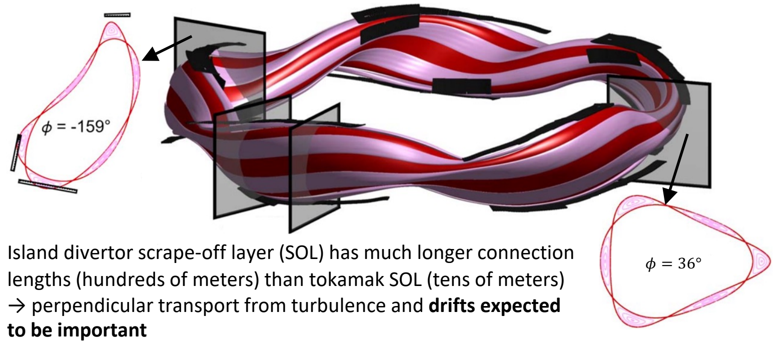
Motivation for studying scrape-off layer drifts

W7-X island divertor: large magnetic islands intersect divertors, exhausting heat and particles from fusion-relevant plasmas

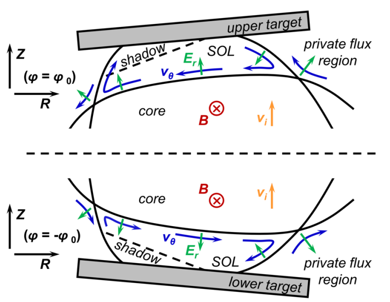


Island divertor scrape-off layer (SOL) has much longer connection lengths (hundreds of meters) than tokamak SOL (tens of meters) → perpendicular transport from turbulence and **drifts expected to be important**

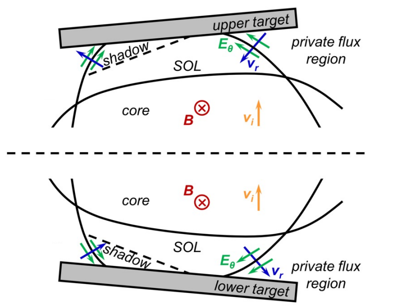
Divertor heat flux deposition profile previously shown to be affected by $\mathbf{E}\times\mathbf{B}$ drifts [K. Hammond et al, PPCF **61** 125001 (2019)]

Goal: Investigate drift flows throughout the scrape-off layer using experimental flow measurements and simplified modelling

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



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

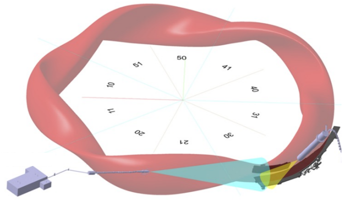


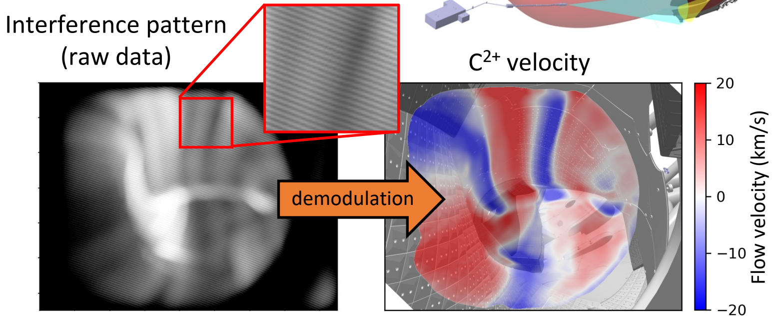
Coherence imaging spectroscopy on W7-X

Coherence imaging spectroscopy (CIS): 2D polarization interferometer that measures impurity emission and flow velocity (usually C III line at 465 nm) [V. Perseo et al, RSI **91** 013501 (2020)]

- ~1 cm spatial resolution
- ~50 ms time resolution

CIS viewing geometry



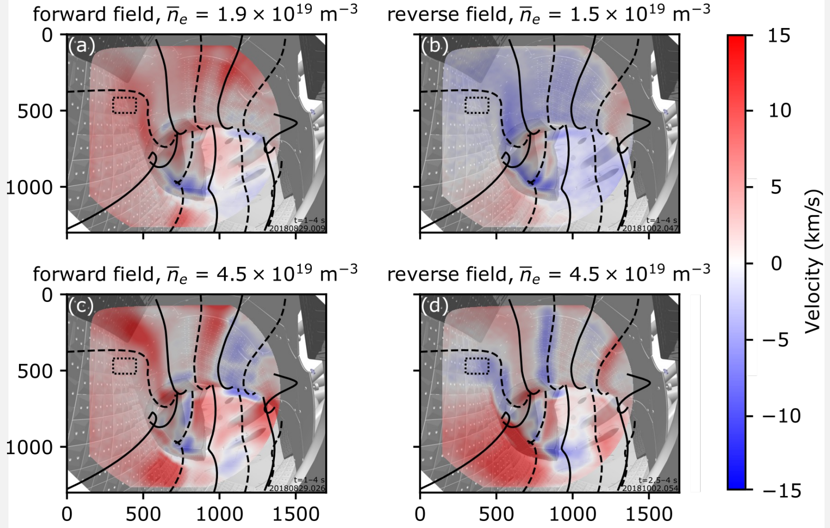


Effects of drifts on CIS flow measurements

Experiment on W7-X was performed to investigate effect of drifts on SOL

- Low-iota magnetic configuration was used as it has lowest error fields and longest connection lengths, maximizing importance of drifts
- Experimental approach: discharges with matched core plasma parameters but **oppositely directed magnetic field → opposite drift direction**

Field reversal experiments show **drifts contribute substantially to SOL flows**



At low density ($n_e < 2\times10^{19}\ \mathrm{m}^{-3}$), measured flow pattern is largely unidirectional and reverses direction when field reverses → drifts strongly affect SOL flows

At high density, CIS measures a counter-streaming flow pattern

- Positions of counter-streaming flow bundles shift when field reverses → drifts affect flow pattern, but effect is smaller than at low density

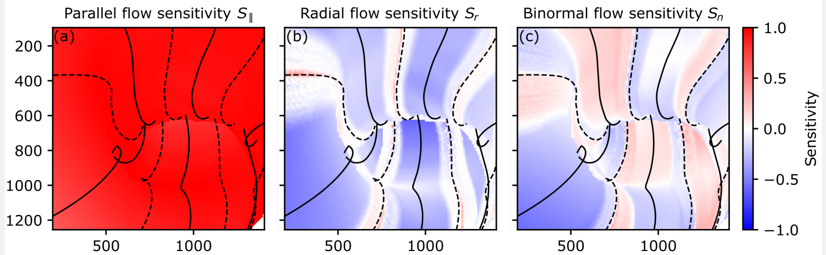
Forward model for CIS flow measurements

A **simple forward model** for CIS flow images is used to aid interpretation of measurements

$$v_{\mathrm{CIS}} = \frac{\int_L \varepsilon\left(v_\parallel \hat{\mathbf{b}} + v_r \hat{\boldsymbol{r}} + v_\theta \widehat{\boldsymbol{\theta}}\right)\cdot \hat{\ell}\, dl}{\int_L \varepsilon\, dl}$$

ε: C III emissivity
$v_\parallel$: C^{2+} parallel velocity
v_r: C^{2+} island radial velocity
v_θ: C^{2+} island poloidal velocity
$\hat{\ell}$: vector for CIS line of sight

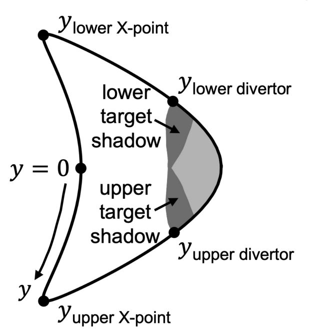
Sensitivity of CIS to each flow component



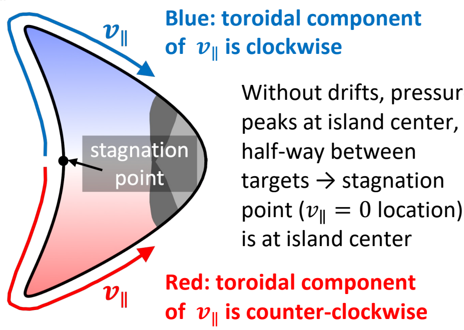
Over entire field of view, CIS is at least 5x more sensitive to parallel flow than perpendicular flow → **CIS observations of flow reversal reflect reversal of parallel flow**

Physics picture of how drifts affect $v_\parallel$

Model geometry



$v_\parallel$ without drifts



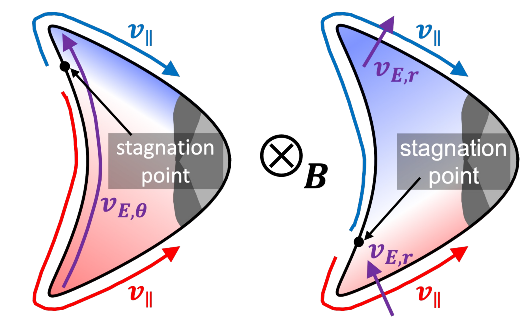
Blue: toroidal component of $v_\parallel$ is clockwise

Without drifts, pressure peaks at island center, half-way between targets → stagnation point ($v_\parallel = 0$ location) is at island center

Red: toroidal component of $v_\parallel$ is counter-clockwise

$v_\parallel$ with poloidal drift

$v_\parallel$ with radial drift



Drift transport causes particles to build up in upper or lower half of island → stagnation point shifts poloidally from island center toward X-point → $v_\parallel$ now has preferential direction throughout majority of island

Poloidal $\mathbf{E}\times\mathbf{B}$ drift transports particles poloidally → stagnation point shifts in same direction as drift

Radial $\mathbf{E}\times\mathbf{B}$ drift creates asymmetric transport between island SOL and private flux region → stagnation point shifts toward half of island where $v_{E,r}$ transports particles into SOL

Simple SOL drift model

To interpret experimental measurements, the island SOL is modelled as a **1D simple SOL with poloidal $\mathbf{E}\times\mathbf{B}$ drifts**

Simple SOL: $\nabla_\parallel T = 0$, no currents, no ionization in SOL

- Strictly only applies to low-density plasmas in sheath-limited regime; less accurate at higher density

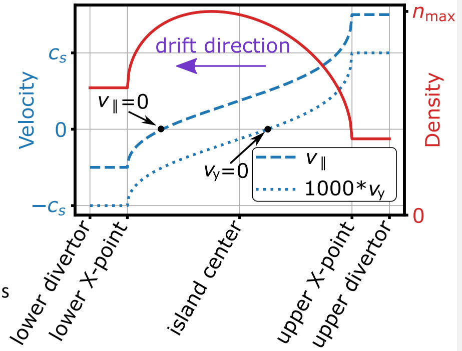
1D model in island poloidal direction: $v_y = \Theta v_\parallel + v_{E\times B,\theta}$

- Θ: island internal field line pitch; key parameter governing importance of ∥ vs ⊥ transport

Key model results/insights:

- Drift strength: $\gamma = v_{E\times B,\theta}/\left(2c_s \tan\theta_p\right)$
- 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)

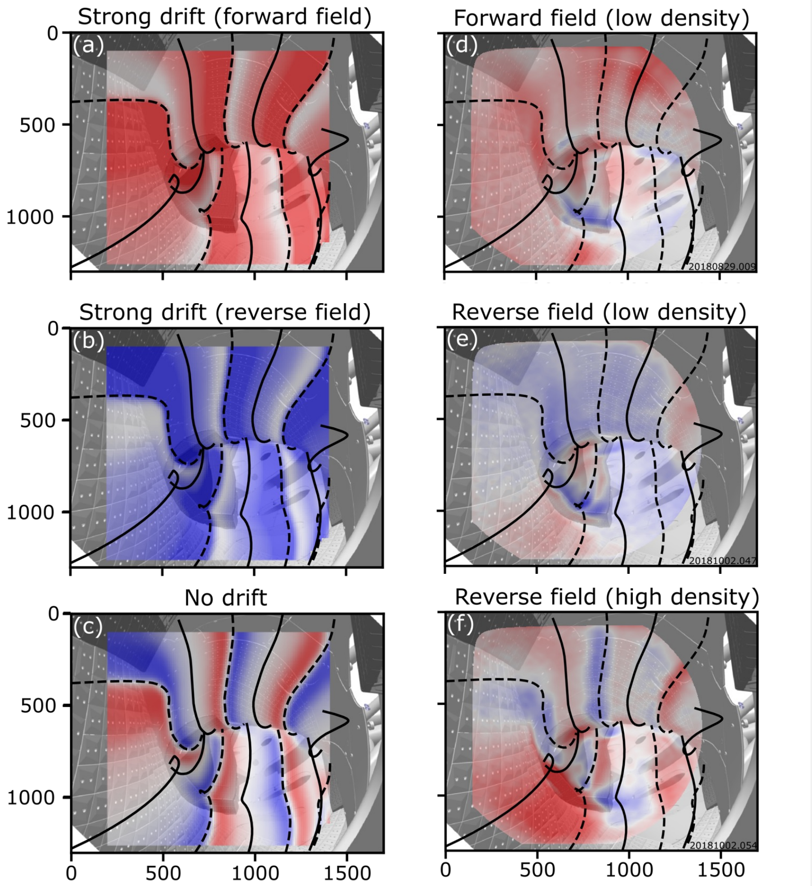
Velocity and density poloidal profiles from model



Comparison between model and measurements

Synthetic flow images from simple SOL drift model

Experimental flow images measured by CIS



At low density, both model and experimental measurements show near-unidirectional flow that is consistent in direction → drifts cause substantial shift of stagnation point

At high density, drift transport becomes less important, causing the near-unidirectional flow pattern to transition to a counter-streaming flow pattern

Conclusions

- CIS measurements from field-reversal experiments show that drifts affect SOL parallel flow, especially at low density
- A forward model for CIS and a simple SOL drift model are developed to interpret experimental measurements and understand how drifts affect parallel flows
- Modelled flow images agree in sign and broad spatial structure with experimental measurements, implying that drifts induce a substantial shift of the parallel flow stagnation point in low-density ($n_e < 2\times10^{19}\ \mathrm{m}^{-3}$) conditions
- Drift effects decrease with increasing density

EUROfusion

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