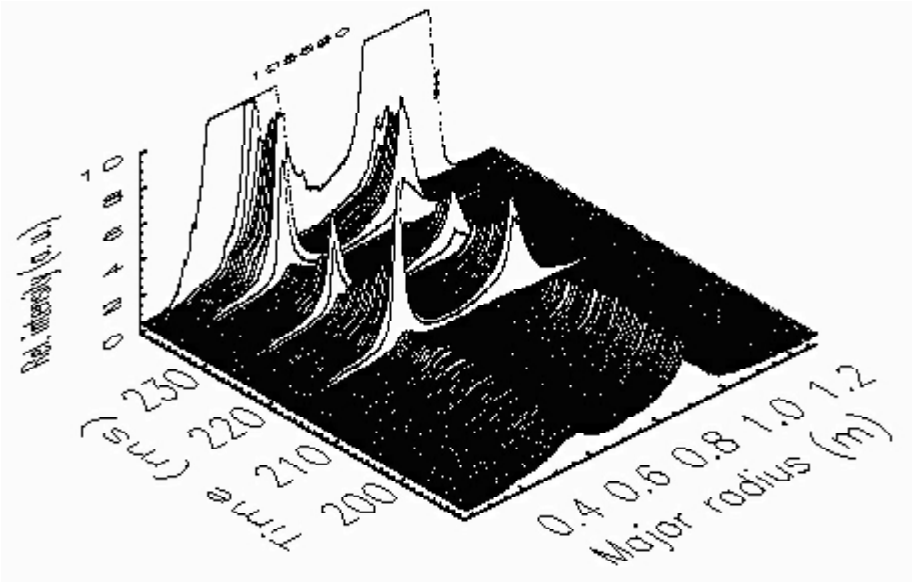
- CHERS measures Doppler broadening (T_i) and shift (v_{tor}) of CVI line excited by heating NBI
  - Modulated NBI discriminates CX-excited from intrinsic edge emission



- NPA spectra of intrinsic H component during D-NBI
  - Can separately measure slowing-down spectra of energetic D

Edge Plasma Diagnostics Are Being Developed

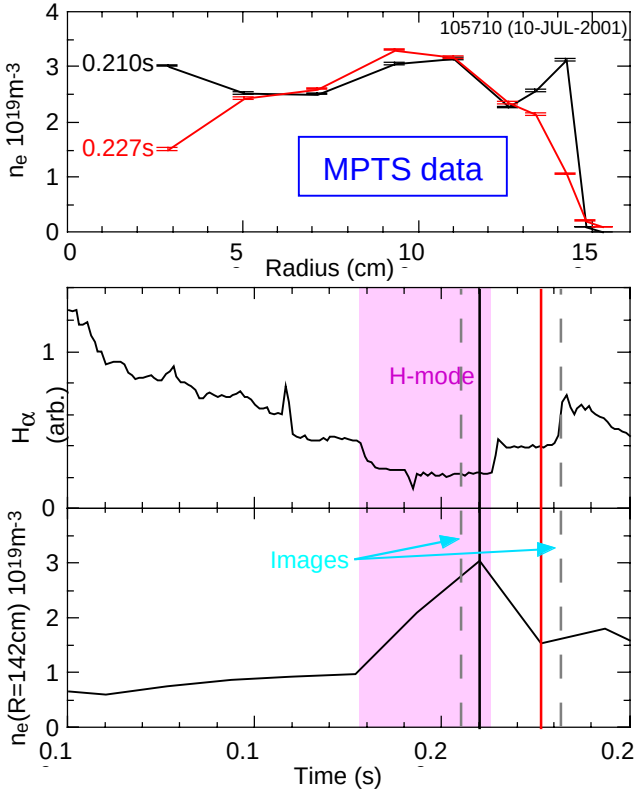
- Prototype IR imaging of plasma facing components *[ORNL]*
- 5 fast neutral pressure gauges installed in divertors & midplane *[UW]*
- Evaluating fixed Langmuir probes in several divertor tiles
- Exposure coupons used to estimate average particle fluxes *[SNL]*
- Measuring H_α across divertor with high resolution 1D camera *[ORNL]*

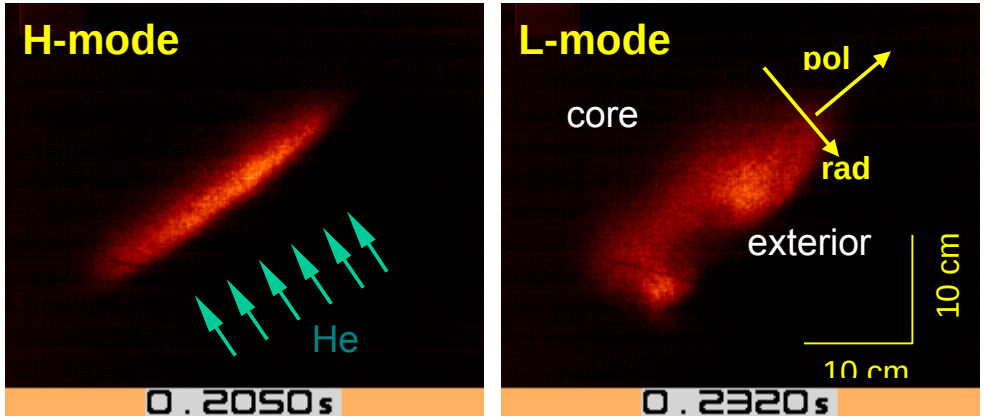


- Evolution of H_α emission from divertor region during H-mode phase

Imaging Emission from Gas Puff Shows Edge Structure

- Images of He line emission from multiple directed gas jets aimed at edge of D plasma (and *vice versa*)
  - 10μs exposures at 1ms intervals
- Significant change in edge structure occurs at H – L transition





Diagnostic Upgrades in Preparation for Next Run

- Thomson scattering ⇒ *20 ch. @ 60Hz*
- IR camera ⇒ *additional camera and views for heat fluxes. [ORNL]*
- Fast ion losses ⇒ *probe with E, pitch angle resolution*
- *MSE polarimeter - first 2 (of 10 final) channels [Nova Photonics]*
- Charge Exchange Recombination Spectroscopy (CHERS) ⇒
  ~75 ch. in conjunction with MSE collection optics
- *Fast scanning edge probe for n_e, T_e, fluctuations [UCSD]*
- Neutral particle analyzer ⇒ *horiz., vert. scan.*
- FIReTIP ⇒ *additional 4 ch. for profile determination [UCD]*
- *More robust coils* for B_{pol} measurements, particularly on center stack
- High frequency, up to *5MHz*, Mirnov coils on outboard side

New capability

Diagnostic Development in Next Year, and Beyond

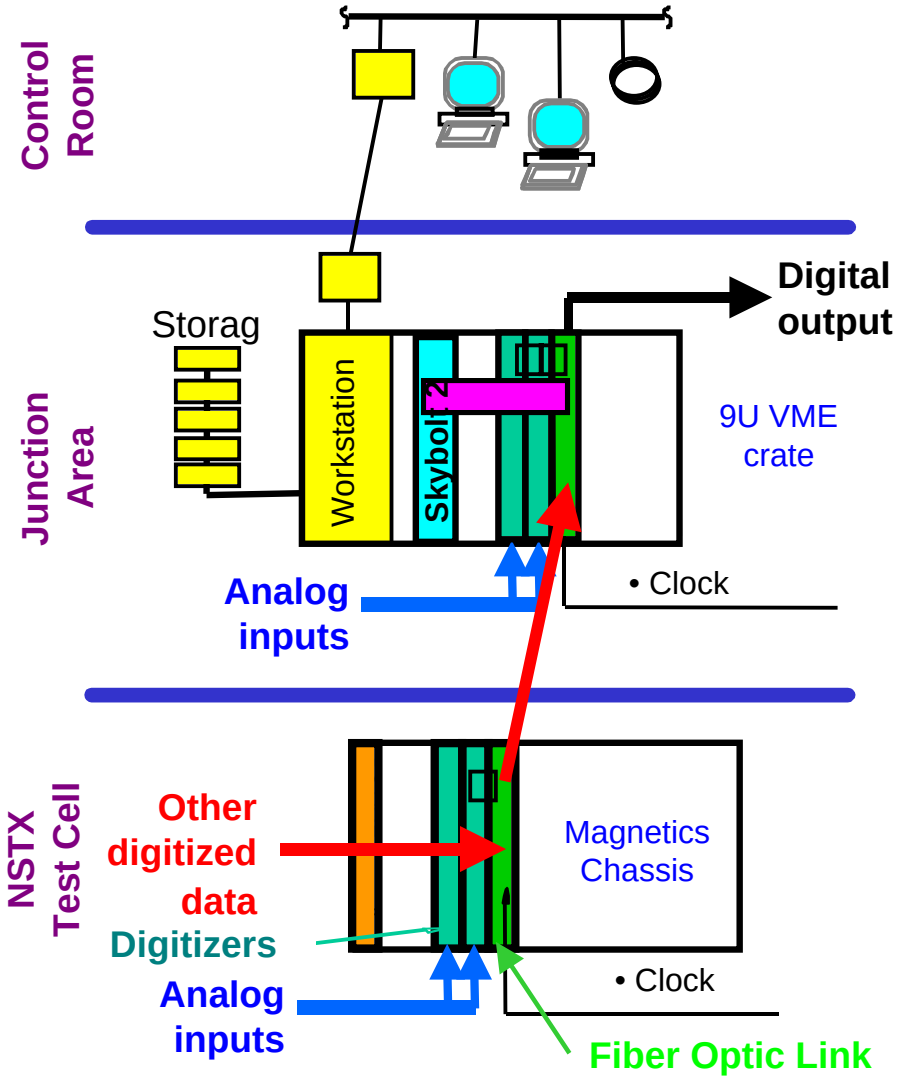
- X-ray imaging diagnostics
  - Pinhole camera for internal flux surface shapes *[with U. Wisconsin]*
  - Fast (MHz) tangential x-ray camera *[Princeton Scientific Instruments]*
  - New compact USXR arrays for multiple toroidal views *[JHU]*
- Microwave interferometer using frequency-swept 1mm source *[UCLA]*
- 2-D divertor imaging with fast visible camera *[Hiroshima U.]*
- Laser Induced Fluorescence MSE polarimeter *[Nova]*
  - Measure emission from energetic H-atoms excited by tunable laser
  - In combination with collisional emission MSE, measure $J_\phi(r)$ and $E_r(r)$
- Plan to develop fluctuation diagnostics in longer term (not yet funded)
  - Imaging reflectometer $\Rightarrow$ scale for ITG turbulence
  - 1mm small-angle scattering $\Rightarrow$ scale for ETG turbulence

Plans for Real-Time Control System

- Currently operating with flux-extrapolation algorithm from a few measurement loops to provide control of I_p, Z-position and outer gap
  - Preprogram currents for elongation and limiter/divertor configuration
- Next phase will use 4-processor real-time computer operating with
  - Full magnetic sensor data, supplemented with
  - Real-time diagnostic data as it becomes available, *e.g.* MSE
  - rtEFIT algorithm *[GA]* for control of multiple gaps
  - Control of gas feed valves
- Eventual aim for control of profiles
- Algorithms for CHI startup and transition to inductive sustainment require research and development
  - Need to distinguish toroidal current on open and closed flux surfaces

D. Gates, D. Mueller

Control System Upgrade Hardware



- High Speed low-latency digital data acquisition FPDP + Fiberchannel
  - Capability to handle distributed analog sources
- "Skybolt 2" computer (4 G4 processors at 333MHz ⇒ 10GFlop)
- Expandable up to 64 processors in one chassis
- Up to 768 channels of data
- 50MB/s sustained data rate

Summary

- We have improved diagnostic coverage substantially in the past 2 years
  - Detailed analysis of magnetic equilibrium based on external sensors
  - Profile diagnostics: MPTS, CHERS, bolometer array, SXR arrays
  - Comprehensive spectroscopy

$\Rightarrow$ These have enhanced machine capabilities and enabled significant experimental progress

- There are plans for many improvements
  - MSE, multi-chord interferometry, scanning NPA, locked mode coils, edge measurements,... advanced fluctuation diagnostics
- There are major challenges too
  - Improved control system $\Rightarrow$ rtEFIT
  - Real-time control of heating and fueling for profile control
  - CHI control