Coherence Imaging Spectroscopy Measurements of Ion Flows in the W7-X Scrape-off Layer

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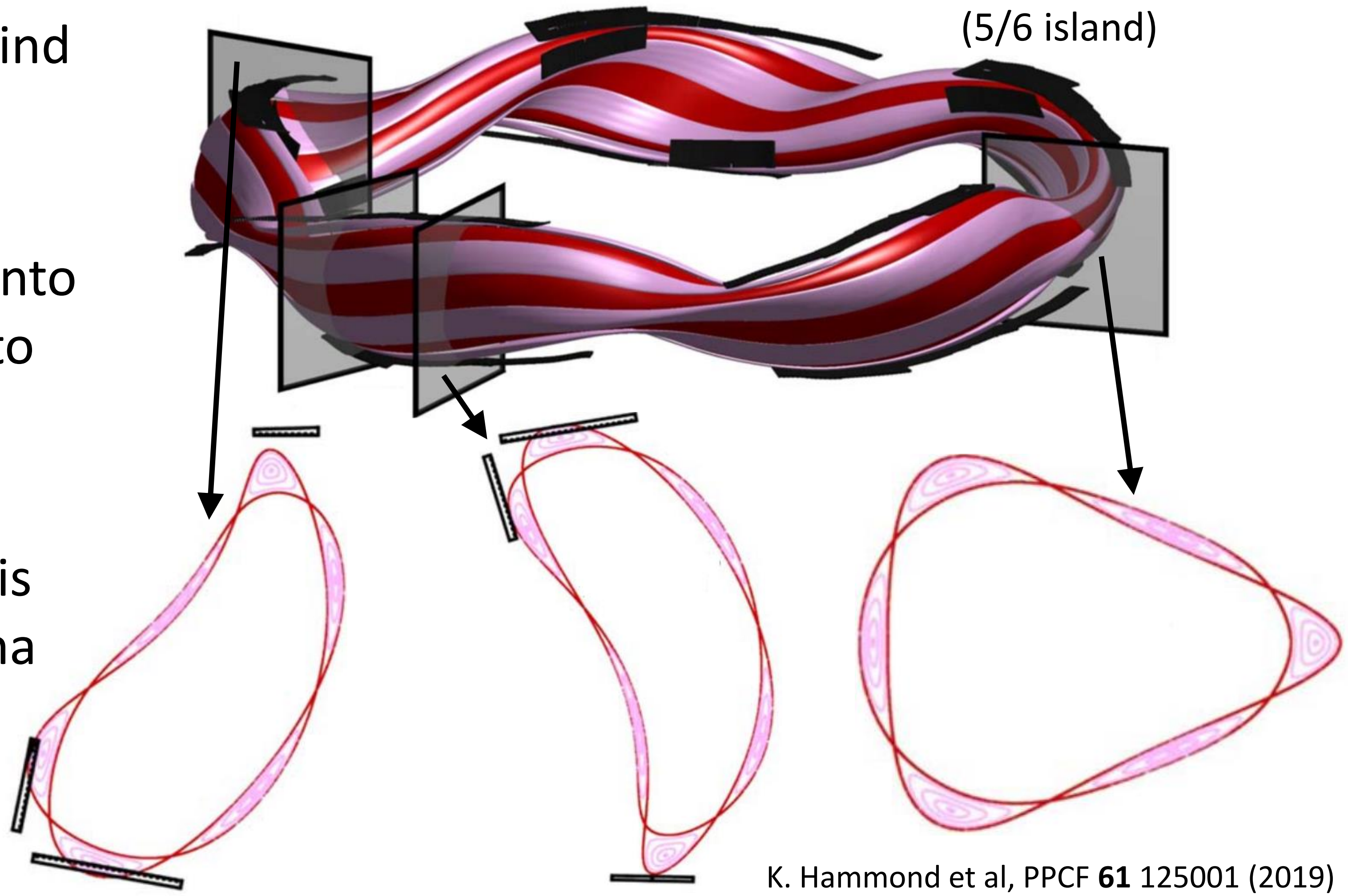
W7-X uses an island divertor to exhaust heat and particles from fusion-relevant plasmas

- Large magnetic islands helically wind around the confined plasma
- Islands intersect divertor targets
  - Particles that cross separatrix into islands travel along field lines to closest target
  - 10 targets (graphite)
- Plasma-material interaction zone is removed from the confined plasma

W7-X low-iota configuration
(5/6 island)



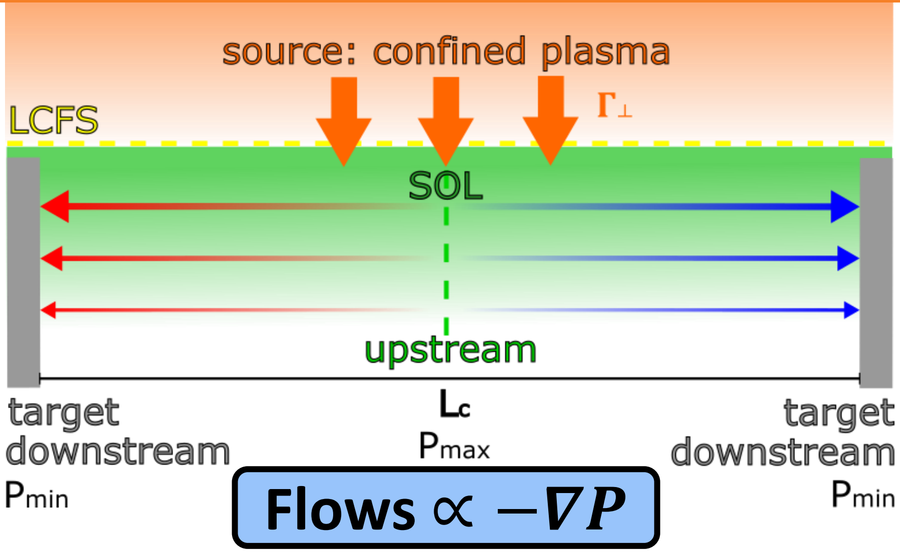
K. Hammond et al, PPCF **61** 125001 (2019)

Flow measurements in the W7-X scrape-off layer are an important tool for understanding divertor physics

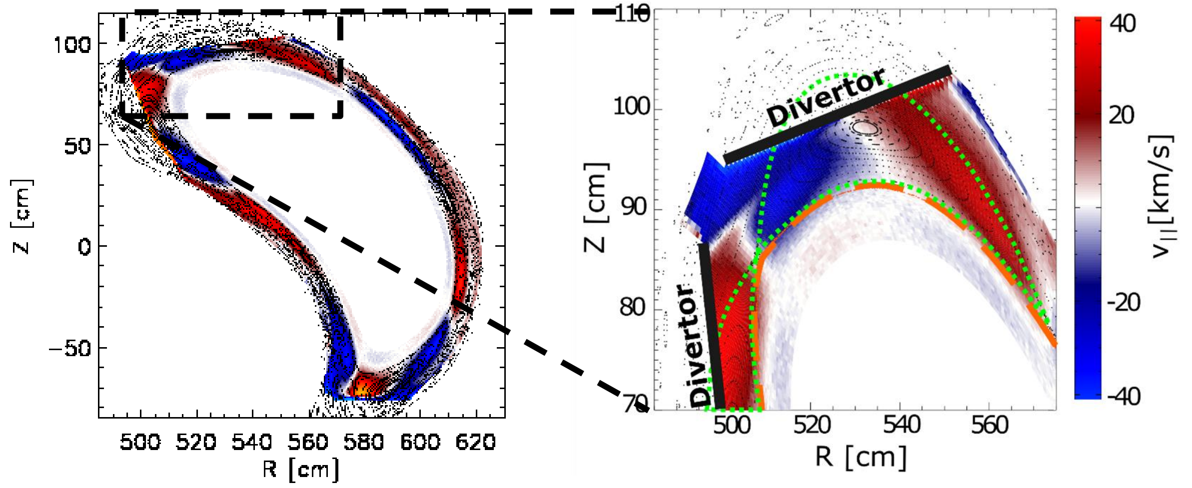
- Magnetic island geometry of W7-X was predicted,[1] and then experimentally verified,[2] to have counter-streaming flows
  - Challenging to study these flows with dispersive spectroscopic techniques

Key research question:
How are scrape-off layer flows affected by drifts?

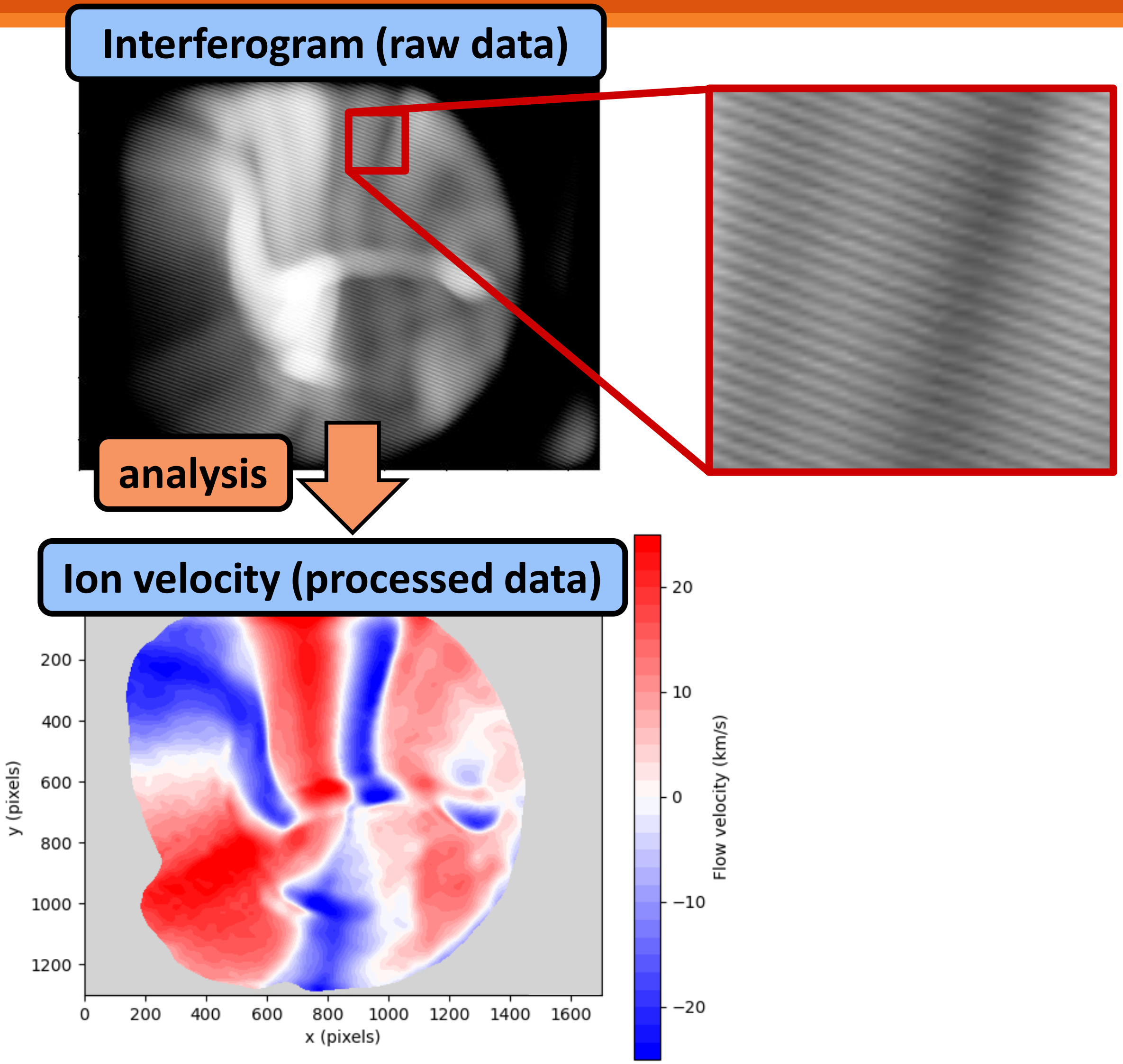
[1]Y. Feng et al, NF **46** 807 (2006)
[2]V. Perseo et al, NF **59** 124003 (2019)



Parallel flow prediction from EMC3-EIRENE



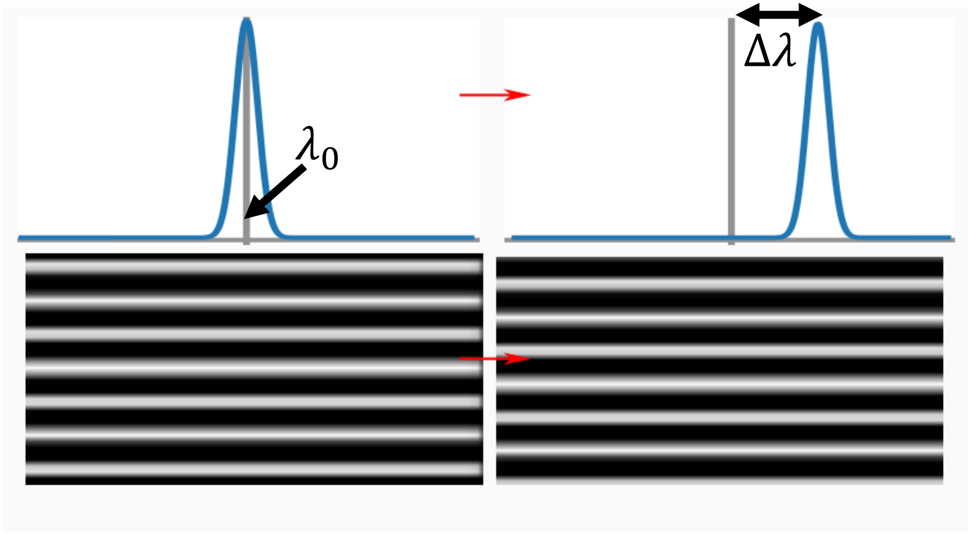
Coherence imaging spectroscopy makes high resolution flow measurements by encoding Doppler information into interferograms



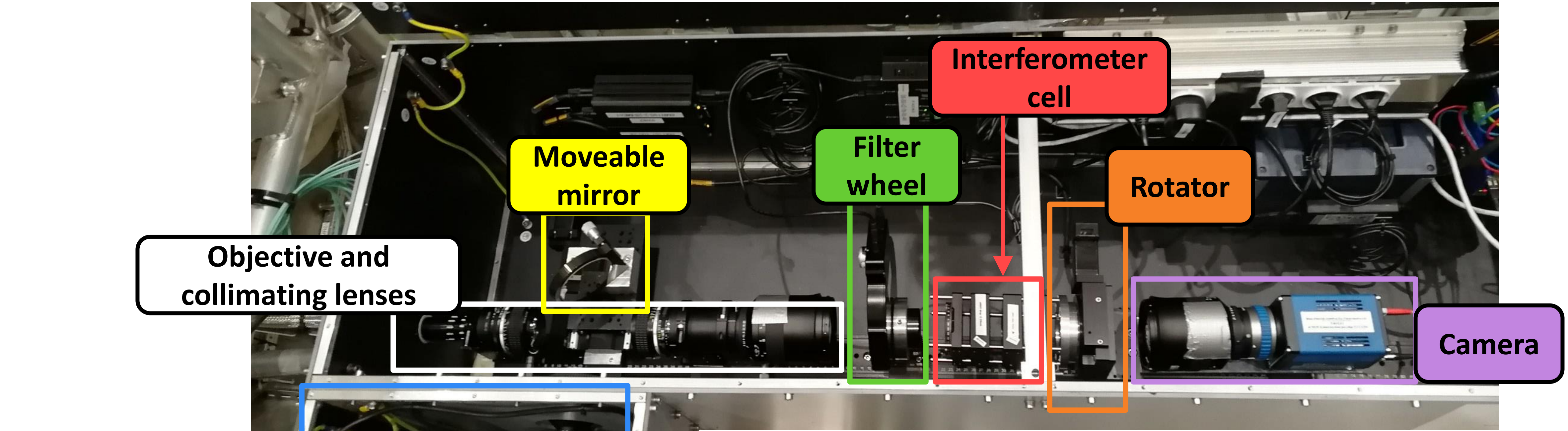
Doppler shift

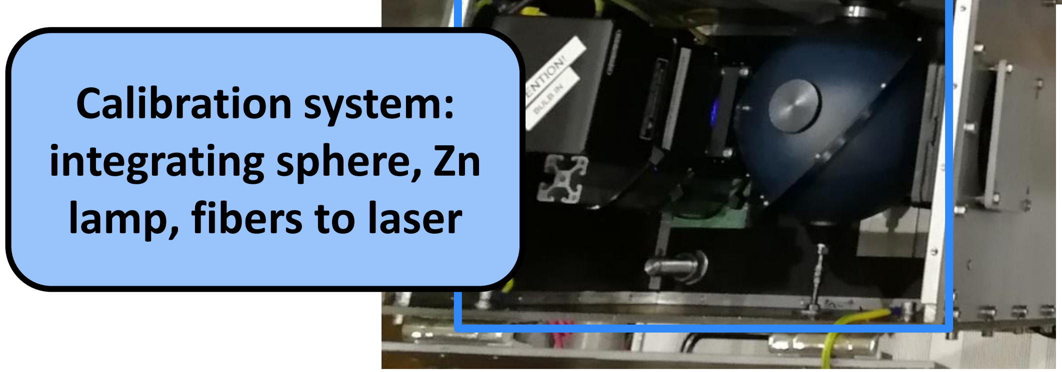
Ion velocity along the line-of-sight shifts wavelength of the emission line, resulting in a shift of the interference pattern

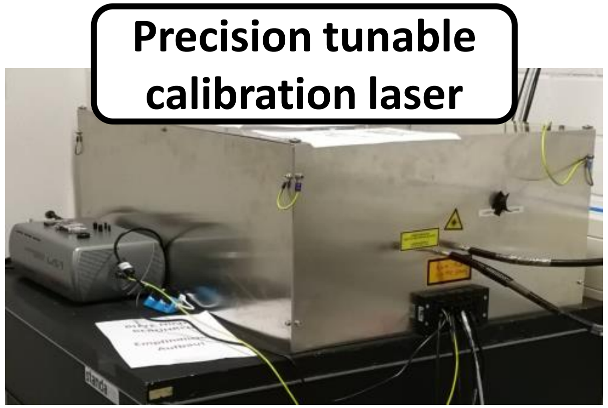
$$\frac{\Delta\lambda}{\lambda_0} = \frac{v_i}{c}$$



Main CIS hardware is remotely controllable and contained in a box ~4 m from W7-X's vacuum vessel







Laser specs

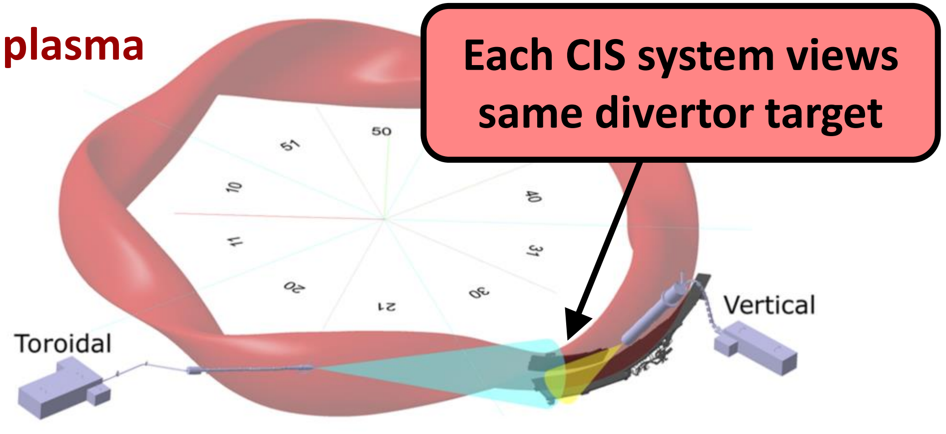
Wavelength range: 450–525 nm & 540–650 nm

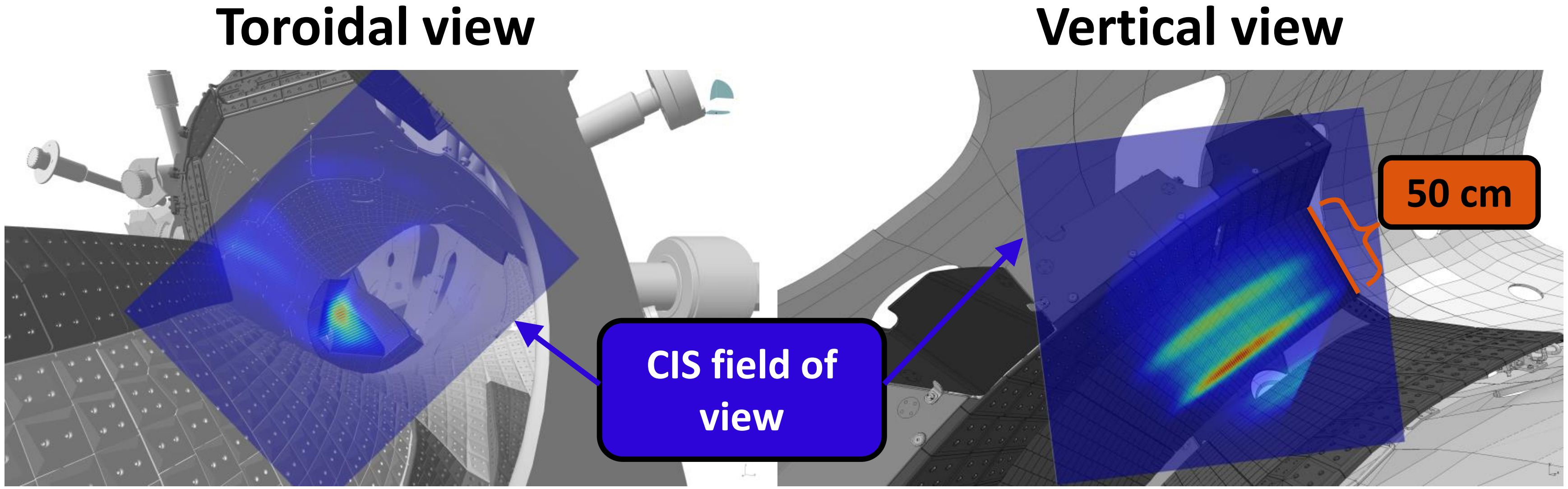
Precision: <0.1 pm

Linewidth: <1 MHz

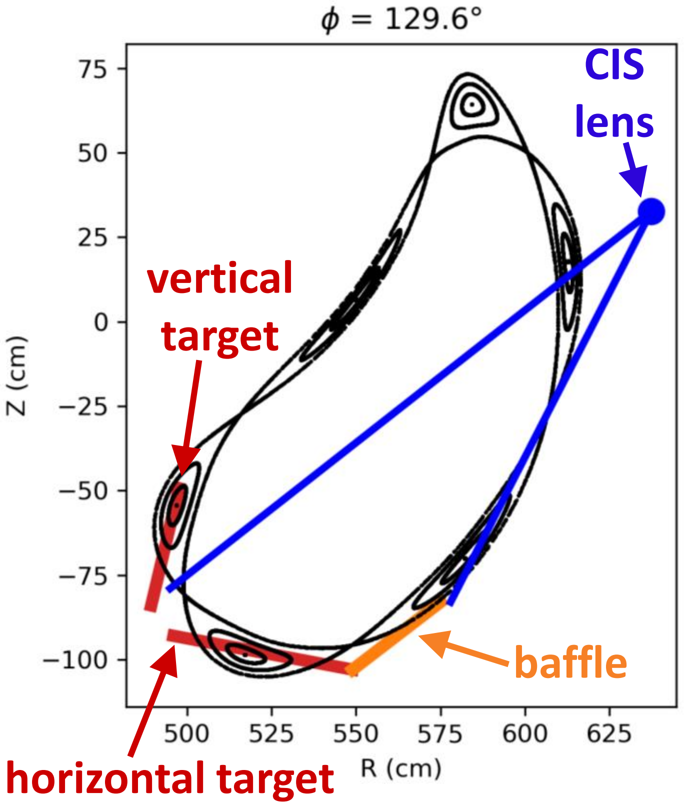
V. Perseo et al, RSI **91** 013501 (2020)

W7-X has two CIS systems, enabling toroidal and vertical flow components to be measured



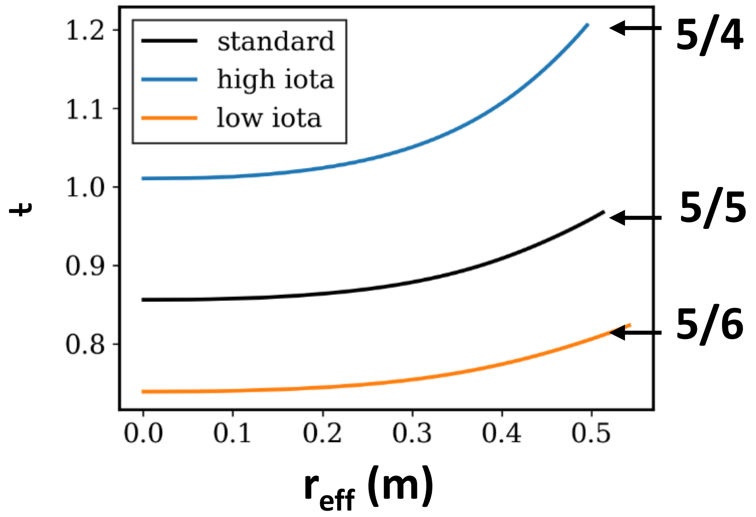


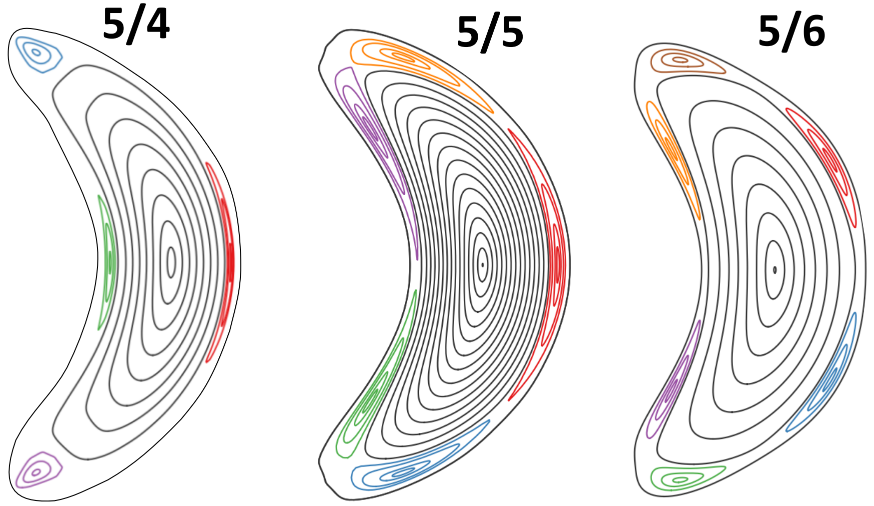
Angle of view for vertical system (low-iota configuration)



Low-iota magnetic configuration is ideal for investigating effect of drifts on scrape-off layer flows

- $\mathbf{E} \times \mathbf{B}$, ∇B, and curvature drifts can play an important role in scrape-off layer (SOL) dynamics
  - Can broaden heat & particle fluxes and alter location where they strike the divertor
- Low-iota configuration's 5/6 island chain does not resonate with the dominant $n = 1$ and $n = 2$ error fields in W7-X
  - Also has longest connection lengths in W7-X, maximizing influence of drifts on heat & particle fluxes[1]





V. Perseo, Dissertation Talk (2020)

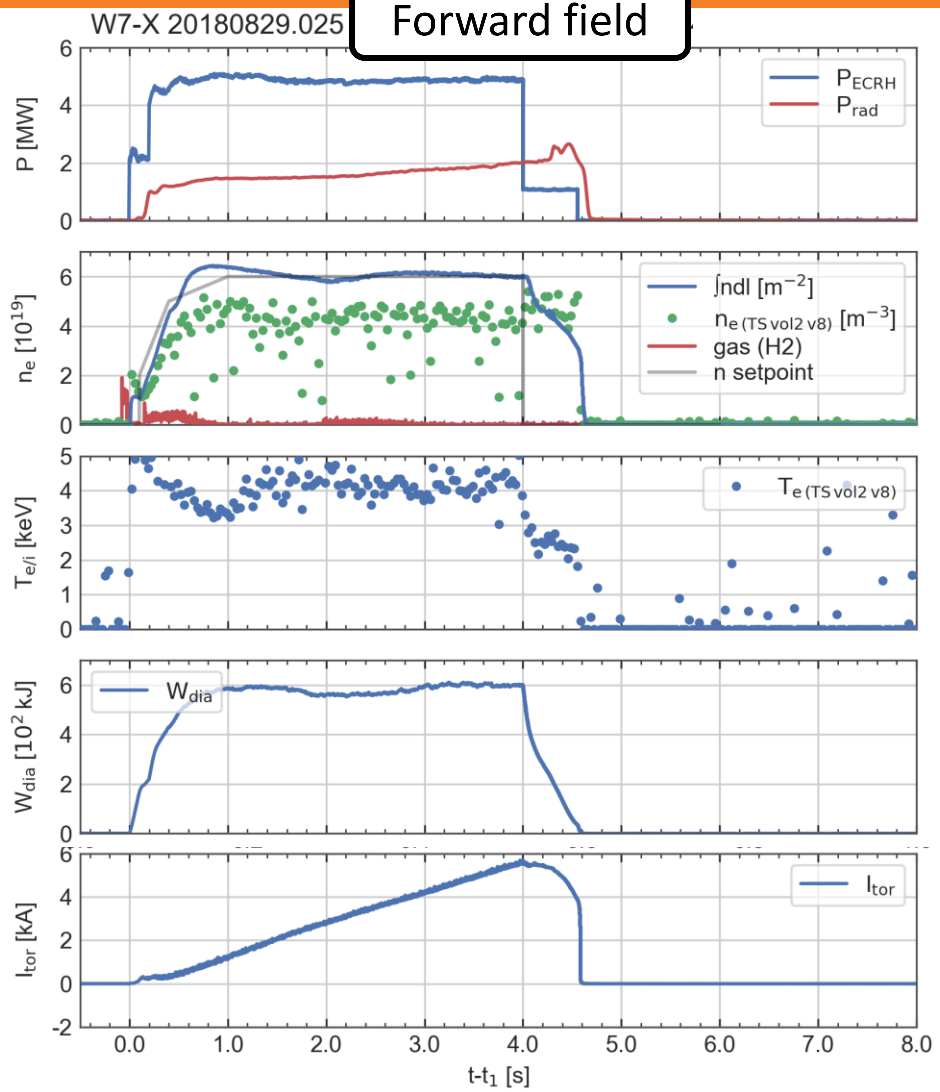
[1]K.C. Hammond et al, PPCF **61** 125001 (2019)

Experiment in low-iota configuration was performed to investigate drift effects

- Density and heating power scanned from shot to shot, while all other parameters were kept fixed
  - Line-averaged electron densities: 2–6 x 10^{19} m^{-2}
  - ECH powers: 2–5 MW

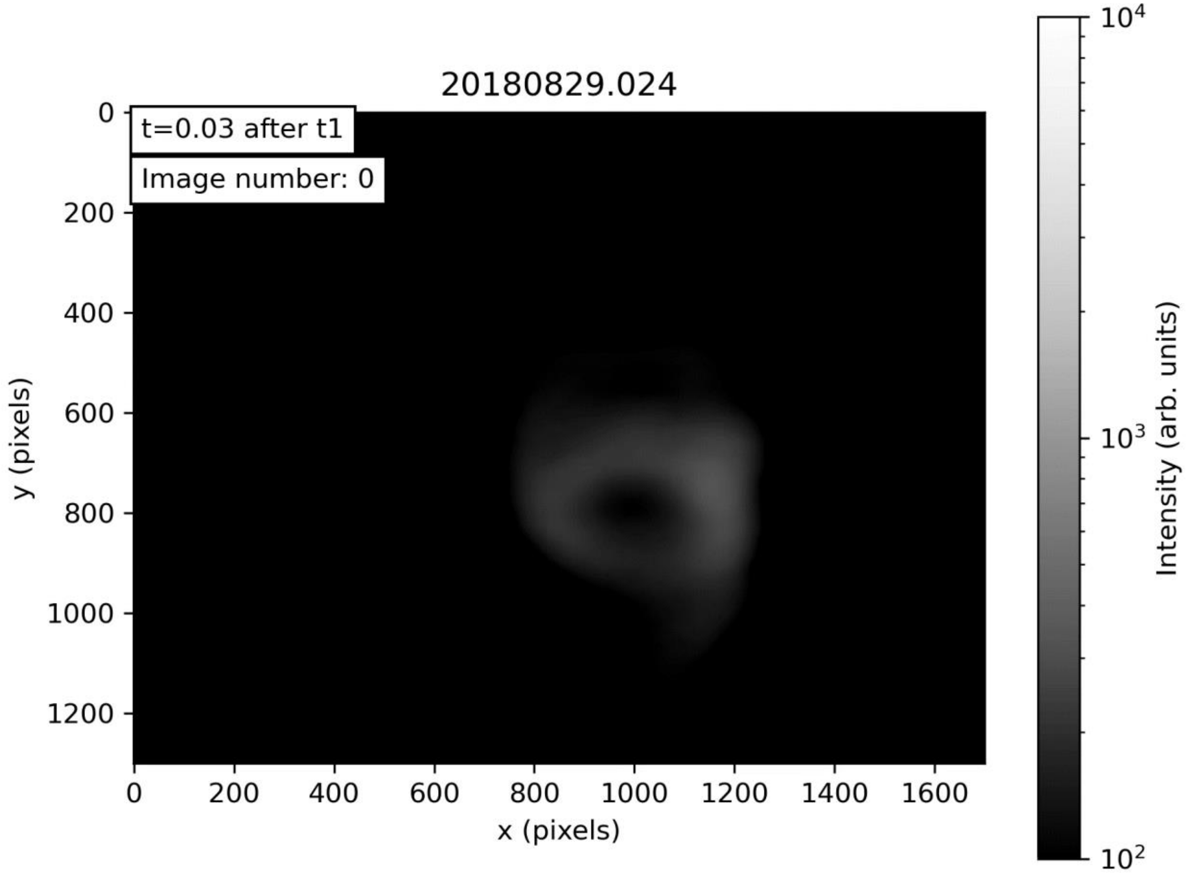
- Field direction reversed to investigate drift effects
  - Drift velocities reverse with field direction
  - ∇p-driven flows not expected to change with field direction, provided upstream conditions are matched

Forward field

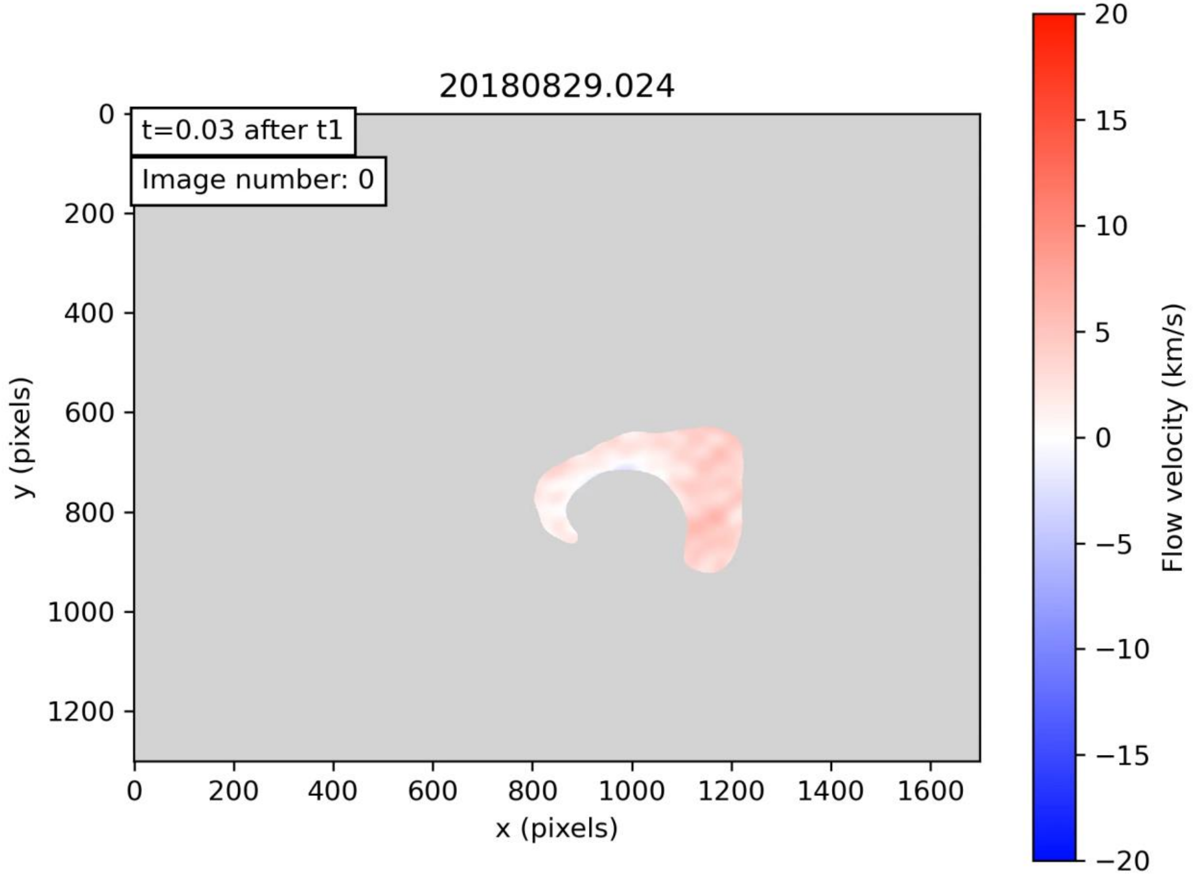


CIS measures stationary flows throughout the discharge

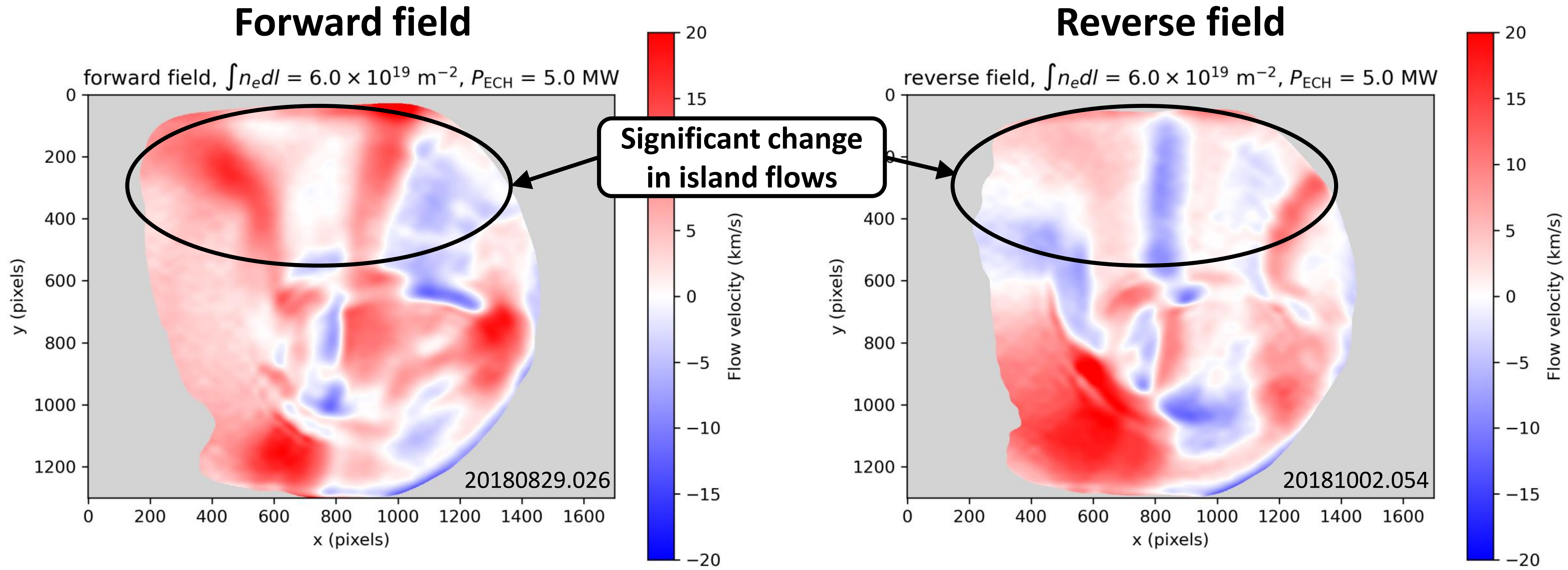
C^{2+} emission intensity



C^{2+} toroidal flow velocity



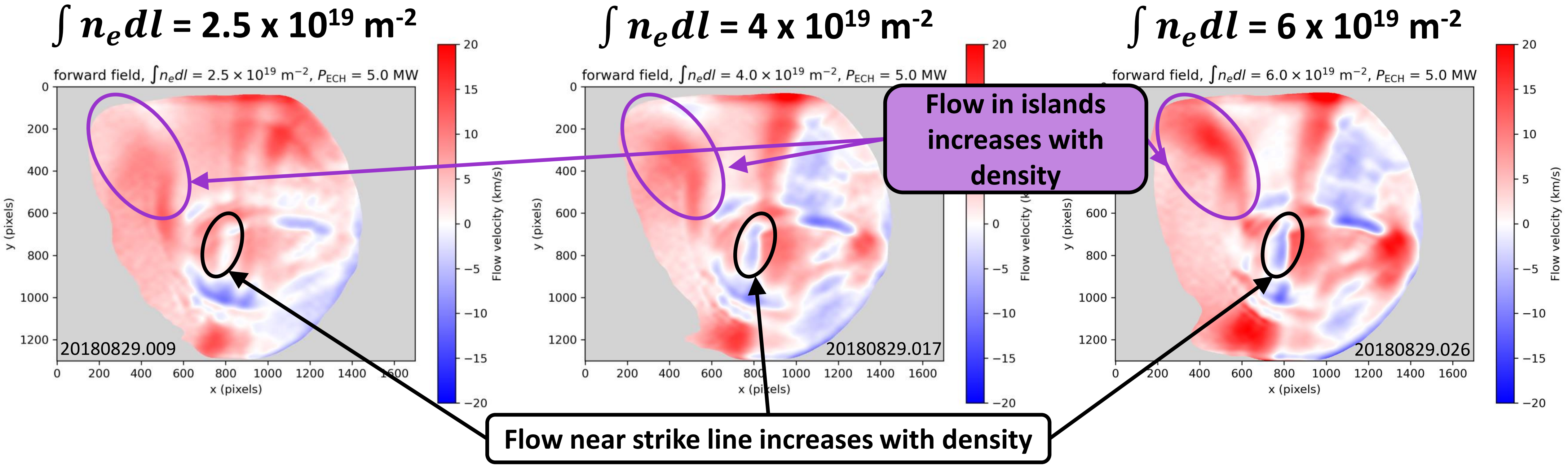
Reversing field direction causes toroidal flow to change significantly



Highest density, highest power discharge from the experiment (other discharges show similar, but less significant, flow changes)

Large flow change upon field reversal implies that drifts contribute significantly to SOL flows

Toroidal flows have more structure and larger amplitudes with increasing density



Counterflows grow larger with increasing density, consistent with expected increase of pressure gradient flow drive

Downstream temperatures decrease by factor of 2–3 with increasing density, so CIS emission volume may change (future modelling will investigate)

Conclusions

- In the low-iota configuration, coherence imaging spectroscopy observes large changes in toroidal and vertical SOL flows when field direction is reversed, implying drifts contribute significantly to the flows

- Counter-streaming flows have largest amplitude at highest density (6×10^{19} m^{-2}) and highest ECH power (5 MW) from the experiment

- Future modelling (EMC3-EIRENE) will be used to interpret flow measurements in the complex magnetic island geometry of W7-X

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