Soft X-ray measurements of transport and MHD activity in the core and edge NSTX-U plasma

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NSTX Diagnostic Collaborations – 03/08/21

JHU Contributions to NSTX-U 5-year plan research goals

The goals for the JHU diagnostic collaboration are to upgrade, maintain, and operate a set of **soft X-ray and VUV diagnostics** on NSTX-U to contribute to a broad range of research goals including:

- MHD (ELMs, NTMs, RWMs)
- transport (extrinsic impurities, heat/cold pulse)
- boundary physics (pedestal dynamics, boundary motion)

Objective 1

1.a.ii.) Determine pedestal scaling (height, width) at lower collisionality.
1.a.iii.) Investigate impurity transport, especially high-Z transport prior to any PFC changes, and ability to control e.g. with HHFW
1.c.) Investigate the role of shaping and wall conditioning in determining core transport and pedestal characteristics
2.a.i - iii.) Validate theory, modeling and high-fidelity simulation predictions of transport with comprehensive experimental data
2.c.) Validate the role of 3D field effects on core and pedestal performance

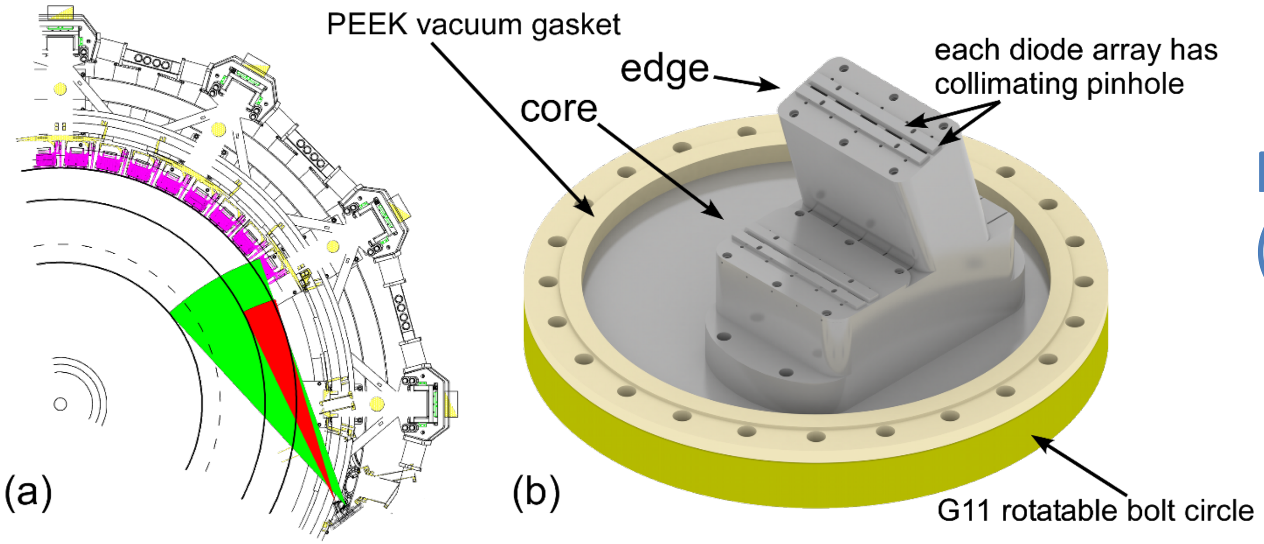
Objective 2

1.a.) Access small-ELM and ELM-free regimes with high f_{BS}
1.b.iii.) Induce and control impurity transport via profile control in ELM-free and small-ELM regimes
1.c.) Integrate heat flux mitigation with long pulse scenarios
2.a.i) Advance capabilities of real-time equilibrium boundary reconstruction and MIMO control of the boundary shape
2.b) Understand operational stability boundaries at high β_N *and develop reduced models*
3.a) Establish high non-inductive fraction operation and validate integrated predictive simulations

Objective 3

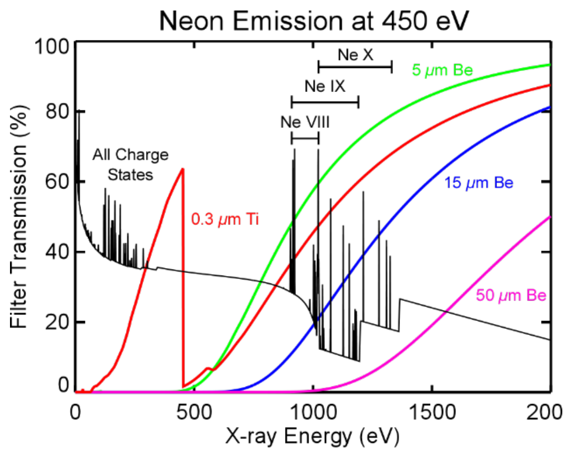
2.) Develop and evaluate power exhaust techniques for mitigating high projected NSTX-U heat fluxes

JHU diagnostic hardware include filtered soft X-ray diode arrays and spatially resolved VUV spectra

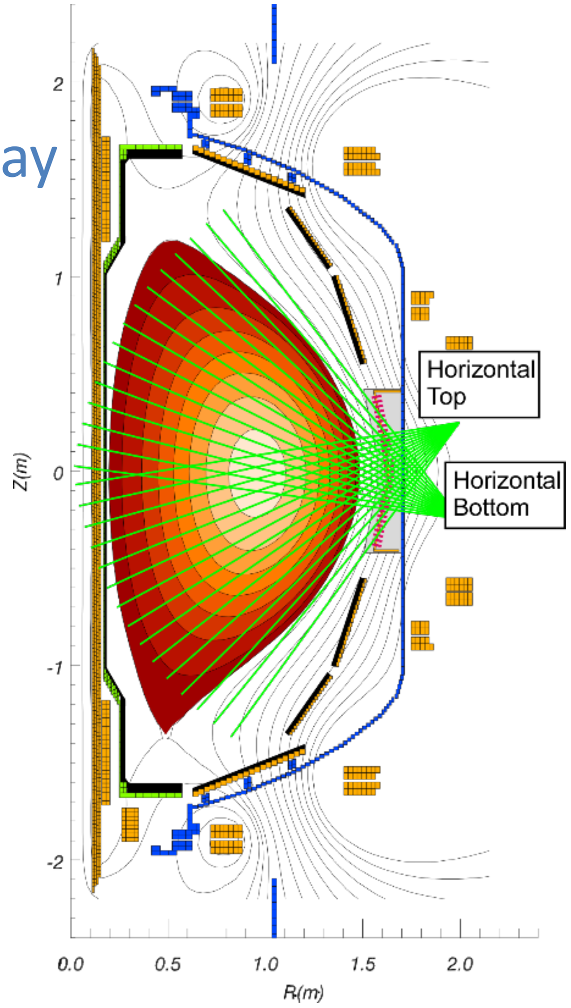


Multi-Energy Soft X-ray (ME-SXR)

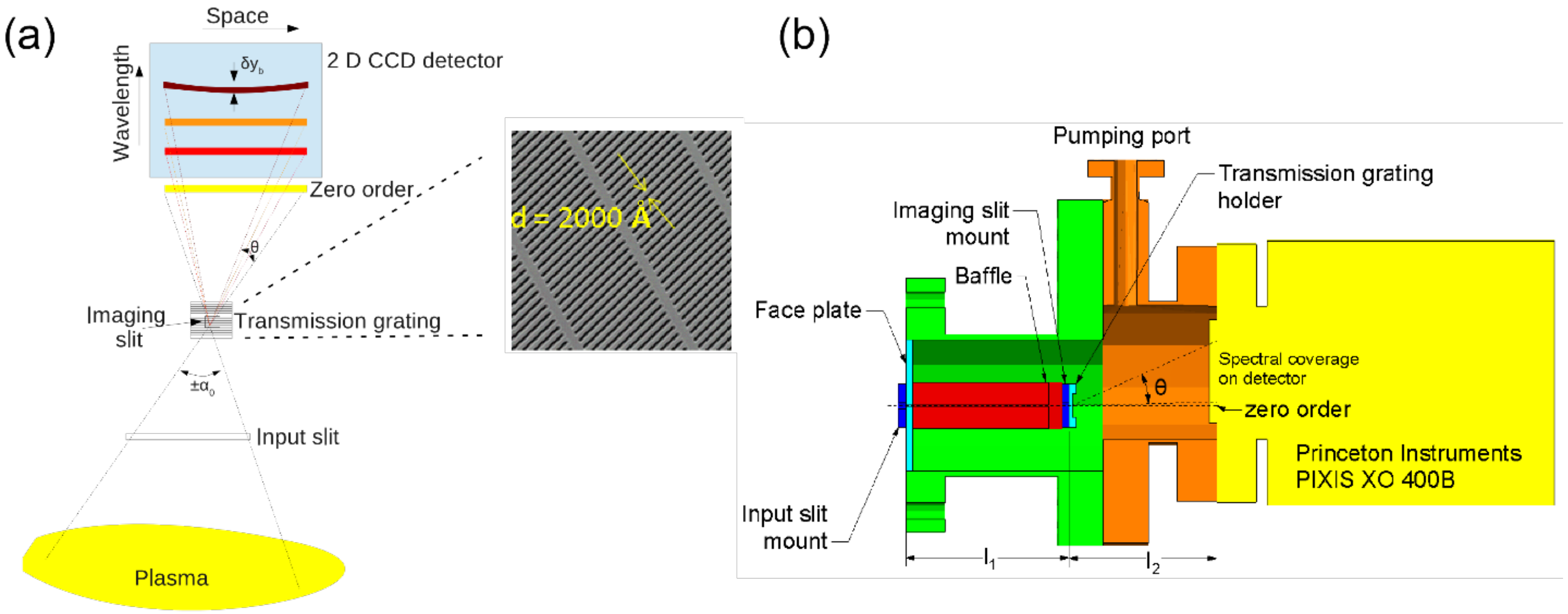
(a) schematic showing edge (red) and core (green) ME-SXR fields of view on NSTX-U and (b) CAD model of present ME-SXR diagnostic.

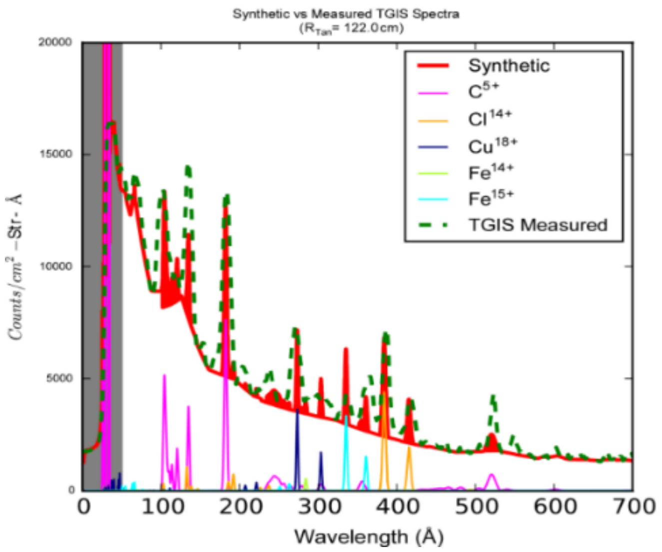


Poloidal Ultra-Soft X-ray (USXR) Arrays



JHU diagnostic hardware include filtered soft X-ray diode arrays and spatially resolved VUV spectra





Modeled and measured TGIS spectrum.

Transmission Grating Imaging Spectrometer (TGIS) (Gen II)

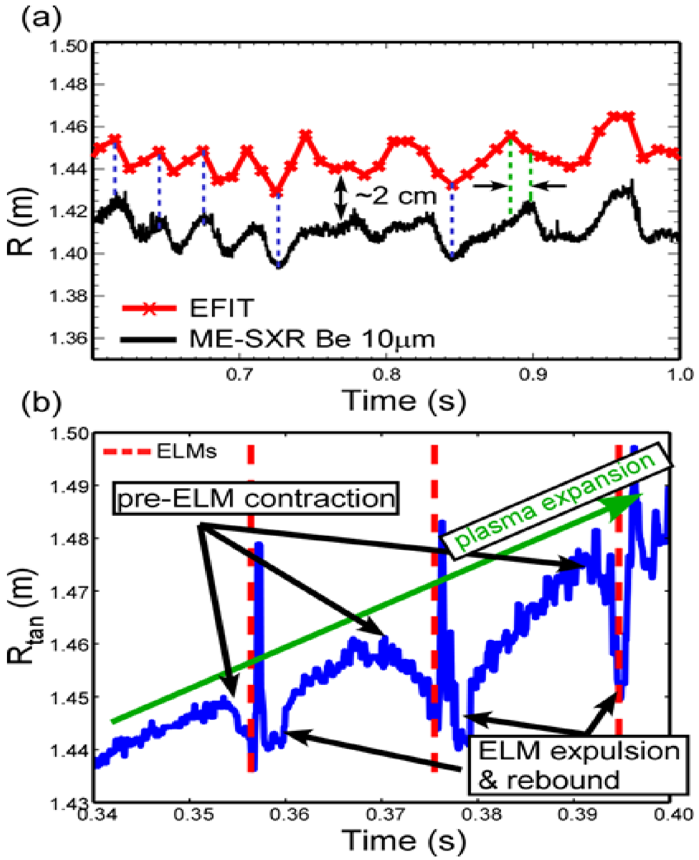
showing (a) schematic of grating imaging chain and (b) hardware implementation using a direct detection CCD camera.

High resolution Soft X-ray measurements provide high speed dynamics of boundary and pedestal

Curve fitting (1st or 2nd degree) of filtered SXR edge channels to find ‘boundary’

- EFIT offset corresponds to filter energy cut-off
- Tracks EFIT boundary with high time resolution
- Extrapolation provides sub-cm precision
- Phase shift can identify non-axisymmetric modes

- High time resolution for ELM cycle dynamics
- ME-SXR measurements improve pedestal details



SXR measurements showing a) a slow RWM/external kink in shot 133775, and b) a series of SXR 5 μm boundary contractions/expansions during ELM cycles for shot 142194.

Objective 1: *1.a.ii, 1.c, 2.c*

Objective 2: *2.a.i*

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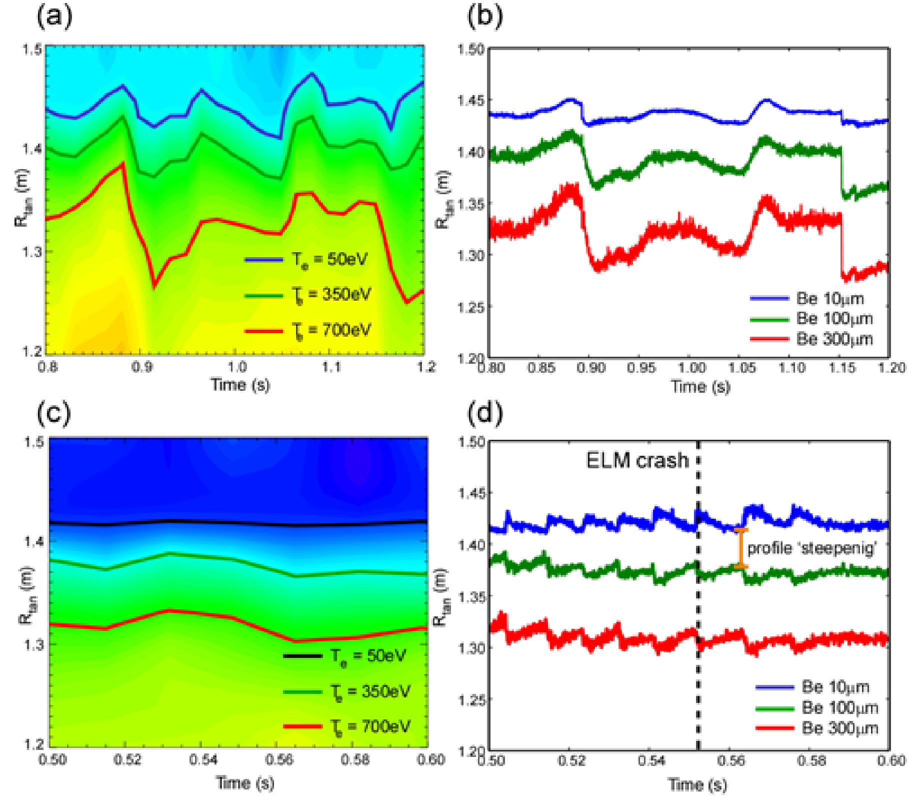
High resolution Soft X-ray measurements provide high speed dynamics of boundary and pedestal

Multi-Energy SXR signals track different iso-temperature boundaries

- Continuous, high time resolution measurements (10 kHz)
- High resolution pedestal measurements
- Captures ELM cycle dynamics



Comparison between a) MPTS contours of constant Te and b) ME-SXR boundary for NSTX shot 135700 and c) MPTS and d) ME-SXR boundary for NSTX shot 133048.

Objective 1: *1.a.ii, 1.c, 2.c*

Objective 2: *2.a.i*

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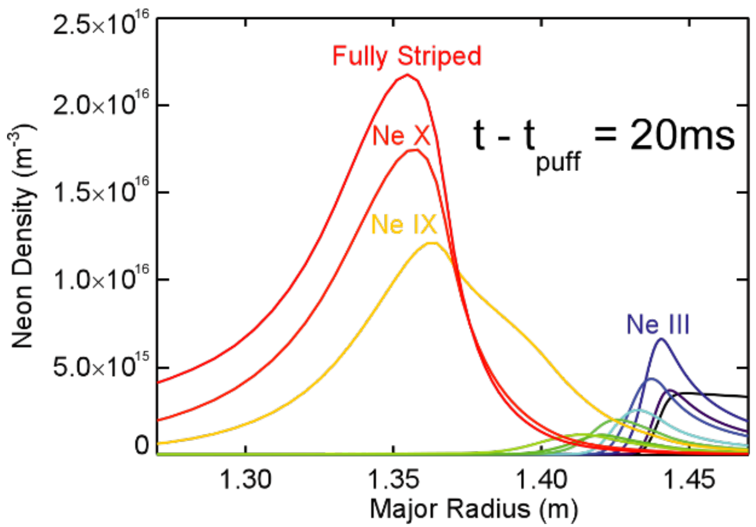
ME-SXR spectral sub-sampling provides good constraints for STRAHL impurity transport code

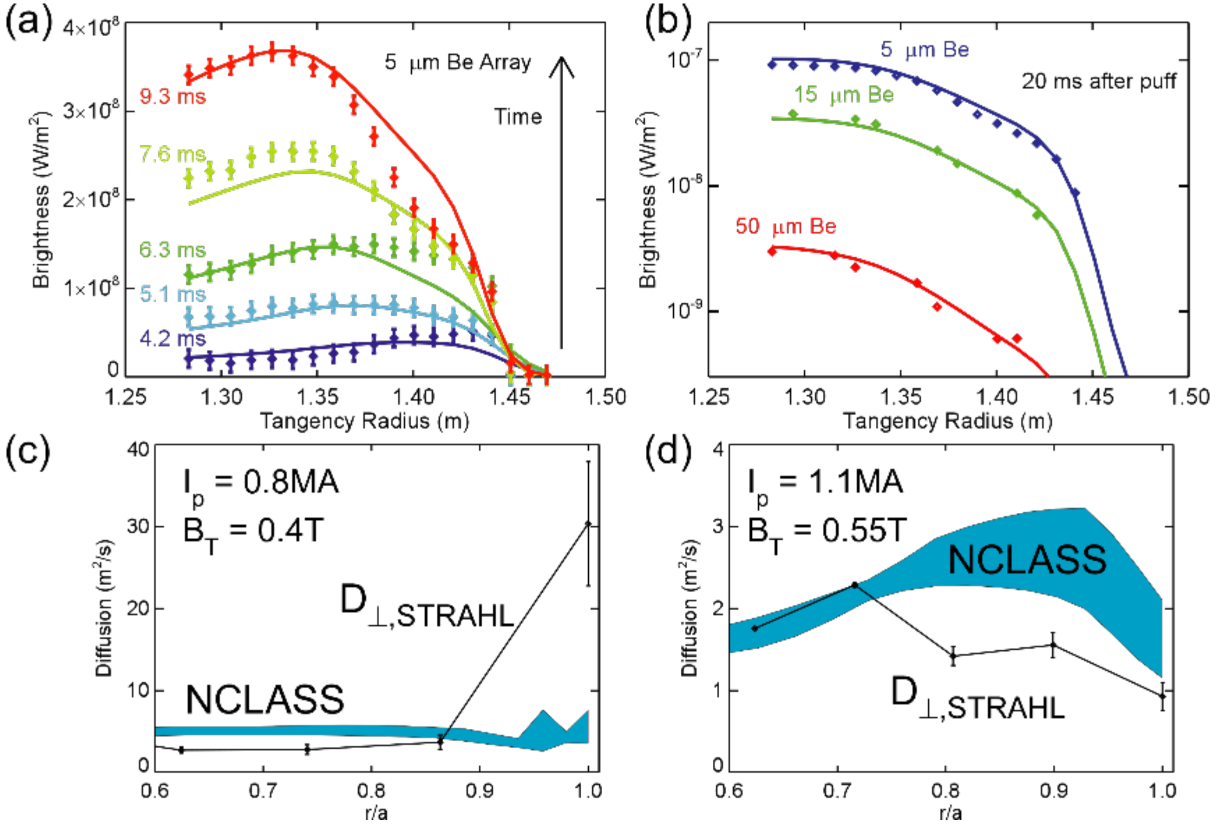
Transport measurements using SXR emission from Neon injection



Simulated neon charge state distribution in NSTX plasma following gas puff.

Objective 1: *1.a.iii, 2.a.i-iii*

Objective 2: *1.b.iii*



Using STRAHL to generate transport coefficients by fitting (a) ME-SXR profiles in time and (b) each ME-SXR array simultaneously with results for (c) low field and (d) high field NSTX plasmas.

Machine learning combines slow/accurate bolometry with fast unfiltered AXUV diode signals for P_{rad}

Training

Inputs

- Raw AXUV signals
- Impurity line brightness

Training data

- Bolometer emissivity

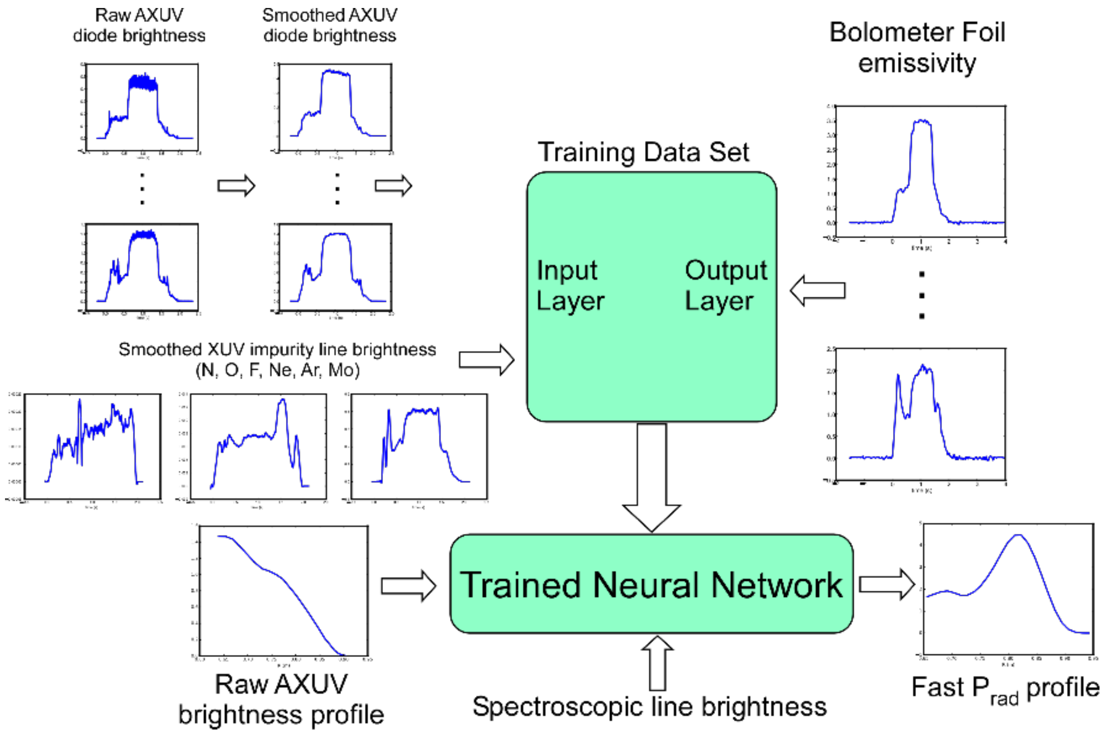
Implementation

Inputs

- Raw AXUV signals
- Impurity line brightness

Output

- Fast P_{rad} profile



Raw AXUV diode brightness

Smoothed AXUV diode brightness

Bolometer Foil emissivity

Training Data Set

Input Layer

Output Layer

Smoothed XUV impurity line brightness (N, O, F, Ne, Ar, Mo)

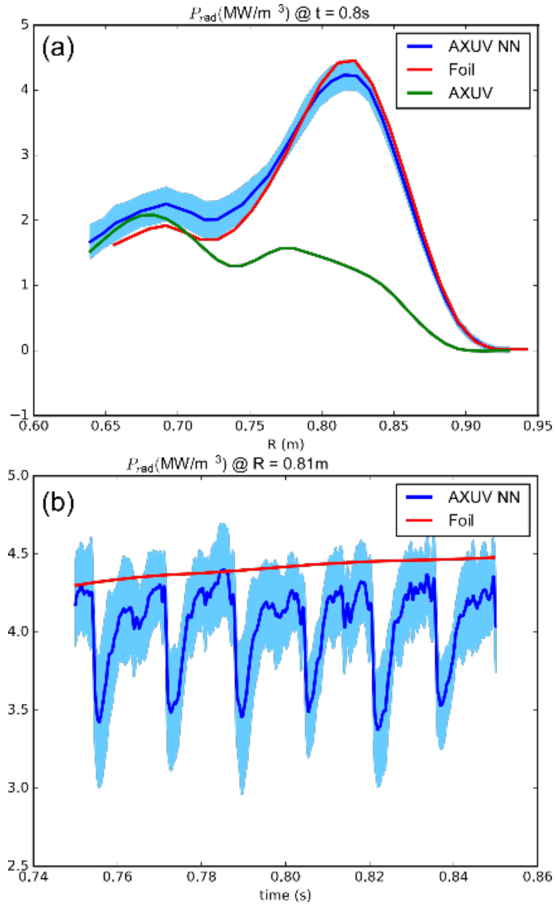
Trained Neural Network

Raw AXUV brightness profile

Spectroscopic line brightness

Fast P_{rad} profile

Workflow schematic of neural network for fast radiated power measurements.



(a) comparison of radiated power profiles and (b) radiated power over sawtooth cycles on C-MOD

Objective 2: *1.c*

Objective 3: *2.*

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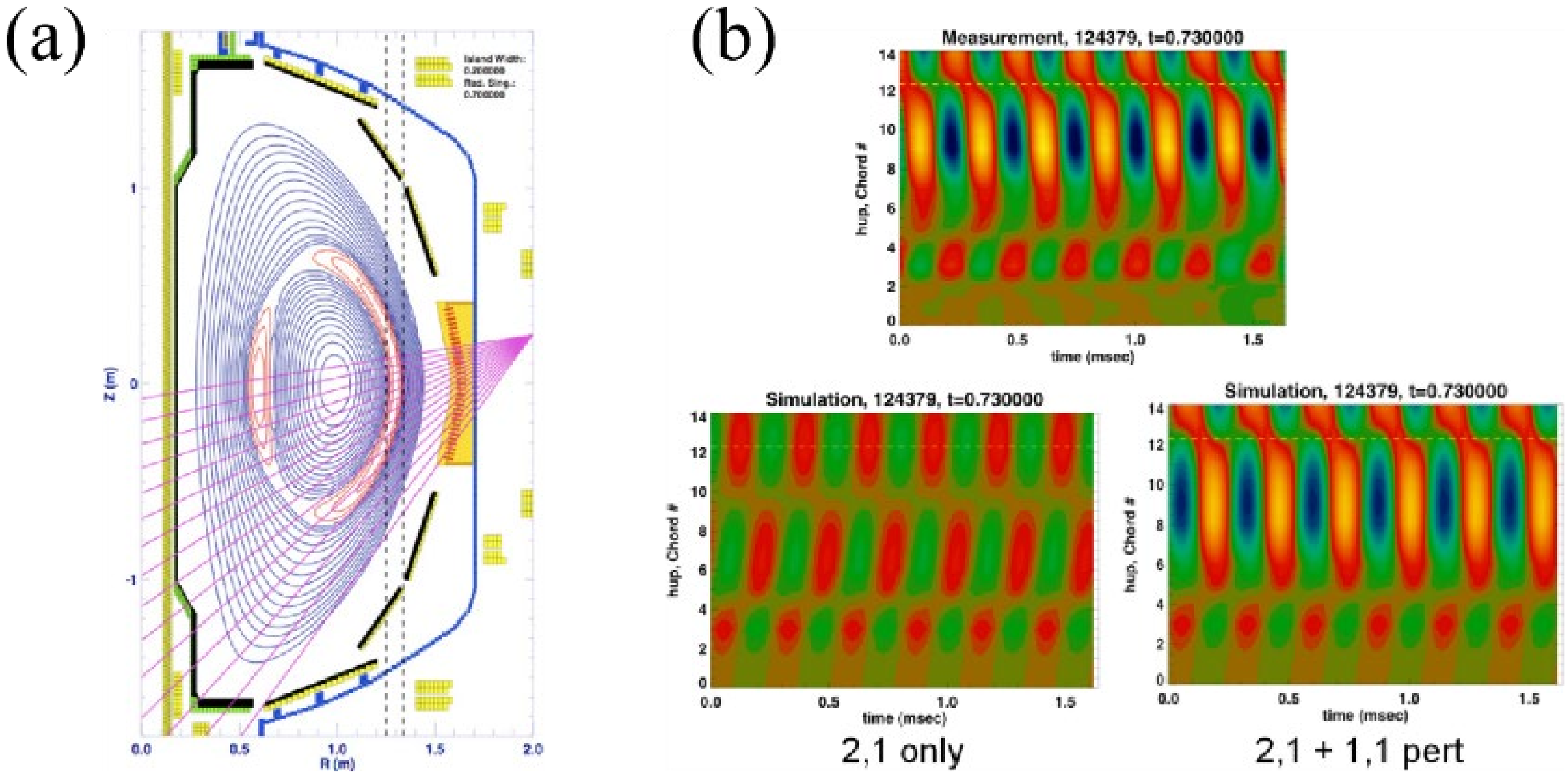
Poloidal USXR arrays provide fast (500 kHz) measurements of MHD phenomena



2,1 only

2,1 + 1,1 pert

(a) Diagram showing reconstructed island equilibrium and positions of USXR chords for NSTX shot 124379, t=0.730. (b) Comparison of simulated perturbed plasma state with and without (1, 1) component to measured multichord signal.

Objective 1: *2.c*

Objective 2: *2.a.i*

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NSTX Diagnostic Collaborations – 03/08/21

Initial work has focused on off-site hardware and software development

- New AXUV-SP2 diodes obtained for USXR arrays (Optodiode, Inc. custom fab run)
- Development of amplified diode testing station (gain/bandwidth, frequency response, noise)
- New beryllium filters for USXR arrays (5, 15, 50, 150 μm)
- Phidget hardware for filter positioning system (replaces computer, stepper controller, steppers, LabVIEW)
- Princeton Instruments ProEM CCD python library module

Upcoming work:

- Test & replace diodes, refurbish USXR arrays (Summer 21)
- Assemble upgraded TGIS (Summer 21)
- Test/calibrate upgraded TGIS (Fall 21)

Personnel and Responsibilities:

Kevin Tritz (PI): USXR refurbishment, on-site management and research
Dan Stutman (co-PI): TGIS assembly and testing, off-site management
Deepak Kumar (eta June 21): TGIS assembly, testing, calibration, and installation
Post-doc (eta Spring/Summer 22): on-site operation and maintenance, research

5-Year work plan supports NSTX-U research objectives

Year 1:

ME-SXR and USXR refurbishments
TIGS detector upgrade
PI camera python module
Validate data acquisition workflow

Year 2:

ME-SXR/USXR operations in support of NSTX-U research
Impurity injection transport experiments
Investigate extrinsic impurity injection for cold pulse generation
Install upgraded TGIS

Year 3:

ME-SXR/USXR operations in support of NSTX-U research
Thermal transport experiments using cold pulses
Machine learning impurity identification using TGIS data

Year 4-5:

ME-SXR/USXR/TGIS operations in support of NSTX-U research
Continue JHU transport experiments in expectation of new NSTX-U plasma regimes