Light Impurity Transport at an Internal Transport Barrier in Alcator C-Mod

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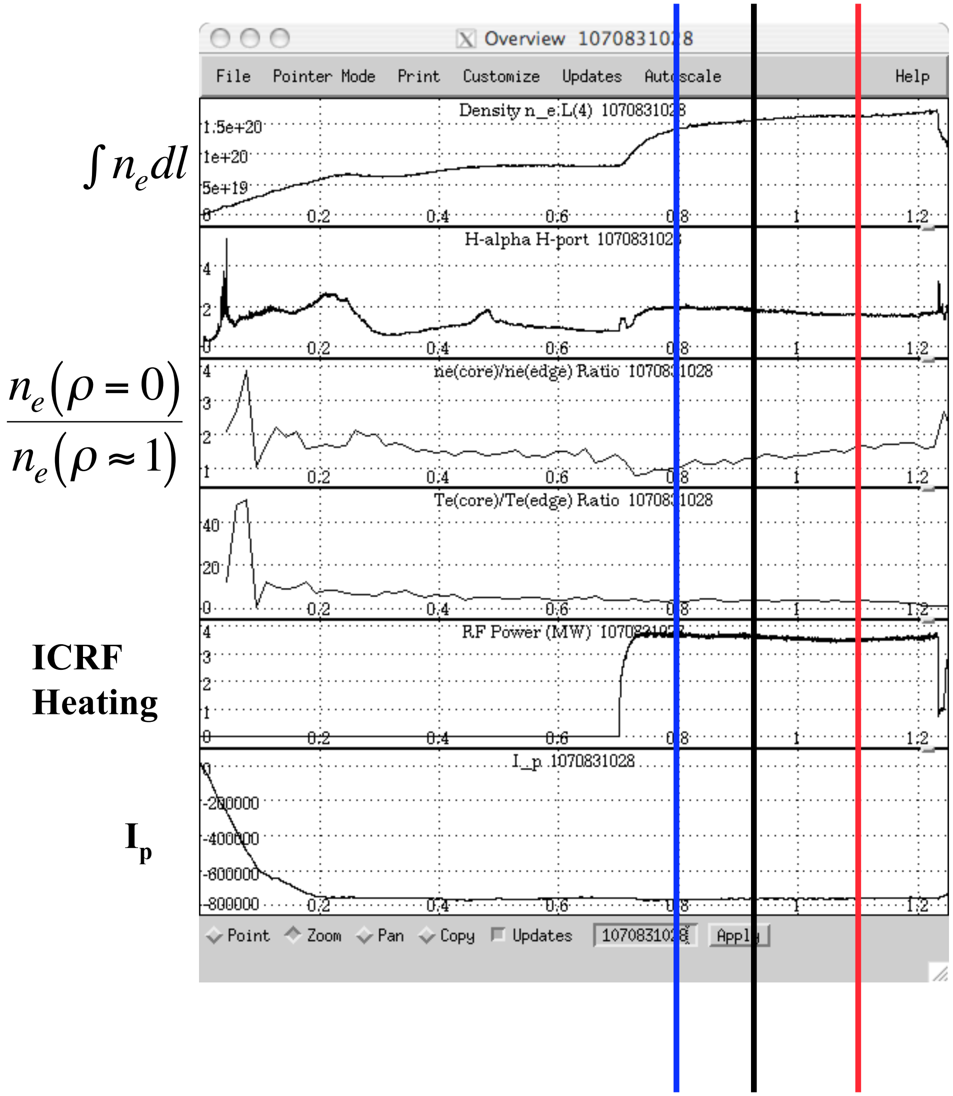
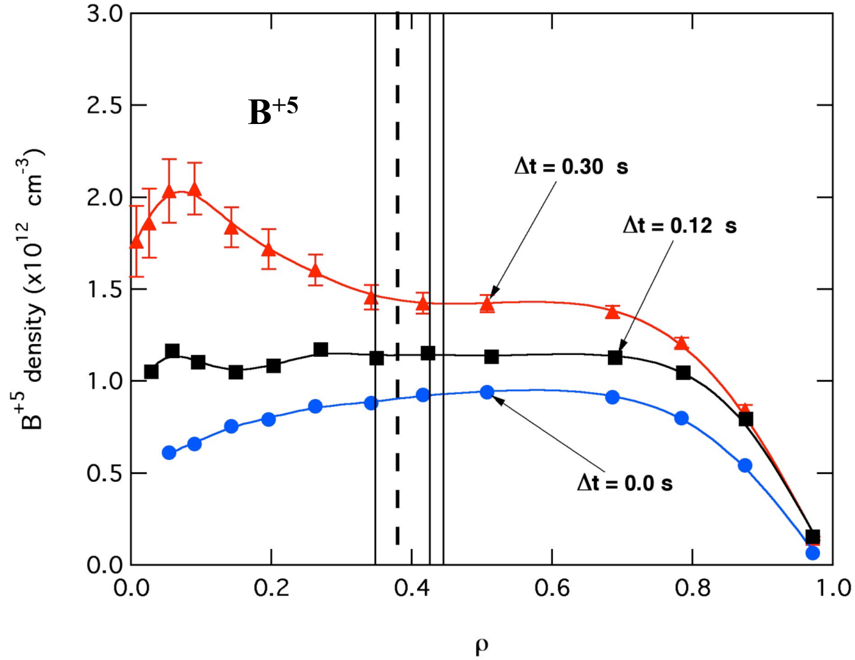
Light Impurity Transport at an Internal Transport Barrier in Alcator C-Mod

- Internal transport barriers have peaked main-ion profiles and higher core reactivity
- Peaked impurity profiles increase radiation lesses and dilute the fuel
- All profiles for C-Mod are measured except for light impurities and we know that there are sometimes differences between light and heavy impurities
- This data will complete the particle profiles set for C-Mod
- Outline
  - Light impurity profiles compared to plasma profiles
  - Transport
    - Profile analysis
    - Numerical simulation
  - Neoclassical comparison
  - Conclusions and future work

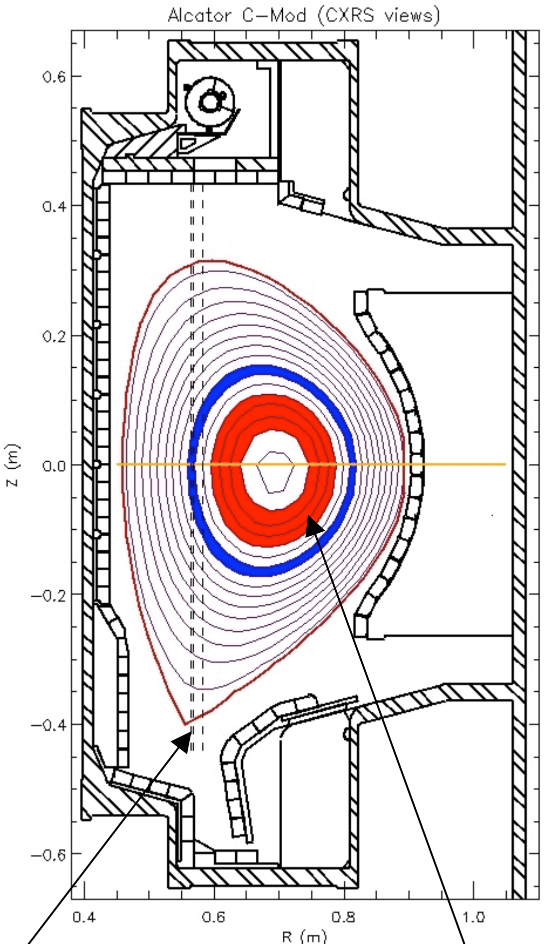
Boron Profiles Steepen During ITB

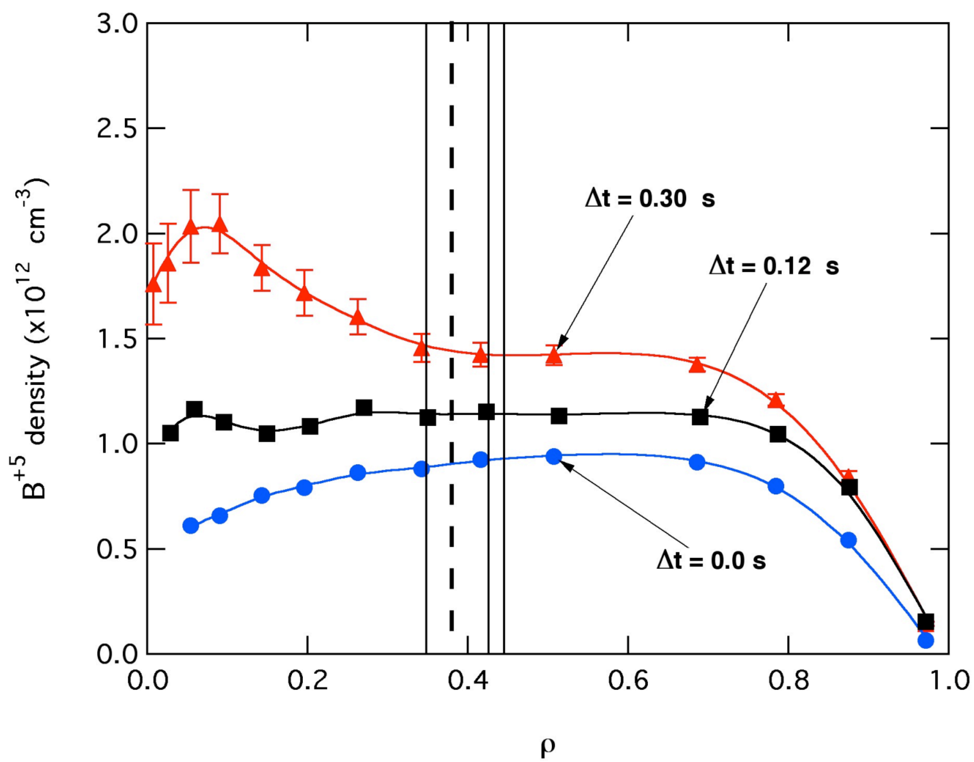




- B^{+5} = total boron density, $\rho < 0.8$
  B^{+4} IP =340 eV
- Boron profile steepens in the ITB
- Hollow profiles: future research

Plasma Shape, Heating Location, and ITB Location



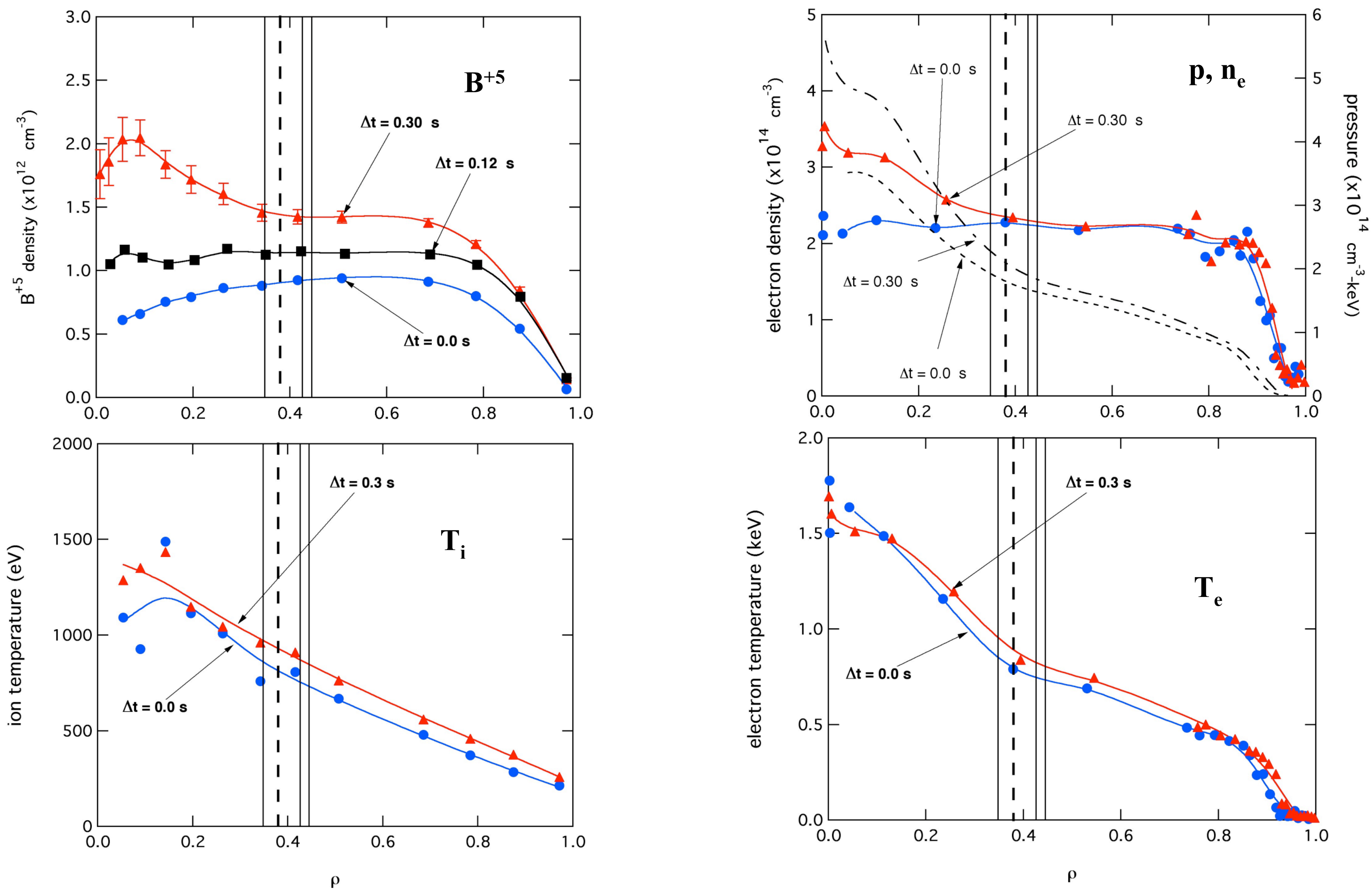


RF resonances

ITB region

Grad B drift is in the favorable direction

Comparison to Other Plasma Profiles



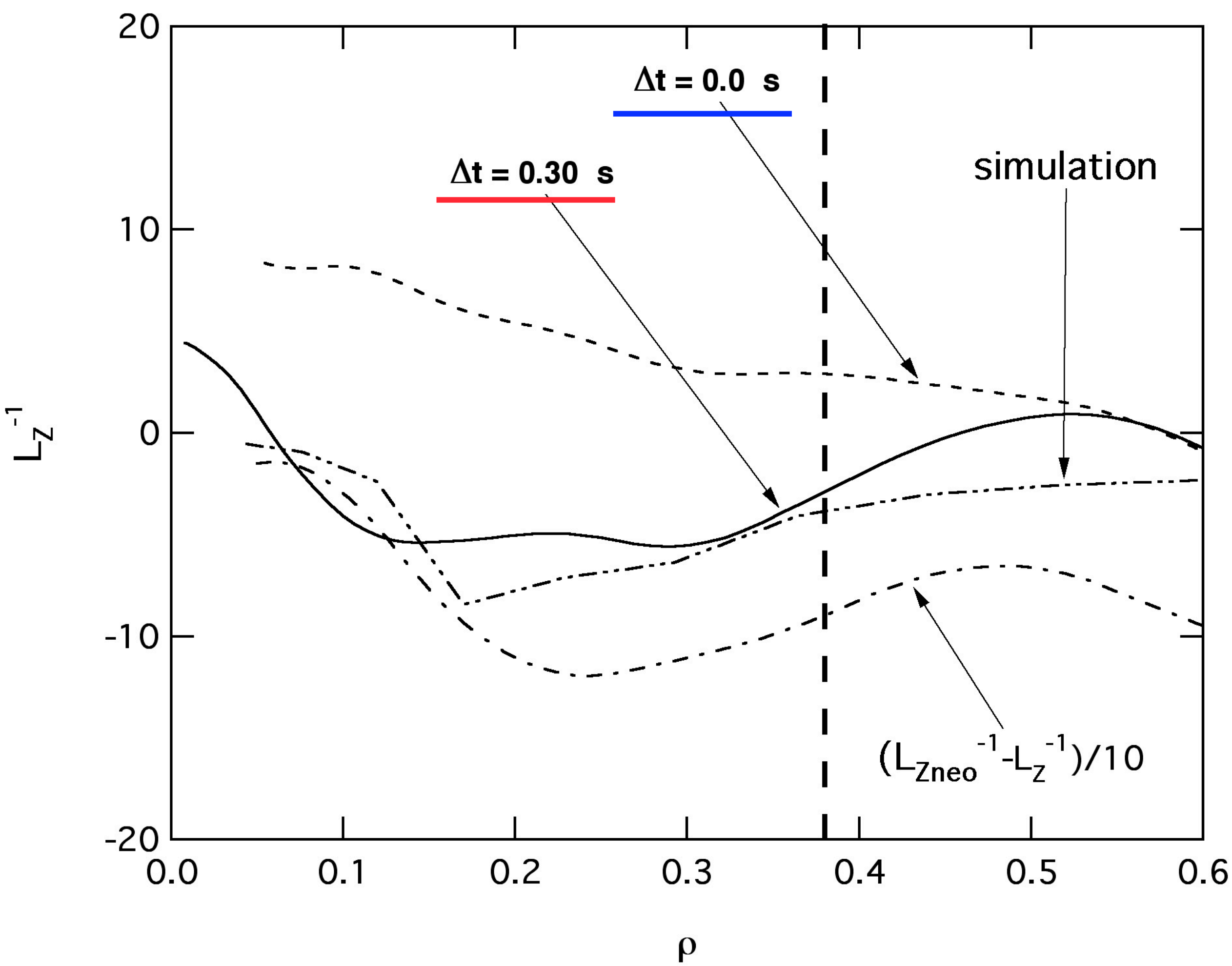
Impurity Transport
Profile Analysis

$$\frac{\partial n_j^z}{\partial t} + \nabla \bullet \Gamma_j^z = S_j^z$$

$$\Gamma_j^z = -D\frac{\partial n_j^z}{\partial t} + v n_j^z$$

$$\frac{\partial n_j^z}{\partial t} = 0$$

$$\left(L_z\right)^{-1} = \frac{1}{n_j^z}\frac{\partial n_j^z}{\partial r} = \frac{v}{D}$$



Simulation of Impurity Transport

Review

$$\frac{\partial n_j^z}{\partial t} + \nabla \bullet \Gamma_j^z = S_j^z$$

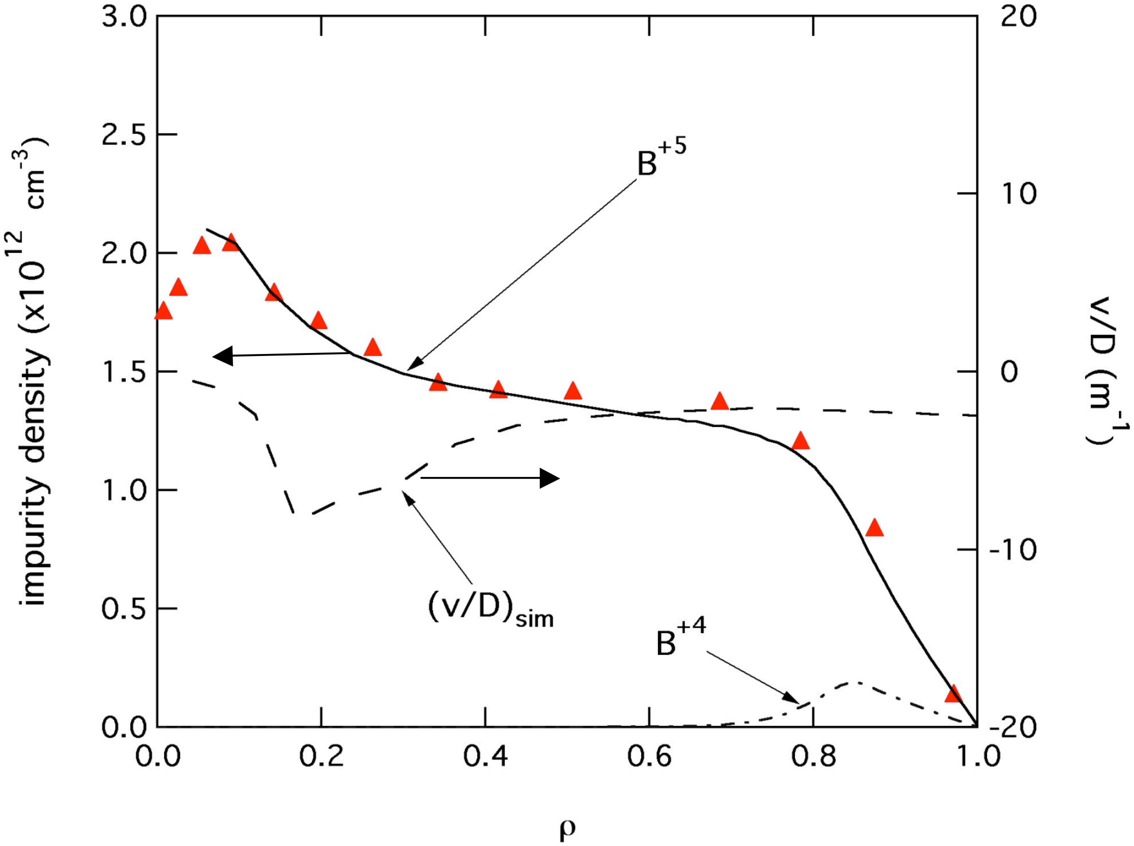
fixed background
$n_e(r,t)$, $n_i(r,t)$, $T_e(r,t)$, $T_i(r,t)$

$$\Gamma = -D\frac{\partial n_z}{\partial r} + n_z v$$

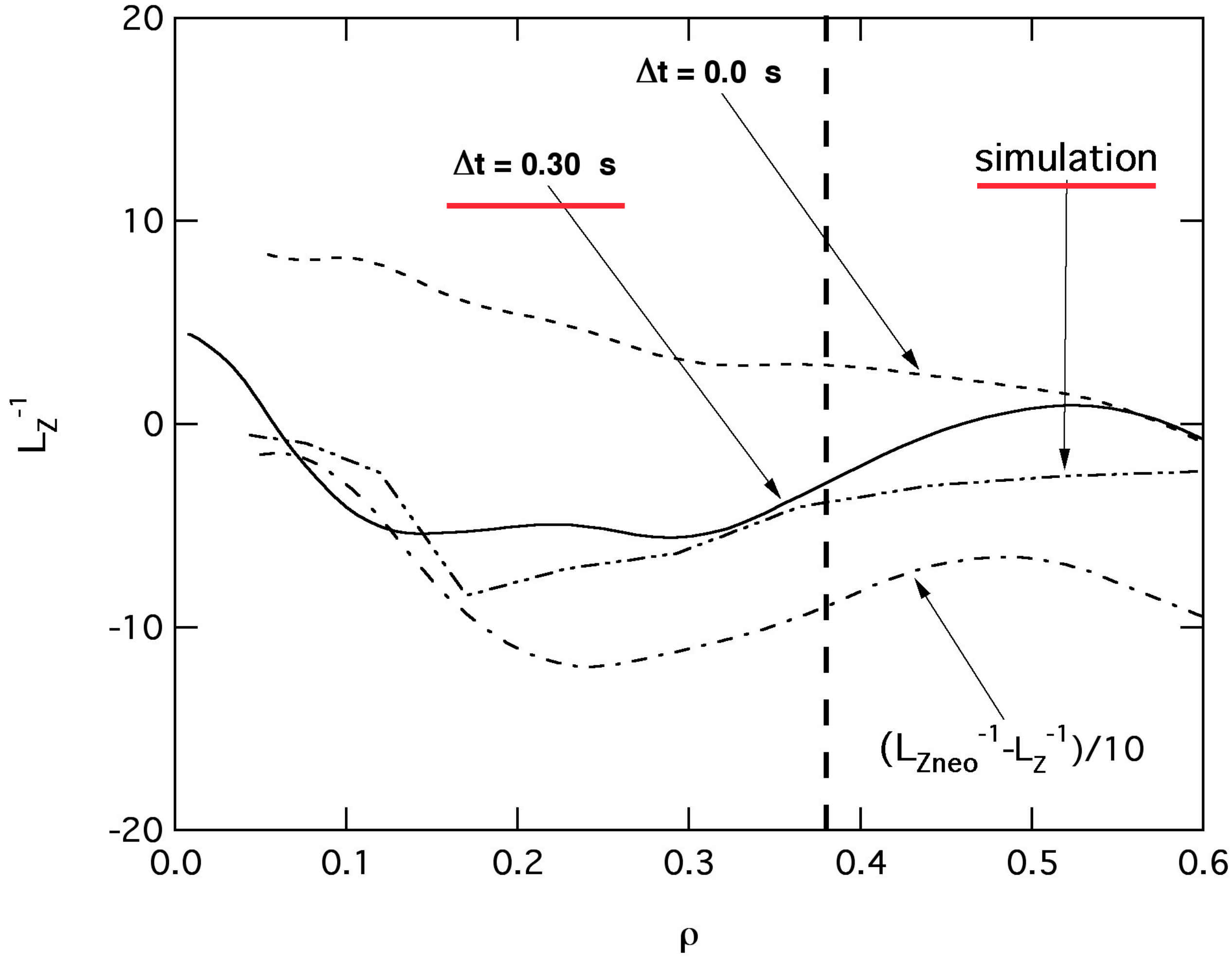
$$S_j^z = -I_j^z n_j^z n_e + I_{j-1}^z n_{j-1}^z n_e + \alpha_{j+1}^z n_{j+1}^z n_e - \alpha_j^z n_j^z n_e + S_B^z$$

$$A_{ionization\ stage}^{impurity\ species}$$

Results



Impurity Transport Simulation



Prediction for Impurity Transport

$$\Gamma_z = \Gamma_{Anom} + \Gamma_{coll}$$

- **Γ_{coll}, neoclassical transport**
  collisions of particles in a toroidal magnetic field
- **Γ_{anom}, turbulent transport**
  convection of density fluctuations by fluctuating E×B drift velocity
- **For neoclassical transport and for turbulent transport within quasilinear theory**

$$\Gamma_z = -D\frac{\partial n_z}{\partial r} + v_z n_z$$

$$v_z = v_{Anom} + v_{coll}$$

$$D_z = D_{Anom} + D_{coll}$$

Neoclassical Predictions for v/D

benchmark confinement

$$\left(\frac{v_{neo}}{D_{neo}}\right) = \frac{Z_I}{Z_D}\left(\frac{1}{n_D}\frac{dn_D}{dr} + K\frac{1}{T_D}\frac{dT_D}{dr}\right)$$

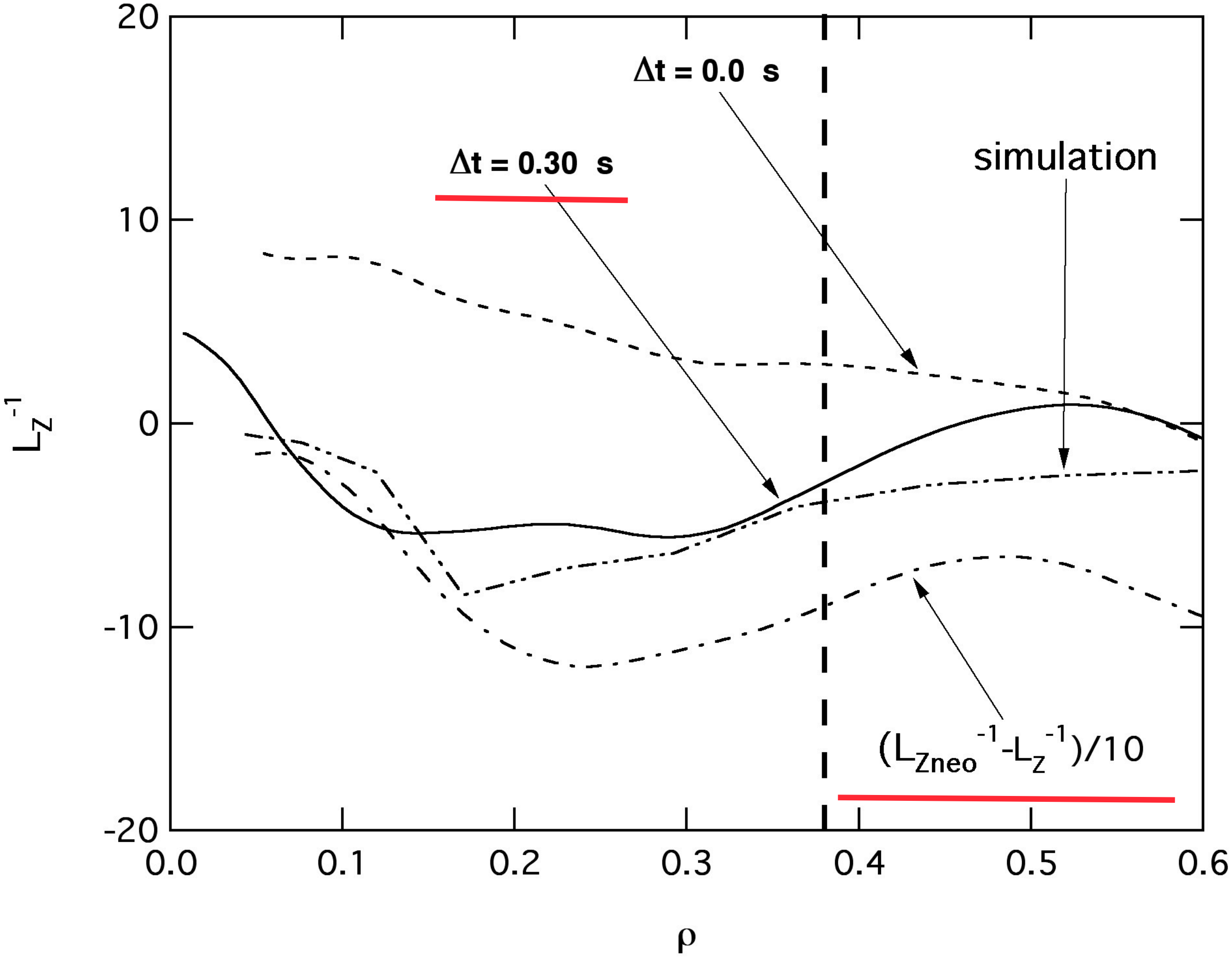
$\varepsilon^{-\frac{3}{2}} < \nu_*$ Pfirsch-Schulter K = -0.5; Ar, Mo

$1 < \nu_* < \varepsilon^{-\frac{3}{2}}$ banana-plateau K = 1.5; B

$\left(\frac{v_{neo}}{D_{neo}}\right) < 0$ pinch

$\left(\frac{v_{neo}}{D_{neo}}\right) > 0$ screening -- or small

Impurity Transport
Neoclassical Comparison



$$\left(\frac{v_{neo}}{D_{neo}}\right) = \left(L_{Zneo}\right)^{-1}$$

More Predictions for v/D

$$\Gamma_z = -D\frac{\partial n_z}{\partial r} + v_z n_z$$

examples of turbulent v/D

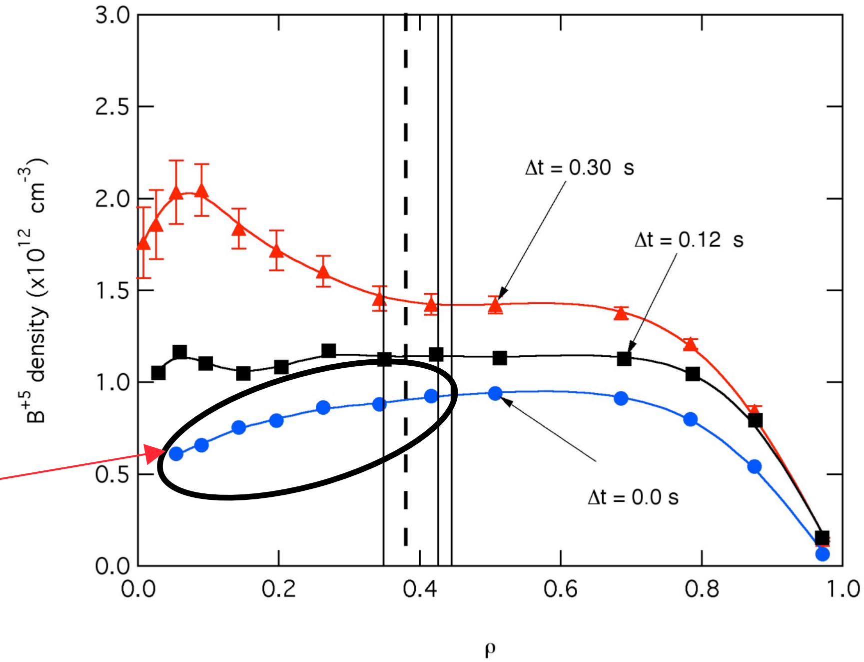
pinch name	dependence	direction	charge dependence	mass dependence	refs
curvature	$\propto \frac{1}{q}\frac{\partial q}{\partial r}$	$\frac{\partial q}{\partial r} > 0$ $\Rightarrow$**inward**	$\neq f(Z)$	$\neq f(A)$	**1,2,3,4,5**
thermodiffusion	$\propto \frac{1}{T}\frac{\partial T}{\partial r}$	**TEM⇒inward** **ITG⇒outward**	$\frac{1}{Z}$	$\neq f(A)$	**1,3,2,6**
parallel compression		**TEM⇒outward** **ITG⇒inward**	$\frac{Z}{A}$	$\frac{Z}{A}$	**1,2,3**

1 Guirlet, R., et al., 2006 PlasmaPhys. Control. Fusion 48 B63
2 Dubuit, N., et al., 2007 Phys. Plasmas 14 042301
3 Angioni C and Peeters A G 2006 Phys. Rev. Lett. 96 095003
4 Isichenko M B et al 1995 Phys. Rev. Lett. 74 4436
5 Baker D R and Rosenbluth M N 1998 Phys. Plasmas 5 2936
6 Coppi B and Spright C 1978 Phys. Rev. Lett. 41 551

Next Step: Hollow Profiles?

pinch name	dependence	direction	charge dependence	mass dependence
curvature	$\propto \frac{1}{q}\frac{\partial q}{\partial r}$	$\frac{\partial q}{\partial r} > 0 \Rightarrow$ inward	$\neq f(Z)$	$\neq f(A)$
thermodiffusion	$\propto \frac{1}{T}\frac{\partial T}{\partial r}$	TEM⇒inward ITG⇒outward	$\frac{1}{Z}$	$\neq f(A)$
compression		TEM⇒outward ITG⇒inward	$\frac{Z}{A}$	$\frac{Z}{A}$

$$\Gamma_z = -D\frac{\partial n_z}{\partial r} + v_z n_z$$



Conclusions

- In the region of an ITB in Alcator C-Mod, boron peaks. The hollow or flat profile observed in L-mode and early H-mode evolves to one in which the local boron density exceeds that in the plasma region outside the ITB.
- Boron accumulates in the ITB region. This follows from the comparison of main ion and impurity gradient.
- Inward convection increases relative to the diffusion.
- Comparisons with neoclassical transport indicate that anomalous transport is reduced in the ITB, but for these discharges, neoclassical transport does not predict the impurity peaking or scale length of the gradients.
- For the Alcator C-Mod ITB, light impurity transport shares with heavy impurity transport, both peaking and increased inward convection.