Effects of drifts on scrape-off layer transport in W7-X

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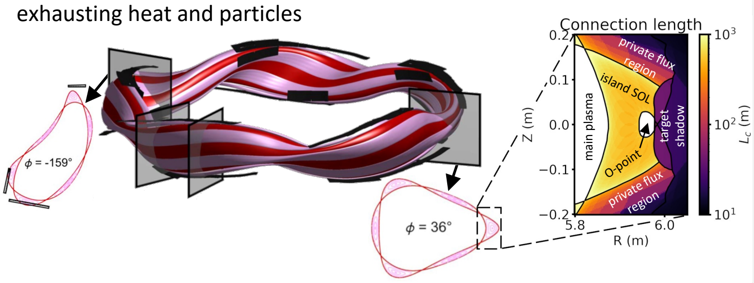
Motivation for studying scrape-off layer drifts

W7-X island divertor: magnetic islands intersect divertors, exhausting heat and particles

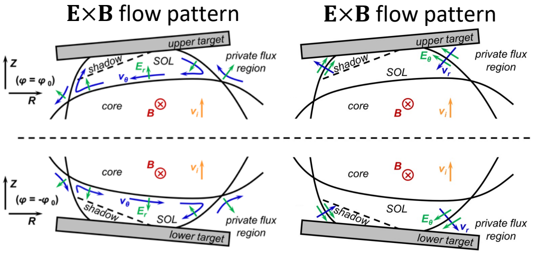


Island divertor SOL has much longer connection lengths than tokamak SOL (hundreds vs tens of meters) → perpendicular transport from turbulence and **drifts expected to be important**

- $\mathbf{E}\times\mathbf{B}$ drift: resonates with islands → large contribution
- Diamagnetic drift ($\nabla p\times\mathbf{B}$): largely divergence-free, and non-divergence-free component does not resonate with islands → weak contribution

Divertor heat flux deposition profile is affected by $\mathbf{E}\times\mathbf{B}$ drifts [K. Hammond et al, PPCF **61** 125001 (2019)]

Expected poloidal $\mathbf{E}\times\mathbf{B}$ flow pattern | Expected radial $\mathbf{E}\times\mathbf{B}$ flow pattern

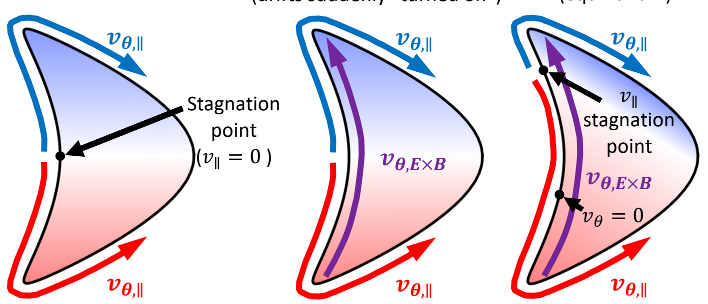


Goal: experimentally investigate drift flows throughout the scrape-off layer

Simple SOL model with poloidal $\mathbf{E}\times\mathbf{B}$ drift

In low density plasmas with a simple SOL the poloidal $\mathbf{E}\times\mathbf{B}$ drift is dominant → want to model how this drift affects density and flows

Parallel flow in island without drift | **Parallel flow in island with drift**: Initial situation (drifts suddenly "turned on") | Final situation (equilibrium)



Poloidal transport in islands exclusively driven by poloidal component of parallel flow: $v_{\theta,\parallel} = v_\parallel \sin(\theta_p)$

- θ_p: field line pitch (≈ 0.001)
- Stagnation point at island center (halfway between targets)

Poloidal transport in islands driven by $v_{\theta,\parallel}$ and $E\times B$ drift: $v_{\theta,E\times B}$ → particles start building up in upper half of island

- Net poloidal velocity: $v_\theta = v_{\theta,\parallel} + v_{\theta,E\times B}$

$v_\parallel$ stagnation point shifts toward X-point in direction of $v_{\theta,E\times B}$ due to shift of density (pressure) profile

- $v_\theta = 0$ point shifts in opposite direction

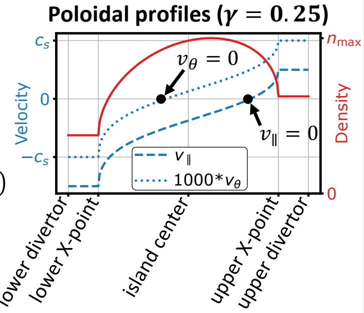
Simple SOL model with $v_{\theta,E\times B}$

- 1D poloidal particle and momentum transport equations
- Assumes constant $v_{\theta,E\times B}$ and constant T_e along field lines

Key model results/insights:

- Drift strength: $\gamma = v_{\theta,E\times B}/(2c_s\tan\theta_p)$
- Divertor density asymmetry $\propto \frac{1+\gamma}{1-\gamma}$
- $v_\parallel$ stagnation point shift $\propto 3\gamma - 4\gamma^3$
- $v_\theta = 0$ point shift $\propto -\gamma$ (implications for impurity transport)

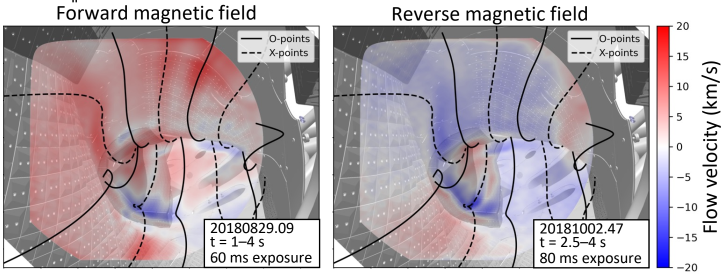
Poloidal profiles ($\gamma = 0.25$)



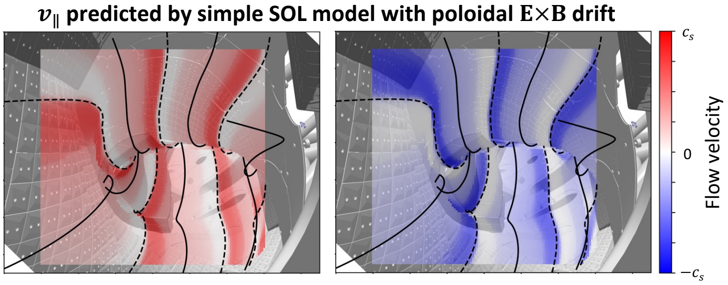
$v_\parallel$ stagnation point shift in low-density plasmas

Low density plasmas ($n_e < 2\times10^{19}\ \mathrm{m^{-3}}$) have largely unidirectional flow pattern that reverses with field direction, consistent with stagnation point shift predicted by simple SOL drift model

$v_\parallel$ measured by coherence imaging spectroscopy (CIS)



$v_\parallel$ predicted by simple SOL model with poloidal $\mathbf{E}\times\mathbf{B}$ drift

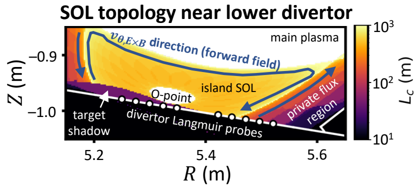


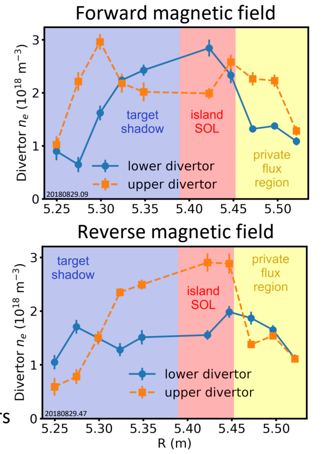
CIS measurements imply $\gamma \gtrsim 0.5 \rightarrow v_{\theta,E\times B} \gtrsim 120\ \mathrm{m/s}$

Drift-induced divertor density asymmetry

Density asymmetry between upper and lower divertors is consistent in sign with simple SOL drift model across different topological regions

SOL topology near lower divertor

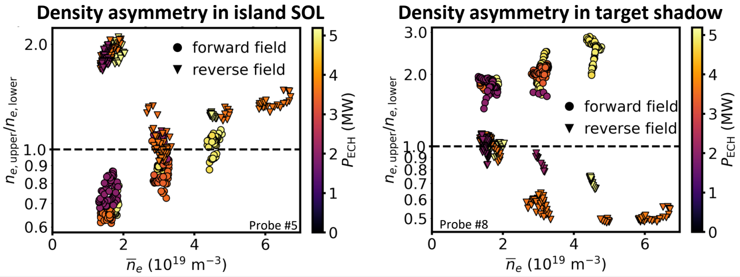




In low density plasmas, $n_{upper}/n_{lower} \approx 2 \rightarrow \gamma \approx 0.3 \rightarrow v_{\theta,E\times B} \approx 80\ \mathrm{m/s}$, somewhat lower than estimate from CIS

As n_e increases, divertor asymmetry disappears in island SOL, but increases in target shadow

Density asymmetry in island SOL | **Density asymmetry in target shadow**



Conclusions

- At low density, poloidal $\mathbf{E}\times\mathbf{B}$ drift causes stagnation point to shift toward X-point and induces density asymmetry between upper and lower divertors
- As density increases, drift-induced asymmetries decrease in the island SOL but persist in the target shadow regions

EUROfusion

Work supported by US Department of Energy grant DE-SC0014529. This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.