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

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Alcator C-Mod

## 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 0.1 s. This system is used as an actuator for studies of impurity transport, where calcium is often used as it is 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 from helium-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, I-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

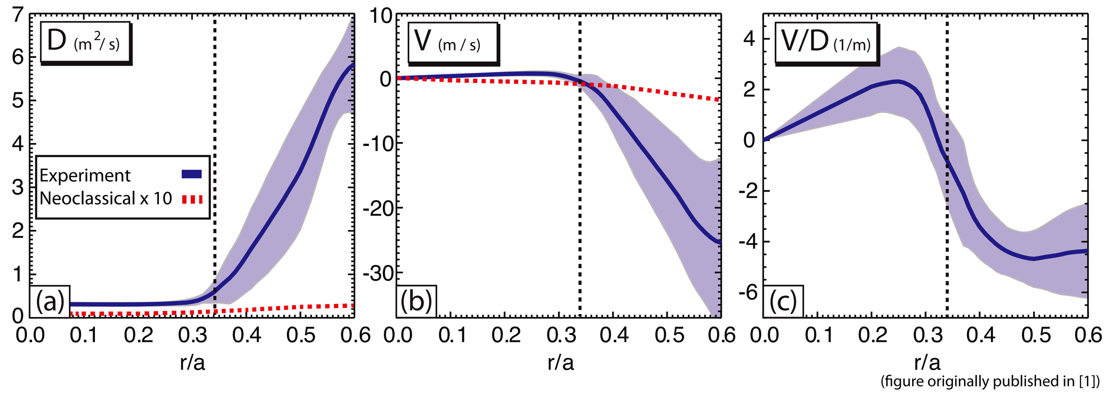
### Controlled impurity injections are a very powerful tool to probe transport

- Small (nonperturbative) injection of a non-intrinsic, non-recycling impurity (such as calcium) enables systematic study of impurity transport [1, 2].
- Larger injections are used to induce cold pulses to investigate non-local thermal transport [3] (see C. Gao et al., JP8.00080).

### Hardware overview

- Motorized steering for between-shot positioning.
- Piezoelectric steering for in-shot movement of beam.
- Fast steering and 10 Hz laser repetition rate enables multiple injections into a shot.

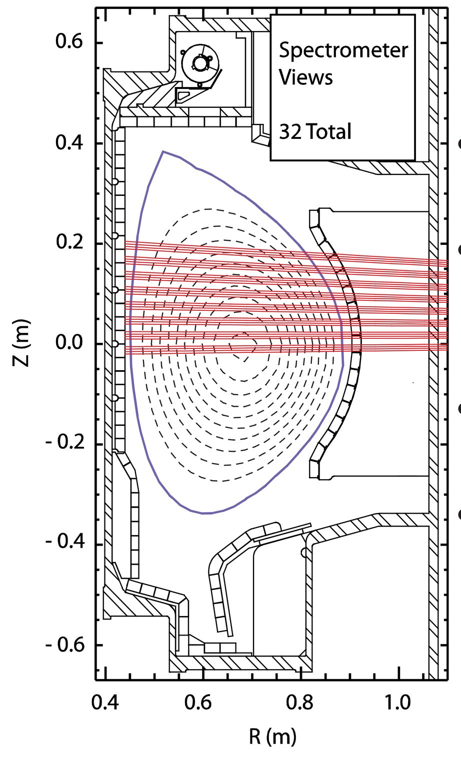
### Impurity transport coefficient profiles have been successfully measured for L-mode plasmas




- Iterated with the STRAHL code [4] to find the profiles of the diffusivity $D$ and convective pinch velocity $V$ that match the observed evolution of the Ca XIX emission profile.
- Comparisons to GYRO have been performed, and have found that the GYRO predictions are within the domain of plausibility defined by the experimental uncertainties [1].
- The objective of the present research is to apply this methodology to a wider range of scenarios in order to better understand impurity transport in a broader range of plasma regimes.

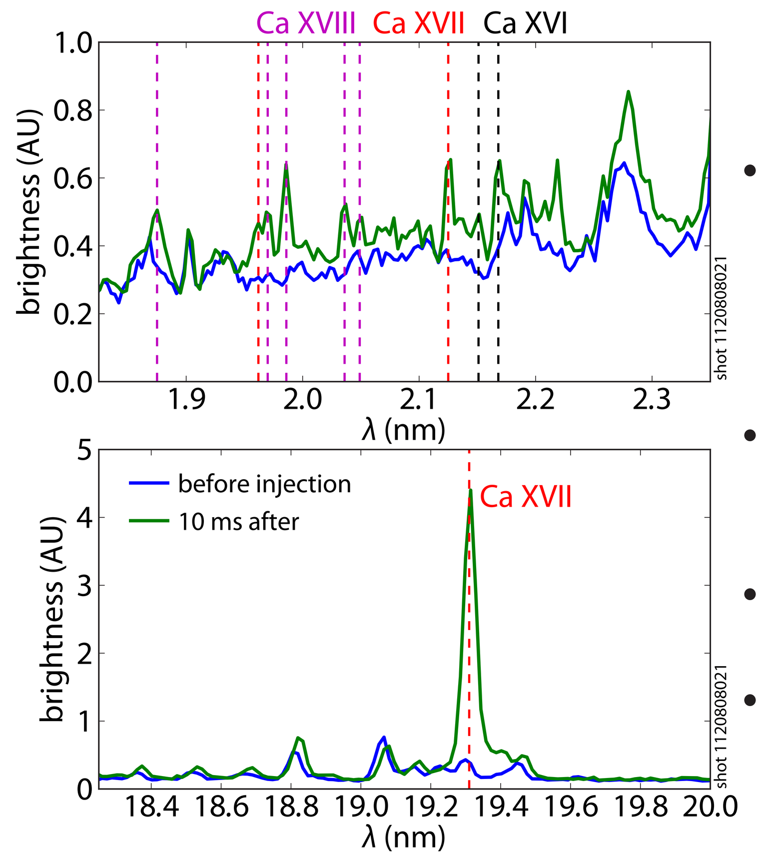
## A variety of diagnostics track the injection

### An x-ray imaging crystal spectrometer observes emission profiles from high charge states



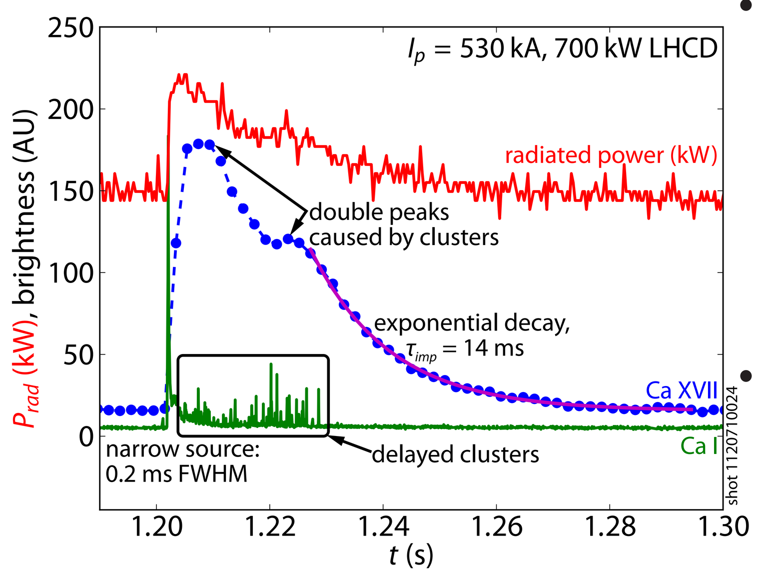

- Calcium is typically injected: non-intrinsic and non-recycling.
- The spectrometer can be configured to view emission from either Ca XIX or Ca XX.
- 32 spatial channels, up to 6 ms time resolution.
- Combining the data from multiple injections at 10 Hz enables an effective time resolution of 2 ms.

### Two VUV grating spectrometers observe line-integrated emission from lower charge states




- Two compact, VLS grating, flat-field spectrometers from LLNL EBIT lab [5, 6].
- 1–6.5 nm and 10–29 nm spectral ranges.
- Line-integrated core view.
- 2 ms frame rate.

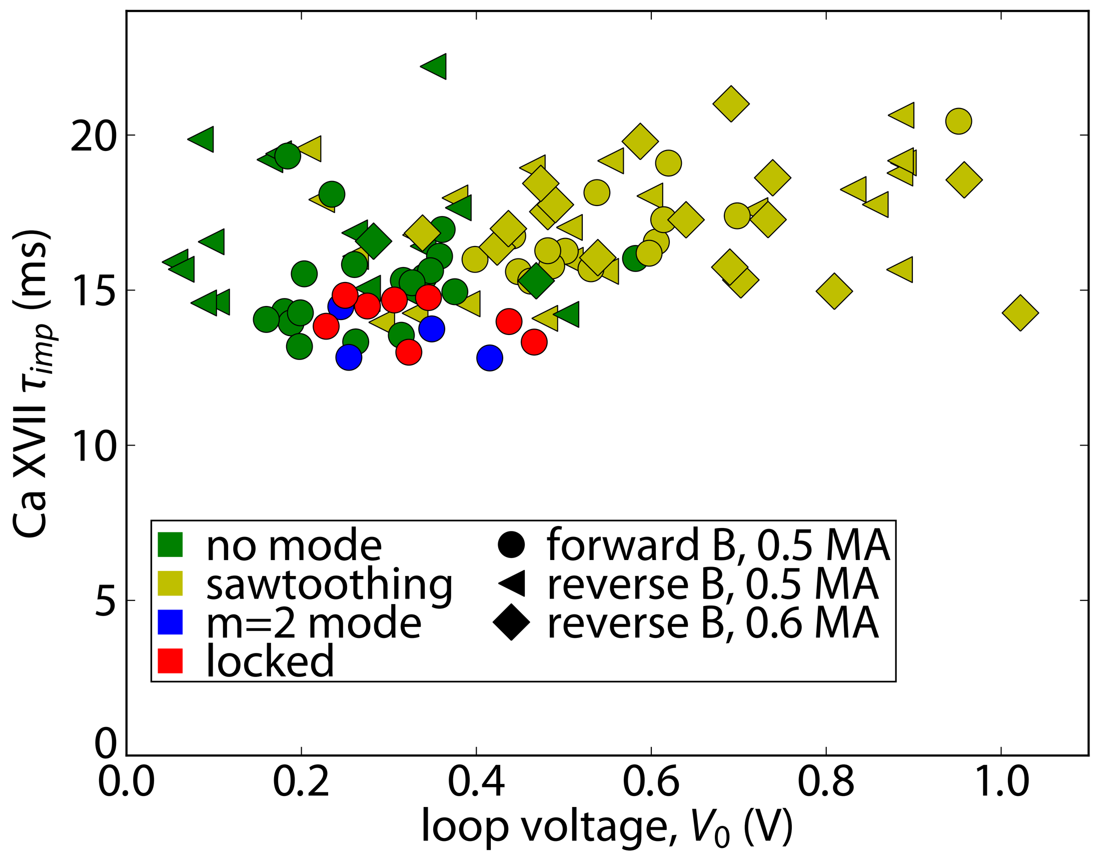
### Additional diagnostics provide further information on the injection




- A variety of soft x-ray diagnostics and bolometers provide information on radiation from all charge states.
- A filtered PMT coaxial with the injector measures the Ca I impurity source.

## Preliminary look at the effect of LHCD shows little change in *global* confinement

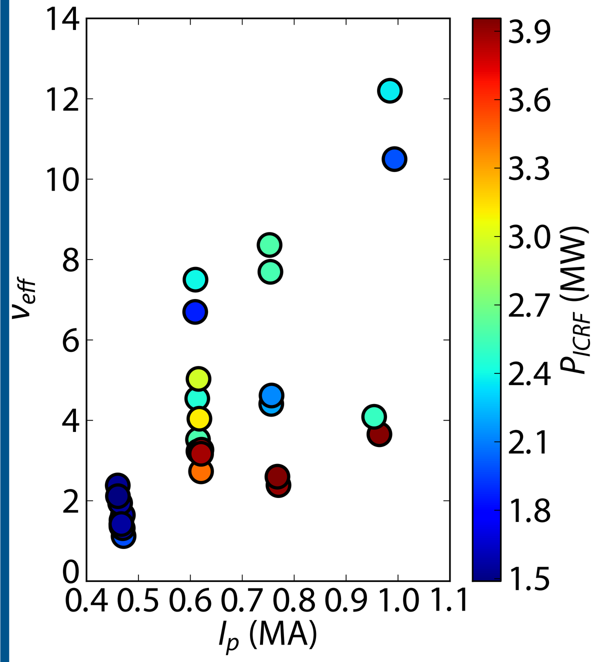
### A scan of LHCD power was used to vary the loop voltage and suppress sawteeth




- 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 XX (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 Ware pinch ($\Gamma_W \propto V_0$) is negligible.
- Further work is required to obtain emissivity and transport coefficient profiles and look for other effects related to the suppression of sawteeth.

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

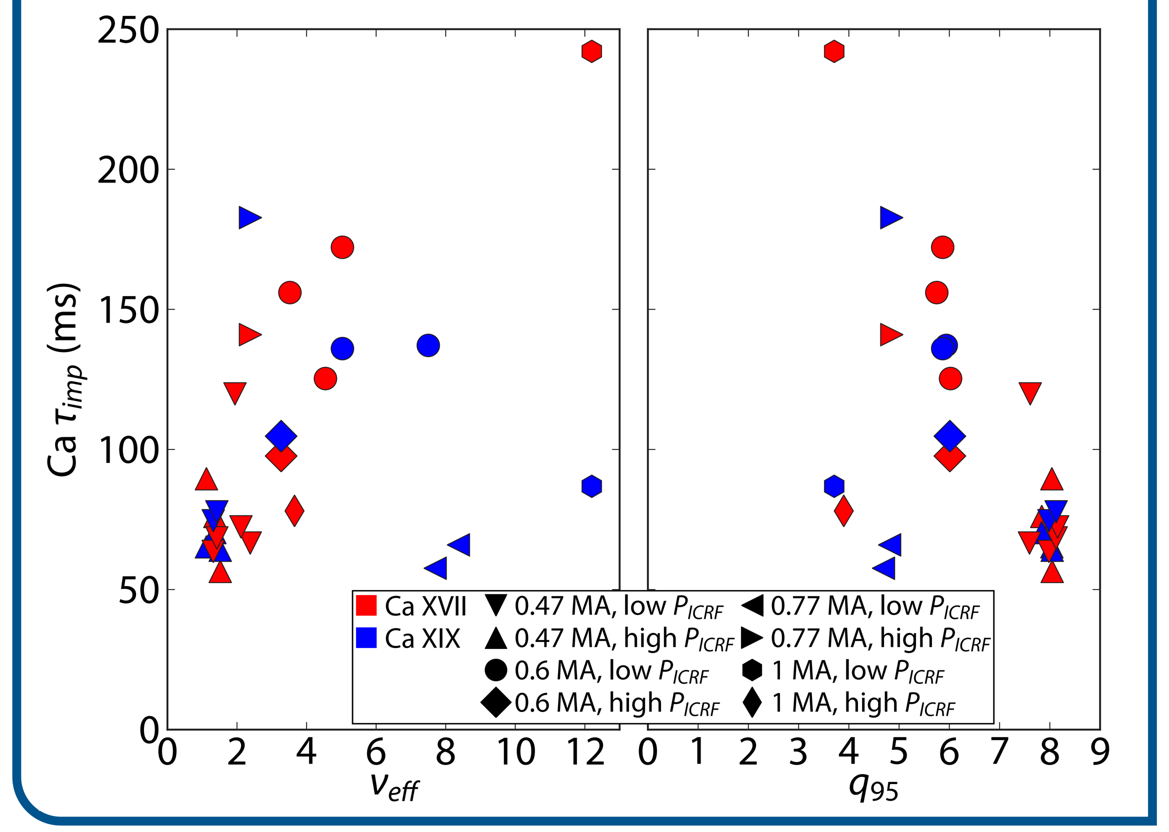
### A current/power scan was used to access a wide range of $\nu_{eff}$




- Density peaking in H-modes has been observed [8] to scale with $\nu_{eff} = 0.1 Z_{eff} \langle n_e \rangle R / \langle T_e \rangle^2$.
- A scan of $I_p$ and $P_{ICRF}$ was used to modulate $\nu_{eff}$.
- Ca was injected into the plasmas in order to look for a connection to the main ion particle transport.

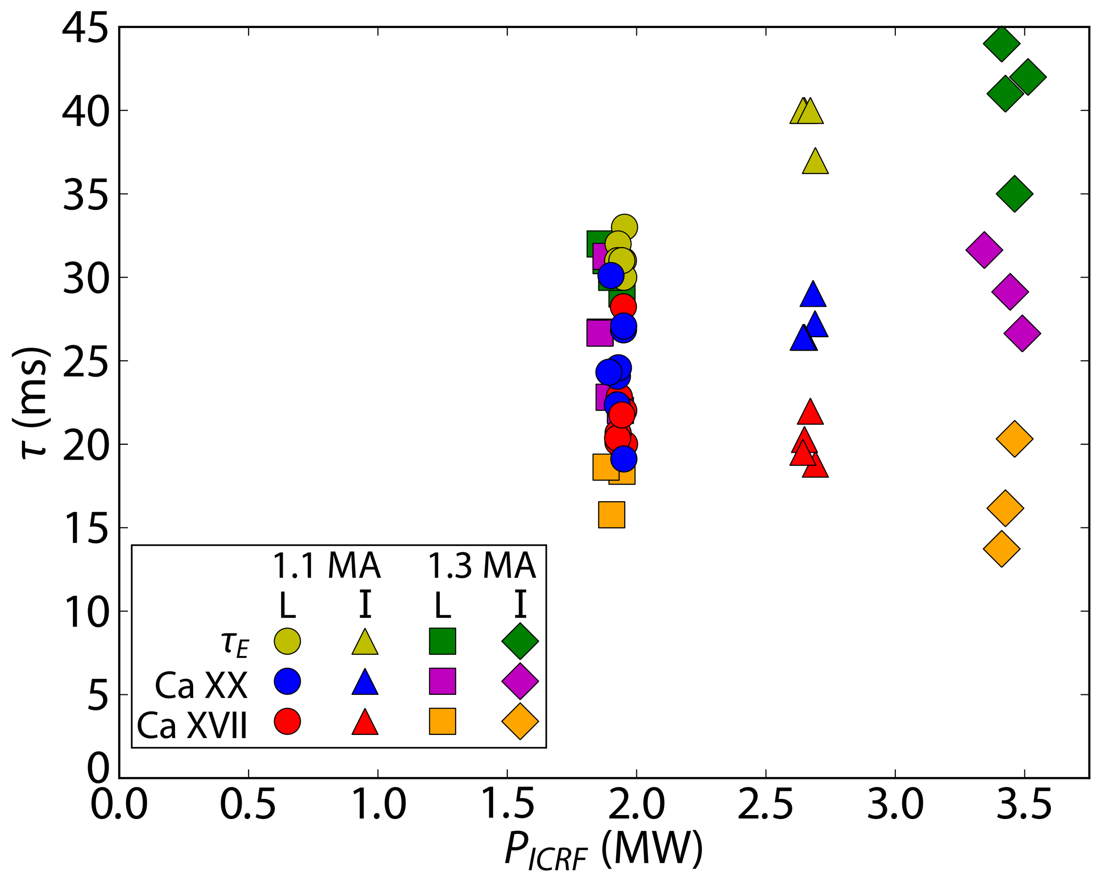
### Initial analysis of global confinement results shows dependencies on $\nu_{eff}$ and $q_{95}$

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




## Global impurity confinement shows little change across the L/I power threshold

### Ca was injected into plasmas just above and just below the L/I power threshold




- The energy confinement time shows a definite increase across the L-I threshold while the impurity confinement time remains roughly the same.
- This is consistent with the fact that I-mode plasmas exhibit H-mode-like energy confinement and L-mode-like particle confinement [9]. See also A. Hubbard et al., JP8.00075.
- At higher ICRF powers, the Ca XX confinement time is higher than the Ca XVII confinement time, consistent with the results in §7.4 of [10].
- Further work is required to extract information on the transport coefficients and plasma fluctuations in order to identify what detailed differences in impurity transport there may be between L- and I-mode.

## 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 $\nu_{eff}$.
  - Investigate relationship between changes in the impurity transport and peaking of the main ion density.
- Detailed analysis of I-mode scan: Investigate changes in fluctuations and transport coefficient profiles across the L-I threshold.

## References

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