Development of Laser Blow-Off Impurity Injection Experiments for the HSX Stellarator

C. Clark, D.T. Anderson, F.S.B Anderson, K. Likin, J.N. Talmadge, K. Zhai,

HSX Plasma Laboratory, Univ. of Wisconsin, Madison, USA

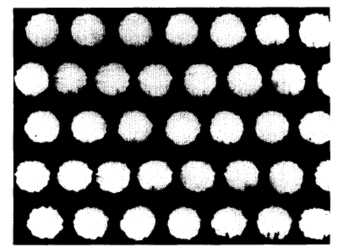
Overview and Motivation

- Impurity control and effective helium exhaust are open areas of research for the stellarator reactor concept
  - The expected "Ion Root" operating point of a stellarator reactor is predicted to enhance impurity confinement
  - Some stellarators have seen unexpected, and unexplained increase in impurity transport under specific operating conditions
    - W7-AS had an "High Density H-mode"[Grigull, '01]
    - LHD has an impurity "hole" [Iiyoshi, '99]
- We have undertaken an experimental program to measure the impurity transport properties of the HSX stellarator. Our goals are to:
  - Inject aluminum neutrals into HSX plasmas using a laser blow-off technique
  - Measure the resulting radiation using AXUV photodiode arrays
  - Determine the impurity diffusivity and convective velocity using the STRAHL code
  - Compare these findings with neoclassical models and with measurements taken in other stellarators

Impurity Injection by Laser Blow-Off

Laser Blow-Off Technique:

- A glass slide with a vapor deposited, 0.5–2.0 µm thick, layer of the selected material is back-illuminated with a laser
  - Creates short burst of neutrals, which ballistically enter the plasma
  - Energy spectrum of neutrals can be influenced by laser energy density
  - Number of neutrals can be controlled with spot size and film thickness
- Aluminum is the impurity that we will be injecting because it's laser blow-off properties have been well characterized [Marmar, '75 & Breton, '80]

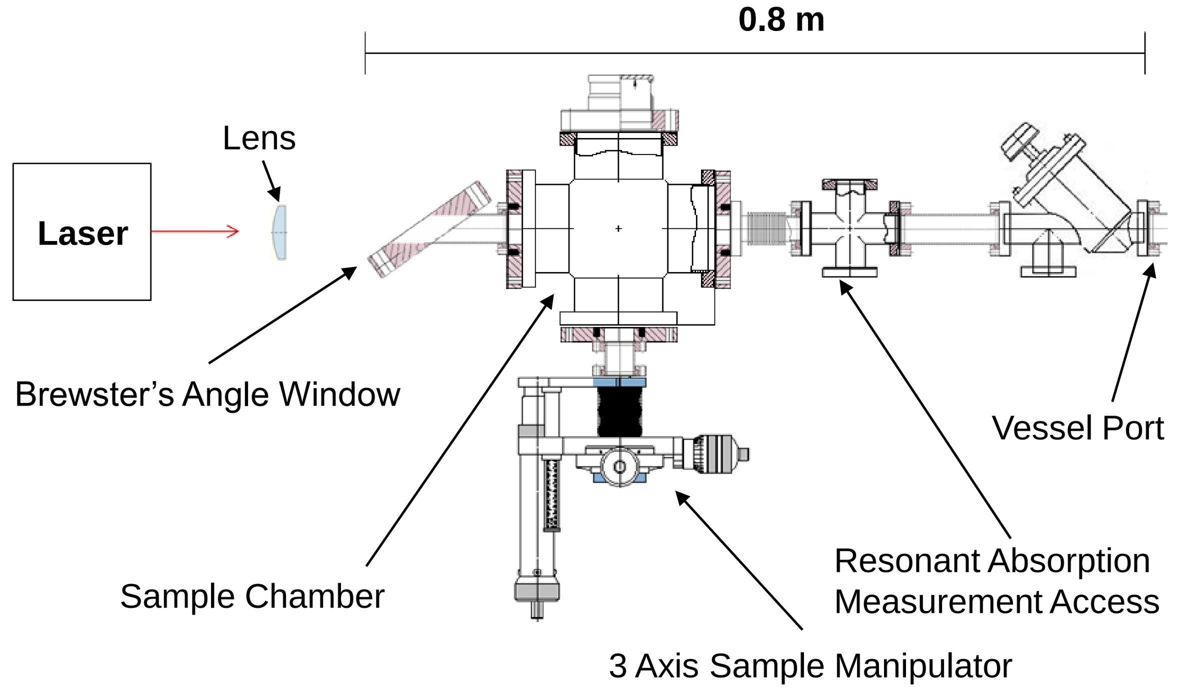


A laser blow-off target that has been repeatedly irradiated [Marmar, '75]

HSX Beam Line Details:

- Laser: 800 mJ YAG – Surelight III
  - Allows use of up to a 4 mm spot
- Solid angle of injection: 3×10^{-3} sr
- Spot size adjustable by movable lens
- Each pulse is projected to inject at least 10^{16} neutrals into the plasma

The HSX Laser Blow-off Beam Line



Status:

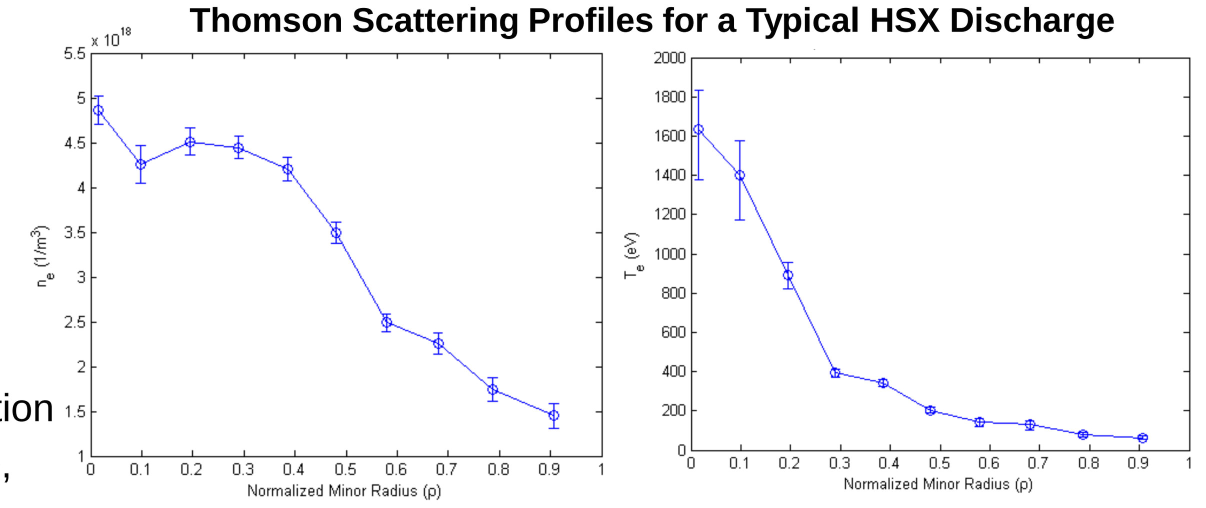
- Simulations of the trace level impurity radiation have confirmed feasibility
- The laser has been procured
- The beam line has been assembled

Simulation of Stationary Trace Impurity Radiation

Selecting Plasma Parameters:

- Relevant plasma parameters were taken from a set of representative discharges
  - Magnetic Mode: QHS
  - ECH Power: 44 kW
  - B_{Axis}:1 T
  - Wall Conditioning: Carbonization
- The plasma is assumed to be pure, aside from the trace aluminum

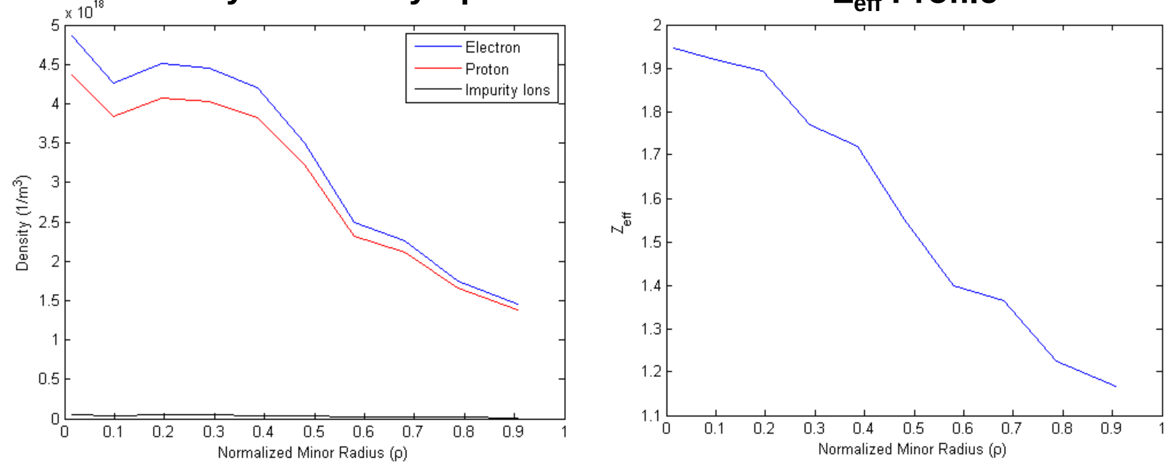
Thomson Scattering Profiles for a Typical HSX Discharge



ADAS [Summers, '04] Simulation of Ionization Equilibrium:

- The aluminum density assumed to be 1% of the electron density
  - Actual profile will depend on transport specifics
  - Total number of impurity ions injected is controllable
- Coronal equilibrium is assumed
- Charge exchange on neutral hydrogen has a significant effect
  - In B = 0.5 T discharges, n_H was found to be ~ 10^{16} m^{-3}

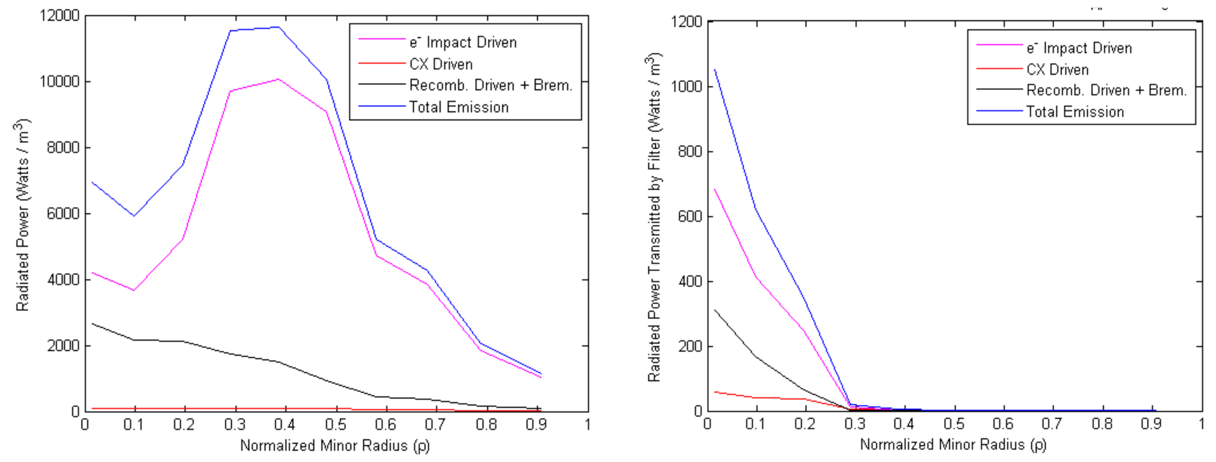
Density Profiles by Species **Z_{eff} Profile**



ADAS Simulation of Impurity Radiation Profiles:

- Total emissivity from the aluminum was calculated with ADAS
  - Integrated: P_{tot} = 1.65 kW
- The portion of the emissivity that would transmit through a 5 µm beryllium filter was also calculated
  - Integrated: P_{SXR} = 10 W

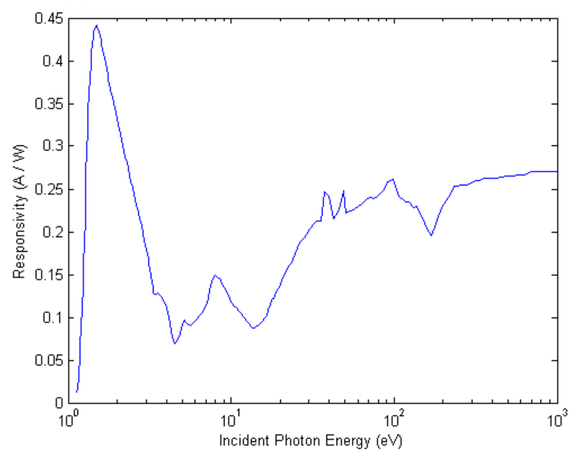
Total Radiated Emissivity Profile **Soft X-Ray Emissivity Profile**



Proposed Impurity Radiation Detectors

- Impurity radiation will be detected with AXUV photodiode arrays
- Each 20 channel AXUV-20EL chip will have its elements aligned in a poloidal plane
- The detectors will view the plasma through a 1 mm pinhole to achieve spatial resolution
- A beryllium filter can be rotated over the pinhole so that the photodiode only detects the soft X-ray emission
  - This will only come from the very core
- The energy dependent responsivity to lower energy photons will have to be accounted for using ADAS

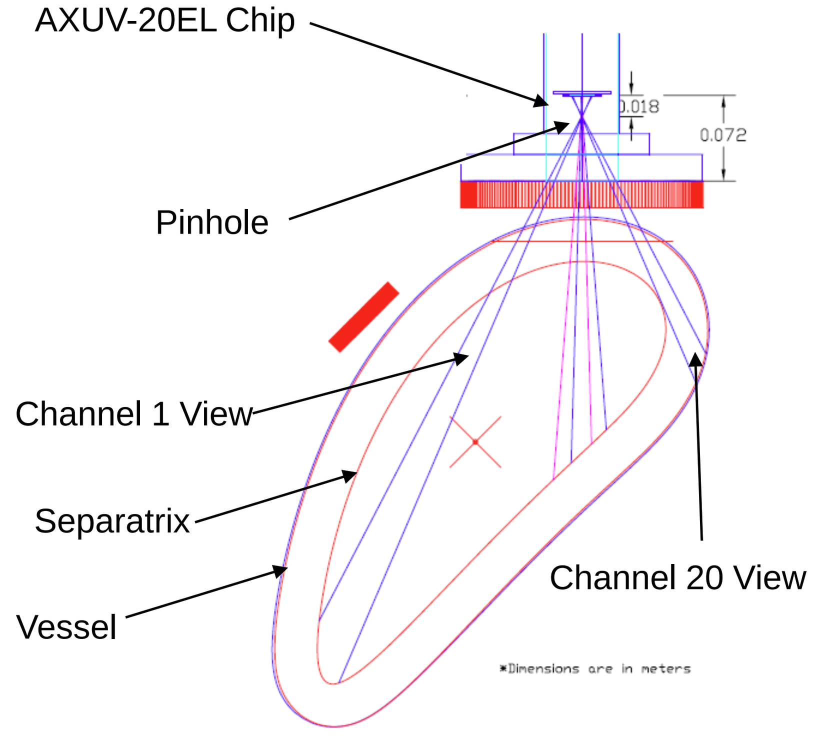
Energy Dependent AXUV Responsivity



Reconstruction of Impurity Emissivity Profile

Determining the View of Each Detector:

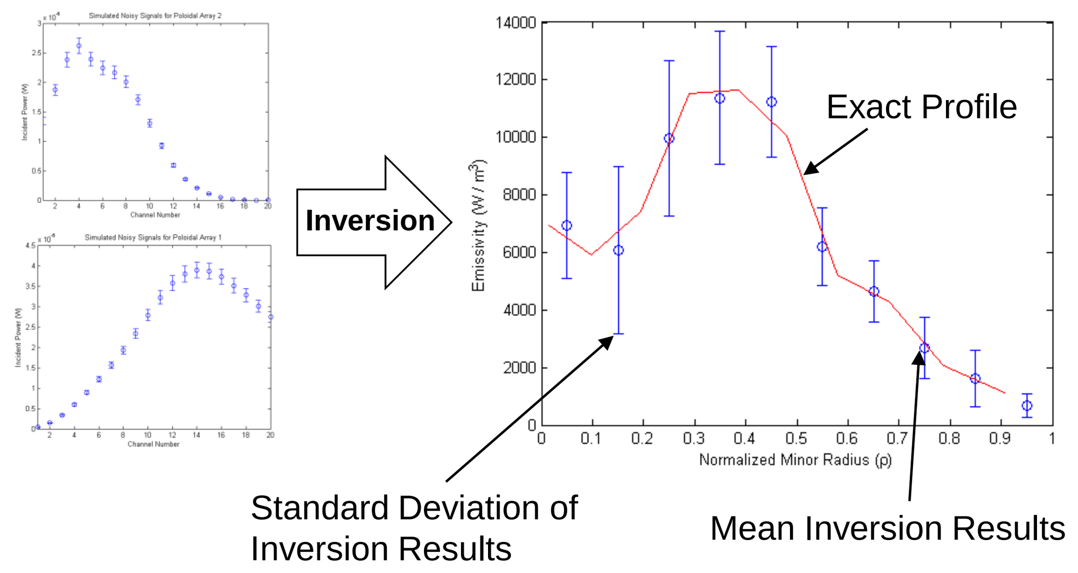
- The volume around the paraxial ray is discretized
- The solid angle of the detector, as viewed from the center of each volume element, is calculated
  - This gives the relationship between the emission in each volume element and the signal at the detector
- The contributions from discrete portions of the radial profile are expressed as a vector that relates the 1D emissivity to the power incident on the detector



Synthetic Diagnostic with Noisy Data:

- Exact expected signals are calculated for each detector from the view information and the emissivity profile
- A Monte-Carlo code adds uncorrelated noise (5% std. dev.) to the exact signal predicted for each detector
  - At each iteration, a least-squares inversion is performed
- The mean and standard deviation of the inversion results are compared to the exact profile

Detector Signals With Noise Added **Comparison of exact emissivity profile and inversion results**



Calculating Transport Quantities with STRAHL

- The transport code STRAHL [Behringer, '87] is used to solve the 1-D continuity equation for each impurity charge state
  - Includes the source / sink term due to ionization / recombination from adjacent charge states

$$\frac{\partial n_{I,Z}}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r} r\left(D\,\frac{\partial n_{I,Z}}{\partial r} - v\, n_{I,Z}\right) + Q_{I,Z}$$

- ADAS is used for atomic data calculations
- The background plasma parameters are assumed to be constant and are inputs to the code
- Temporal and spatial impurity source rates, diffusivities and convective velocities are inputs to the code
- The code outputs the time dependent emissivity profile
- When used in conjunction with a nonlinear optimization algorithm, STRAHL can be used to determine the impurity convective velocity and diffusivity from the time dependent emissivity

52nd Annual Meeting of the Division of Plasma Physics, November 8 – November 12, 2010, Chicago, IL