Investigation of Impurity Transport in Alcator C-Mod Using Laser Blow-Off Impurity Injection

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Abstract

Alcator C-Mod is equipped with a multi-pulse laser blow-off impurity injector, capable of injecting a small amount of a given impurity into the plasma as frequently as once every 90 s. This system is used as an actuator for studies of impurity transport, where calcium is often used as a non-intrinsic and non-recycling. To observe the effect of the injection, a high-resolution x-ray imaging crystal spectrometer captures temporally-resolved profiles of the emission fromholmium-like calcium. These emission profiles can then be analyzed to obtain temporally-resolved profiles of the impurity diffusivity and convective pinch velocity. Injections have been performed in a variety of plasmas including L-modes, H-modes, L-modes and plasmas with high fractions of lower hybrid current drive. C-Mod’s combination of an impurity injector with a high-resolution x-ray spectrometer provides a powerful system for probing the behavior of impurity transport in these various regimes.

Multi-pulse laser blow-off impurity injector; controlled introduction of impurities

Controlled impurity injections are a very powerful tool to probe transport
• Small (non-inertial) injections of a non-intrinsic, non-recycling impurity (such as calcium) enables systematic study of impurity transport [1, 2].

Hardware overview
• Motorized steering for between-shot positioning.
• Periodic steering for ion shot movement of beam.
• Fast steering and 10 Hz laser repetition rate enables multiple injections into a shot.

Impurity transport coefficient profiles have been successfully measured for L-mode plasmas

A variety of diagnostics track the injection
• An x-ray imaging crystal spectrometer observes emission profiles from high charge states
  - Calcium is typically injected: non-intrinsic and non-recycling.
  - The spectrometer can be configured to view emission from either Ca XIX or Ca XX.
  - 32 spatial channels, up to 6 ms time resolution.
  - Combining the data from multiple injections at 10 Hz enables an effective time resolution of 2 ms.

Preliminary look at the effect of LHCD

A scan of LHCD power was used to vary the loop voltage and suppress sawteeth
• Used USN plasmas with both forward and reverse field.
• At sufficiently high non-inductive current drive fraction, the sawteeth are stabilized.
• Ca XVII and Ca XIX (not shown) confinement times show little change across this threshold in either field configuration.
• This is somewhat surprising given the observed connection between the shape of the impurity transport coefficient profiles and the sawtooth inversion radius in C-Mod [1]. As well as the observed effects of sawteeth on the impurity density profiles both in these discharges and on other machines [7], this seems to imply that the sawtooth pinch (\(P_{\text{t}} = V_{\text{S}}/V_{\text{ah}}\)) is negligible.
• Further work is required to obtain emissivity and transport coefficient profiles and look for other effects related to the suppression of the sawteeth.

Future Work

Detailed analysis of LHCD scan
• Extract transport coefficient profiles using STRAHL [4].
• Compare sawtoothing and sawtooth-suppressed plasmas to look for changes in the transport coefficient profiles once sawteeth are no longer present.

Detailed analysis of EDA H-mode scan
• Obtain more accurate values for \(\nu_{\text{eff}}\).
• Investigate relationship between changes in the impurity transport and peaking of the main ion density.

Detailed analysis of I-mode scan: Investigate changes in fluctuation and transport coefficient profiles across the L/I threshold.

A broad range of EDA H-mode conditions have been explored

A current/power scan was used to access a wide range of \(\nu_{\text{eff}}\)
• Density peaking in H-modes has been observed [8] to scale with
  \[\nu_{\text{eff}} = 1.2 Z_{\text{eff}} (n_{\text{ei}}/T_{e})^{1/2}\]
• A scan of \(P_{\text{ICRF}}\) and \(P_{\text{LHCD}}\) was used to study \(\nu_{\text{eff}}\)
• Ca was injected into the plasmas in order to look for a connection to the main ion particle transport.

Initial analysis of global confinement results shows dependencies on \(\nu_{\text{eff}}\)

More work is needed to explain the outliers and look at the behavior of the impurity density and transport coefficient profiles.

References


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