EFFECT OF CROSS-FIELD DRIFTS AND CORE ROTATION ON FLOW IN THE MAIN SCRAPE-OFF LAYER OF DIII–D L-MODE PLASMAS

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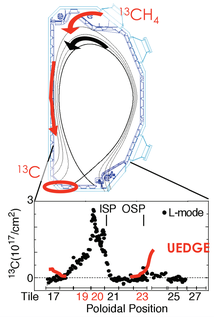
Impurity transport in the main SOL plays key role in material migration in tokamaks



- Primary concern is tritium retention in ITER due to co-deposition w/ carbon

⇒ ^{13}C experiments: carbon migration from the main chamber to the inner divertor

  – Working hypothesis: entrainment of carbon ions in background ion flow

  – **Goal: simultaneously measure D and C ion velocities in the main SOL**

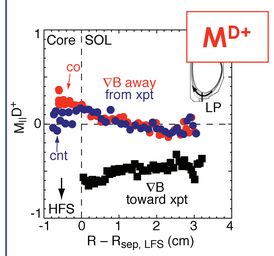
- Present SOL modeling does not reproduce measured ^{13}C deposition profile, unless flow is imposed

⇒ **Goal: clarify underlying physics**

Summary and conclusions

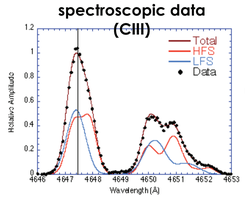
- First simultaneous measurements of deuteron and low charge-state carbon ion flows in the main chamber SOL (crown) of the DIII-D tokamak
  – Low-density (n/n_{GW} ~ 0.25), low-confinement plasmas in upper single-null configuration to enable flow measurements
  – Vary ion **B**x∇B drift direction (↓↑) and core plasma rotation (co/cnt-current)
- At plasma crown, main ion flow M ~0.5 for ion **B**x∇B↑, stagnant for ion **B**x∇B↓
- C^{2+} ions flow toward HFS divertor at HFS of the crown, and toward LFS divertor at LFS of the crown ⇒ possible stagnation point at the tip of the crown
- **Carbon transport not necessarily coupled to main ion flow, other physics processes must also play a role (e.g., ion gradient temperature force)**
- SOL D^+ and C^{2+} flows are independent of core plasma rotation
- UEDGE fluid simulations indicate that main ion flows at the crown are determine by ion **B**x∇B drifts; **E**x**B** drifts dominate plasma transport in the divertor
  – Simulations do not match flow measurements at the crown
  – Carbon transport determined by parallel force due to frictional drag and temperature gradient

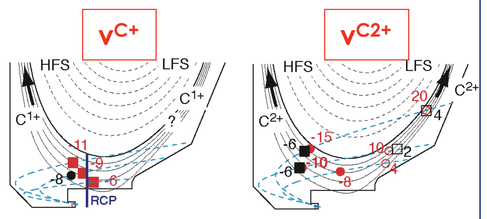
Parallel-B velocities of deuterons and low-charge state carbon ions depend on the ion BxVB direction



	ion BxVB↑	ion BxVB↓
$M_{||}^{D^+}$	Crown HFS: –0.5	~ Zero
$v_{||}^{D^+}$ [km/s] (w/ $T_e = T_i$)	–15 to –35 km/s	
$V_{||}^{C1^+}$ [km/s]	Crown HFS: –5 to –7	HFS: –6 to –8
$V_{pol}^{C1^+}$ [km/s]	Crown HFS: –0.2 to –0.3	HFS: –0.2 to –0.3
$V_{||}^{C1^{+++}}$ [km/s]	Crown HFS: –5 to –10 Crown LFS: +2 to +5	HFS: –10 to –15 LFS: +8 to +20

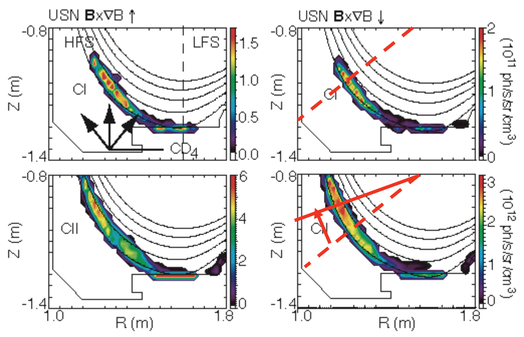
2x9-component fit to spectroscopic data (CIII)





- C^{2+} velocity measurements in the HFS and LFS of the crown indicate stagnation of carbon flow at tip of the crown
- **Coupling between main and carbon ions insufficient to explain results in ion BxVB↓ case**
- Parallel-**B** D^+ and C^{2+} velocity not affected by direction of core toroidal rotation
  – Use co-current and counter-current NBI to drive core rotation
  – Toroidal rotation from CXRS C^{6+} measurements at $\Psi_N \approx 0.8$:
  20 km/s (co-I_P) → 20 km/s (cnt-I_P) (-5x10^{-2} Nms (co) → 5x10^{-2} Nms (cnt))

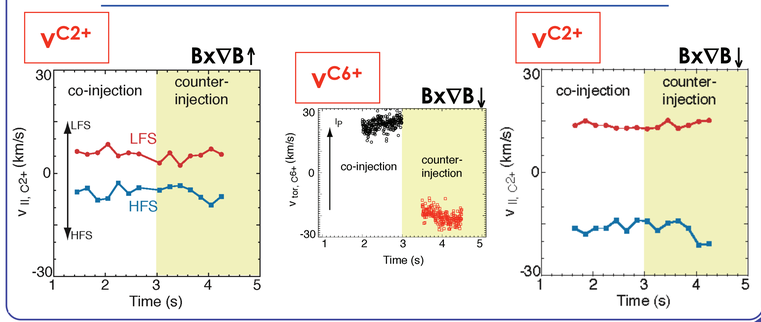
Poloidal C^+ velocities inferred from plasma imaging in HFS crown are unaffected by change of ion BxVB direction



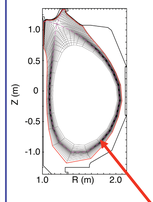
- Measurements enabled by toroidally symmetric CD_4 injection
- Estimate $v_{pol}^{C^+}$ from poloidal shift of emission peak and atomic physics:

$$v_{pol}^{C^+} \cong \frac{\Delta s_{pol}^{CI \to CII}}{t_{ioniz}^{C^+ \to C^{2+}}}$$

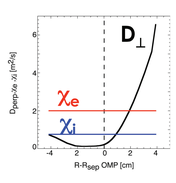
Parallel-B C^{2+} velocities near separatrix are higher in ion BxVB↓ configuration, and unaffected by core toroidal rotation

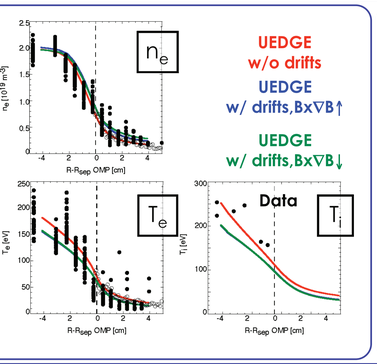


Predictive scrape-off layer modeling with the multi-fluid edge code UEDGE, including cross-field drifts, and radially varying diffusivities



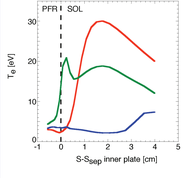
- Grid: 48x28 non-orthogonal cells: 0.9 ≤ Ψ_N ≤ 1.09
- SOL transport models:
  – Parallel-**B**: Braginskii equations with kinetic 'corrections' (D), force balance equation (C)
  – Radial: diffusive with coefficients adjusted to match upstream n_e, T_e, and T_i (D), same coefficients for C
- Simulations w/ and w/o cross-field particle drifts due to **E**x**B** and **B**x∇B, both **B** directions
- Carbon produced by phys. and chem. sputtering at the plates, and chem. sputtering at the "walls"





UEDGE w/o drifts
UEDGE w/ drifts,BxVB↑
UEDGE w/ drifts,BxVB↓

Simulations w/ drifts predict divertor plasma more consistent w/ measurements



- ExB drifts dominate poloidal transport in divertor

⇒ Partially detached inner divertor in ion BxVB↑ config.

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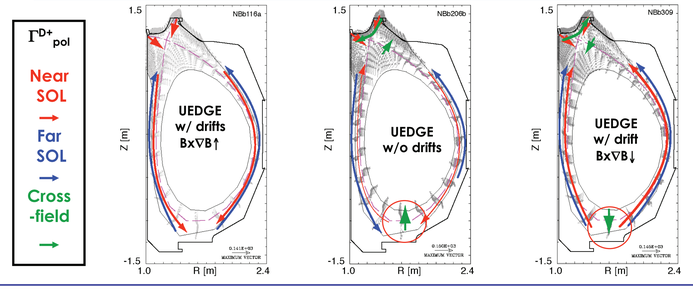
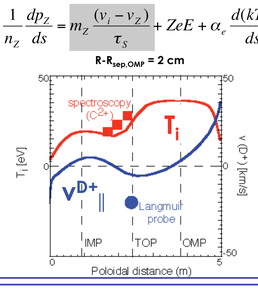
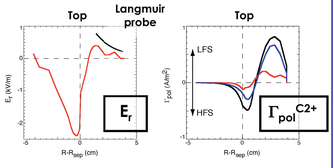
D^+ flow pattern at the crown determined by ion BxVB drift: pressure sink in ion BxVB↑, pressure hill in ion BxVB↓



Transport of low charge-state carbon ions determined by entrainment in D^+ flow and ion temperature gradient force

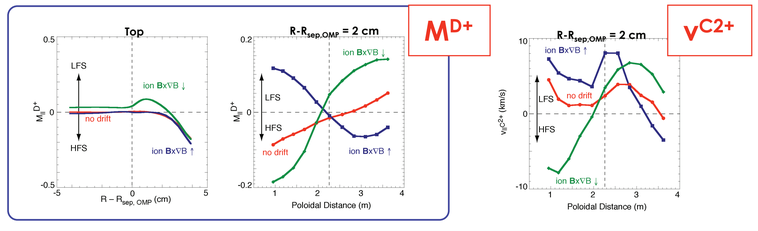
$$\frac{1}{n_Z}\frac{dp_Z}{ds} = m_Z\frac{(v_i - v_Z)}{\tau_s} + ZeE + \alpha_e\frac{d(kT_e)}{ds} + \beta_i\frac{d(kT_i)}{ds}$$





- HFS: exp - $F_{\nabla Ti}/F_{fric} \approx 0.1$ vs. UEDGE - $F_{\nabla Ti}/F_{fric} \approx 1$
- UEDGE underestimates radial electric field at crown ⇒ poloidal C^{2+} flow dominated by parallel component

At the crown, UEDGE simulations predict low-flow D^+ plasma for both BxVB configurations; flow of C^{2+} ions is predominately toward LFS divertor (inconsistent w/ measurements)



Imposing toroidal momentum at the UEDGE core boundary drives flow in the core and near-separatrix SOL, and not in the far SOL (ion BxVB↑ configuration)