Impurity Transport Research at the HSX Stellarator

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

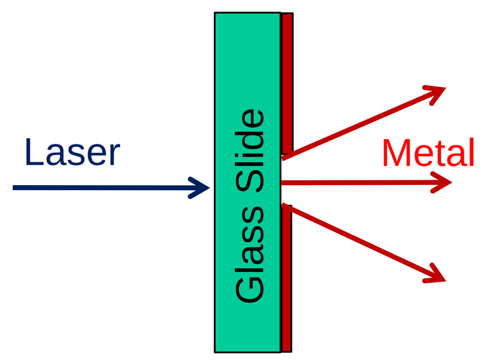
HSX Plasma Laboratory, Univ. of Wisconsin, Madison, USA

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 a "High Density H-mode"[Grigull, '01]
    - LHD has an impurity "hole" [Ida, '09]
  - No clear path exists to satisfactory impurity handling in a reactor scale stellarator
- 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 the neoclassical model using the PENTA code
- Progress has been made toward the experimental goals
  - Aluminum has been injected into HSX discharges
    - The injection was visible on a photodiode
    - The injection did not perturbing the background plasma parameters
  - Two photodiode pinhole cameras have been installed on HSX, and five more are under construction.
  - A code has been developed to invert the photodiode signals into an emissivity profile

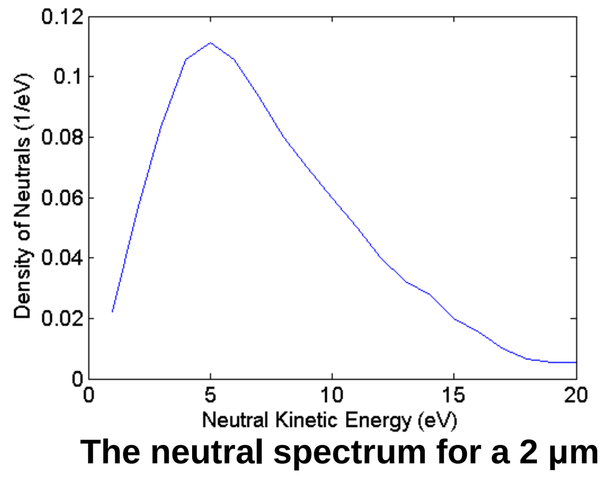
Laser Blow-Off

- A glass slide with a 0.5–2.0 μm thick layer of the selected material is back-illuminated with a laser
  - This creates short burst of neutrals, which ballistically enter the plasma
  - The energy spectrum of neutrals is a function of the laser energy density, film thickness, and material
  - The number of neutrals injected can be controlled with spot size and film thickness
- The laser blow-off properties of aluminum have been particularly well characterized by other researchers [Marmar, '75 & Breton, '80]



A schematic view of the laser blow-off process

A laser blow-off target that has been used on HSX

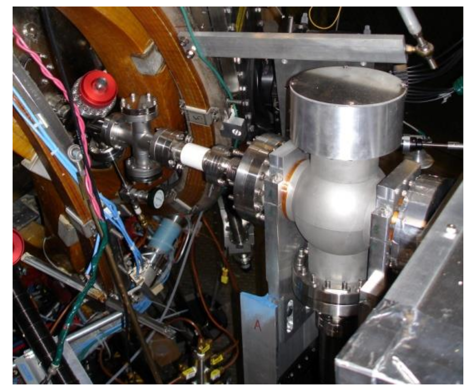


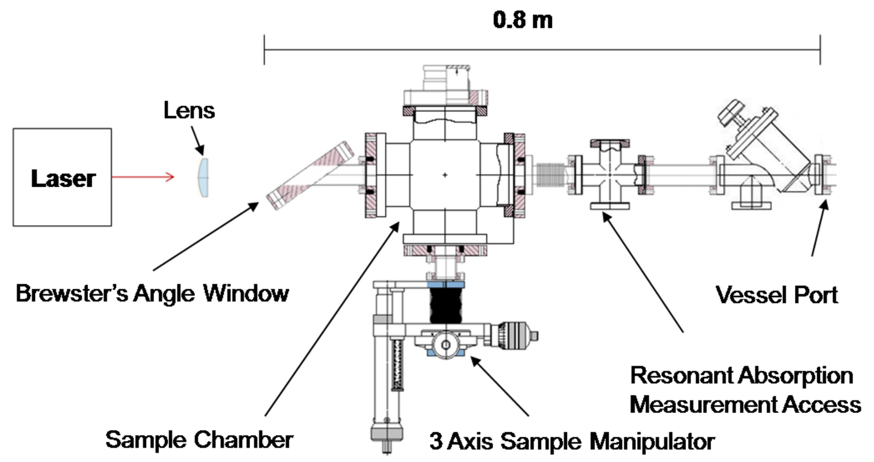
The neutral spectrum for a 2 μm aluminum film illuminated with a 7 J/cm² laser pulse [Breton '80]

The HSX Laser Blow-Off System

HSX Beam Line Details:

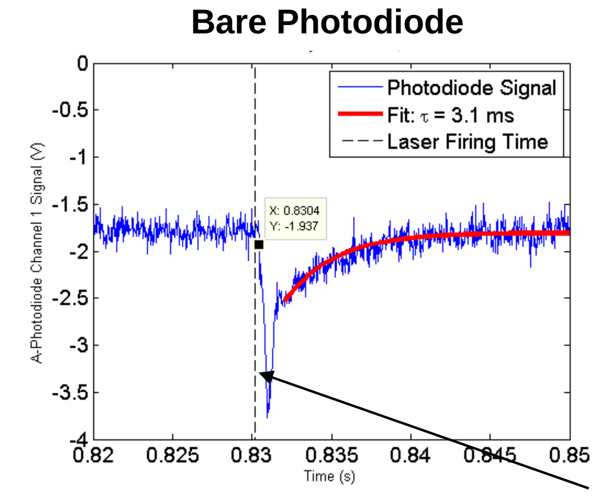
- Laser: 850 mJ YAG – Surelight III
  - Allows use of up to a 4 mm spot at 7 J/cm²
- Solid angle of injection: 3 x 10^{-3} sr
- Spot size adjustable by movable lens





Typical Injection Results:

- Injections are typically performed with:
  - 1 μm aluminum layer

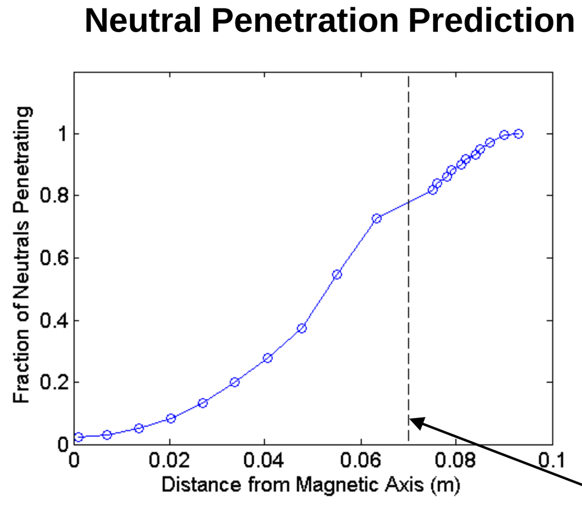


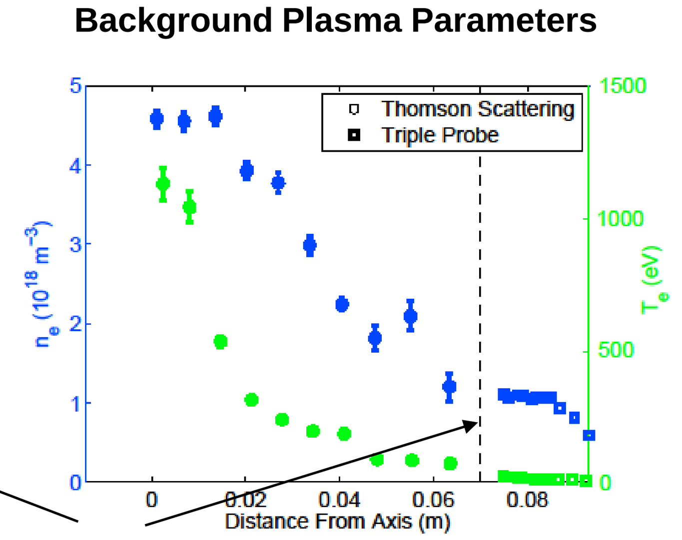
Background Parameters

Laser Firing Time

Simulation of Impurity Beam Penetration:

- Considers only electron impact ionization
  - Atomic data from ADAS
- Neutral spectrum taken from [Breton '80]
- Projects adequate deposition within the confinement volume





Last Closed Flux Surface

Importance of Chromium Layer

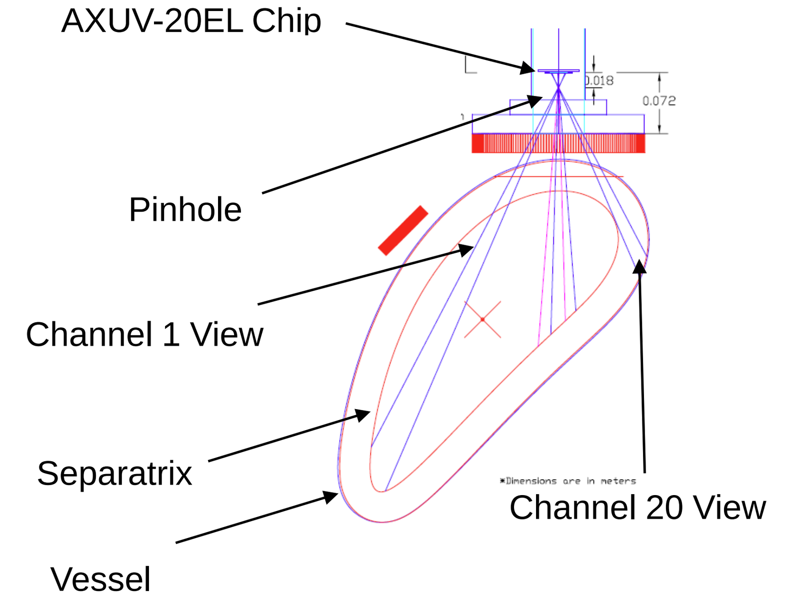
Comparison of Injection with / without Chromium

Reconstruction of Impurity Emissivity Profile

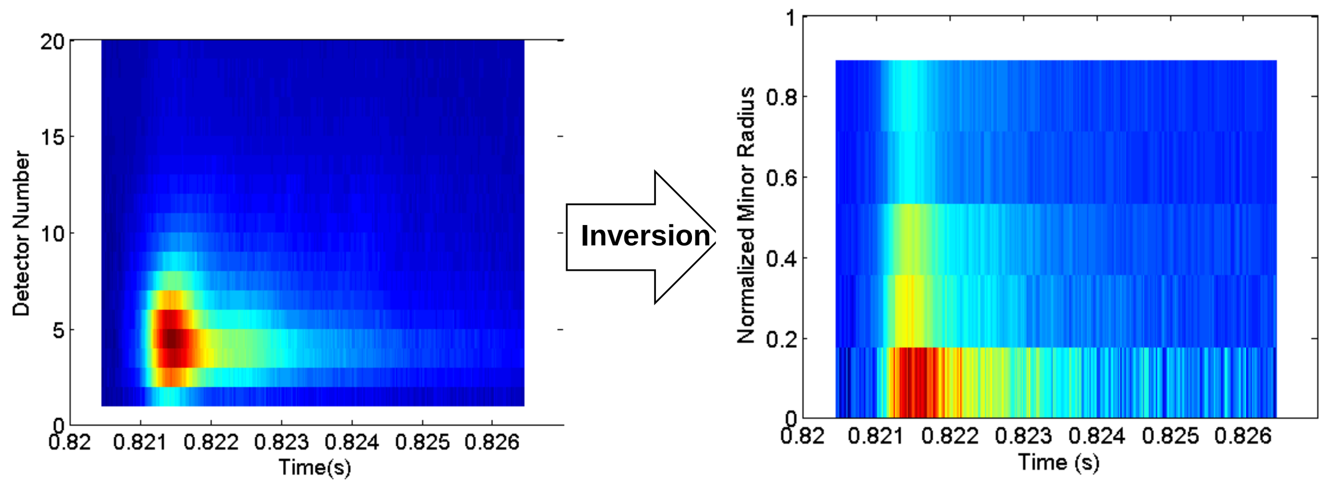
- Impurity radiation will be detected with AXUV photodiode arrays
  - Two have been installed on HSX
  - Five more are under construction
- The detectors view the plasma through a 1 mm pinhole to achieve spatial resolution
- Filter can be used to limit the spectrum of light reaching the photodiode

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
- Since each volume element is small, it is taken to be located at a single radial location
  - The volume elements can be binned into the appropriate portion of a matrix relating the 1D emissivity profile to the power incident on each detector



Results:



Calculating Transport Coefficients with STRAHL

- The transport code STRAHL [Behringer, '87] is used to solve the 1-D continuity equation for each impurity charge state, including 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

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