Impact of convective transport on ITER edge-plasma properties*

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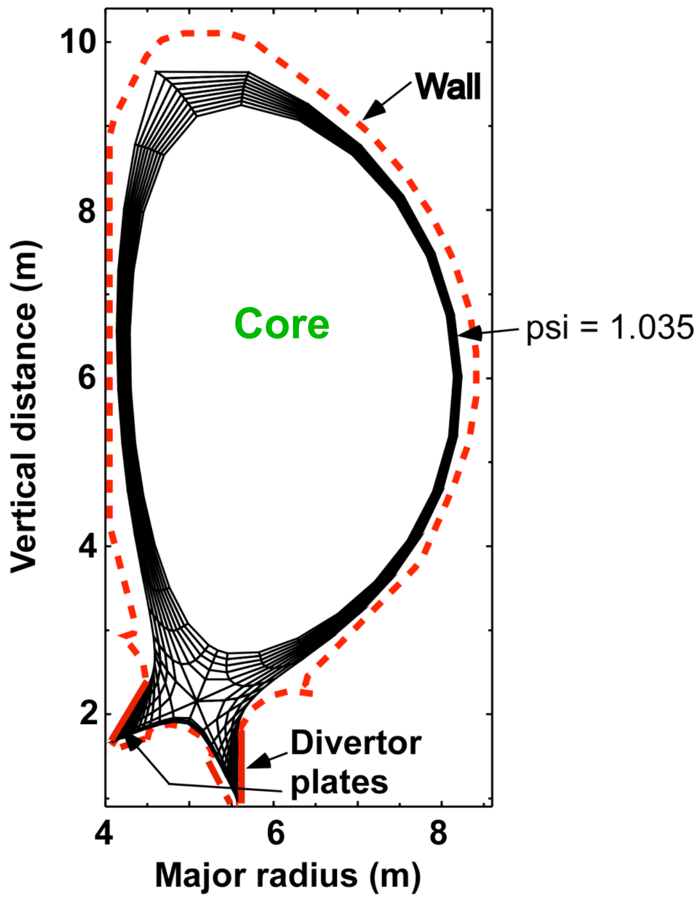
ITER utilizes a single-null divertor with steeply-inclined divertor plates

Poloidal cross-section showing edge-plasma region



- Nearly vertical plates reduce heat flux & facilitate plasma detachment
- Carbon radiation helps reduce T_e near strike point to allow He pumping

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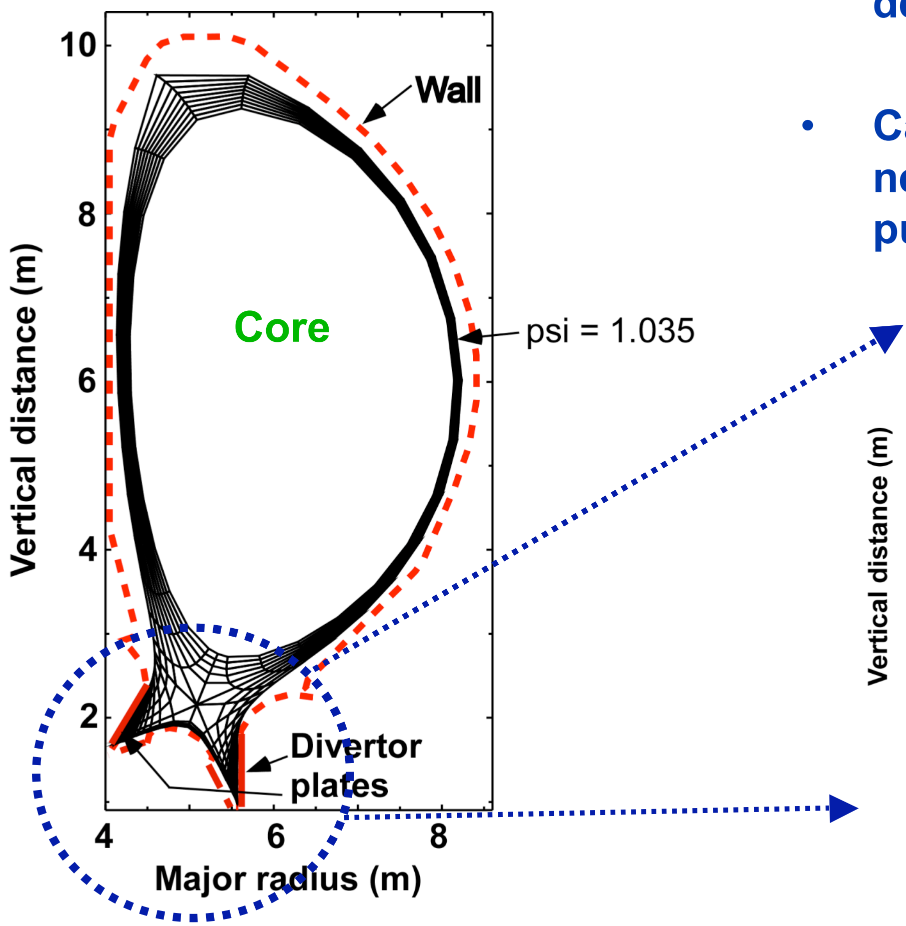

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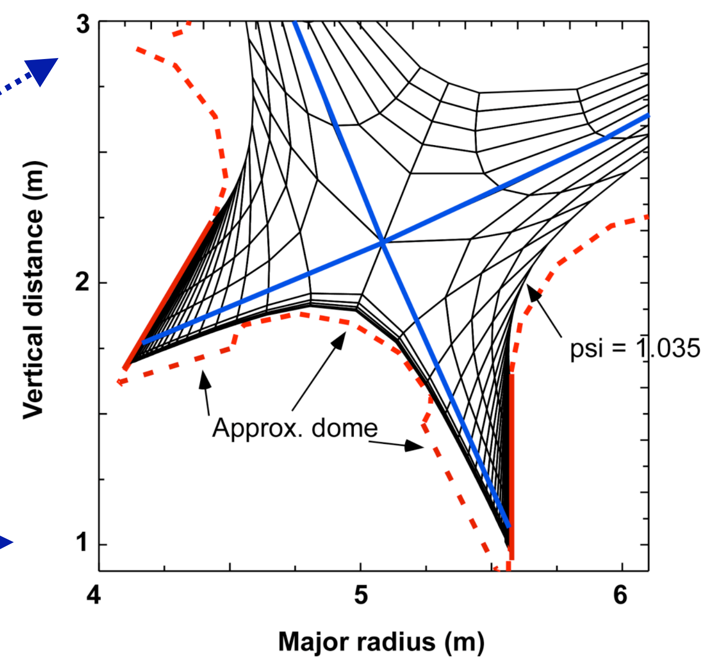

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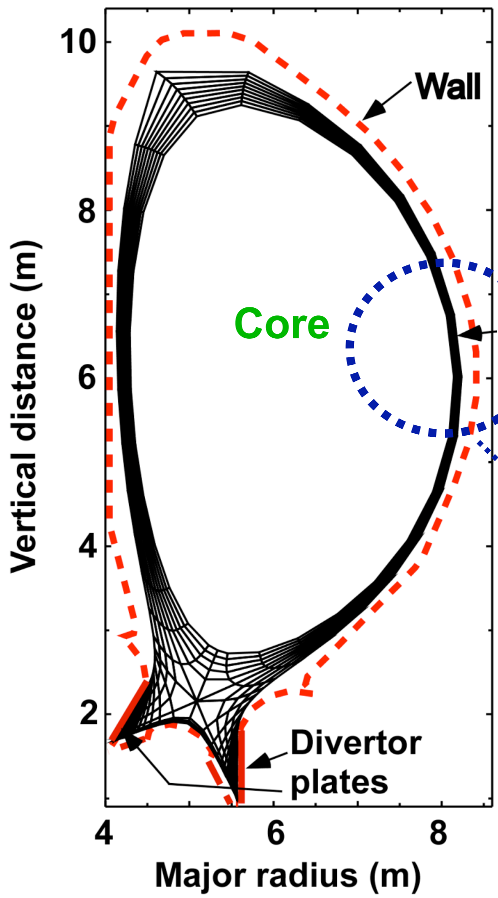

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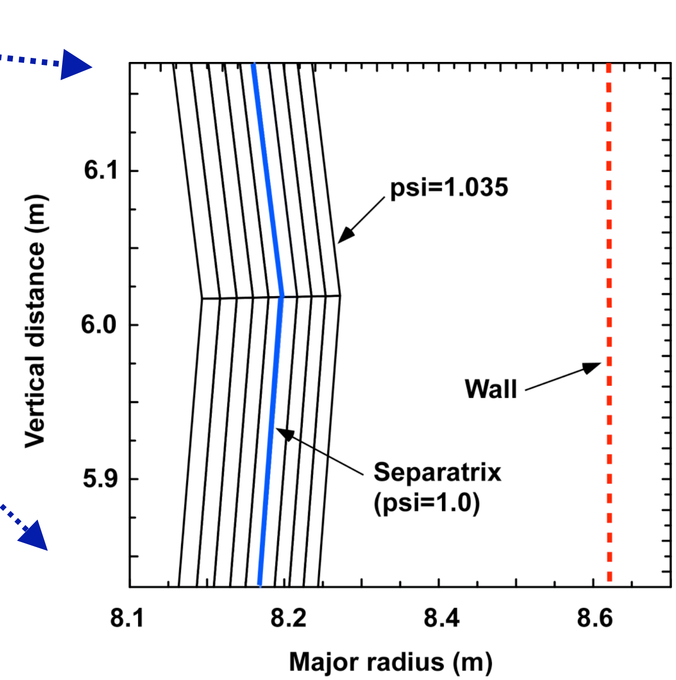

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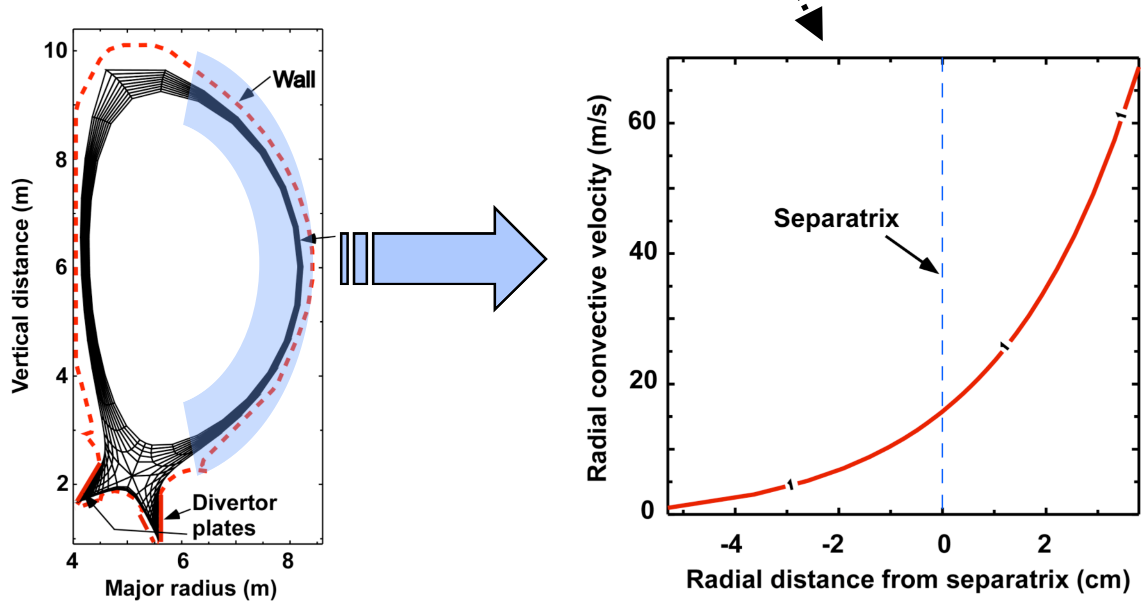
Previous ITER divertor-plasma modeling assumed diffusive radial transport only; we add convection

- **ITER assumes 100 MW power input to SOL**
- **Here carbon modeled as a 3% concentration**
- **Anomalous radial diffusion set at D = 0.3 m^2/s, $\chi_{e,i}$ = 1 m^2/s**
- **We add a radial convection term on outboard side, as experiments and simulations imply**

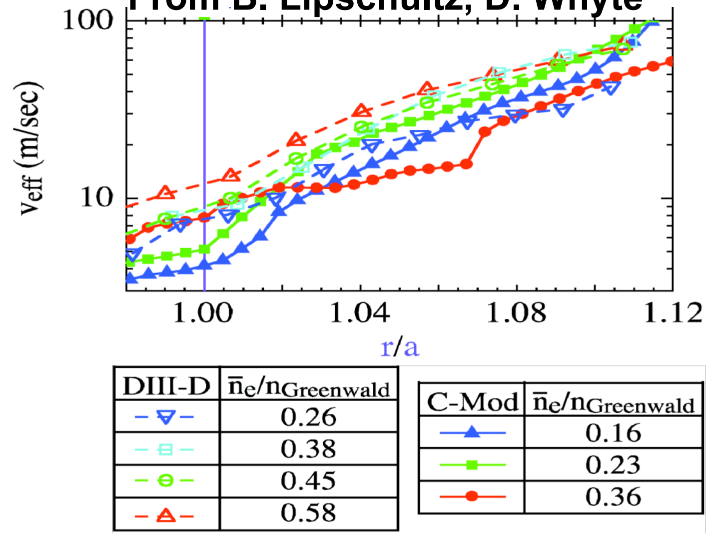
radial particle-flux $\Gamma_n = -Ddn/dr + V_{conv}n$



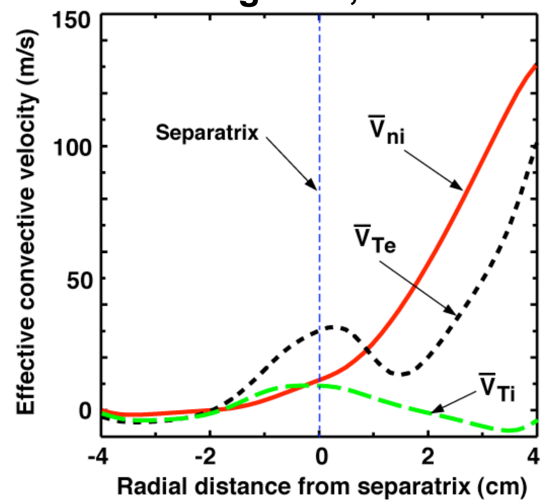
Why? - there is experimental and theoretical evidence for strong outward convection in SOL

- Gas-puff imaging shows outward moving filaments ("blobs") (Zweben et al.)
- Probes see outward moving perturbations (Boedo, Rudakov)
- Ionization balance from H-alpha (Lipschultz, Whyte)
- Theory and edge turbulence simulations show outward convection (Krasheninnikov, Pigarov et al.; Rognlien, Xu et al.)

From B. Lipschultz, D. Whyte



From Rognlien; 3D BOUT

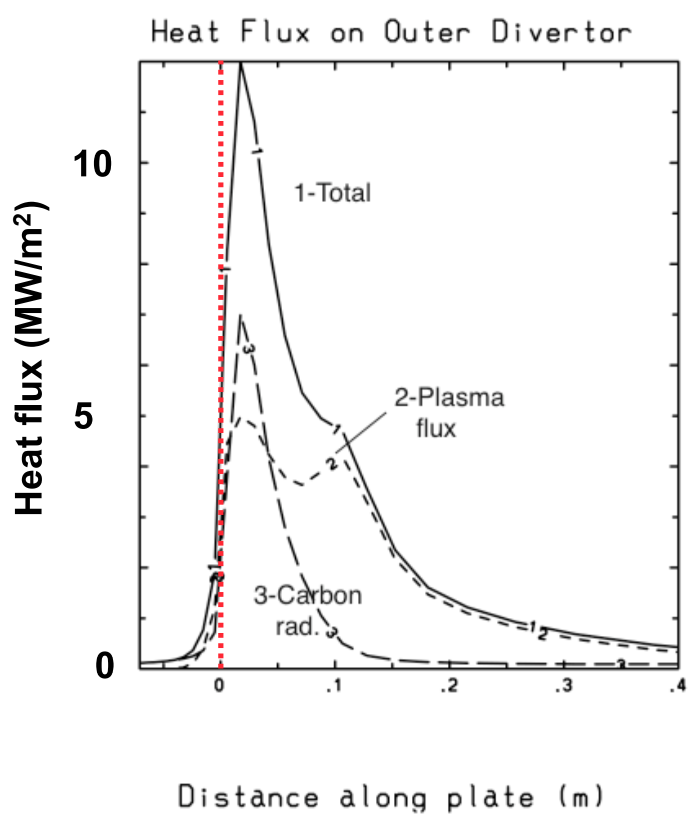


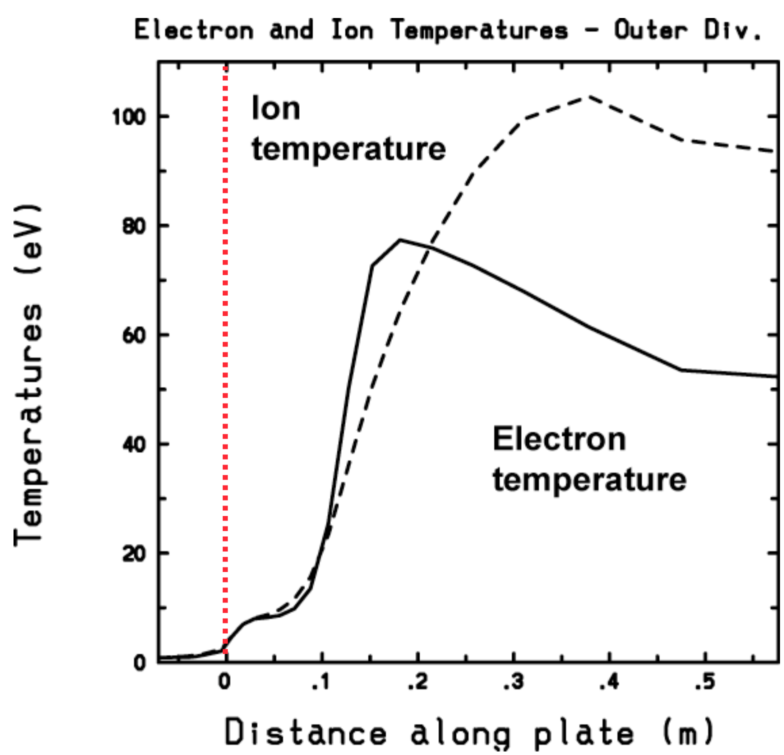
But we don't know the scaling of V_{conv} with size, edge temperature, strong H-mode flow shear …

- Consequently, we can parameterize the effect by considering a range of V_{conv} cases, from a maximum of 100 m/s to 0 m/s.
- Divertor conditions near separatrix are relatively insensitive
- Midplane radial particle and energy fluxes are sensitive

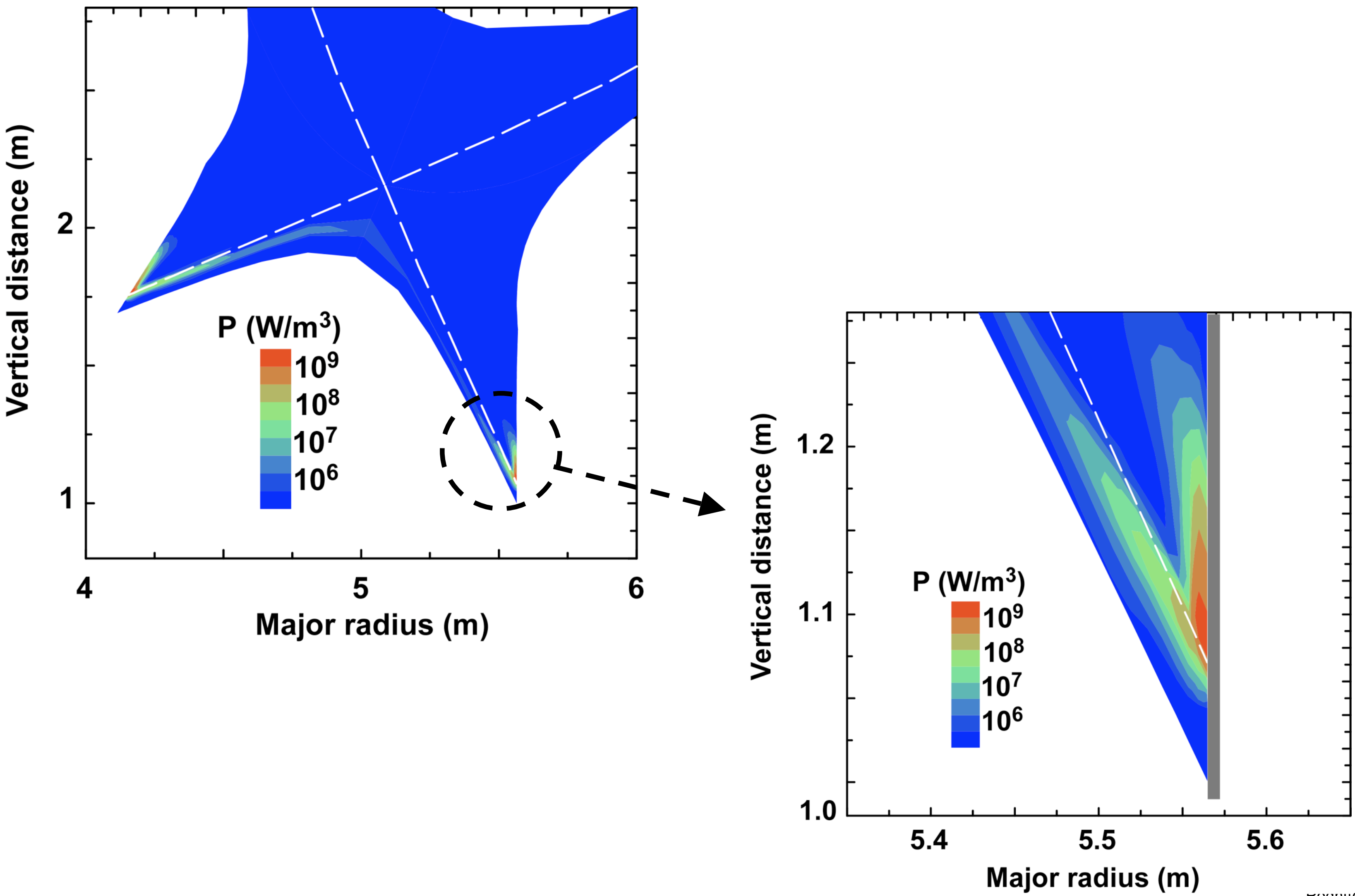
With no convection, we obtain conditions typical of past ITER divertor-plasma modeling

- **Anomalous radial diffusion set at D = 0.3 m^2/s, $\chi_{e,i}$ = 1 m^2/s**
- **Peak heat-flux on outer divertor = 12 MW/m^2**
- **~50% of the power is radiated by carbon**





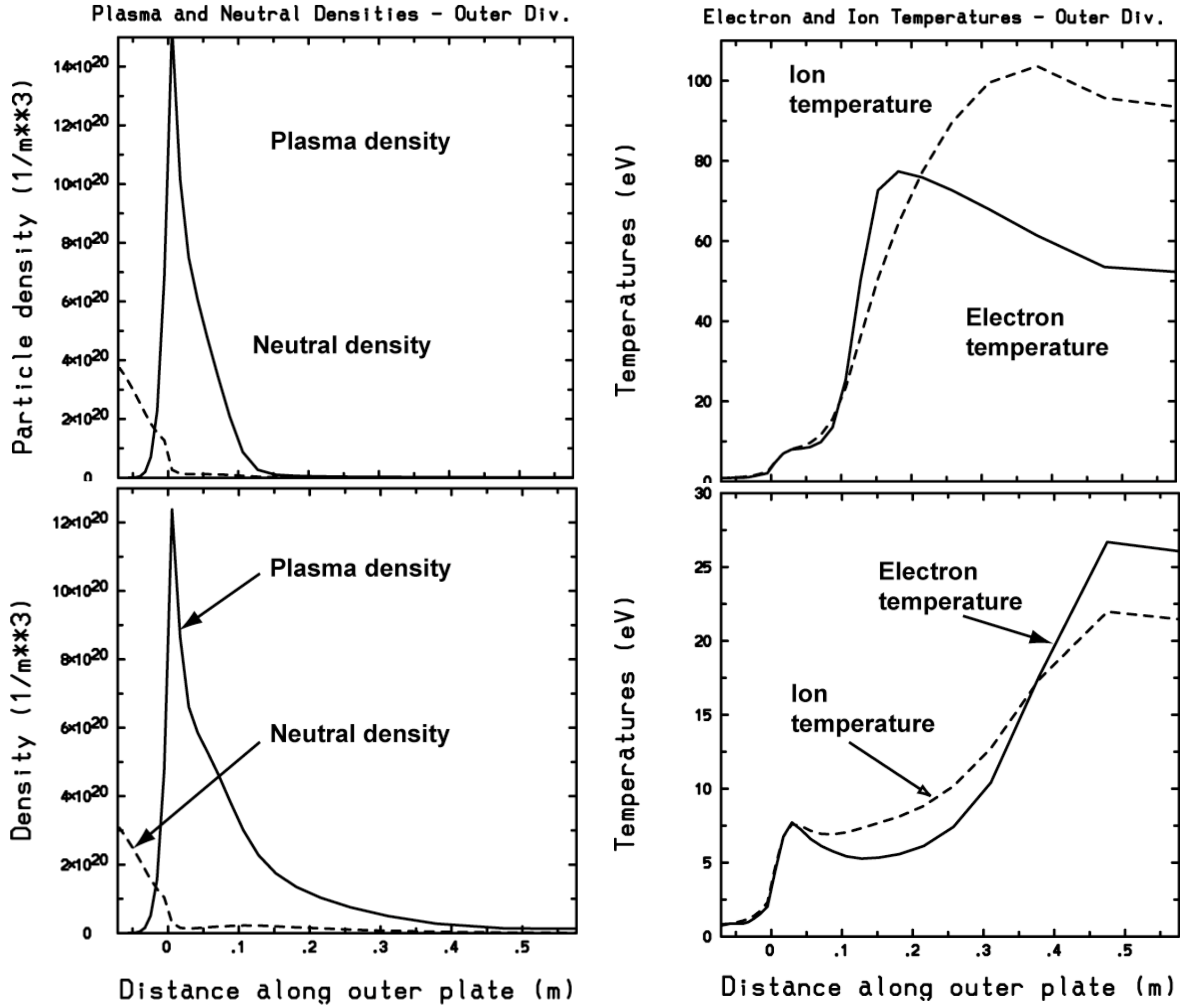
Carbon radiation is localized near the divertor plates; neon would be more diffuse



Convection applied to ITER shows some radial broadening of profiles at the divertor

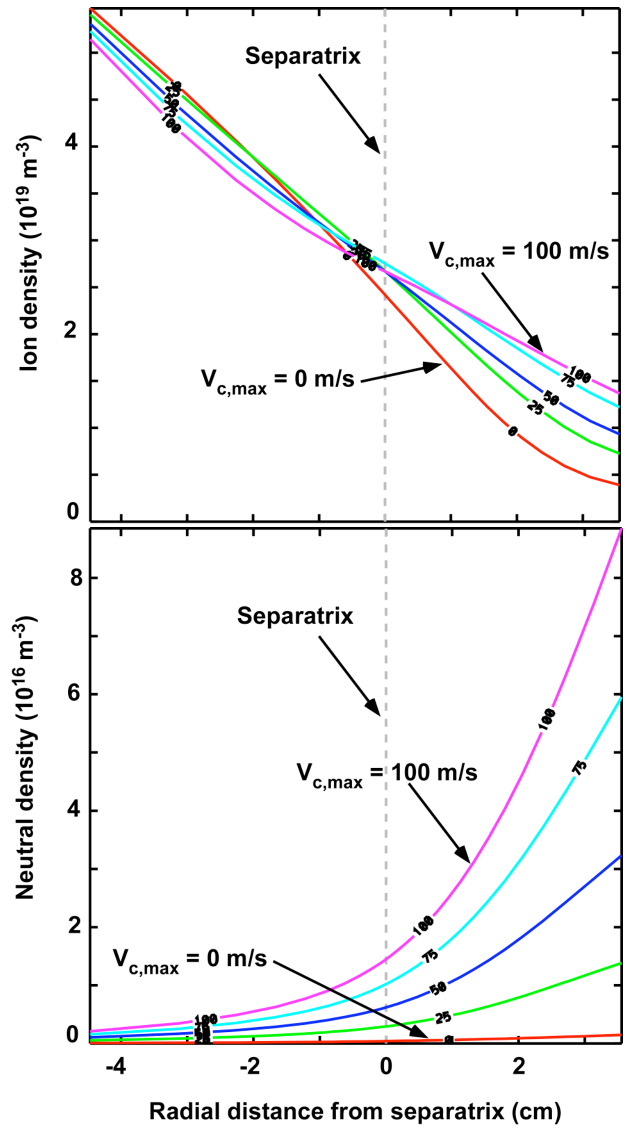
Without convection →

With convection →



Outer midplane density profiles near the wall change substantially with convection

- Plasma density increases near the wall
- Neutral density increases at a faster rate owing to recycling
- Higher neutral density inside the separatrix ==> substantial charge-exchange loss and sputtering (Kotschenreuther, Rognlien, Valanju Fusion Eng. Design, '04)



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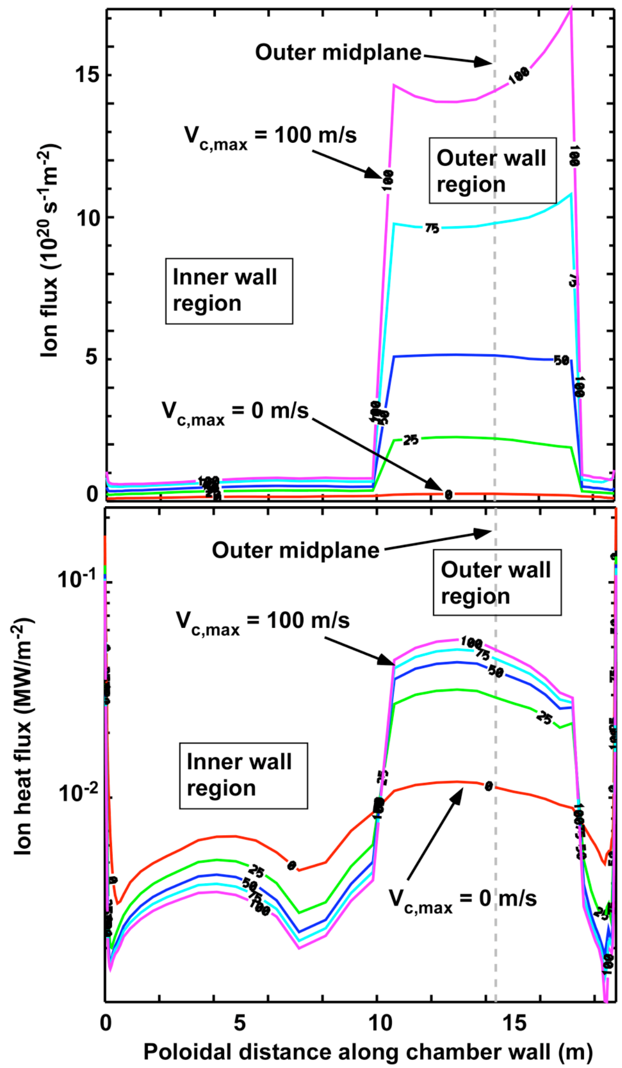
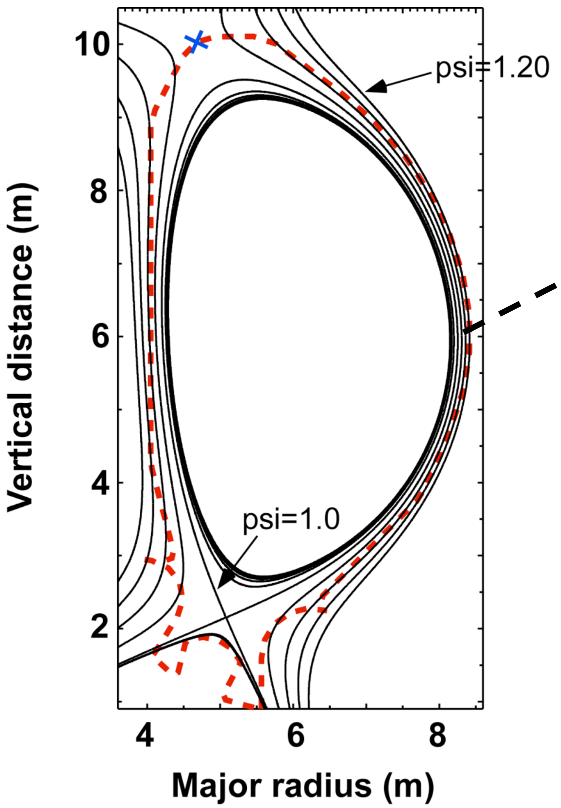
Plasma fluxes to the wall increase more than local density owing to ionization of recycled gas

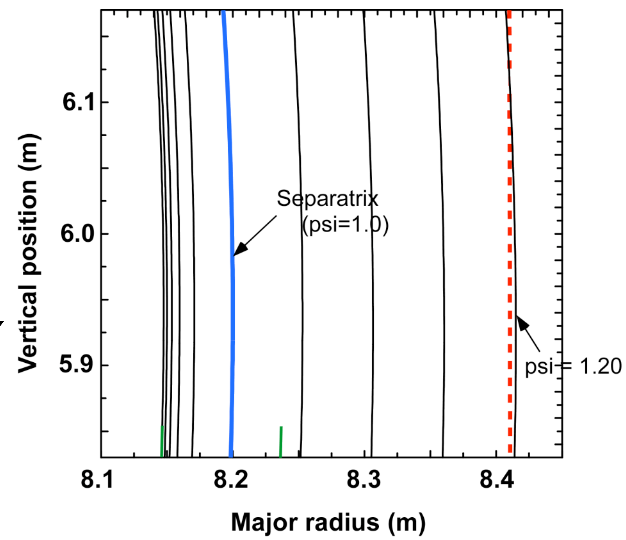
- Since n_i and V_{conv} increase, the nV flux is much larger
- Ionized neutrals contribute the flux
- Ion temperature decreases some owing to cold ionization source; ion energy flux slower
- Hot cx-neutrals, sheath drop to be added to energy flux



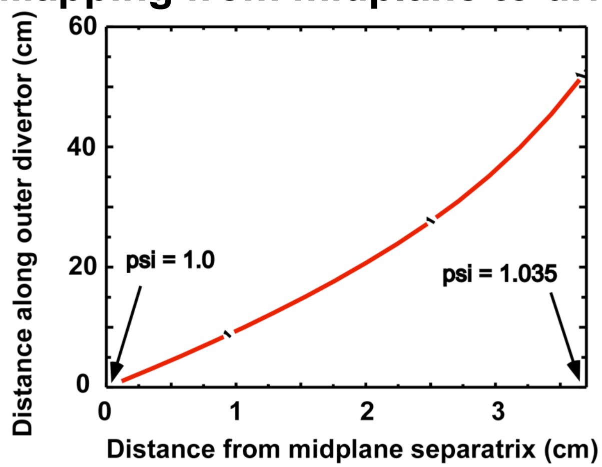
Extending flux surfaces beyond $\Psi_n = 1.035$ into the "gap" region shows an upper X-point

Mapping along flux surfaces gives plate (and wall) intersections





Mapping from midplane to divertor



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Enhanced plasma fluxes can substantially increase ITER Beryllium wall sputtering

- These hydrogen plasma fluxes supplied to J. Brooks for WBC simulations of wall sputtering
- The "gap" plasma is an extrapolation from UEDGE; impacts ionization of Be
- Later: Be sources can be used within UEDGE to determine competition between transport along and across flux surfaces; requires understanding Be cross-field transport
- Iterate on hydrogen plasma if Be sputtering changes main edge plasma

Summary and plans

- Even moderate radial convection produces substantial plasma fluxes to the wall for ITER

- Sputtering of material (Be) from plasma and cx-neutrals can be large

- Gap plasma (for $\Psi_n > 1.035$) needs a better model; UEDGE can perform unbalanced double-null simulations that will help

- Scaling of convective transport for hydrogen and beryllium needs improvement