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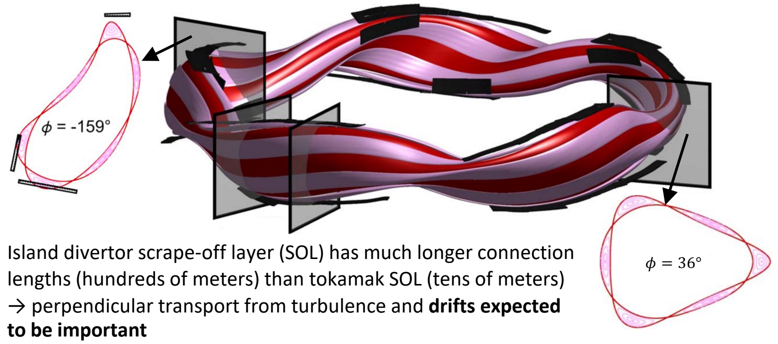
Drift velocity and ion temperature measurements in the W7-X scrape-off layer using coherence imaging spectroscopy

Motivation for studying scrape-off layer drifts

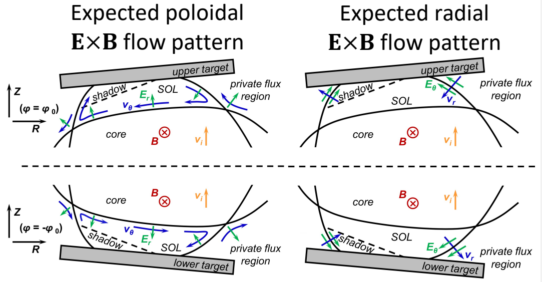
W7-X island divertor: large magnetic islands intersect divertors, exhausting heat and particles from fusion-relevant plasmas



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 is affected by **E**×**B** drifts [K. Hammond et al, PPCF **61** 125001 (2019)]

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

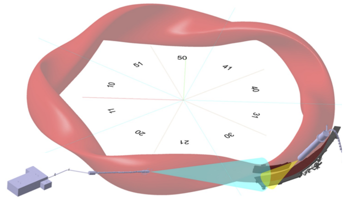

Expected poloidal **E**×**B** flow pattern

Expected radial **E**×**B** flow pattern

Coherence imaging spectroscopy on W7-X

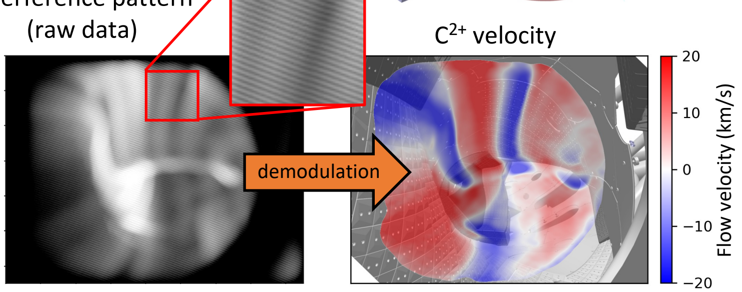
Coherence imaging spectroscopy (CIS): 2D polarization interferometer that measures impurity emission and flow velocity (usually C III line at 465 nm) [V. Perseo et al, RSI **91** 013501 (2020)]
- ~1 cm spatial resolution
- ~50 ms time resolution

CIS viewing geometry



Interference pattern (raw data)

C^{2+} velocity



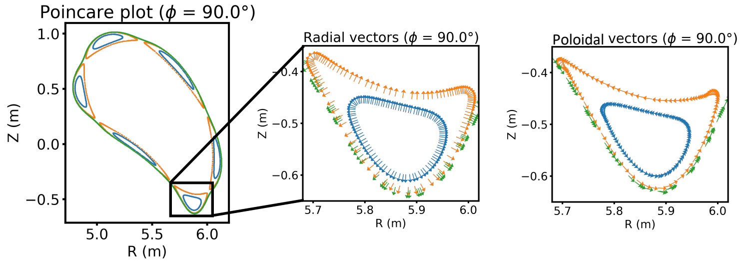
Forward model for CIS flow measurements

A **simple forward model** for CIS flow images was developed to aid interpretation of measurements

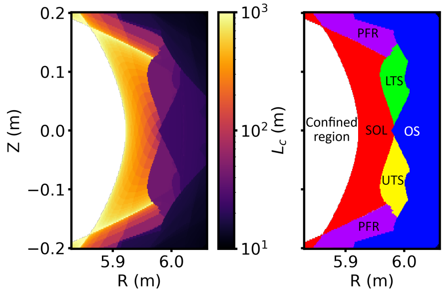
$$v_{\mathrm{CIS}} = \frac{\int_L \varepsilon\left(v_\parallel \hat{\mathbf{b}} + v_r \hat{\boldsymbol{r}} + v_\theta \widehat{\boldsymbol{\theta}}\right)\cdot \hat{\ell}\, dl}{\int_L \varepsilon\, dl}$$

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

Directions vectors $\hat{\mathbf{b}}$, $\hat{\boldsymbol{r}}$, and $\widehat{\boldsymbol{\theta}}$ calculated from Poincare maps [see poster PP11.00062 by J.C. Schmitt in this session]

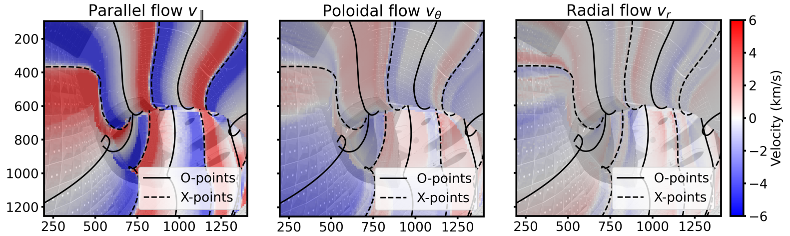


Target-target connection lengths used to divide edge plasma into **distinct topological regions**:
- island scrape-off layer (SOL)
- private flux region (PFR)
- target shadowed regions (LTS, UTS, and OS)



Basic assumptions on the ***ε*, $v_\parallel$, v_r, and v_θ profiles** are made:
- ε distributed uniformly throughout island SOL
- $v_\parallel$ directed toward closest target linearly increasing velocity
- v_θ uniform throughout SOL (**E**×**B** flow pattern with constant $\nabla_r T_e$)
- v_r from **E**×**B** flow pattern with linearly increasing E_θ toward target

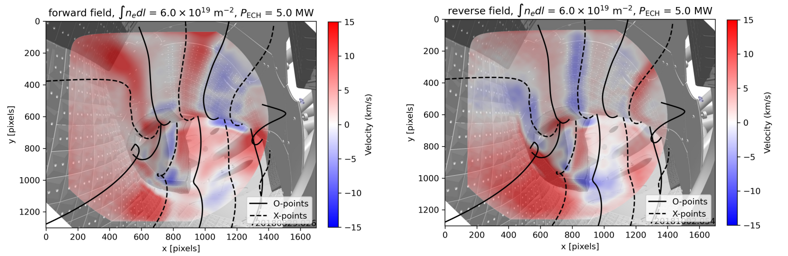
Synthetic CIS flow images for each flow component



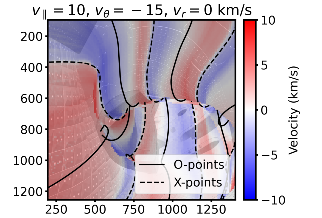
Drift flow investigation with CIS

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 fields** → similar $v_\parallel$ but opposite v_r, v_θ

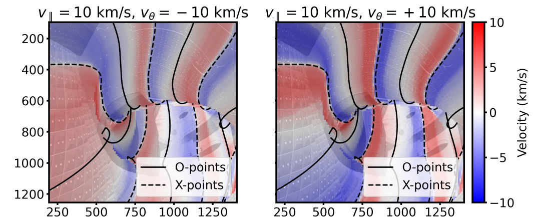
Field reversal experiments show **drifts contribute substantially to SOL flows**



Simple forward model cannot capture many of the experimentally observed flow features
- Forward model with $v_\parallel = 10$ km/s, $v_\theta = -15$ km/s, $v_r = 0$ km/s is best match to reverse field experimental measurements



Forward model shows that poloidal drift flows shift the zero-flow (or 'watershed') position in CIS images



Conclusions

- CIS measurements show that drifts contribute substantially to SOL flows in the low-iota configuration
- A simple forward model for CIS images was developed to understand how drift flows affect CIS measurements
- The model cannot explain many of the features in experimentally measured CIS images and needs further improvement
- The model does indicate that poloidal **E**×**B** flows are responsible for shifting the watershed position in CIS images

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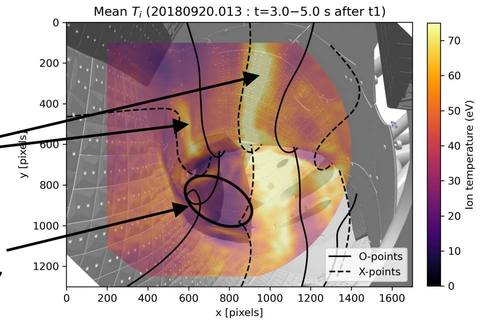
Initial scrape-off layer T_i measurements

C^{2+} impurity ion temperature estimated throughout the SOL by assuming line width governed by instrument broadening, Doppler broadening, and Zeeman splitting
- CIS instruments were optimized for flow measurements, not T_i

Bands of high T_i aligned with islands

Low T_i near divertor, in agreement with spectrometer measurements [D. Gradic et al, NF **61** 106041 (2021)]

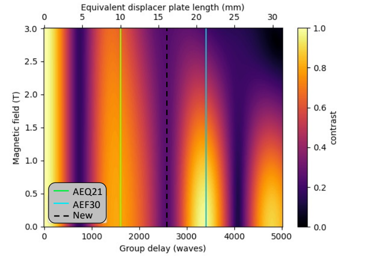


C^{2+} temperature measurements are spuriously large: T_i = 30–100 eV, while other measurements show T_e = 10–40 eV
→ there are likely additional broadening mechanisms that need to be accounted for, e.g., bremsstrahlung, line-of-sight integration effects, and spectral contamination

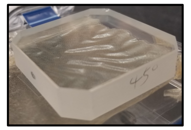
Diagnostic improvements for T_i measurements

Birefringent crystals used to form interference pattern in **existing two CIS instruments were optimized for maximum interference pattern contrast**, i.e., optimized for velocity measurements, not necessarily T_i

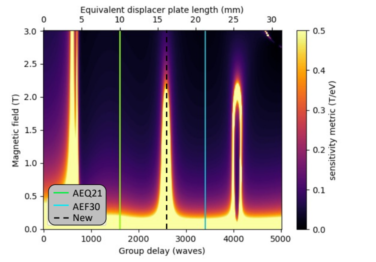
Contrast due to Zeeman splitting (C III @ 465 nm)



New crystals optimized for maximum T_i sensitivity and minimum B sensitivity have been procured



Ratio of T_i sensitivity to B sensitivity



Building a CIS instrument utilizing the new multi-delay approach [J.S. Allcock et al, RSI **92** 073506 (2021)], which can better distinguish between Doppler broadening and other broadening mechanisms