Drift effects in the scrape-off layer of W7-X

Matt Kriete[1]

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AUBURN UNIVERSITY

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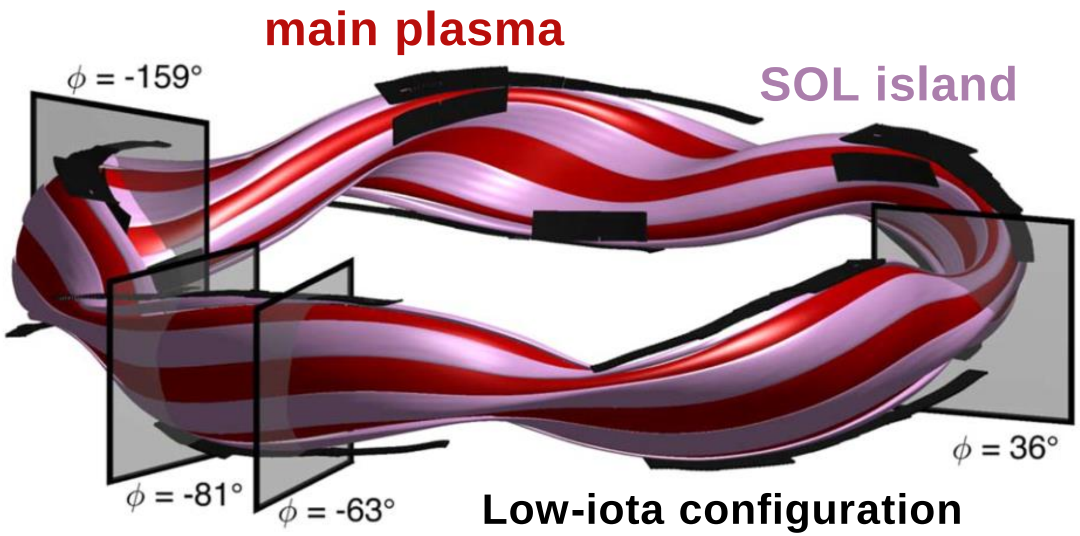
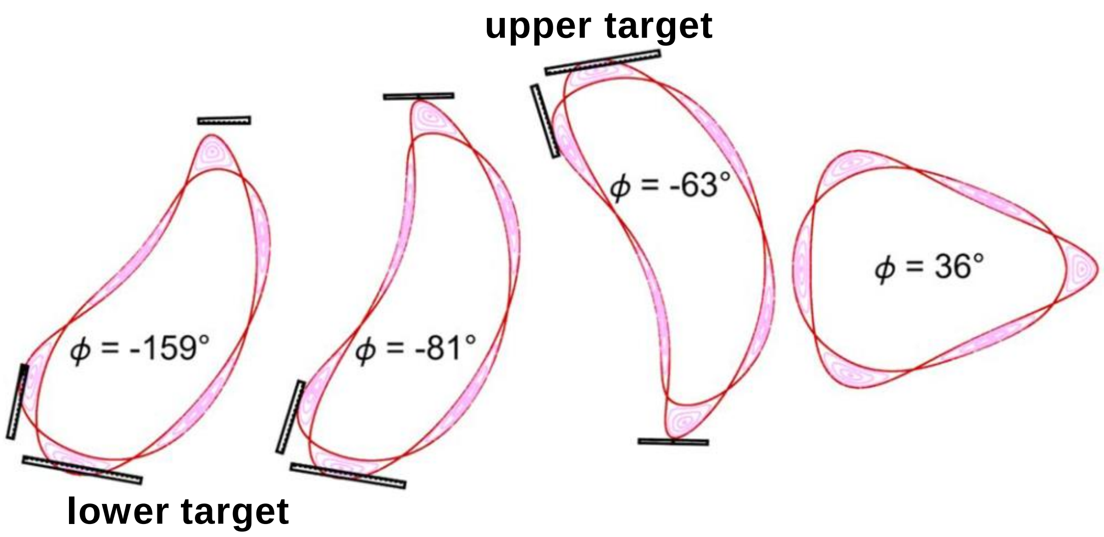
Wendelstein 7-X

Drifts impact scrape-off layer transport and plasma-wall interactions

- W7-X utilizes an island divertor: scrape-off layer (SOL) formed by intersection between magnetic islands and divertor targets
- Island divertor SOL has long connection lengths (~100x larger than tokamak SOL) → ⊥ transport stronger than ∥ transport
- $E \times B$ drifts are an important ⊥ transport mechanism → can impact SOL plasma distribution and heat/particle loads on plasma facing components
  - Previous work has shown poloidal $E \times B$ drifts alter heat flux distribution on divertor in W7-X[1]
- Goal: understand how drifts affect SOL transport



Low-iota configuration

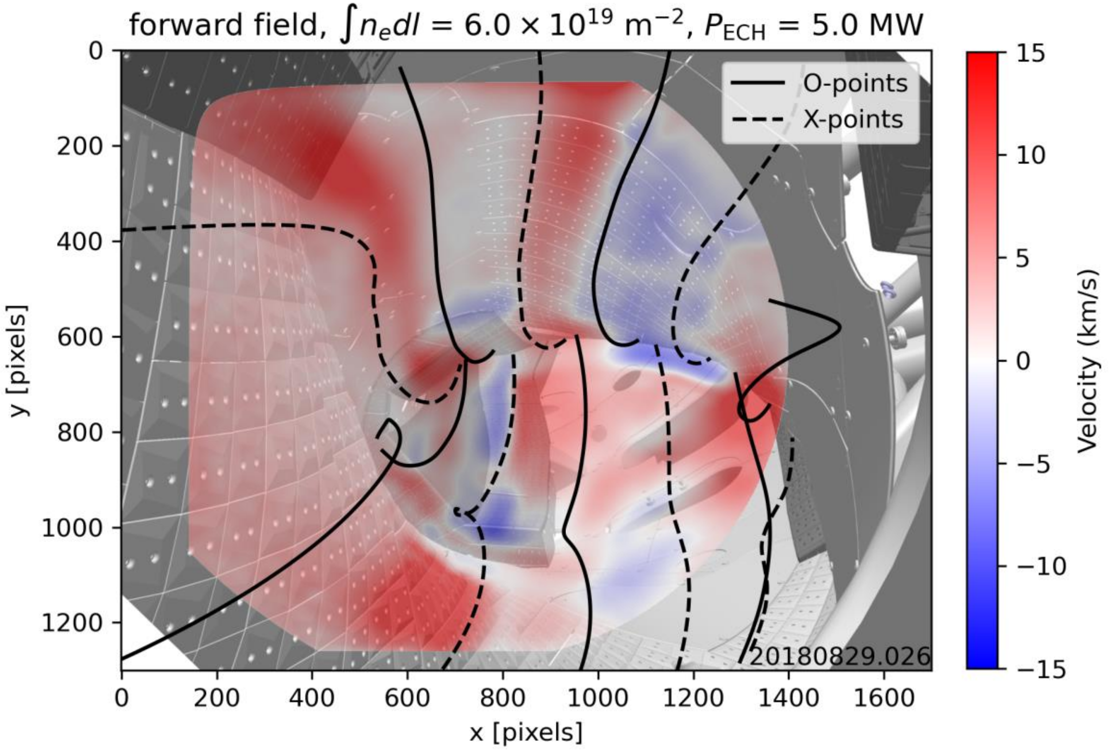


[1]K.C. Hammond et al, PPCF **61** 125001 (2019)

Coherence imaging spectroscopy measurements show drifts alter SOL parallel flows

- Coherence imaging spectroscopy (CIS): camera-based interferometer measuring carbon impurity flows in the SOL
- High-density plasmas exhibit counter-streaming flow patterns aligned with SOL islands
- Counter-streaming flow pattern changes upon field reversal → indication of drift effects
- Low-density plasmas instead exhibit near-unidirectional flow throughout and across multiple islands
  - Flow direction reverses with field → drifts responsible for near-unidirectional flow pattern

CIS velocity measurements (forward field, high density)



D.M. Kriete et al, NF **63** 026022 (2023)

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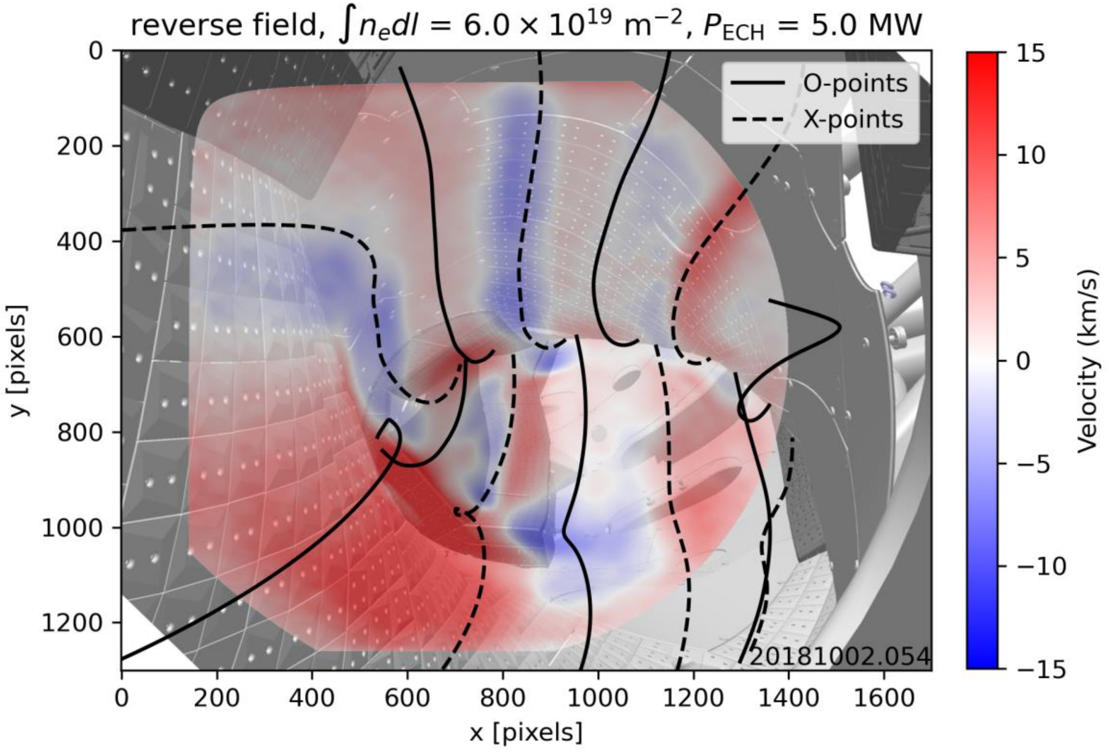

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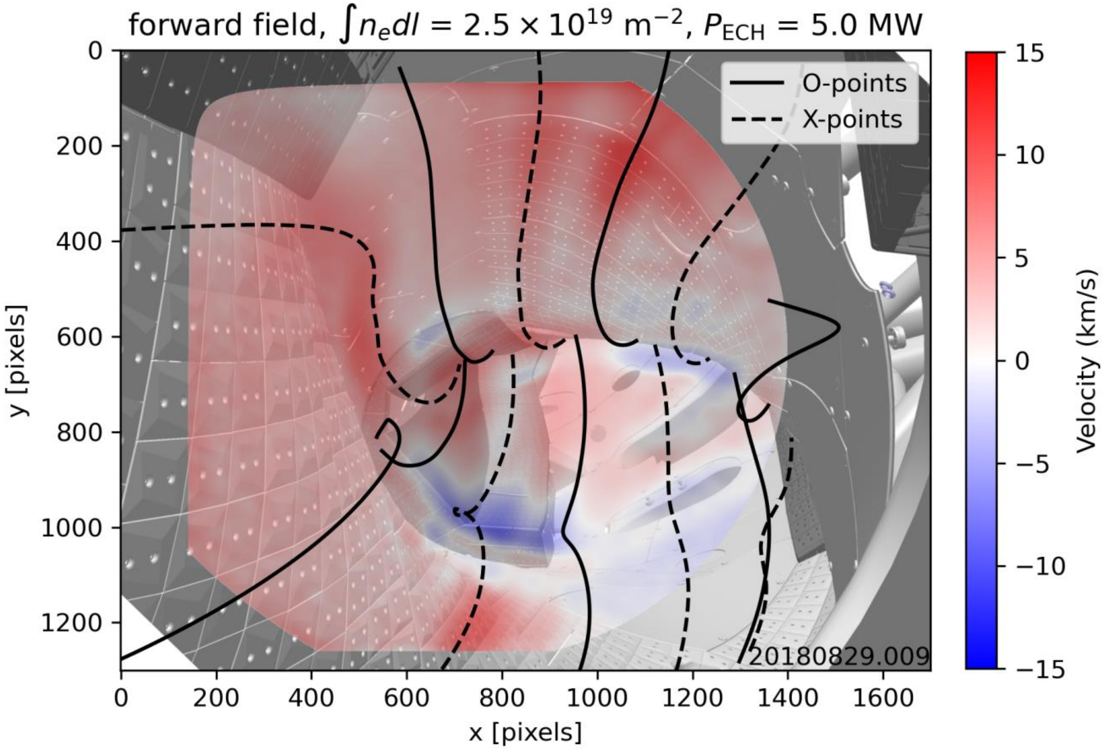

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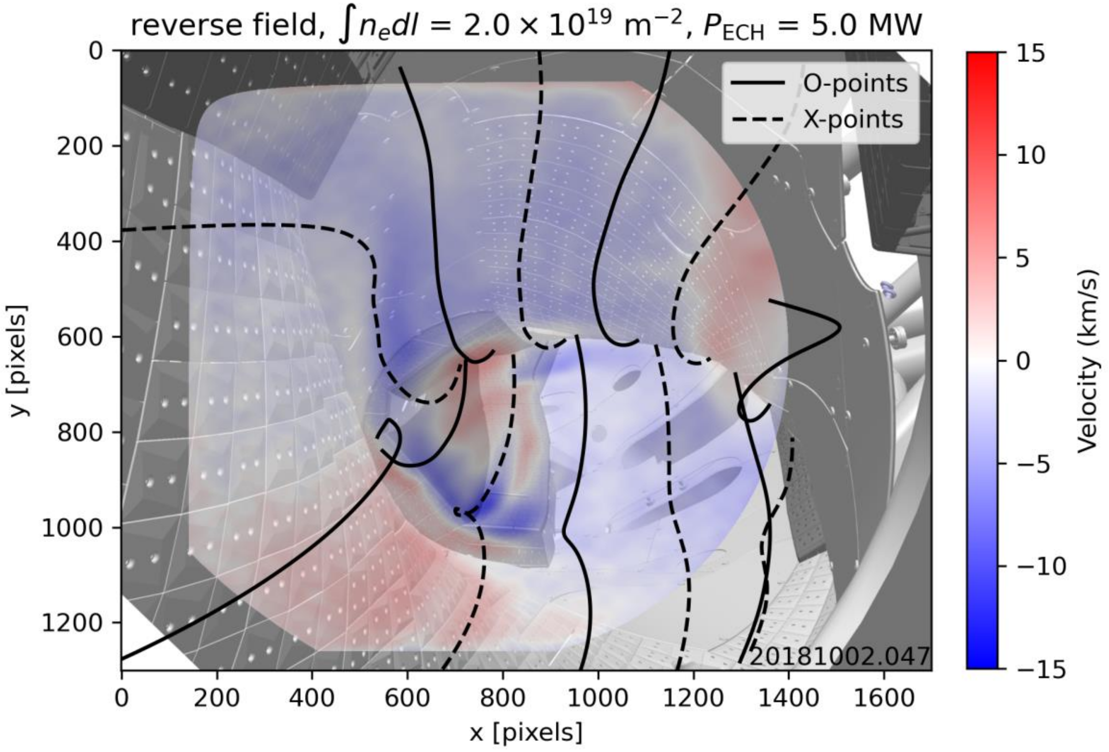


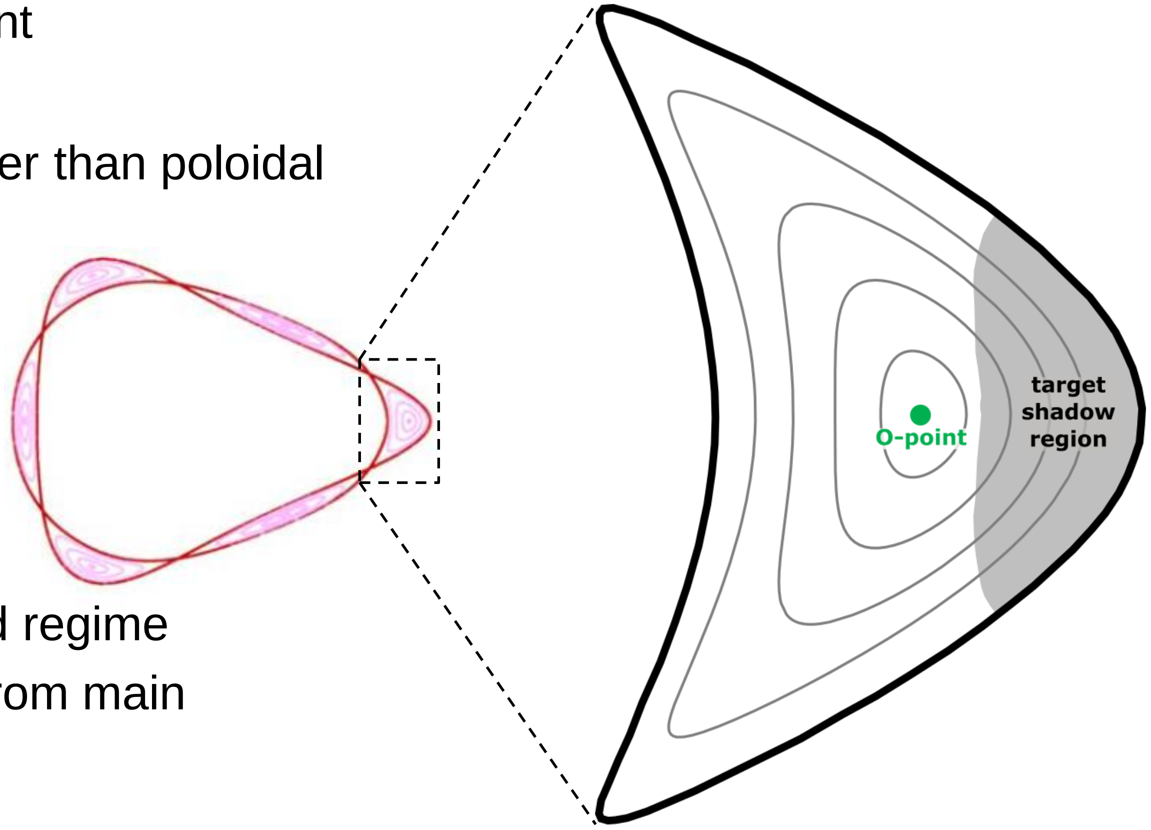
D.M. Kriete et al, NF **63** 026022 (2023)

A 1D island SOL drift model is developed to understand how drifts affect parallel flows

- Poloidal $E \times B$ drifts directions in the island SOL
  - E_r tends to point ⊥ to island flux surfaces in direction of O-point
  - $v_{E,\theta}$ transports particles poloidally about island O-point

- Radial $E \times B$ and diamagnetic drifts expected to be weaker than poloidal $E \times B$ drift for the low-density plasmas being investigated

- 1D island SOL drift model
  - Geometry: 1D in island poloidal direction, focus on outermost island flux surfaces
  - Main assumptions:
    - constant T_e along each field line → sheath-limited regime
    - particle/energy sources dominated by transport from main plasma
    - constant drift velocity



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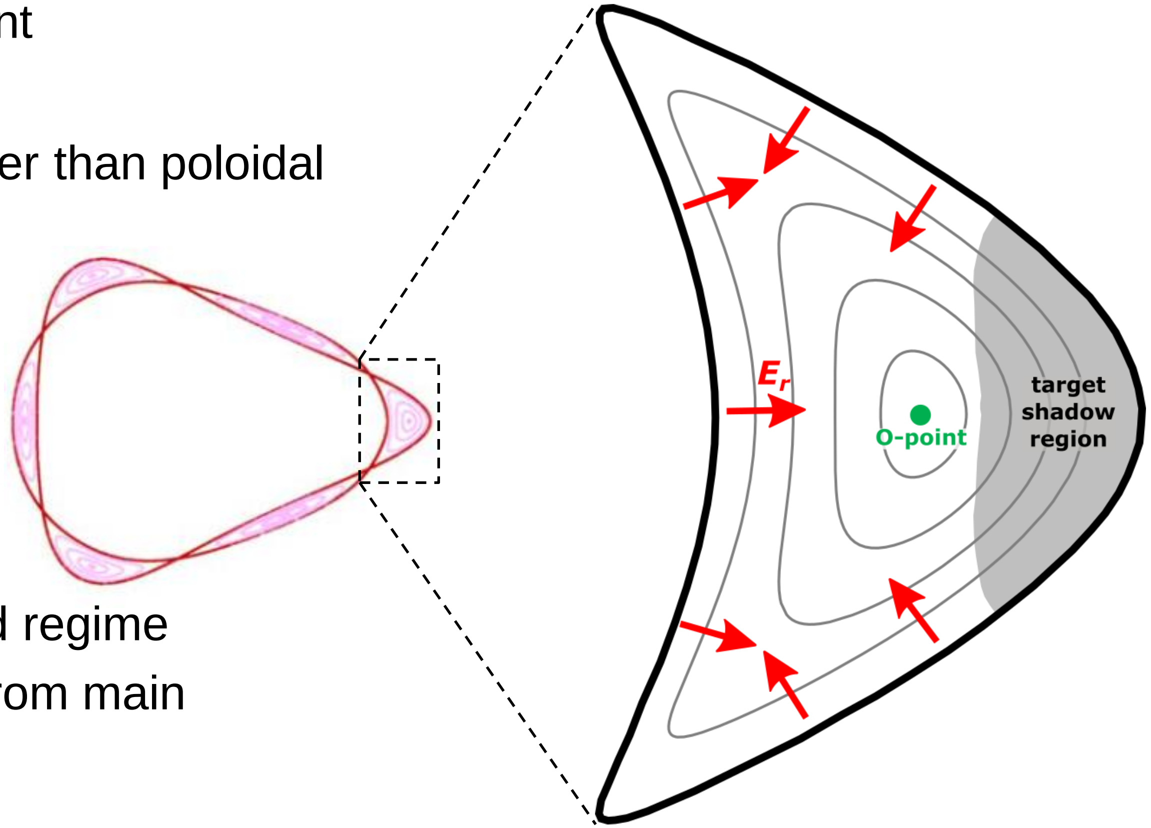

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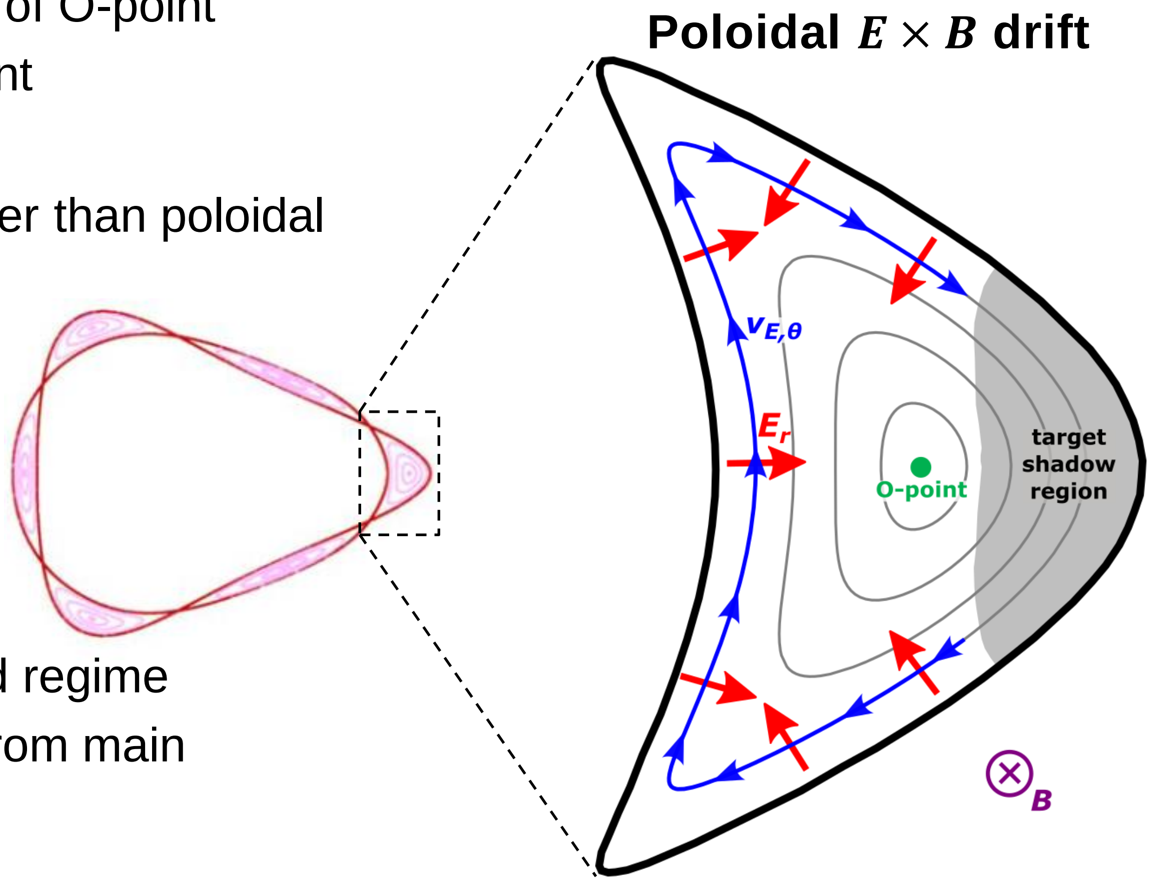

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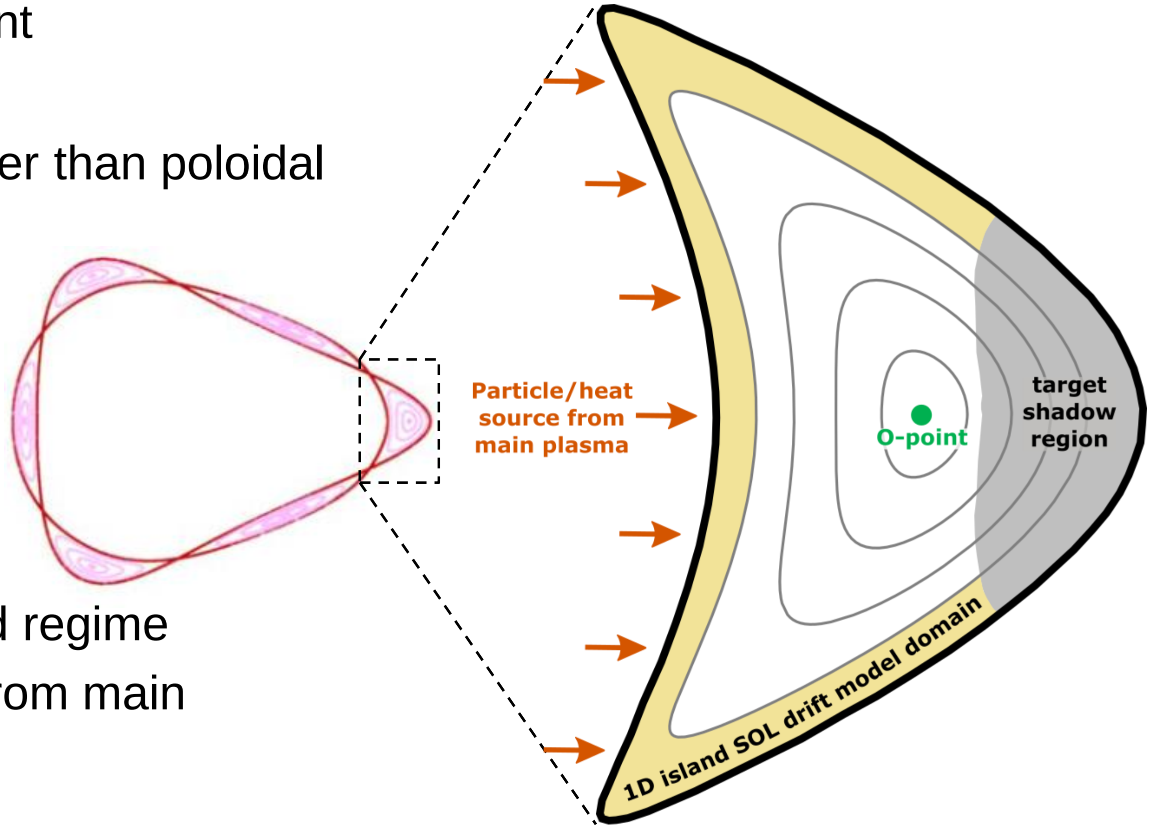
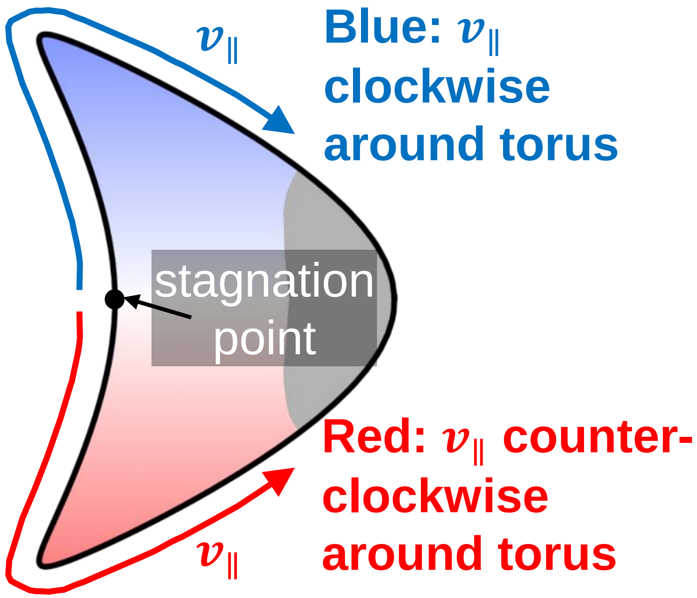


$\mathrm{E} \times \mathrm{B}$ drifts are predicted to alter the SOL pressure distribution, resulting in a poloidal shift of the parallel flow stagnation point

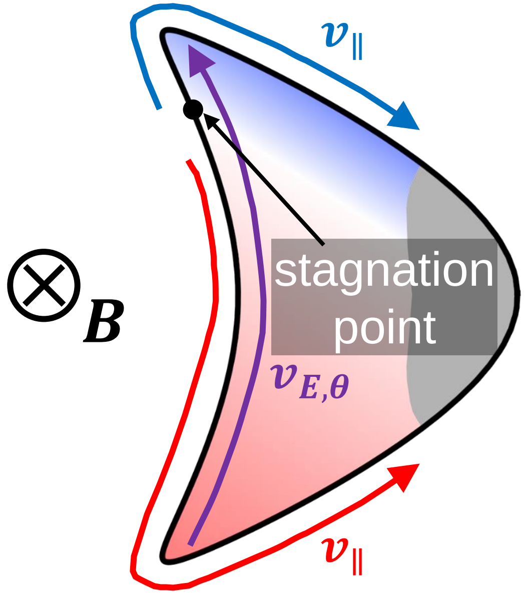
Parallel flow in island without drifts



Poloidal transport in islands exclusively driven by poloidal component of $v_\parallel$

Stagnation point at island center (halfway between targets)

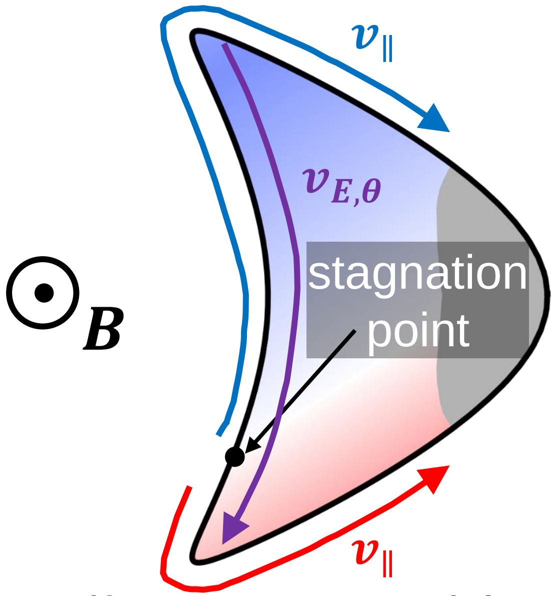
Parallel flow in island with poloidal drift (forward field)



Drift transports particles poloidally → density buildup in upper half of island

Stagnation point shifts toward upper half of island

Parallel flow in island with poloidal drift (reverse field)



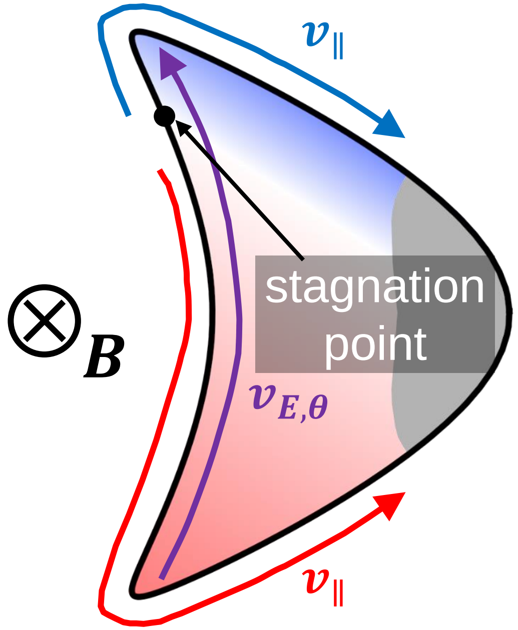
Drift transports particles poloidally → density buildup in lower half of island

Stagnation point shifts toward lower half of island

CIS measurements showing near-unidirectional flow at low density are consistent with poloidal $E \times B$ drift transport

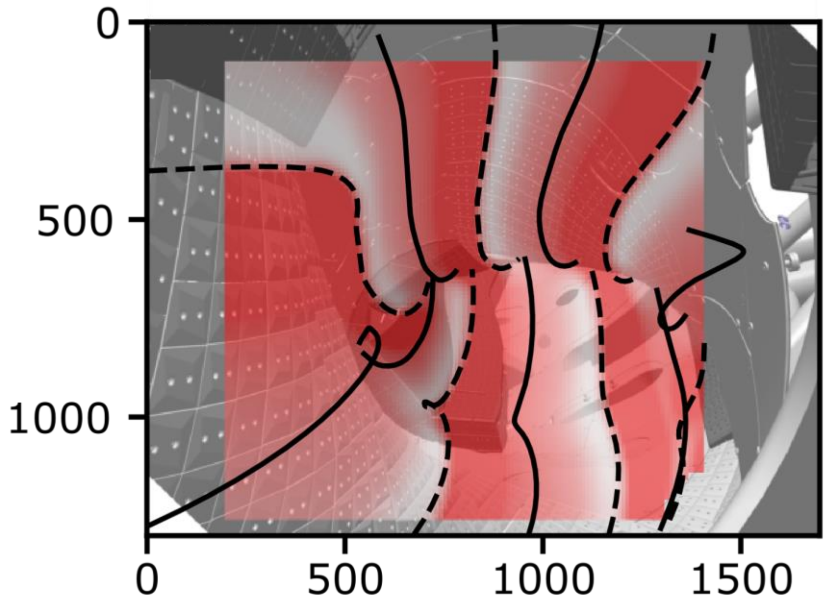
Wendelstein 7-X

Drift model prediction for forward field



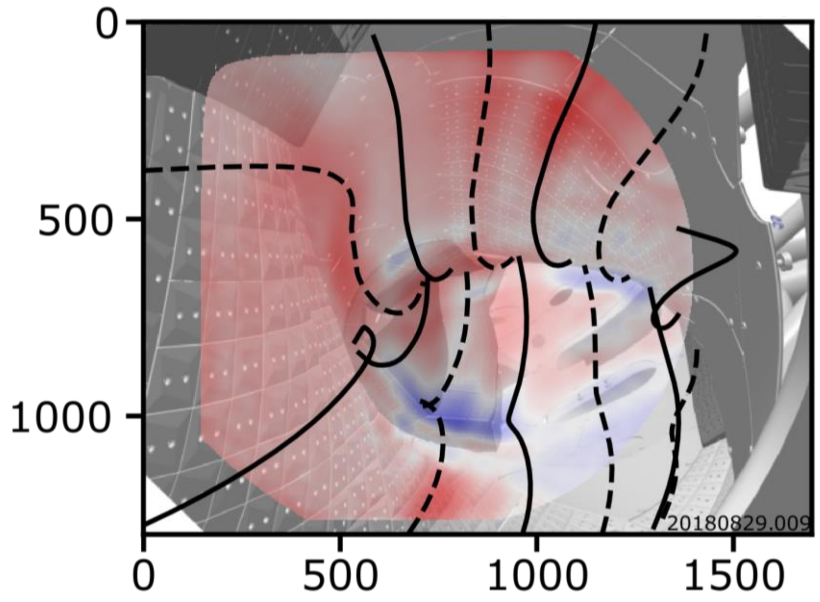
Model predicts that $v_{E,\theta}$ will cause stagnation point to shift poloially clockwise → over most of island $v_{\parallel}$ is in **red** direction

Expected CIS image based on drift model prediction (forward field)



For $v_{E,\theta} \gtrsim 100\ \mathrm{m/s}$, model predicts that CIS will observe a near-unidirectional flow pattern in counter-clockwise (**red**) direction

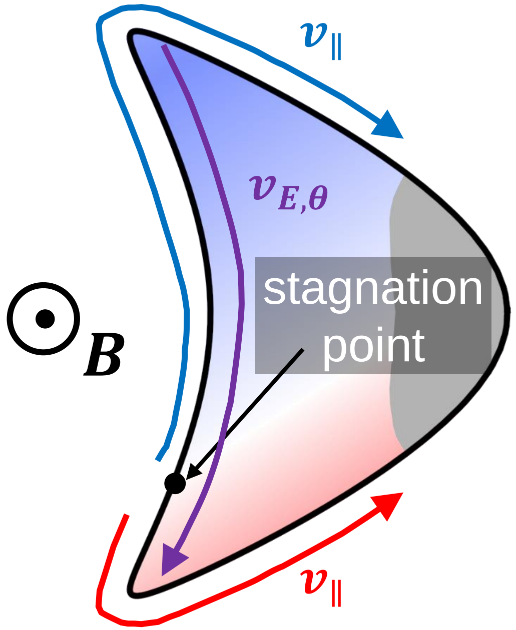
CIS measurements in low-density plasmas (forward field)



CIS image at low density is largely **red**, consistent with prediction

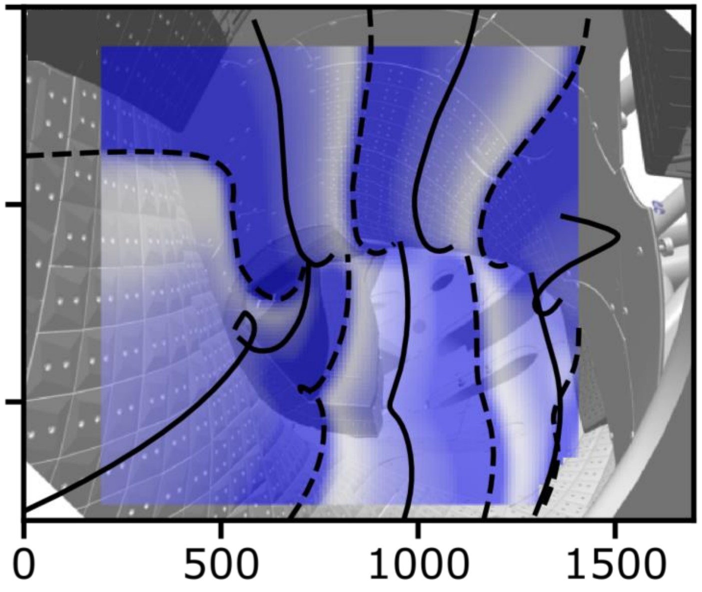
CIS measurements showing near-unidirectional flow at low density are consistent with poloidal $\mathrm{E} \times \mathrm{B}$ drift transport

Drift model prediction for reverse field



Model predicts that $v_{E,\theta}$ will cause stagnation point to shift poloially counter-clockwise → over most of island $v_{\parallel}$ is in **blue** direction

Expected CIS image based on drift model prediction (reverse field)



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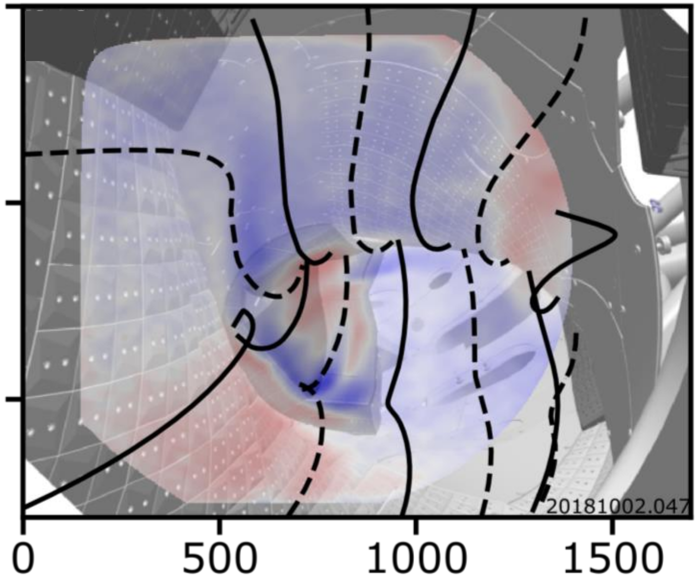
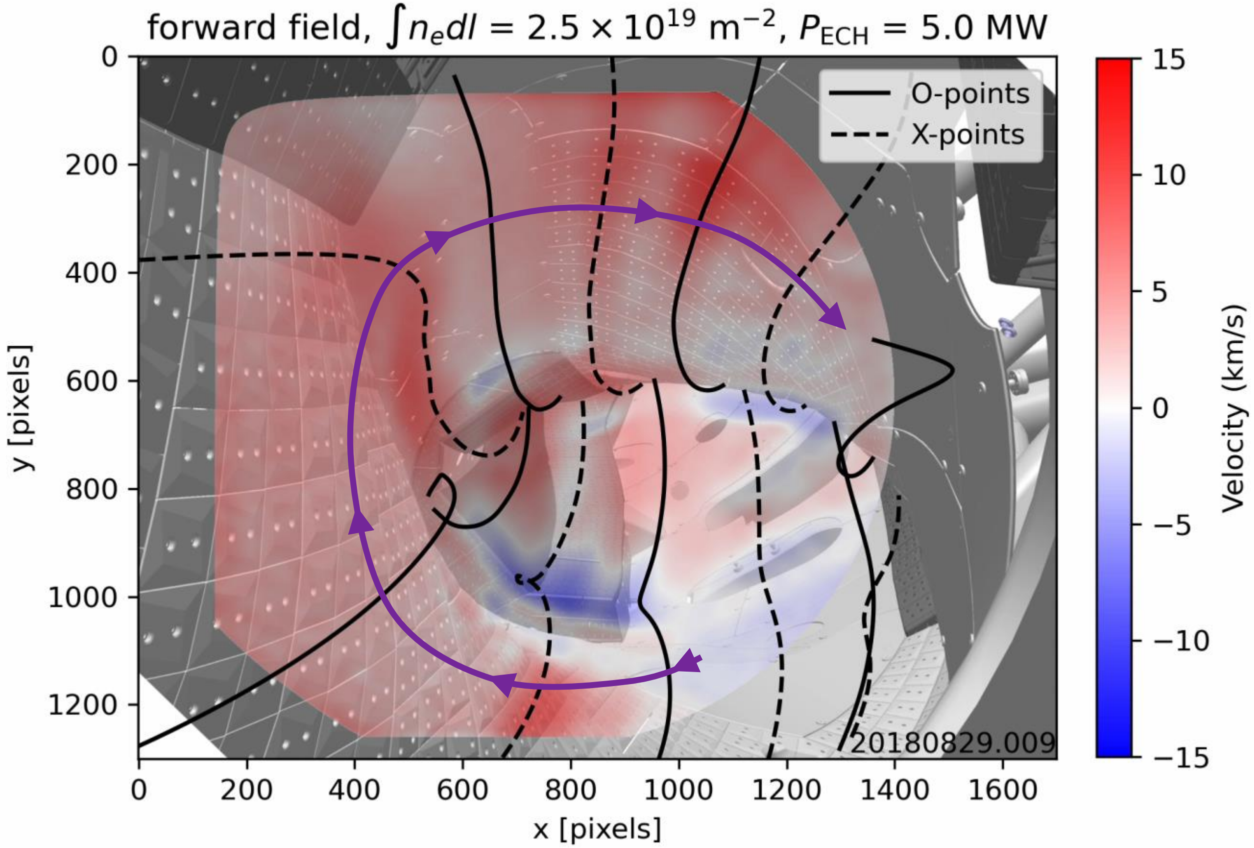


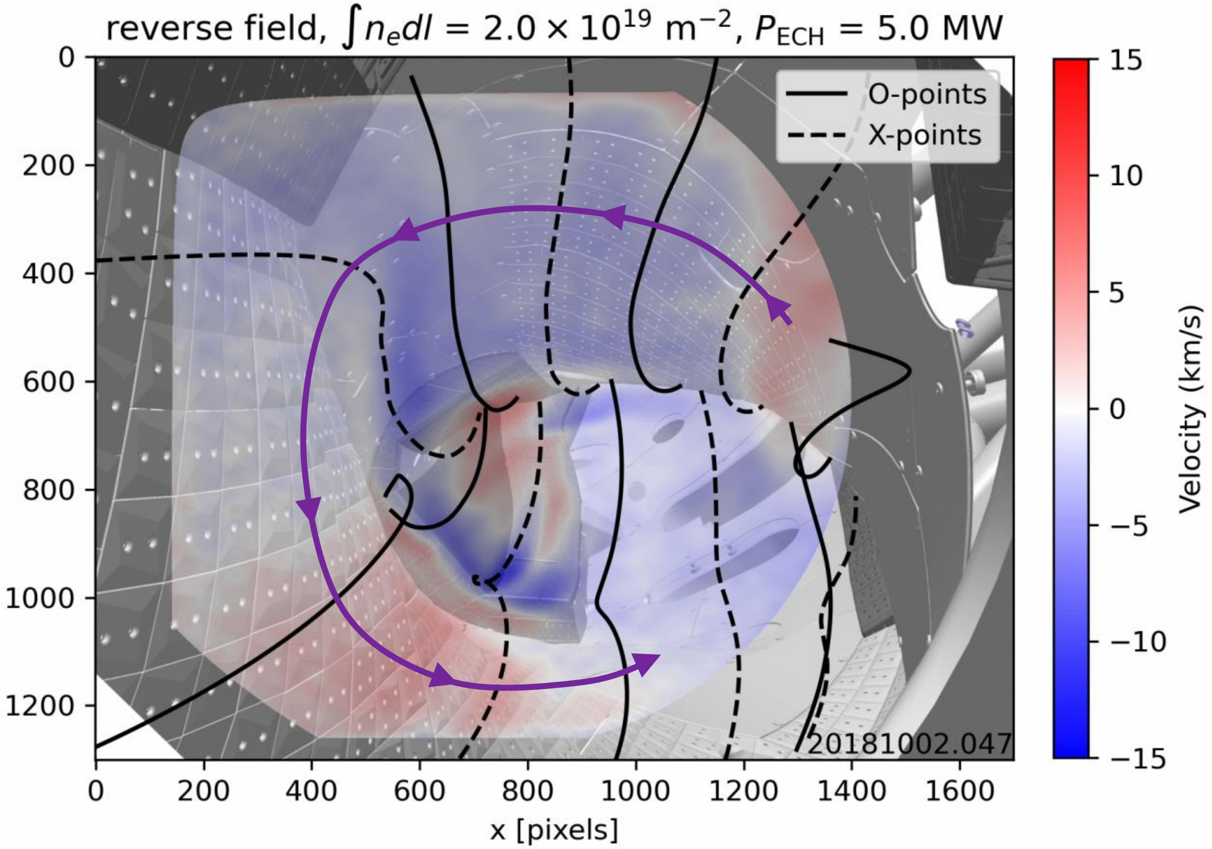
CIS image at low density is largely **blue**, consistent with prediction

In high-density plasmas drifts cause the flow stagnation points to shift position

Forward field: flow bundles rotate clockwise with increasing density

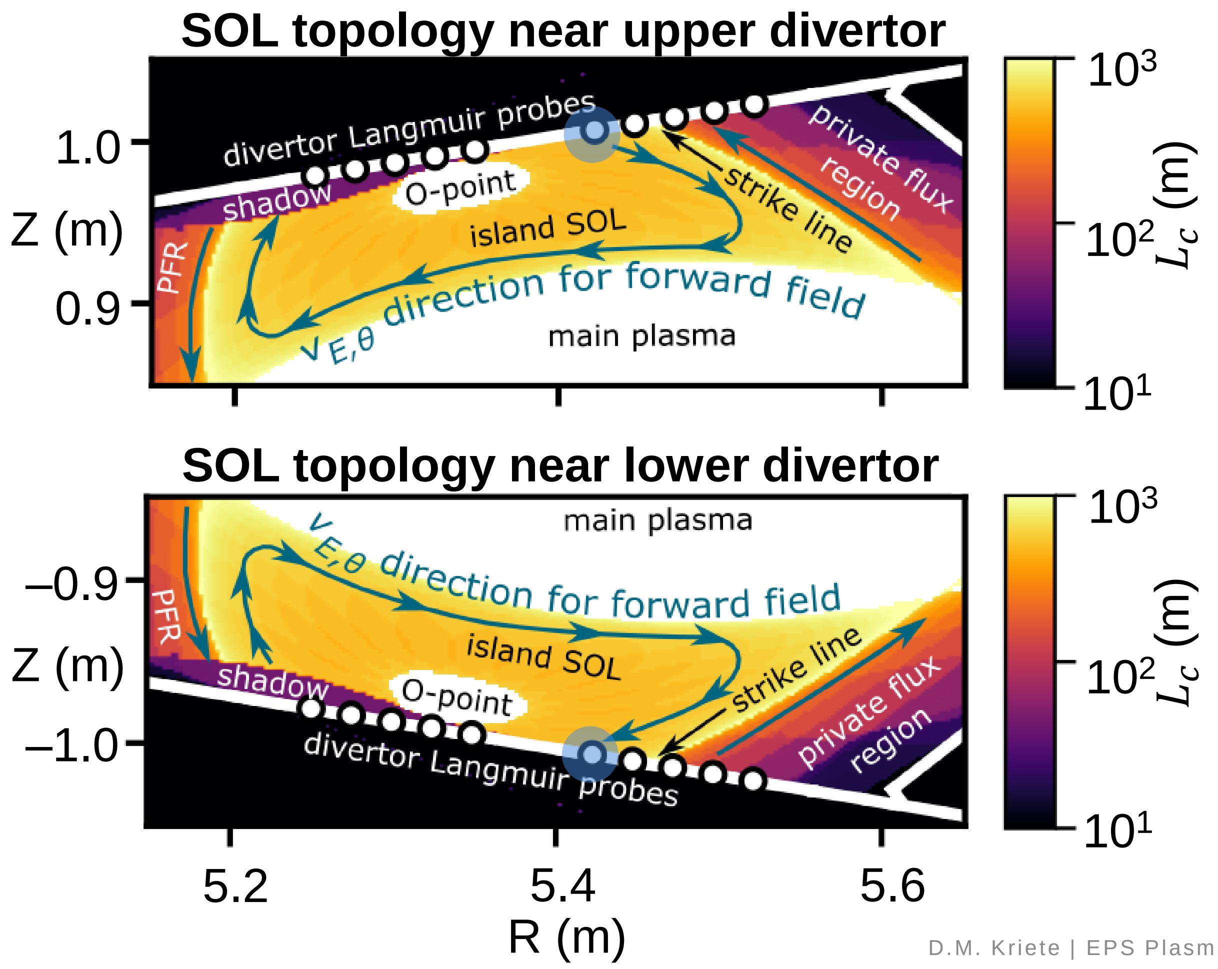


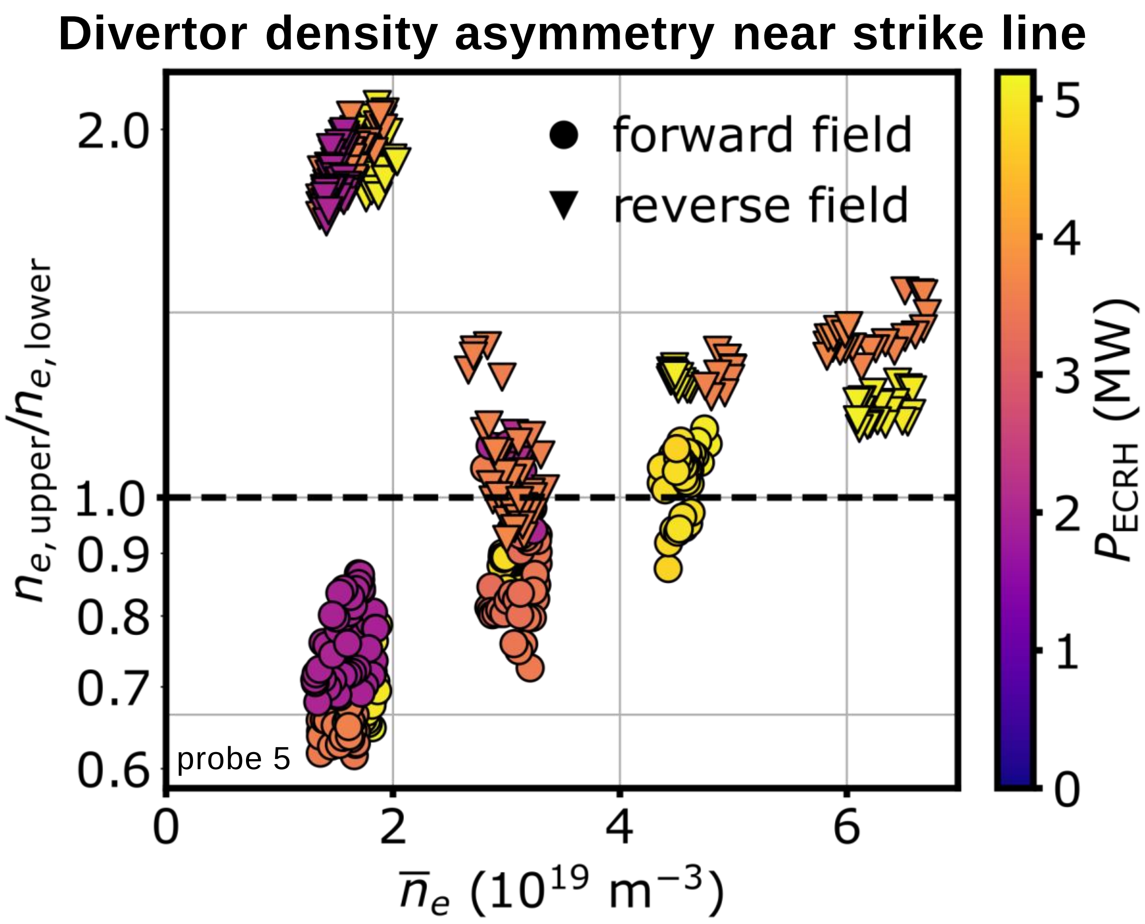
Reverse field: flow bundles rotate counter-clockwise with increasing density



Poloidal $\mathrm{E} \times \mathrm{B}$ drift induces density asymmetries between upper and lower divertors

$v_{E,\theta}$ expected to asymmetrically transport particles toward upper vs lower divertors





- Large upper/lower divertor n_e asymmetry consistent with $v_{E,\theta}$ observed for $\bar{n}_e < 2 \times 10^{19}\ \mathrm{m}^{-3}$
- Asymmetry decreases substantially with increasing $\bar{n}_e$

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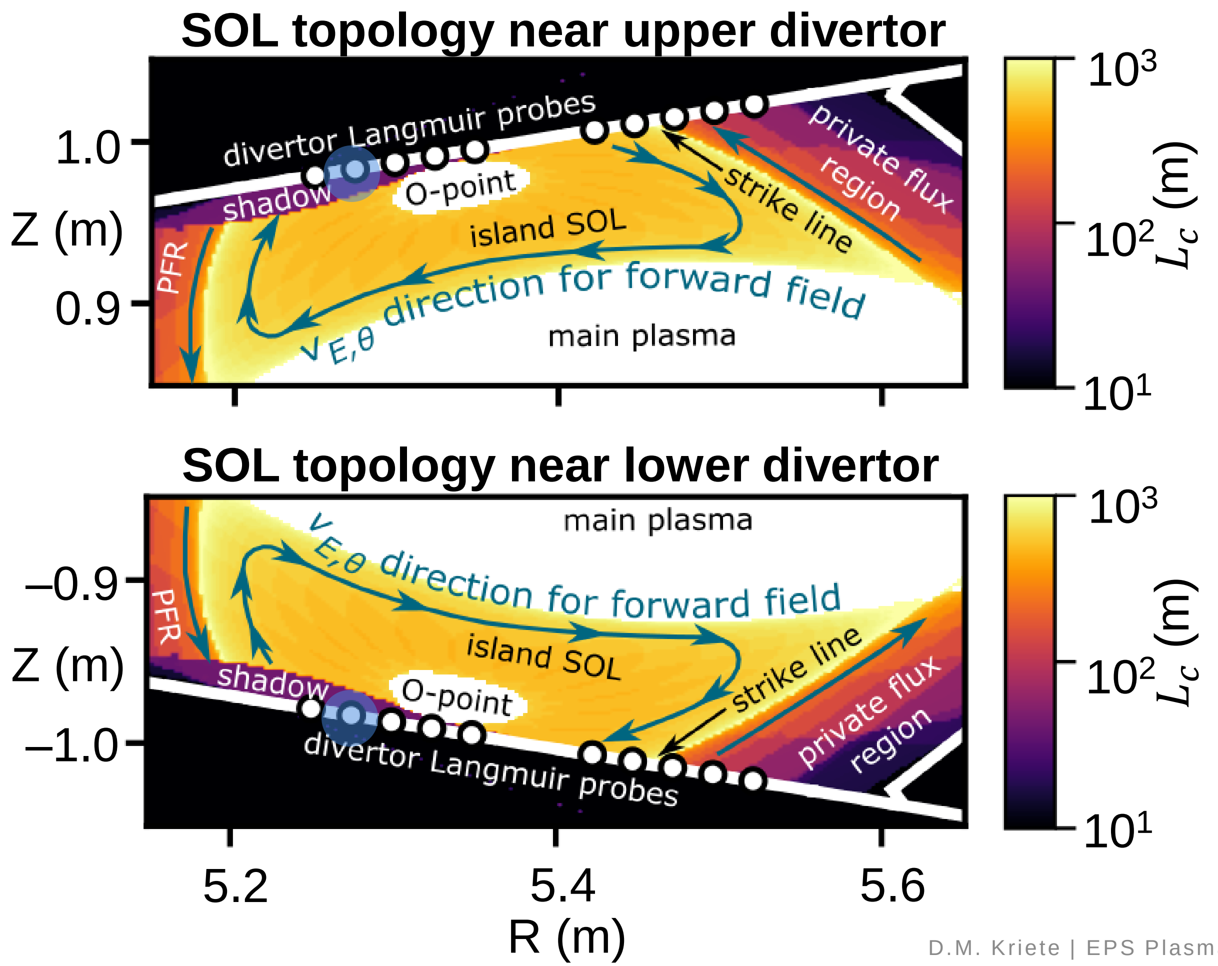
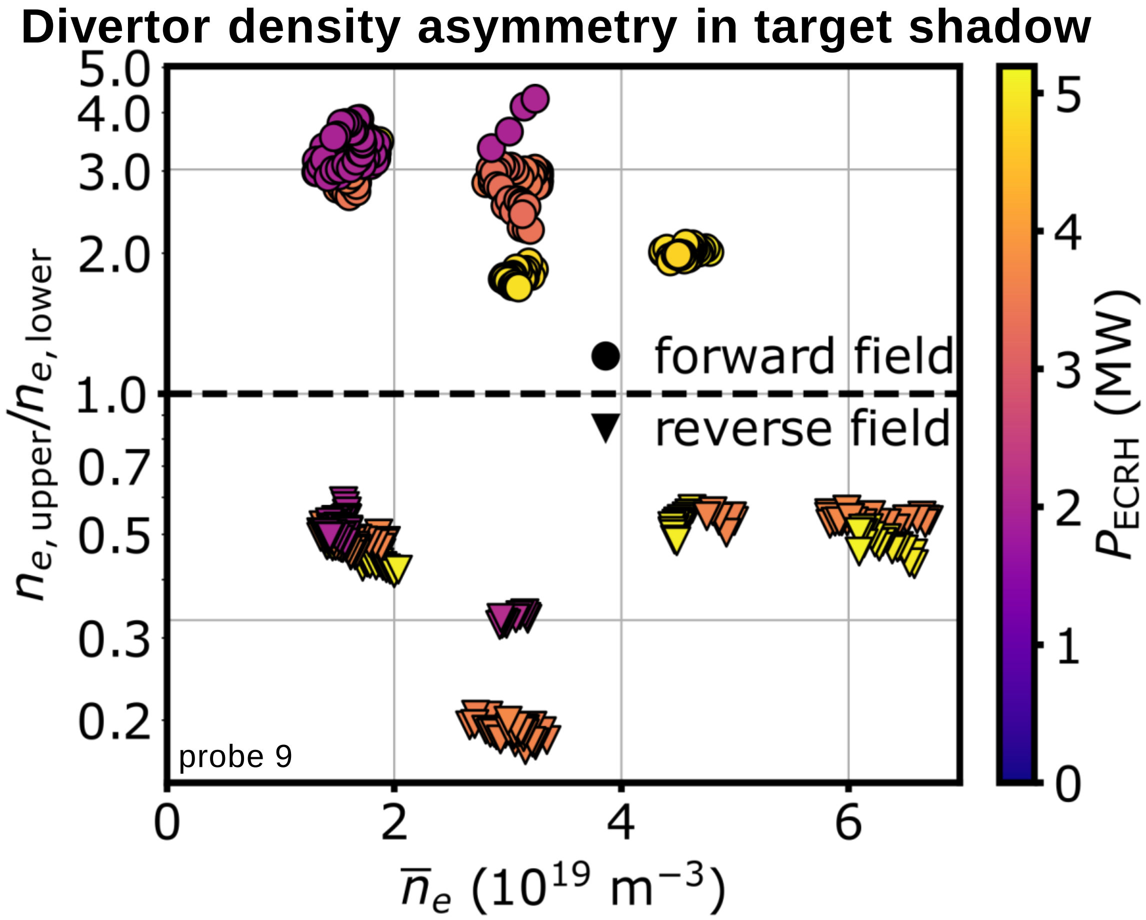
$v_{E,\theta}$ expected to asymmetrically transport particles toward upper vs lower divertors





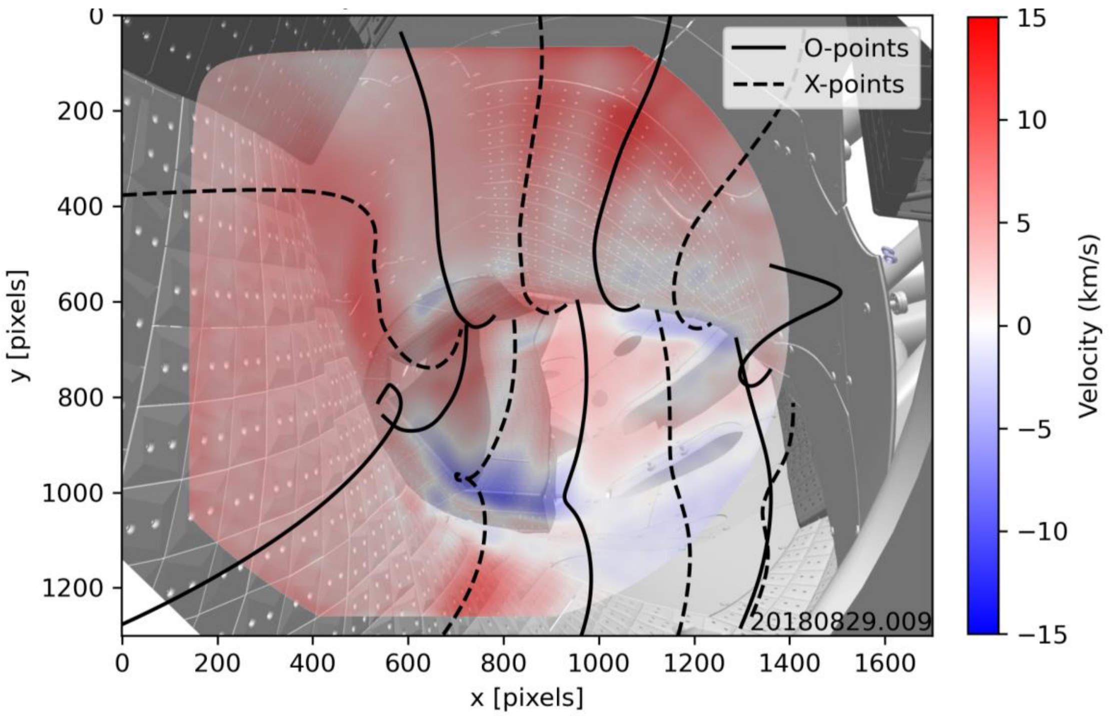
- Large upper/lower divertor n_e asymmetry consistent with $v_{E,\theta}$ observed for all $\bar{n}_e$ in target shadow region

→ Drift is primary transport mechanism into TSR

Impact of drifts on parallel flows is weaker in a magnetic configuration having shorter connection lengths

- In low-iota configuration, CIS observes unidirectional flows for $\bar{n}_e \lesssim 2 \times 10^{19}\ \mathrm{m}^{-3}$
- In standard configuration, counter-streaming flows are observed for $\bar{n}_e \approx 2 \times 10^{19}\ \mathrm{m}^{-3}$
  - Connection lengths 1.5x larger in low-iota than standard → weaker drift effects expected in standard configuration
- Observation of unidirectional flows in standard configuration requires $\bar{n}_e \lesssim 1 \times 10^{19}\ \mathrm{m}^{-3}$
  - Consistent with expectations of weaker drift effects with decreasing connection length

Velocity in low-iota configuration (forward field, $\bar{n}_e = 1.9 \times 10^{19}\ \mathrm{m}^{-3}$)



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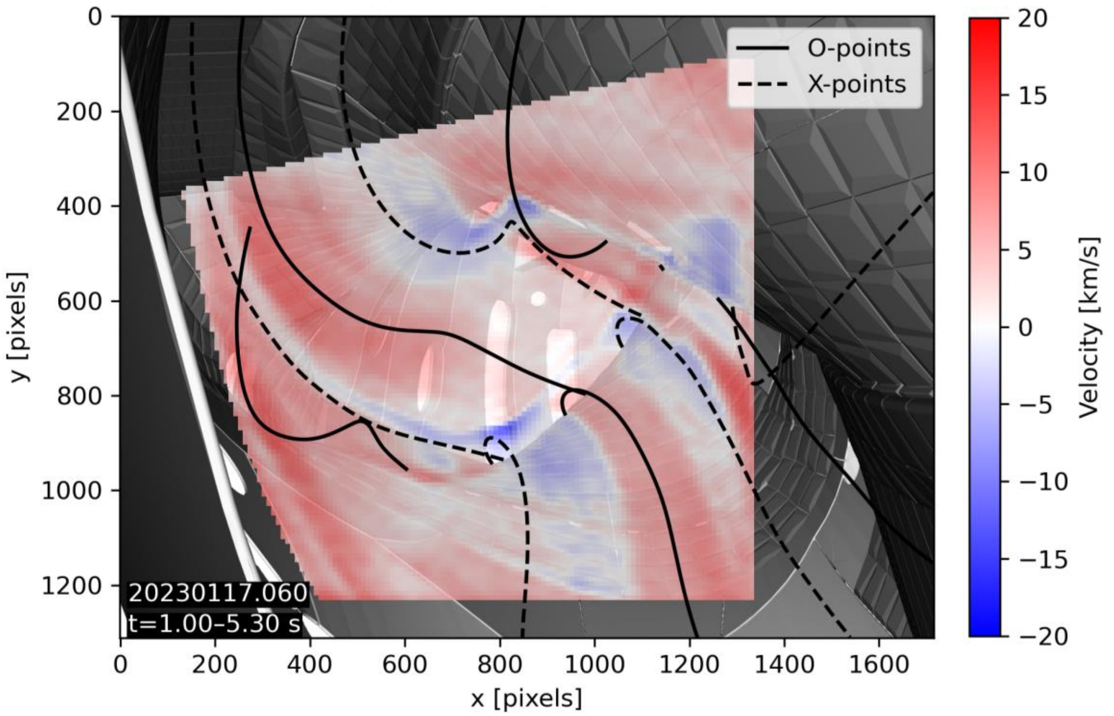
Velocity in standard configuration (reverse field, $\bar{n}_e = 2.2 \times 10^{19}\ \mathrm{m}^{-3}$)



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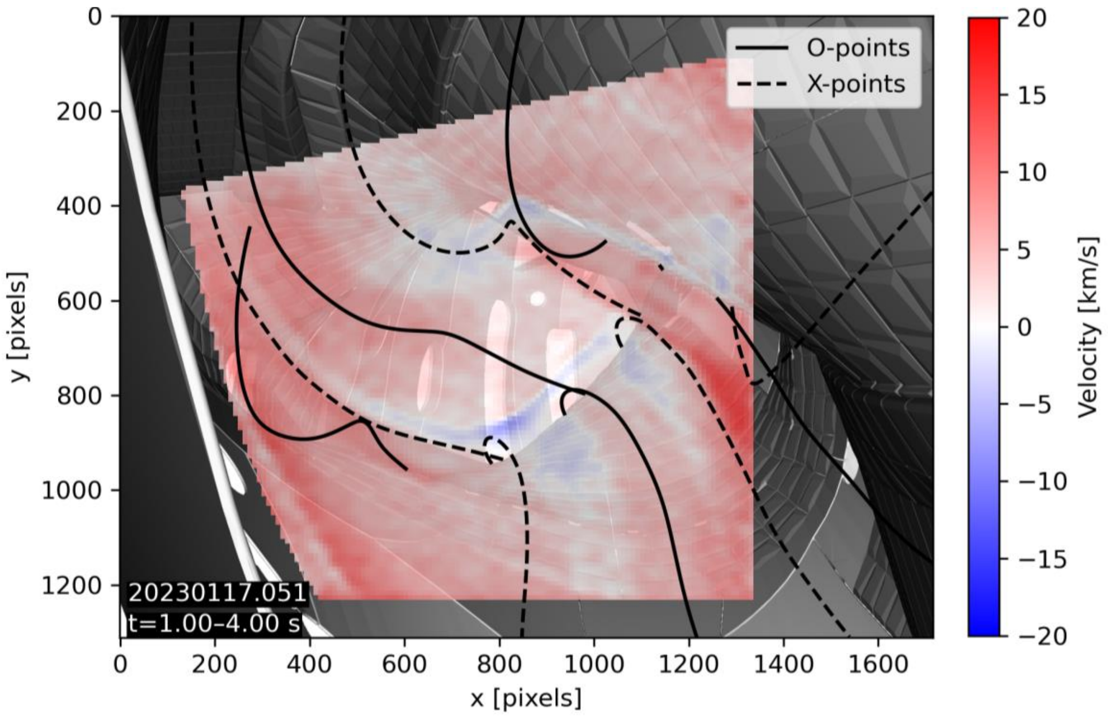
Velocity in standard configuration (reverse field, $\bar{n}_e = 0.75 \times 10^{19}\ \mathrm{m}^{-3}$)



Conclusions

- The $\mathbf{E} \times \mathbf{B}$ drift modifies transport in the island divertor scrape-off layer of W7-X, resulting in changes to the parallel flow structure and density asymmetries between upper and lower divertors

- In the low-iota magnetic configuration, which maximizes the impact of drifts, the parallel flow pattern depends strongly on density
  - At low density, drifts are dominant transport mechanism and lead to near-unidirectional $v_{\|}$
  - In medium-to-high density plasmas, drifts cause stagnation points to shift poloidally

- Divertor density asymmetries near the strike line are observed only at low density, but in the target shadow region strong asymmetries are observed across the entire explored parameter space

- Impact of drifts on $v_{\|}$ is weaker in a magnetic configuration with shorter connection lengths

More information: D.M. Kriete et al., Effects of drifts on scrape-off layer transport in W7-X, *Nuclear Fusion* 63, 026022 (2023)

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EUROfusion

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