DEVELOPMENT OF DIVERTOR PLASMA DETACHMENT CONTROL SYSTEMS ON THE KSTAR TOKAMAK

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October 24, 2022

NSTX-U Physics Meeting

People

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PPPL team includes Florian Effenberg, Federico Nespoli, and Keith Erickson

Florian Laggner (NC State) will work under a Year 1 subcontract

Project is Broken Down into Four Tasks

- Task 1: develop control systems
- Task 2: surrogate model to transform limited diagnostics into useful control parameters
- Task 3: real-time control of the Impurity Powder Dropper (IPD)
- Task 4: interpretive modeling of the KSTAR edge/divertor

Motivation – Develop Controls Needed in ITER and Reactor-Relevant Systems

- establishing and maintaining a proper degree of plasma detachment and properly-positioned “detachment front” is a nontrivial challenge
- successful in existing machines only with the aid of in situ diagnostics that would not survive in a reactor environment
- developing control-oriented “observers” to transform data that can be obtained in real-time in a reactor into useful control parameters is imperative
- actuators such as impurity injection systems on existing machines will not translate to reactors, where implementation challenges lead to less favorable dynamic responses, including longer latency
- innovations will be needed to achieve effective control with less potent actuators
- integration of ELM control and detachment control techniques is important

Detachment Control on KSTAR

Example: detachment control using I_sat measured by Langmuir probes and normalized to a model for attached I_sat in the KSTAR tokamak [Eldon 2022 PPCF]

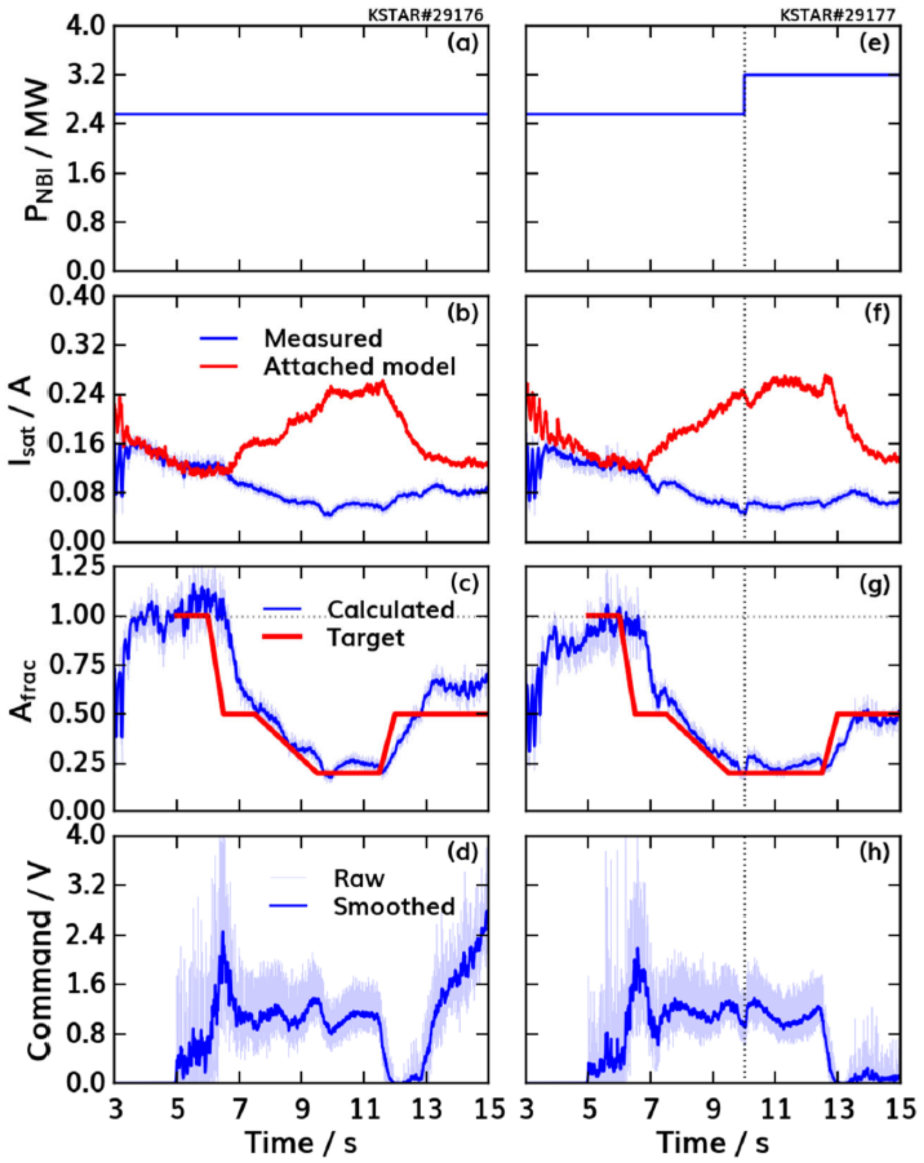
This formulation of the control parameter (attachment fraction A_frac) can adapt to changes in the scenario including heating power

(a, e) NBI heating power

(b, f) measured I_sat from LPs (blue) and model for attached I_sat (red)

(c, g) Calculated A_frac (blue) and reference or target value for the control system (red)

(d, h) Command sent to the gas valve



KSTAR Presents an Opportunity to Address These Challenges

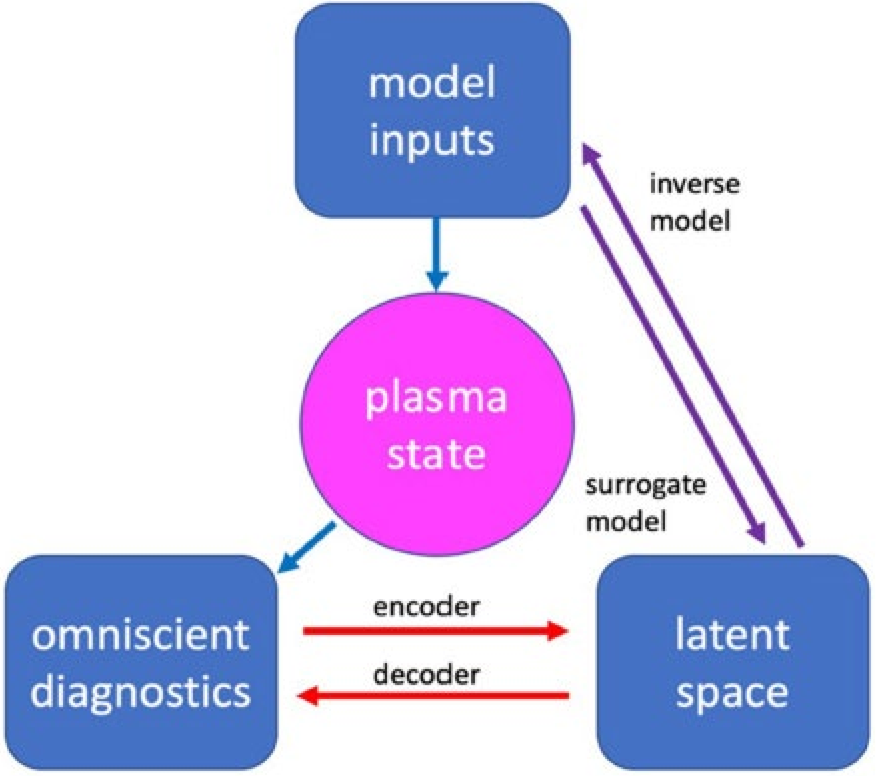
- long pulse plasma operation where the interaction between the plasma and the plasma facing surfaces (or walls) of the device may evolve unfavorably as the walls heat up and are loaded with particles from the plasma cross field exhaust
- integration of effective ELM control with effective detachment control is a major challenge

KSTAR offers the tools to study divertor protection, plasma confinement and pressure regulation, ELM removal, and wall as it offers:

- long pulse discharges
- reactor-relevant wall material
- a precise, repeatable, and multi-species gas injection system
- diagnostics that are (or could be made) available in real-time
- an IPD system that has been shown to provide ELM suppression and in-situ wall conditioning
- a flexible plasma control system (PCS) in which to test and optimize new control, including machine learning (ML) systems

Strategy – Interconnected Omniscient Diagnostics, Latent Space, and Model Inputs

- omniscient diagnostics model describes the plasma state in detail and is validated against physical counterparts when possible
- latent space with reduced dimensionality is identified by a neutral network encoder/decoder
- model inputs (heating power, geometry, gas puff, IPD etc.) are the system actuators



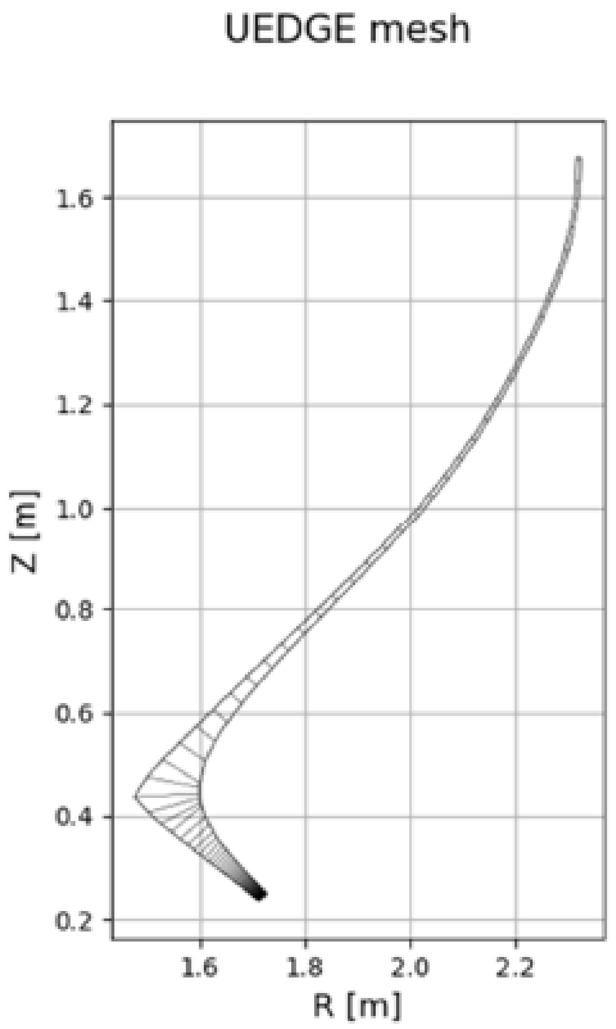
Task 1 – Develop Control Systems

- simple improvements to Langmuir probe detachment control on KSTAR
  - Include more data about system state
  - IPD with the right sensor
- **control system using ML observer as control parameter**
- **closed loop detachment with dropper**
  - **PID policy?**
  - **Wall conditioning, ELM mitigation, radiation?**
  - **Feedback controlled gas puffing with feedforward IPD?**
- MIMO detachment control
- study detachment control dynamics and quantify control performance

red = PPPL tasks

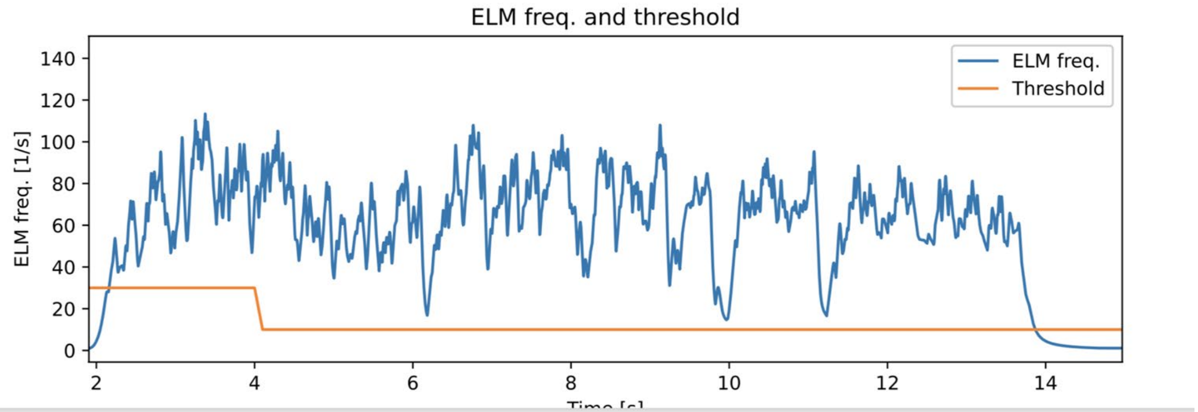
Task 2 – Surrogate Model

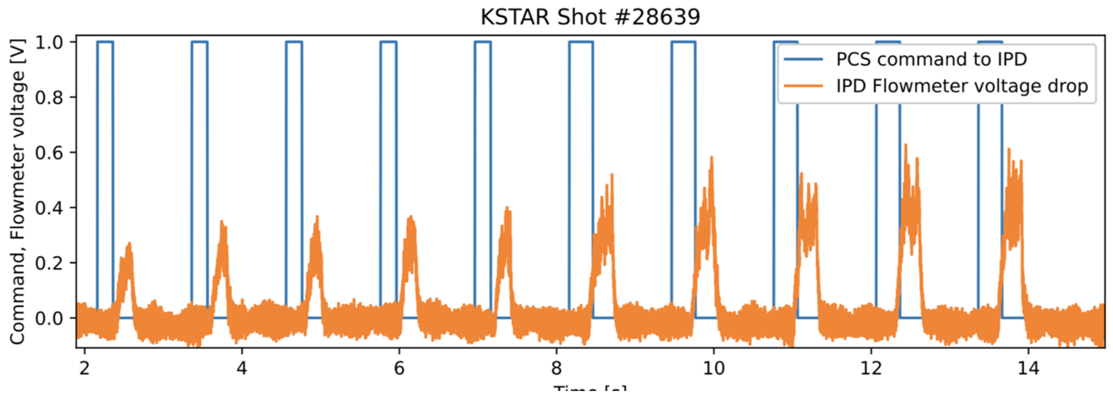
- train ML surrogate model for KSTAR
  - UEDGE
  - KSTAR data
- calibrate KSTAR surrogate model that works offline
- prepare surrogate model inputs
  - ne,SEP, ne,PED, PCS real-time Thomson, P_RAD, f_imp
- project experimental diagnostics to the latent space
- calibrate ML surrogate model predictions with experiment diagnostics
- implement surrogate models in KSTAR PCS
- extend surrogate model to generate additional observers to take advantage of opportunities identified during initial testing and analysis



Task 3 – Real-Time Control of the IPD

- link IPD to KSTAR PCS so it can accept real-time commands
- implement algorithm to translate desired flow rate into commands for dropper
- 2021 - successfully triggered powder from PCS based on processed Dα





Real-time PCS Dα signal processed to compute ELM frequency. Preprogrammed threshold used to trigger IPD bursts

Task 4 – Interpretive Modeling

- analyze plasma during detachment control/while detached
- validate surrogate model

Using SOLPS-ITER or **EMC3-Eirene/DIS/DUSTT**