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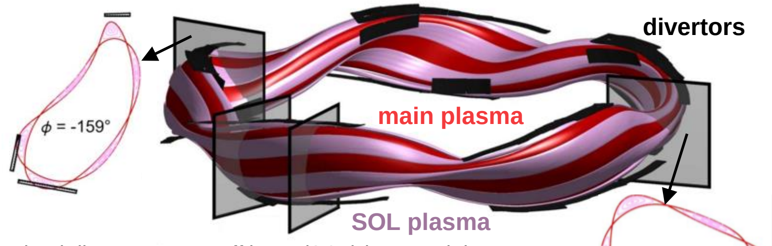
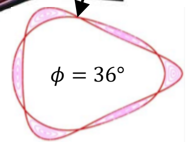
Drift effects and ion temperature measurements in the scrape-off layer of the W7-X stellarator

The W7-X island divertor scrape-off layer

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





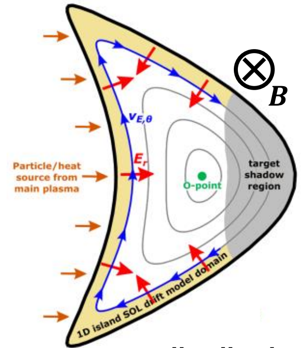
Island divertor scrape-off layer (SOL) has much longer connection lengths (hundreds of meters) than tokamak SOL (tens of meters) → perpendicular transport from turbulence and **drifts expected to be important**

Drifts shown to affect target particle/heat fluxes [K. Hammond et al., PPCF (2019)] and dominate energy transport at low density [E. Flom invited talk, Friday morning]

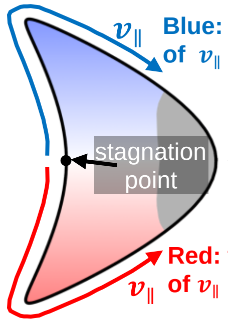
How do drifts affect SOL parallel flows? [D.M. Kriete et al., NF (2023)]

Model for how $\mathbf{E}\times\mathbf{B}$ drift affects SOL $v_\parallel$

Poloidal $\mathbf{E}\times\mathbf{B}$ drift direction



$v_\parallel$ distribution without drift

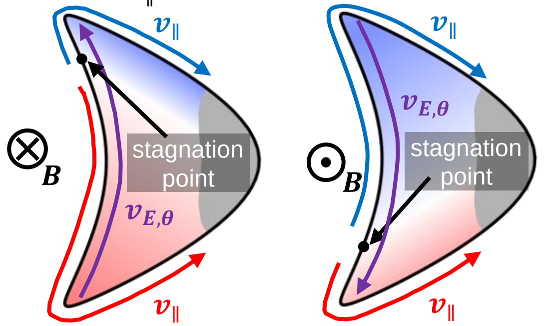


Blue: toroidal component of $v_\parallel$ is clockwise

No drifts → pressure peaks at island center → stagnation point ($v_\parallel = 0$ location) at island center

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

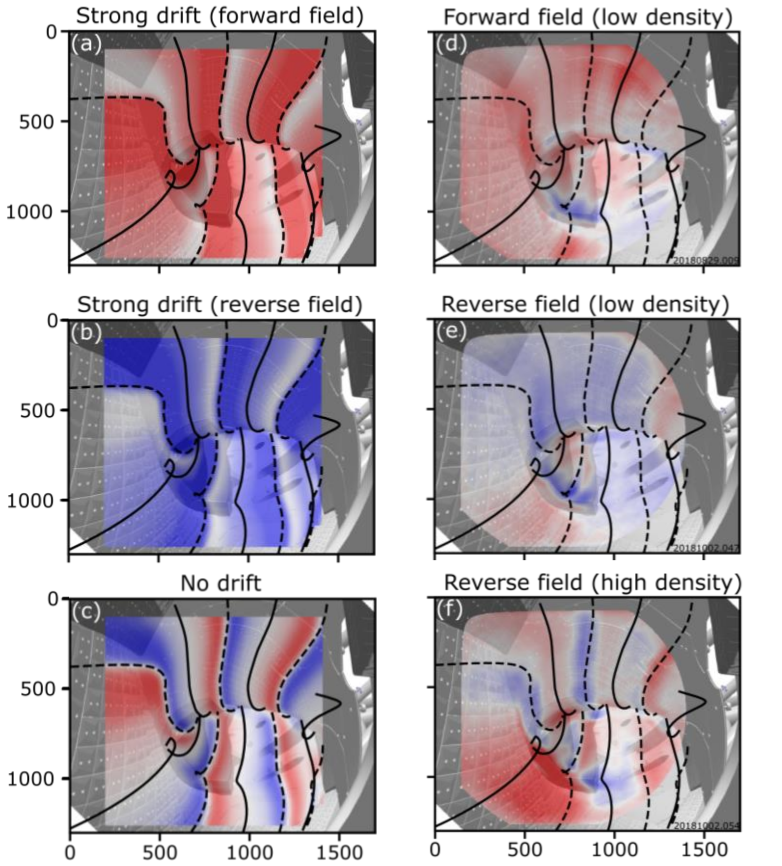
$v_\parallel$ distribution with drift



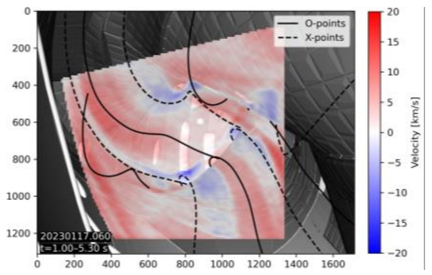
Drift transport causes particles to build up in upper or lower half of island → stagnation point shifts poloidally from island center toward X-point in drift direction → $v_\parallel$ now near-unidirectional throughout most of island

Drift model vs measurement comparison

Synthetic flow images from simple SOL drift model | **Experimental flow images measured by CIS**



- At low density, both model and measurements show near-unidirectional flow that is consistent in direction with drift transport
- At high density, drifts become weaker, causing near-unidirectional flow pattern to transition to a counter-streaming flow pattern



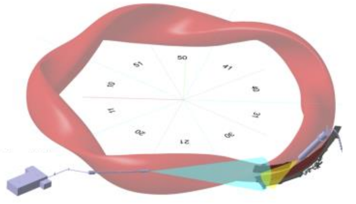
Counter-streaming flows observed at low density in magnetic configuration with shorter connection lengths → drift effects decrease with decreasing connection length

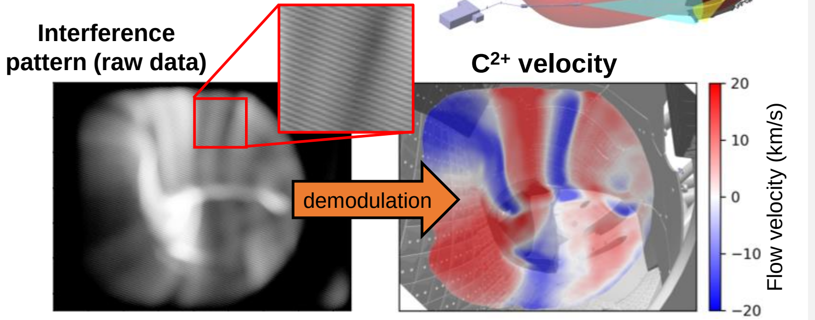
Coherence imaging spectroscopy

Coherence imaging spectroscopy (CIS): 2D polarization interferometer that measures impurity emission and flow velocity (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



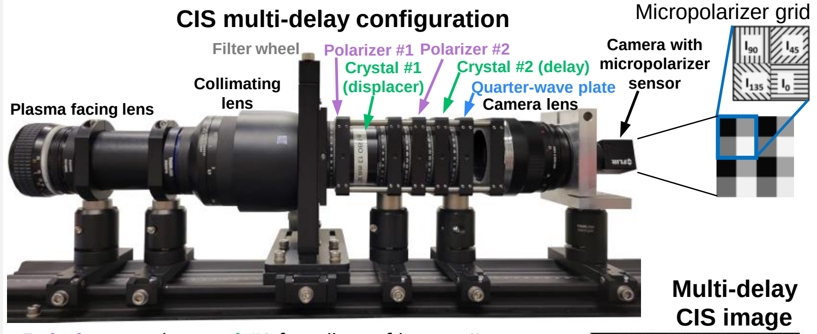


Multi-delay CIS for SOL T_i measurements

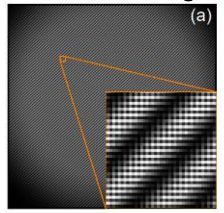
Multi-delay CIS configuration [J.S. Allcock et al., RSI (2021)] enables T_i measurements in SOL (Doppler broadening & Zeeman splitting important)

- Standard CIS: coherence measured at one interferometer delay → limited spectral information → suitable for simple line shapes (Doppler only)
- Multi-delay CIS: coherence measured at **four interferometer delays** → more spectral information → can resolve more complex line shapes (Doppler + Zeeman)

CIS multi-delay configuration



Multi-delay CIS image



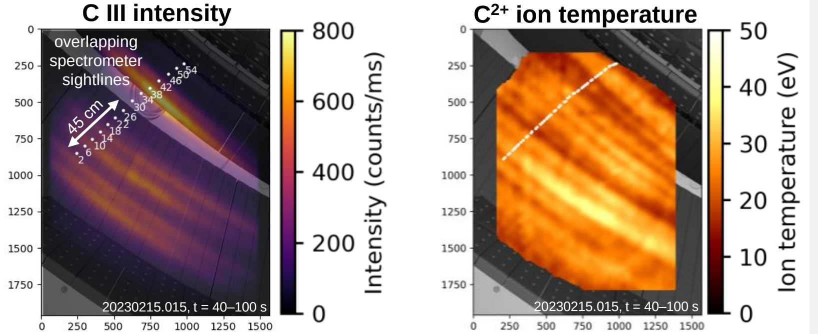
Polarizers and **crystal #1** form linear fringe pattern → coherence encoded at delay $\hat{N}_1$

Crystal #2, **quarter-wave plate**, and **polarization camera** form pixelated fringe pattern → coherence encoded at delay $\hat{N}_2$

Linear & pixelated fringe patterns multiplied together → coherence encoded at delays $\hat{N}_1 + \hat{N}_2$ and $\hat{N}_1 - \hat{N}_2$

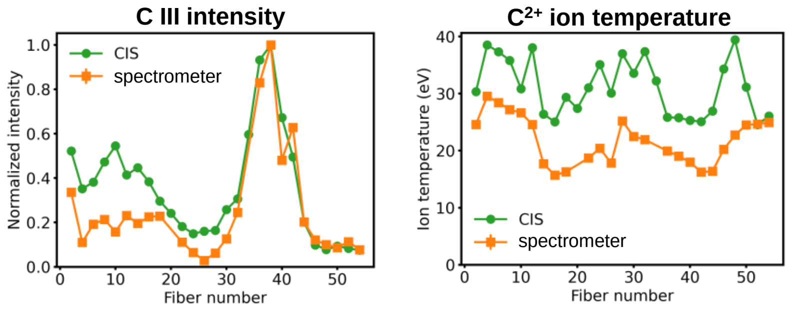
Validation of CIS T_i measurements

Initial multi-delay CIS measurements in W7-X long-pulse plasma



- C III radiation and C^{2+} T_i exhibit toroidally elongated structures
- Inverse correlation between C III radiation and T_i
- $T_i = 15–45$ eV over divertor

Comparison between multi-delay CIS and high-resolution spectrometer



- C III radiation and C^{2+} T_i show similar spatial variation across row of fibers
- CIS T_i is systematically 30% higher than spectrometer T_i

Conclusions

- Coherence imaging spectroscopy provides measurements of impurity ion flow velocity and temperature in the W7-X island divertor scrape-off layer
- Flow measurements in field-reversal experiments show that poloidal $\mathbf{E}\times\mathbf{B}$ drift alters the parallel flow, especially in low-density conditions
- Flow images are interpreted with a simple SOL drift model → poloidal $\mathbf{E}\times\mathbf{B}$ drift induces shift of parallel flow stagnation point by altering island density distribution
- New multi-delay CIS technique provides images of T_i near divertor, comparison against spectrometer shows similar trends and 30% offset

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