Progress on kinetic modeling of lithium transport with MCI

T. E. Evans and R. Deranian
General Atomics

Presented at the:
Plasma Facing Components (PFC) Meeting
PPPL, Princeton, NJ

May 9–11, 2005

DIII-D
NATIONAL FUSION FACILITY

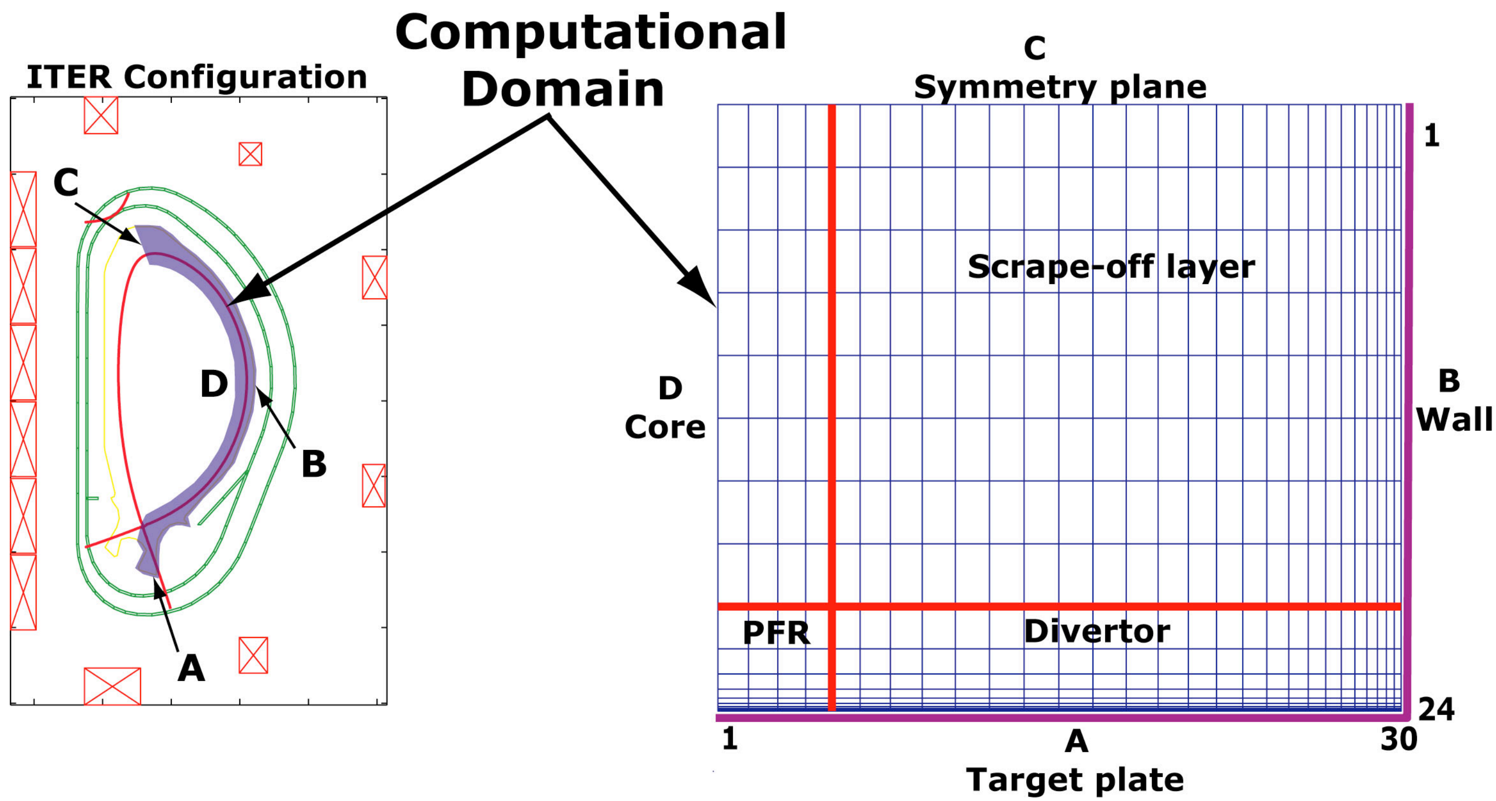
GENERAL ATOMICS

MCI is being modified for kinetic impurity transport studies in the SOL and divertor of ITER

- **Goal → integrate a structured 2D grid representation of the ITER pedestal, SOL and divertor plasma into the Monte Carlo Impurity (MCI) code:**
  - Simulate kinetic transport properties associated with impurity ionization/recombination, thermalization, transport and radiation
  - Compare kinetic simulations with analytic models
  - Study the sensitivity of kinetic simulations to changes in plasma parameters and atomic data
- **The results will be used to validate fundamental impurity transport models in low collisionality ITER relevant plasmas**

GENERAL ATOMICS

A new 2D grid generator is being implemented in MCI for ITER simulations

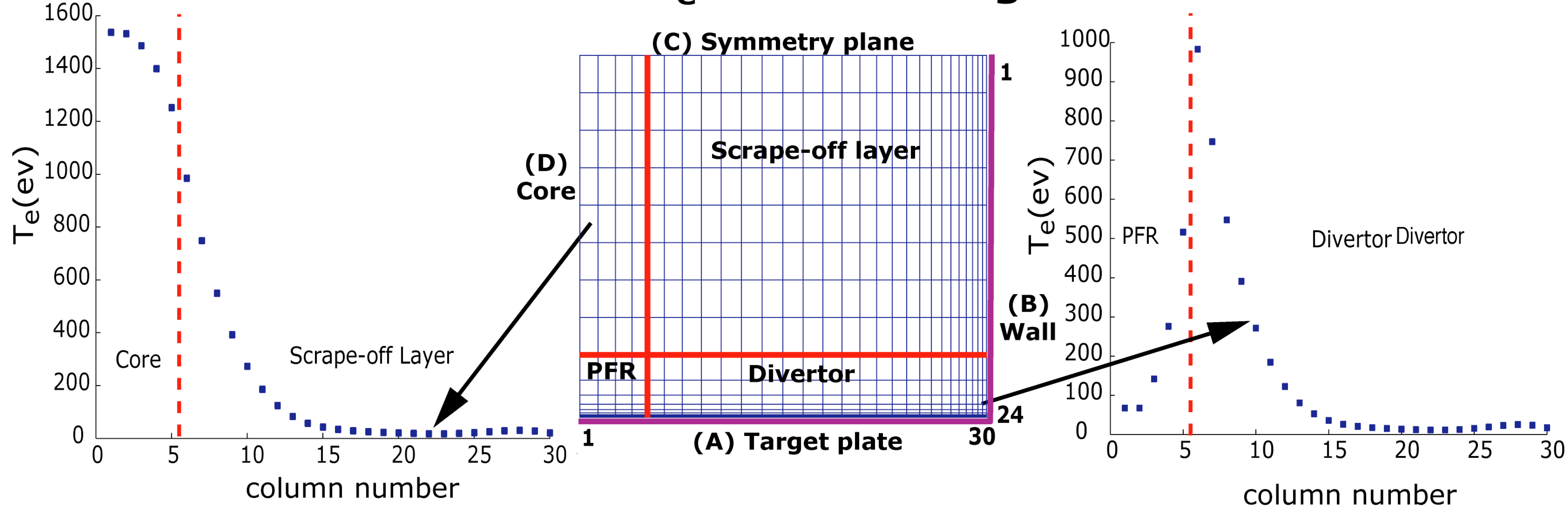


- **Thermal impurity neutrals such as Li, Be will be launched from the wall (B) and ionized/transported through the SOL, divertor and private flux region (PFR) to the target plate (A), symmetry plane (c) and core (D)**
  - Particles are reflected at C and D (flux conservation) but stick at A (sink)

GENERAL ATOMICS

Background plasma parameters from UEDGE are loaded into the 2D MCI grid

UEDGE T_e data on MCI grid

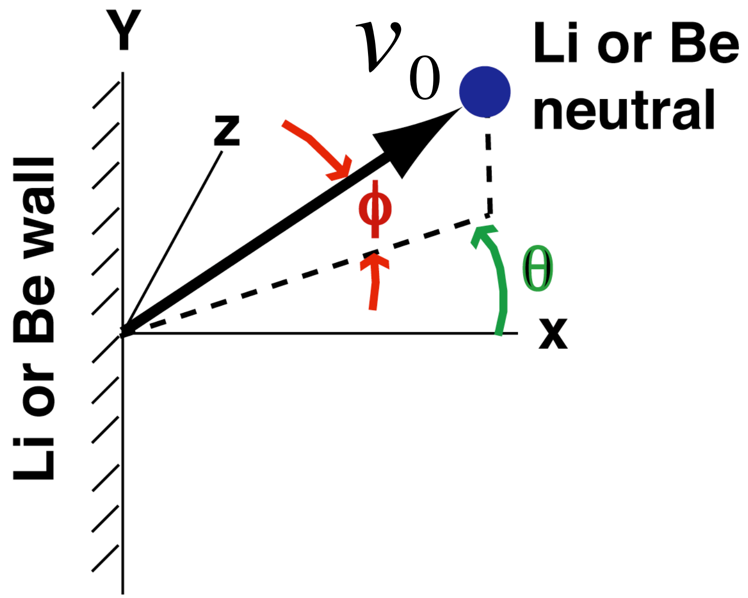


- **Background plasma parameters e.*g*. T_e, T_i, n_e, n_i, and $v_{||}$ calculated with a fluid code (*i.e.* UEDGE) are loaded into the MCI grid**
- **These parameters are used to calculate grid specific atomic data such as ionization and recombination rate coefficients and to carry out kinetic impurity (Li, Be, *etc*.) transport simulations**

Impurity neutrals are launched along the wall with a thermal Maxwellian velocity distribution

- **Impurity neutrals enter the plasma with 3D ballistic trajectories**
  - cosine distribution in ϕ and θ
  - ionization mean free path ($\lambda_{ionization}$) is determined by the initial launch trajectory, velocity (V_0) and local plasma parameters (n_e and $T_e \rightarrow$ ionization rate coefficient)

$$\lambda_{ionization} = v_0 / n_e \overline{\sigma v(T_e)}$$



GENERAL ATOMICS

Impurity ion transport and thermalization is calculated using three characteristic frequencies

$$ds = s_{i+1} - s_i = v_{\parallel,i}\Delta t + C_i\left(\Delta t\right)^2/2 \pm \sqrt{2D_{\parallel,i}\Delta t}$$

$$dv_\parallel = v_{\parallel,i+1} - v_{\parallel,i} = C_i\Delta t$$

$$D_{\parallel,i} = 1.22\times 10^8\left(T_{imp,i}/m_{imp}\upsilon_\parallel\right)$$

$$T_{imp,i+1} = T_{imp,i} + \left(T_{b,i} - T_{imp,i}\right)\Delta t\,\upsilon_{SE}$$

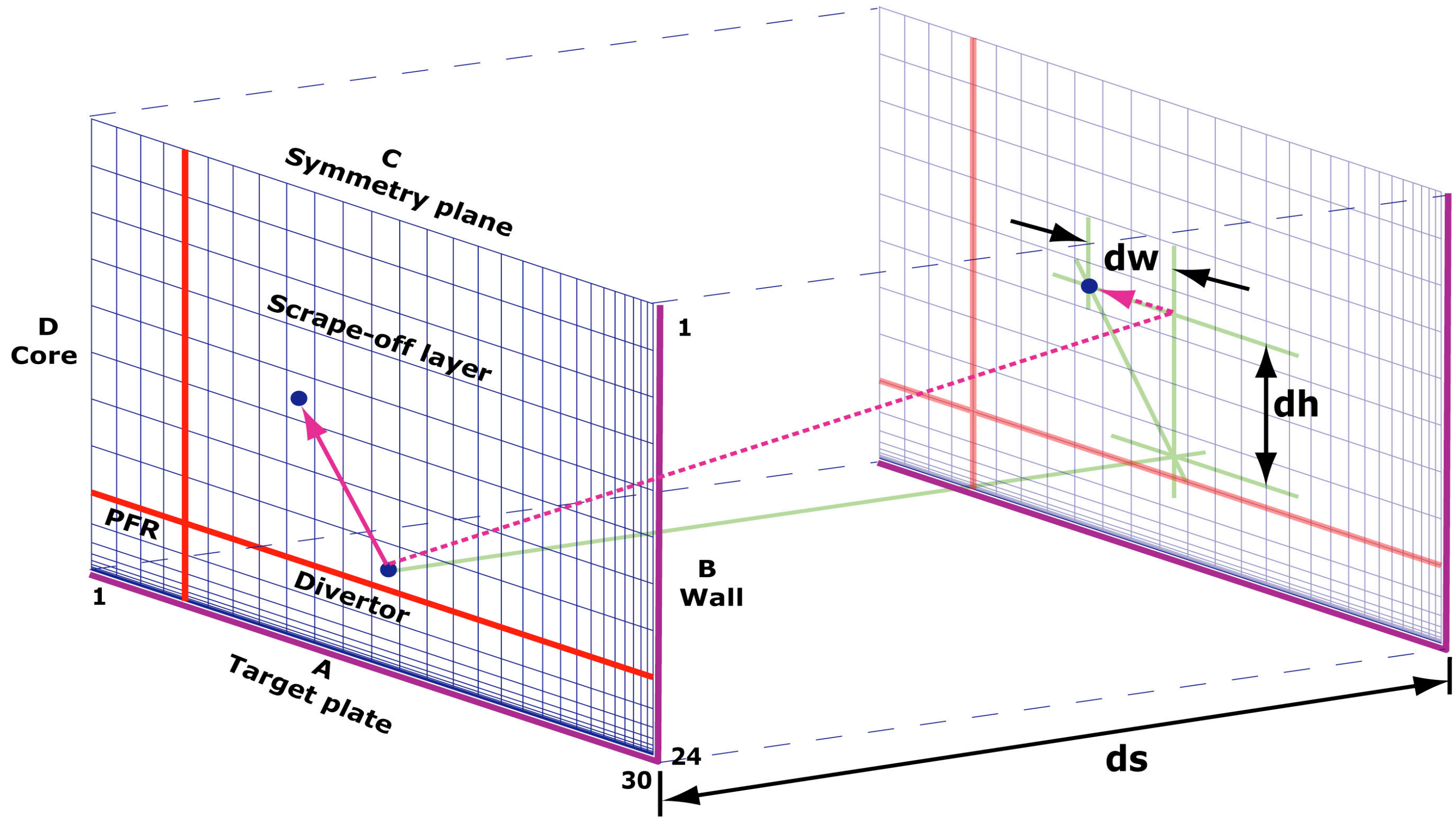
Where:

$$C_i = \frac{eEZ_{imp}}{m_{imp}} + \left(v_{b,i} - v_{\parallel,i}\right)\upsilon_{sl} + \frac{1}{m_{imp}}\left[0.71Z_{imp}^2\frac{dT_e}{ds} + \beta_{imp}\frac{dT_b}{ds}\right]$$

$$\beta_{imp} = \frac{3\left[\mu_m + 7.07Z_{imp}^2\left(1.1\mu_m^{5/2} - 0.35\mu_m^{3/2}\right) - 1\right]}{5.4\mu_m^2 - 2\mu_m + 2.6};\mu_m = \frac{m_{imp}}{m_b + m_{imp}}$$

$$\upsilon_\parallel = \frac{6.8\times 10^4 n_b Z_b^2 Z_{imp}^2 \ln\Lambda}{m_{imp}T_{imp}\left(T_b/m_b\right)^{1/2}} \quad \upsilon_{sl} = \frac{6.8\times 10^4\left(1 + m_b/m_{imp}\right)n_b Z_b^2 Z_{imp}^2 \ln\Lambda}{m_{imp}T_{imp}\left(T_b/m_b\right)^{1/2}} \quad \upsilon_{SE} = \frac{1.4\times 10^5 n_b Z_b^2 Z_{imp}^2 \ln\Lambda}{m_{imp}T_b\left(T_b/m_b\right)^{1/2}}$$

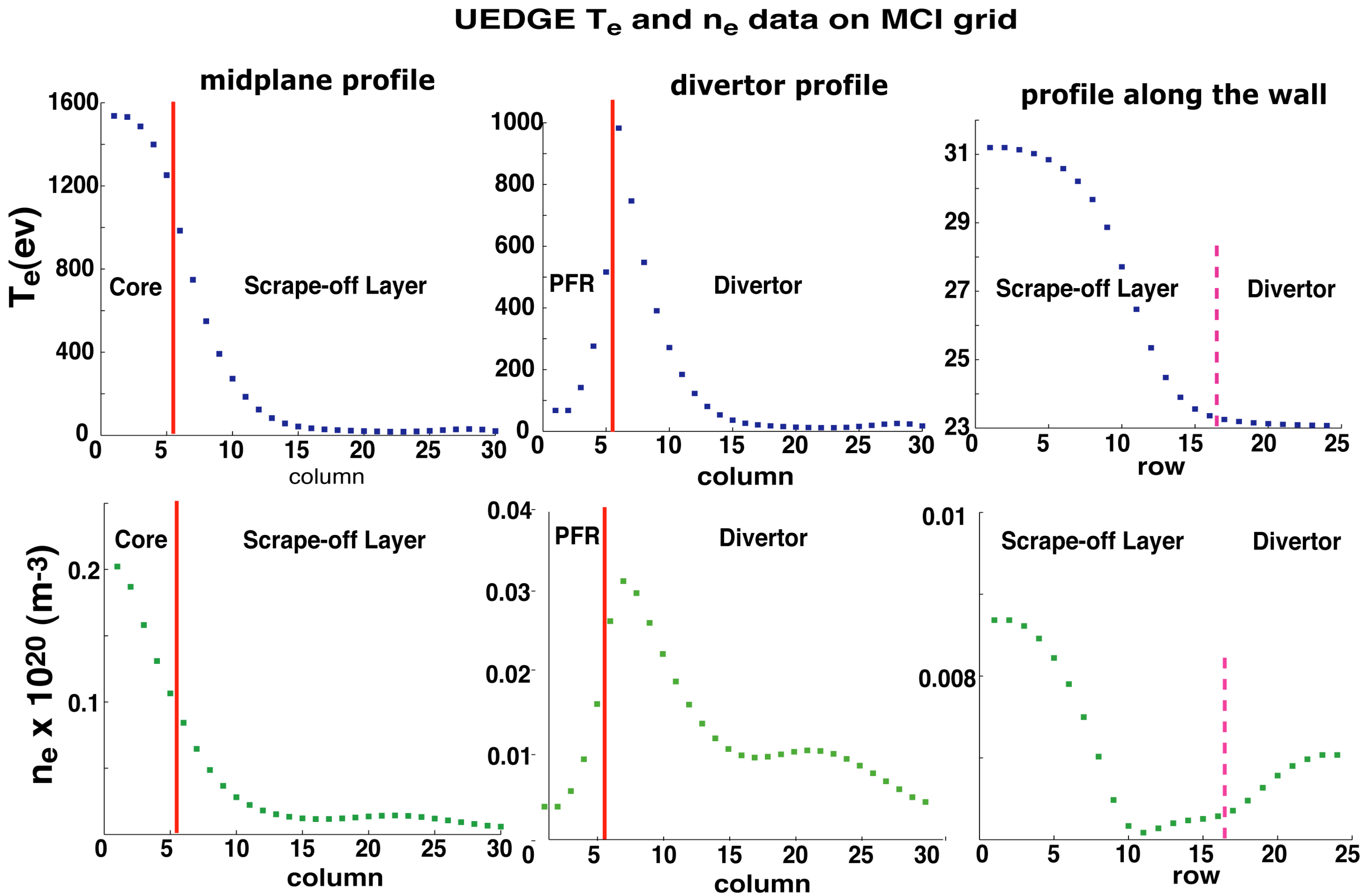
Magnetic data is used to calculate the position of the impurity ions after each transport step



- **MCI typically gets magnetic data from an EFIT equilibrium file but for ITER simulations the magnetic data will be imported from UEDGE**
  - subroutines to replace EFIT data with UEDGE data and calculate dh and dw are needed

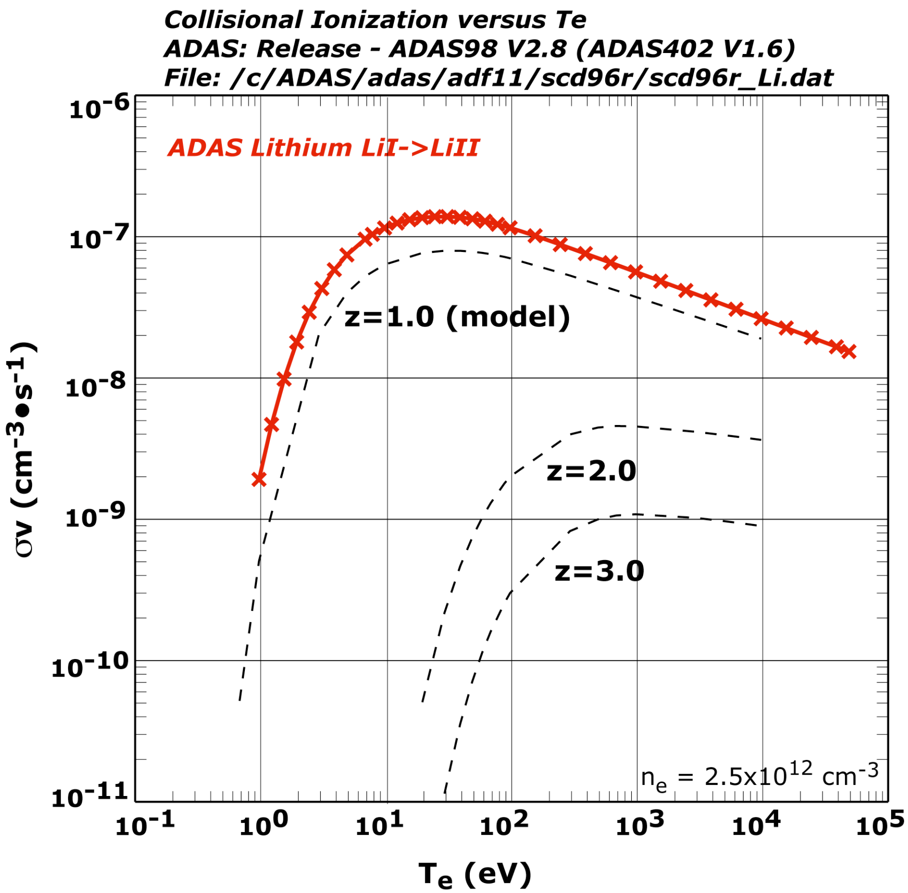
GENERAL ATOMICS

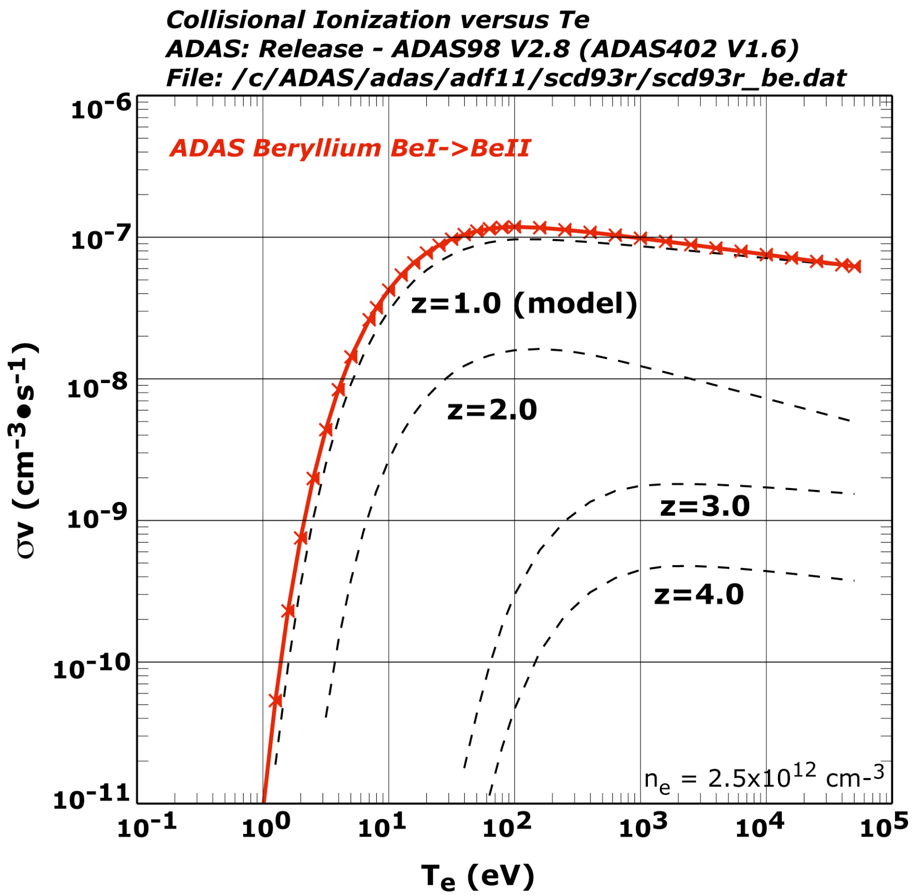
Background plasma parameters are used to calculate impurity ionization, thermalization and transport processes



GENERAL ATOMICS

Atomic data from ADAS is directly integrated into MCI and updated frequently with each new ADAS release



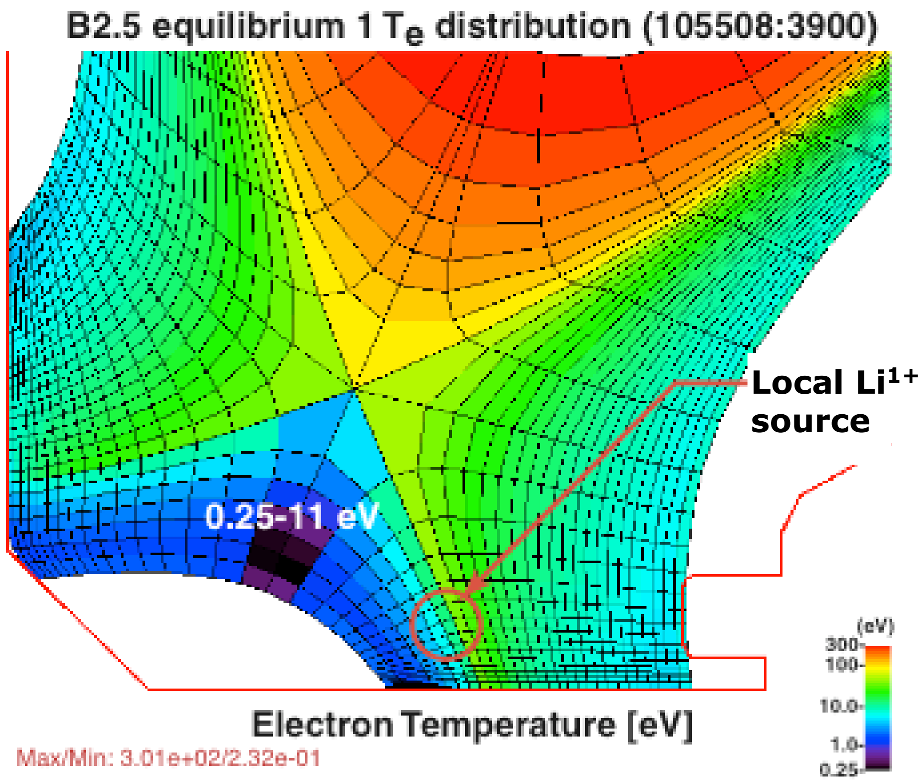


- Recent improvements in the accuracy of the ADAS Li ionization data have resulted from better fundamental data and the ADAS GCR modeling project

GENERAL ATOMICS

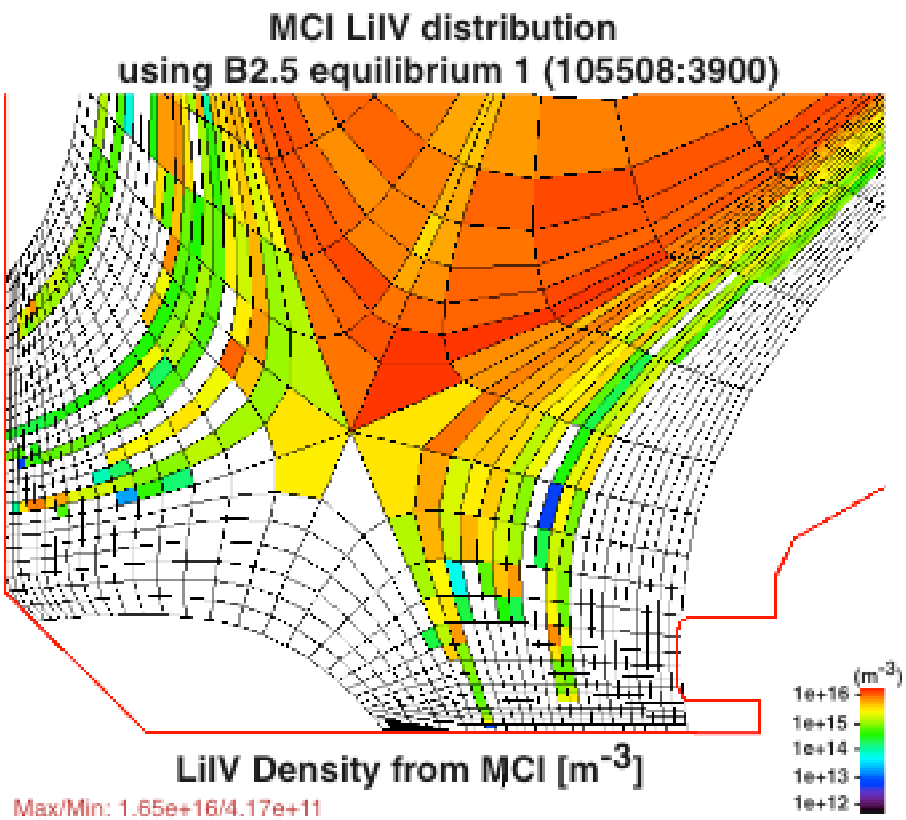
MCI Li transport modeling in DIII-D plasmas provides us with a good set of benchmarks for the ITER simulations

- **Localized Li sputtering from the DIII-D DiMES probe and its transport into the core have been simulated using the MCI unstructured grid and B2.5 plasmas.**
- **Li simulations compared to DIII-D experimental data in order to validate MCI's transport physics models and assess sensitivities to:**
  - Boundary conditions
  - Variations in background plasma solutions
  - Atomic data

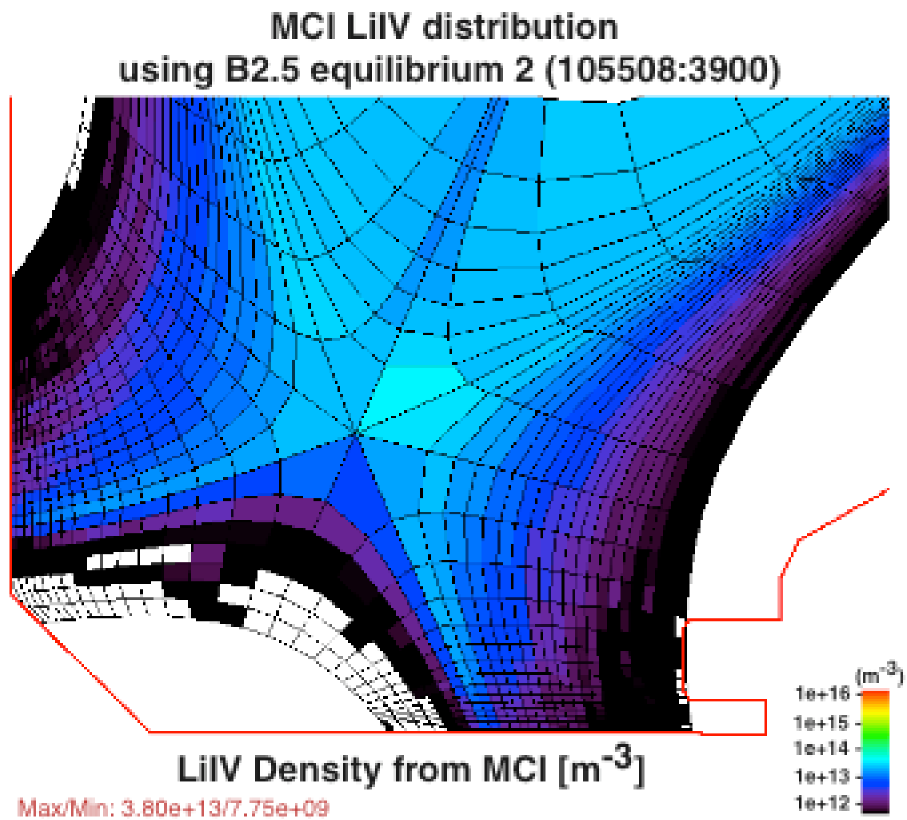


GENERAL ATOMICS

The Li core concentration calculated with MCI is quite sensitive to small changes in divertor recycling



$R_{div\text{-}in}$=0.925 & $R_{div\text{-}out}$ = 0.99
Core Li concentration ~ 0.1%



$R_{div\text{-}in}$= $R_{div\text{-}out}$ =1.0
Core Li concentration ~ 0.0002%

- **A reduction in divertor recycling (a B2.5 free parameter) changes Te near the target and the core Li concentration.**

GENERAL ATOMICS

Tasks and status

- **Changes in the MCI code needed to simulate impurity transport in the ITER pedestal, SOL and divertor plasmas are underway:**
  - Structured 2D grid (completed)
  - Read background plasma and magnetic data from UEDGE file (completed)
  - State-of-the-art Li atomic data (completed)
  - Calculate vertical and horizontal magnetic step size for each parallel diffusion step using cell specific collision frequencies (in progress)
- **Simulate Li and Be thermalization/transport low collisionality ITER plasmas and compare to MCI Li transport results in DIII-D (as well as to the DIII-D Li DiMES experimental data)**
  - Preliminary Li transport modeling and experiments in DIII-D (completed)
  - Future DIII-D Li transport experiments/modeling are being proposed to simulate Be transport in ITER (JET)
    - Li^{1+} ionization data is very similar to Be^{1+} above 30 eV