# Strong SOL turbulent transport - physics basis and consequences*

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# Strong plasma transport in the far scrape-off layer is an important (and controversial) issue

- **Plasma flux to the radial wall, $\Gamma = -D\, d(n_i)/dr + n_i V_{conv}$**

- **Traditionally SOL transport modeling has used constant D**
  - Good fits is often found to experimental divertor plasma profiles
  - Data on main-chamber ionization-radiation and gas pressure is often low & increasing D or $V_{conv}$ with r can improve this

- **Probe measurements on Alcator C-Mod, DIII-D, NSTX sometimes show strong far-SOL transport**
  - Alcator C-Mod -- LaBombard, Lipschultz
  - DIII-D -- Boedo, Rudakov, Whyte
  - NSTX, C-Mod -- Zweben, et al.

**Self-consistent turbulence/transport modeling also finds strong far SOL transport**

**Relevant for PFCs because of enhanced sputtering**

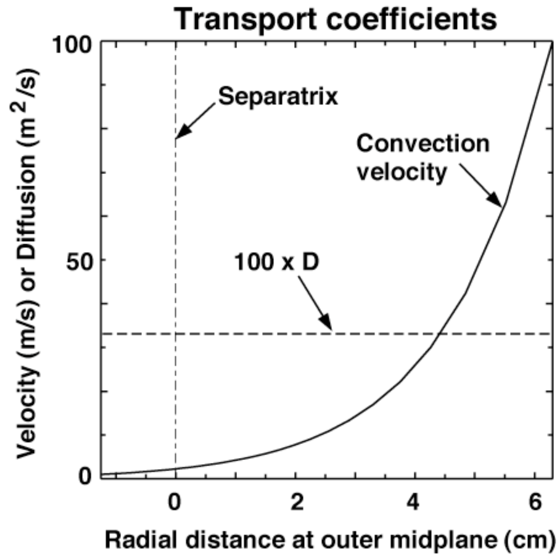
# Plasma outward convection in the outer SOL may be a substantial source of wall sputtering

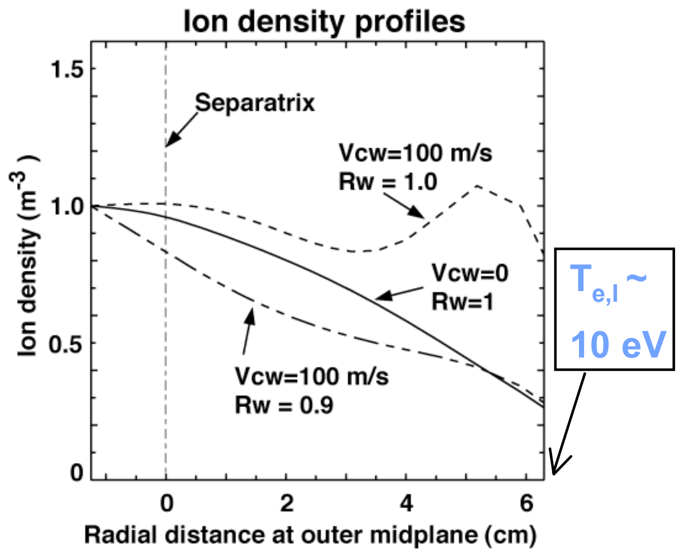
- Exp. data can show large transport in the far SOL, large D and/or $V_{conv}$

- Polarization ExB drift can explain rapid far-SOL transport of existing blobs (Krasheninnikov, D'Ippolito, et al.)

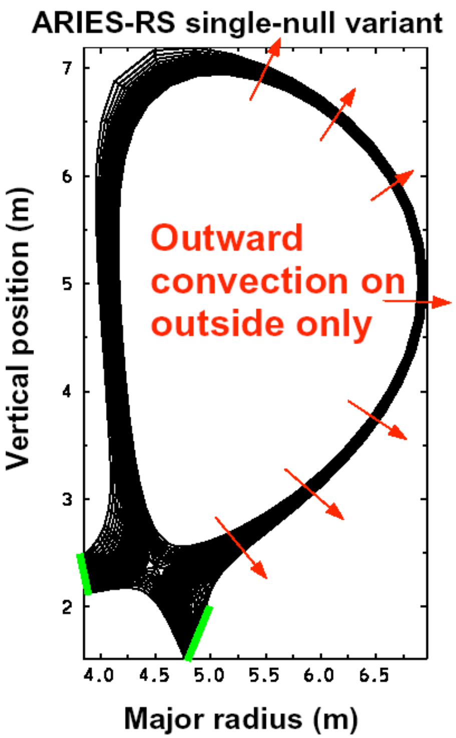
- For modeling, one can often use spatially-dependent D or $V_{conv}$ for hydrogen to yield the same flux

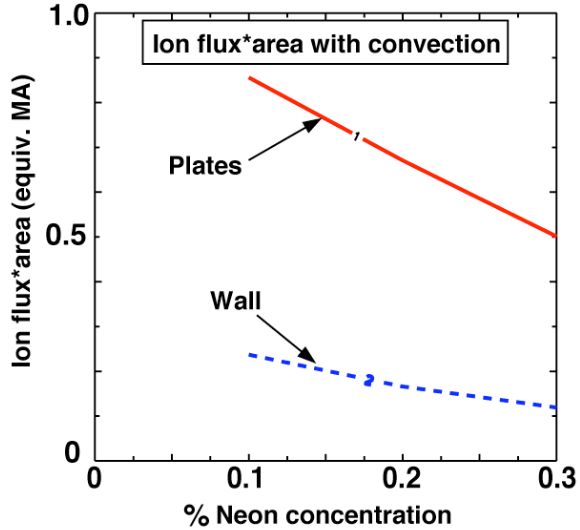
- Taking $V_{conv}$ as inferred from exp. & modeling ARIES-RS charge-exchange sputtering with the NUT neutral code shows substantial main-chamber erosion can occur

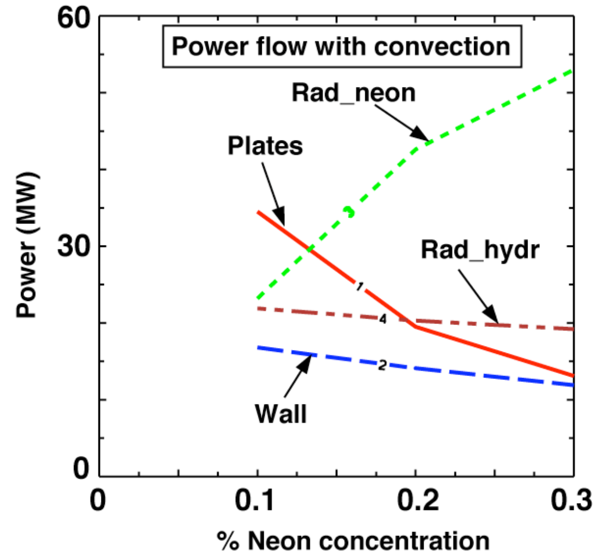


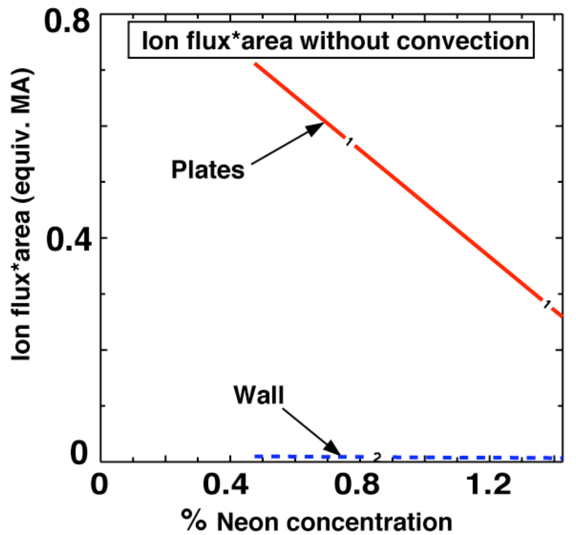



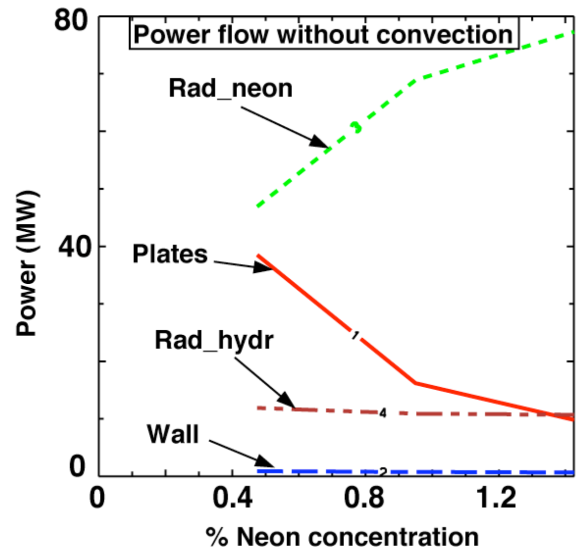
# Comparison with/wo convection shows wall flux changes the most, along with impurity efficiency



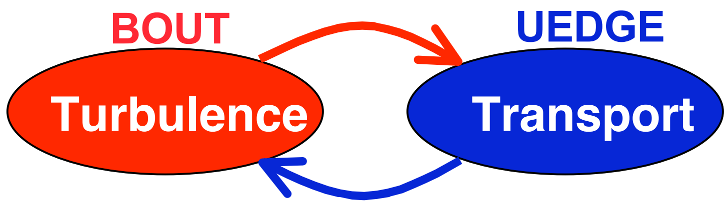



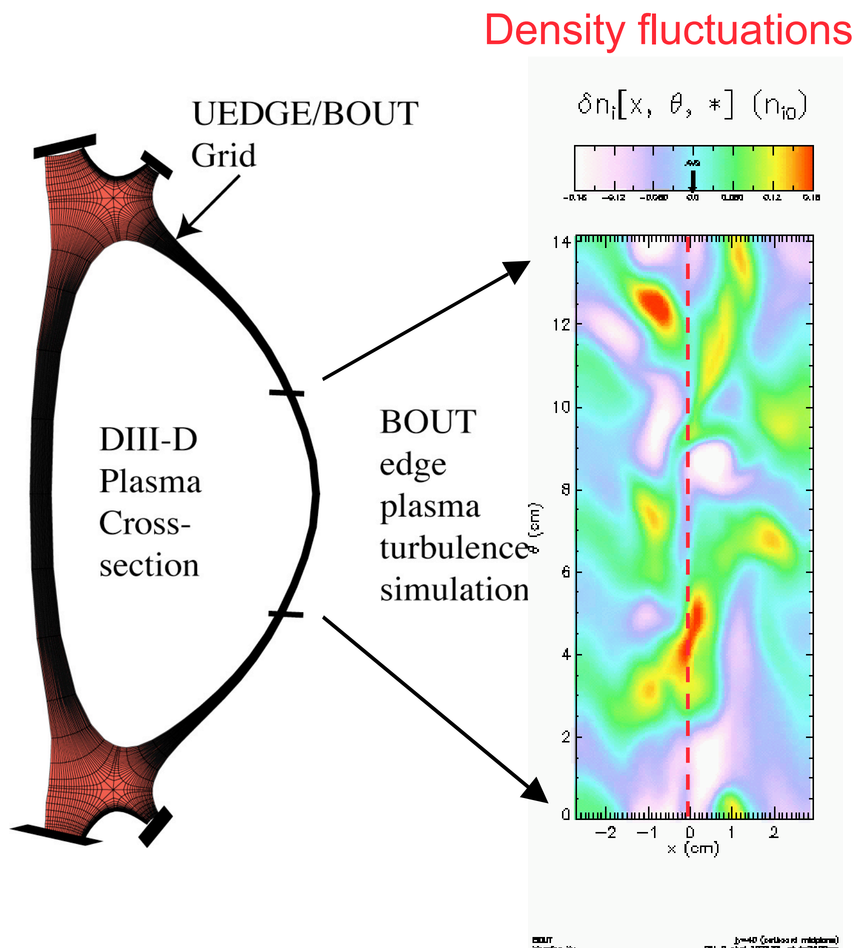




**Plasma wall fluxes used for recycling source in the NUT kinetic neutral code**

# 2D UEDGE and 3D BOUT provide complementary components for edge-plasma modeling




- **UEDGE**
  - 2-D fluid transport model
  - Extensively used for
    - Experimental analysis
    - Edge modeling
- **BOUT**
  - 3-D edge turbulence model
    - Collisional fluid equations
    - Realistic magnetic geometry
  - Benchmarked against Exp..
    - DIII-D (L-mode)
    - C-Mod (QC-mode)
    - NSTX




**Resistive drift-wave turbulence**

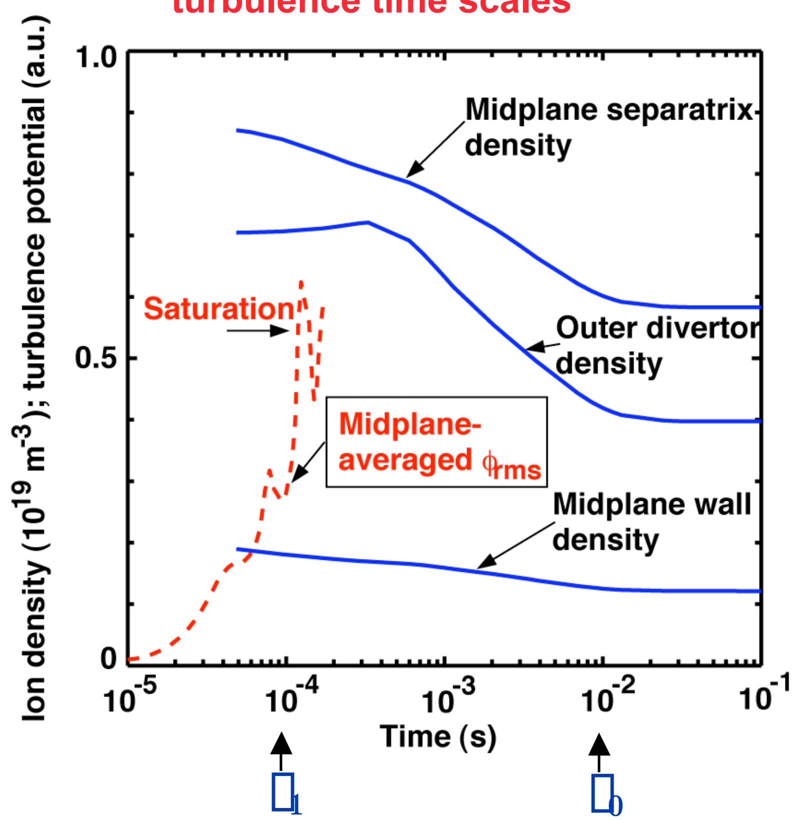
# Turbulence and net transport exhibit widely different characteristic time scales

- Within the iterative coupling scheme, the BOUT turbulence is evolve for a time, $\tau_1$ ~ 50-100 μs

- During the same iteration step, UEDGE takes a large time step, with $\tau_0$ > 10 ms

- Resulting final state is thus a statistical steady-state

Comparison of transport and turbulence time scales




UEDGE evolving from m=3 to m=8 fluxes

# Coupling algorithm uses an iteration over index m; UEDGE & BOUT evolved on own time scales

**Continuity equation is solved for 2D, axisymmetric plasma & neutrals**

$$\partial N_i^m / \partial t + \mathrm{div}(N_i^m V_{||i}^m + \Box_r^{m-1}) = S_{pi}^m$$

**Perpendicular turbulent particle flux comes from BOUT:**

$$\Box_r^{m-1} = (1 - \Box_1)\, \Box_r^{m-2} + \Box_1 < n_i\, v_{ri} >^{m-1}$$

**where $\Box_1$ is a relaxation parameter (~0.25). Likewise, the ion profile in BOUT is updated according to**

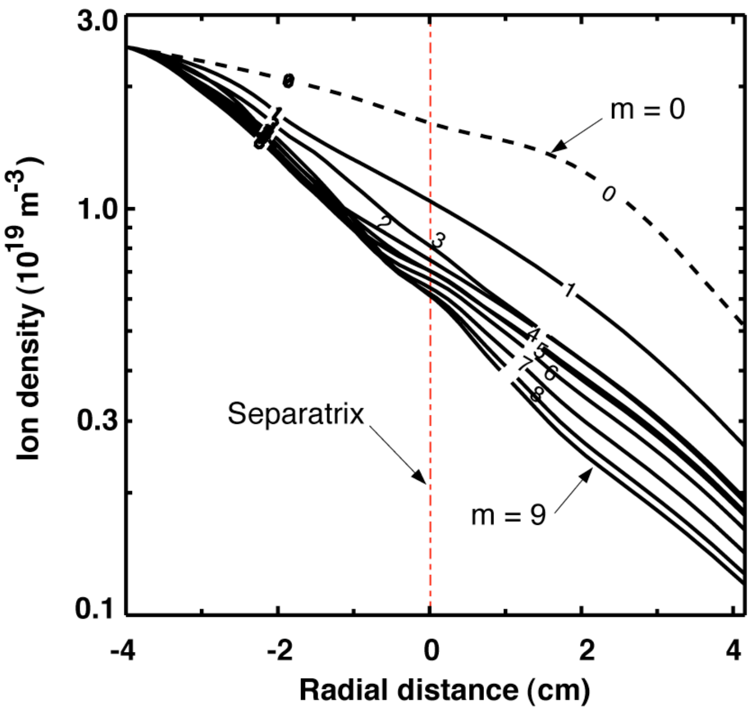
$$N_i^{m-1} = (1 - \Box_0)\, N_i^{m-2} + \Box_0\, N_i^{m-1}$$

**where $\Box_0$ is a second relaxation parameter (~0.5). The parallel ion velocity, $V_{||i}$, is similarly updated from UEDGE to BOUT.**

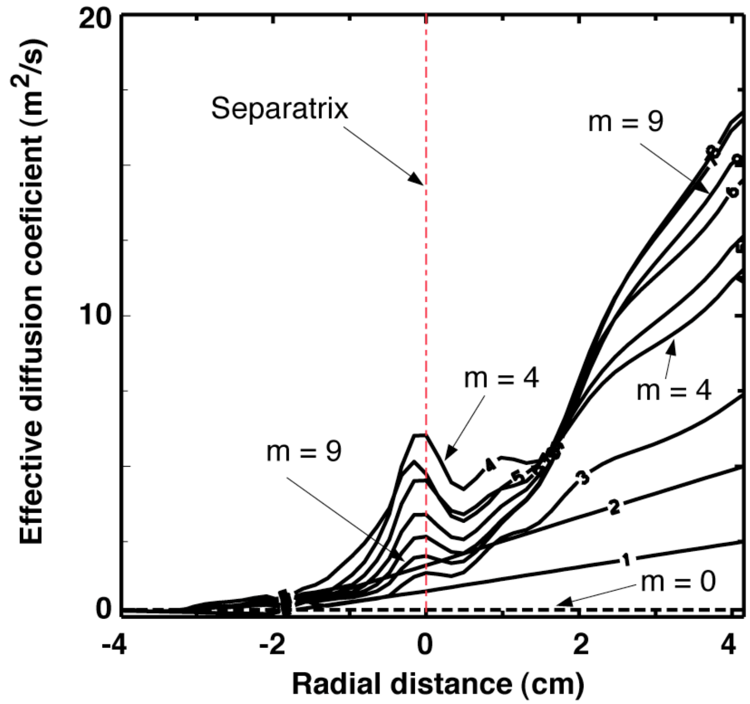
# Result of 9 iterations shows an approach to equilibrium with strong outer-SOL transport: L-mode

- Iterations are performed from m=0 (initial profile) to m=9
- Density profile converges more rapidly than turbulent fluxes

a) Midplane density profile evolution




b) Midplane diffusion evolution

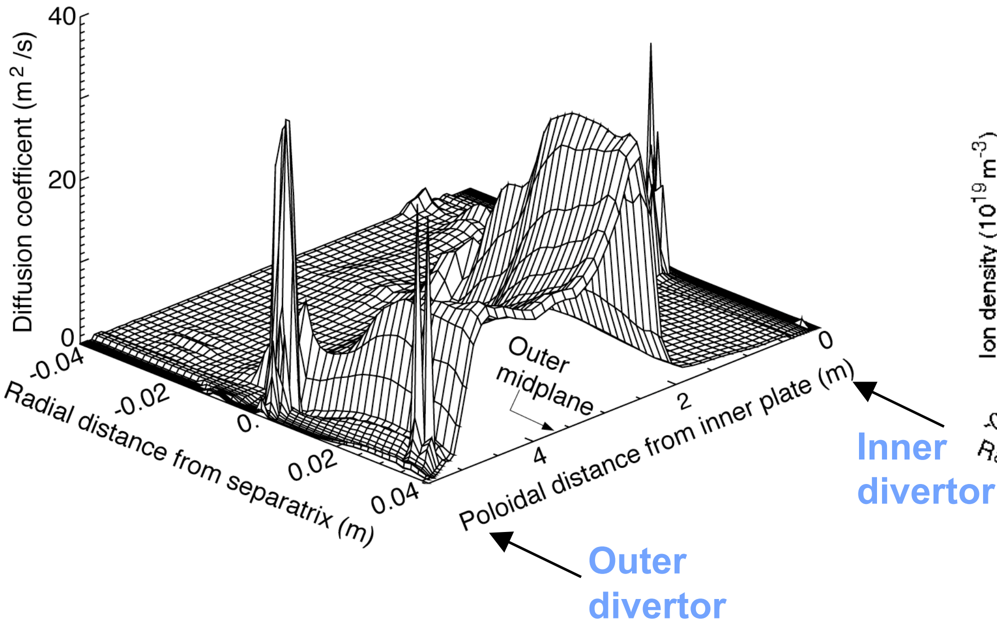


# Surface plots show full structure of final effective diffusion coefficient & neutral density: L-mode

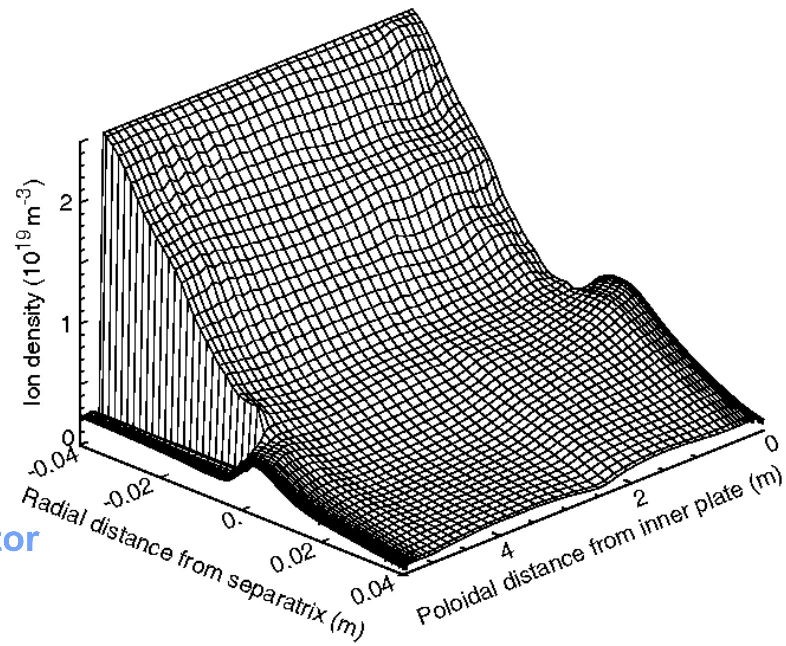
- **Diffusion coefficient has a strong ballooning character as expected for curvature driven modes**

- **Neutrals arise self-consistently from recycling at the divertor and outer wall**

**a) Final effective diff. coeff. (m = 9); equivalent $V_{conv}$ has same form**



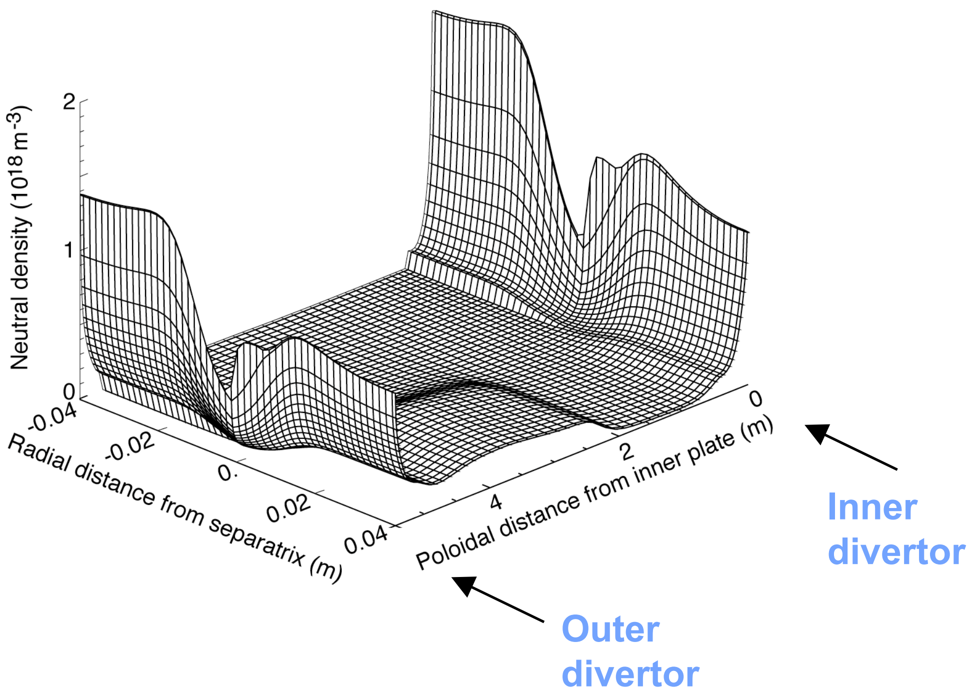

**b) Final ion density**



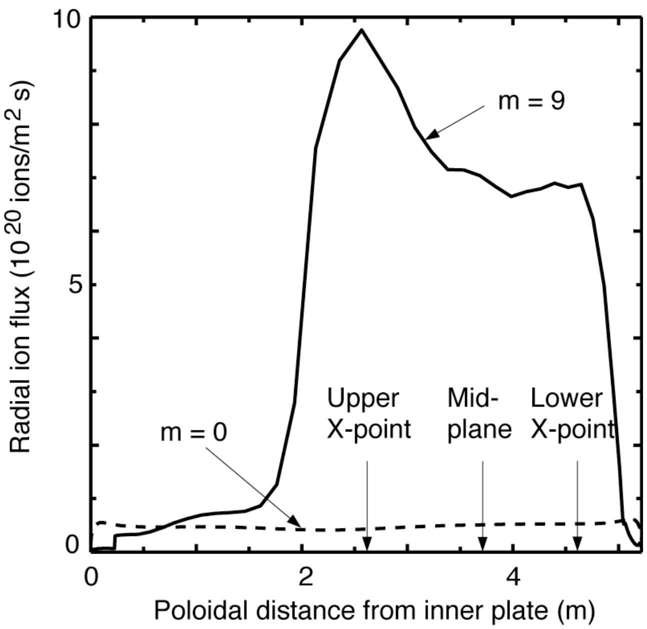
# Self-consistent neutral density shows substantial outer-wall source from strong radial ion flux

- Neutrals arise from recycling at the divertor ($R_p$=0.98) and outer wall ($R_w$=0.9)
- For this example, ion flux to wall is 2.6 times larger than to plates

a) Final neutral density (m = 9)

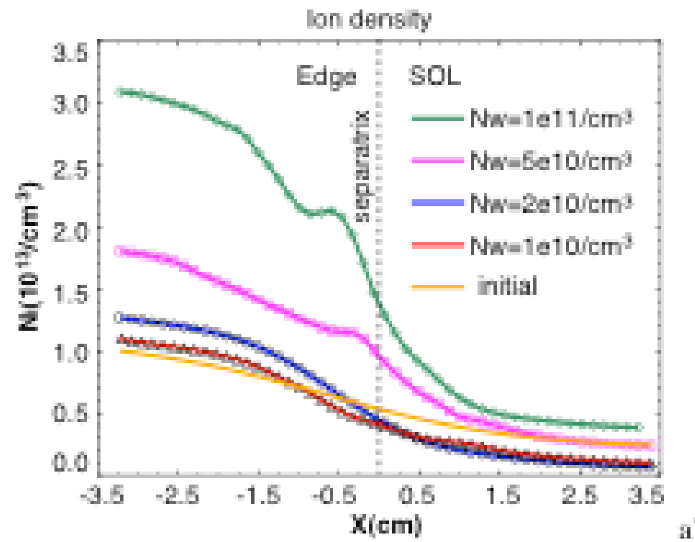


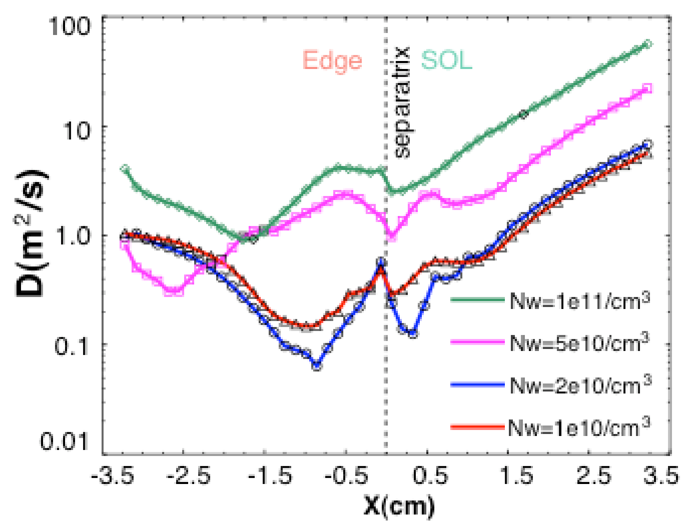

b) Radial ion flux along outer wall



# BOUT can also evolve its own profiles over ~1 ms: initial examples (Xu)

- **Profiles given by the toroidally-average plasma component**
- **Analytic model for neutral source with neutral radial scale-length ~ $(\square_i \square_{cx})^{1/2}$**
- **Series of cases with increased neutral source, but fixed core power (~ 1 ms simulations)**
- **Shows increased pedestal density, but also increased diffusivity owing to decreasing $T_e$**



# Summary

- **Strong plasma transport in the far SOL can substantially increase wall erosion and needs to be well assessed**
  – Self-consistent edge turbulence shown to produce such fluxes, similar in character to probe measurements
  – Larger ion fluxes generate more main-chamber neutrals
  – Charge-exchange products from hotter ions then cause erosion

- **Behavior of different operating regimes (L-mode, H-mode, near density limit) need to be better understood**
  – Experiment and modeling suggest high density is worse
  – ELMs may also produce significant wall flux

- **Helium and wall impurities likely to be transported differently**
  – Helium initiated in core should behave like hydrogen
  – Wall impurities may convect inward initially, before mixing