TH/3-3: Assessment of Scrape-off Layer Simulations with Drifts against L-mode Experiments in ASDEX Upgrade and JET

L. Aho-Mantila\textsuperscript{1}, S. Potzel\textsuperscript{2}, M. Wischmeier\textsuperscript{2}, D. Coster\textsuperscript{2}, H.W. Müller\textsuperscript{2}, S. Marsen\textsuperscript{3}, S. Müller\textsuperscript{2}, A. Meigs\textsuperscript{4}, M. Stamp\textsuperscript{4}, S. Brezinsek\textsuperscript{5}, the ASDEX Upgrade Team and the JET Contributors

\textit{JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK}
\textsuperscript{1}\textit{VTT Technical Research Centre of Finland, Espoo, Finland}
\textsuperscript{2}\textit{Max-Planck-Institut für Plasmaphysik, Garching, Germany}
\textsuperscript{3}\textit{Max-Planck-Institut für Plasmaphysik, Greifswald, Germany}
\textsuperscript{4}\textit{CCFE, Culham Science Centre, Abingdon, UK}
\textsuperscript{5}\textit{Institut für Energie- und Klimaforschung - Plasmaphysik, FZ Jülich, Germany}
Outline

- Introduction
- Influence of drifts on a density scan in ASDEX Upgrade
- Influence of drifts on a N-seeding scan in JET
- Underlying physics
- Conclusions
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In ITER and DEMO, divertor exhaust involves **power dissipation by impurities** and **detachment**

⇒ A possible bottleneck for reactors

Coupled plasma-neutral simulations required for predicting power and particle exhaust

⇒ **plasma fluid / Monte Carlo neutral** code packages

The codes do not reproduce all present-day experimental observations, **predictions uncertain**

⇒ detachment

⇒ divertor asymmetries
The role of drifts in divertor asymmetries

Experimental studies suggest that divertor asymmetries are sensitive to cross-field drifts

e.g. R. Pitts et al, J. Nucl. Mat. 2005

Analytic assessments are not sufficient to verify this, because the ExB drifts are sensitive to temperature and pressure gradients


Activation of drift terms in SOL simulations is computationally challenging and not routinely done
Drift effects modelled using SOLPS5.0

**B2.5**: 2D plasma fluid code

**Eirene**: Monte Carlo neutrals code

+ multiple impurities

**ExB** and **diamagnetic drifts, currents**

\[
q_e, x = \frac{3}{2} n T_e \left( - \frac{b_z}{B h_y} \frac{\partial \Phi}{\partial y} + b_x V_{||} \left( b_x, j_{||}/2en \right) \right) \\
+ \frac{5}{2} n T_e b_z \left( - \frac{D}{T_e + T_i} b_z \frac{\partial p}{n \partial x} - \frac{3}{2} \frac{\partial T_e}{\partial x} \right) - D^m_{AN} \frac{1}{h_x n} \frac{\partial n}{\partial x} \\
- 0.71 b_x j_{||} T_e/e - \kappa_{e\parallel} \frac{b_x^2}{h_x} \frac{\partial T_e}{\partial x} - \kappa_{e\perp} b_z^2 \frac{1}{h_x} \frac{\partial T_e}{\partial x} \\
+ \frac{3}{2} b_z T_e \nu_{ei} \frac{b_z^2}{\omega_{ce} h_x} \frac{\partial n (T_e + T_i)}{\partial x} - \frac{5}{2} n T_e^2 \frac{B_z}{e h_y} \frac{\partial}{\partial y} \left( \frac{1}{B^2} \right)
\]
Modelling is validated against L-mode discharges in ASDEX Upgrade and JET

**ASDEX Upgrade**
- \( B_t = 2.5 \text{T}, \ I_p = 1.0 \text{MA} \)
- \( R \sim 1.7 \text{m}, \ a \sim 0.5 \text{m} \)

**JET**
- \( B_t = 2.5 \text{T}, \ I_p = 2.5 \text{MA} \)
- \( R \sim 3 \text{m}, \ a \sim 1.3 \text{m} \)

**Different divertor configurations**
- Vertical targets (AUG)
- Horizontal outer target (JET)

**Different divertor regimes**
- D fuelling and N seeding

Validation of modelled power exhaust and drift effects:
- Target measurements
- Volume measurements
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Activation of drifts leads to an asymmetric roll-over of the simulated ion fluxes.

\[ n_{\text{sep}} \text{ varied} \]

⇒ Drift effects most significant in the **high-recycling regime** (hot SOL – cool divertor)

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**modelled total ion fluxes**

- **Inner, drifts**
- **Inner, no drifts**
- **Outer, drifts**
- **Outer, no drifts**

- **high-recycling**
- **low-recycling**
- **detached**

\[ \Gamma_{\text{tot}} \text{ [1E22 e/s]} \]

- \[ 0 \]
- \[ 2 \]
- \[ 4 \]

\[ x \times 10^{19} \]

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ASDEX Upgrade
Two regimes considered in detail

1. **Low density**
   - Strong drift effects in the inner divertor

2. **High density**
   - Atomic physics important, weak drift effects at the target
Low density: drifts provide a significantly cooler and denser inner divertor

**Target measurements**

- SOLPS5.0 with drifts
- SOLPS5.0 without drifts
- Langmuir probes

Inner target measurements indicate detachment and do not confirm the high $\Gamma_\parallel$.

Either **drifts** or **particle exhaust** incorrectly modelled.

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**ASDEX Upgrade**

L. Aho-Mantila
25th IAEA Fusion Energy Conference  TH/3-3
Low density: volume measurements confirm the modelled drift effects

**Volume measurements**

- X-point probe measurements confirm higher $\Gamma_\parallel$ in the inner divertor
- SOLPS5.0 with drifts
- SOLPS5.0 without drifts
- Spectroscopy

Stark broadening confirms the modelled high densities in the inner divertor

**Graph**

- $n_e [1e20 1/m^3]$ vs LOS index

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L. Aho-Mantila

25th IAEA Fusion Energy Conference TH/3-3
High density: small discrepancies in the inner divertor

**Target measurements**

![Graph showing target measurements](image)

- SOLPS5.0 with drifts
- SOLPS5.0 without drifts
- Spectroscopy
- Langmuir probes

**Volume measurements**

![Graph showing volume measurements](image)

- $n_e [1 \times 10^{20} \text{m}^{-3}]$
- LOS index

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L. Aho-Mantila

25th IAEA Fusion Energy Conference TH/3-3
High density: strong discrepancies in outer divertor conditions with and without drifts

**Target measurements**

- SOLPS5.0 with drifts
- SOLPS5.0 without drifts
- Spectroscopy

**Volume measurements**

- Measured neutral pressure 6 times higher than modelled

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**SOLPS5.0 with drifts**

**SOLPS5.0 without drifts**

**Langmuir probes**

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**Measured neutral pressure**

6 times higher than modelled
Observed discrepancies

The modelling **overestimates** the inner target peak ion flux by factors 2-3.

The modelling **underestimates** the outer target peak ion flux by a factor of 6.
Problematic regimes encountered when the measurements deviate from the simple 2-pt model.

**Measured** $\Gamma_{\text{tot}}$ **inner / outer**

**vs. 2-pt model** $\Gamma \propto n^2$

Points towards an important role of **plasma-neutral interaction and atomic processes**

- Radiation losses
- Momentum losses
- Volume recombination
- (or convection)

⇒ Reasons for the discrepancies are unclear*
⇒ Not likely to be due to drifts

*S. Potzel et al, Nucl. Fus. 2014
*M. Wischmeier et al, J. Nucl. Mat. 2011
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Drift effects are large throughout a N-seeding scan at low density.

Modelled total ion fluxes:

- High-recycling
- Low-recycling
- Detached

Graph showing the variation of total ion flux with N-seeding level (at/s) and drift effects.

$n_{\text{sep}}$ fixed

$\Gamma_N$ varied
2 regimes considered in detail

1. No seeding
   - Strong drift effects in the inner divertor, similar to AUG

2. N-seeding
   - High-recycling conditions at low density

![Graph showing modelled total ion fluxes](image)
No impurities: drifts yield a cooler and denser inner divertor

Target measurements

Attached inner divertor conditions confirmed by the measurements
No impurities: drift effects confirmed by volume measurements

Volume measurements

With drifts
Without drifts

[Ph/sr/m²/s]

inner divertor

outer divertor

\(D_\gamma\)

\(D_\alpha\)

\(D_\delta\)
N seeding: drifts yield higher ion fluxes when 60% of the heating power is radiated.

**Target measurements**

Drifts increase $\Gamma_{\text{tot}}$ at both targets.

The peak $\Gamma_{\parallel}$ is still underestimated by a factor of 2.

![Graphs showing ion fluxes with and without drifts at inner and outer targets.](image)
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Low density: asymmetries are caused by $E_r$ and currents

1. **Poloidal ExB drifts and currents in the SOL** transport power from the inner divertor to the outer divertor

2. The **ExB drift in the PFR** transports particles from the outer divertor to the inner divertor

Diamagnetic drifts affect the level of divertor heat flux, but not the in-out asymmetry

See also:
The thermoelectric current arises from the $T_e$ asymmetry between the two targets and amplifies the asymmetry caused by the ExB drifts.

Increasing discharge density cools down the upstream SOL, which reduces $T_e$ gradients and leads to smaller asymmetries.
Conclusions

**ExB drifts and currents can lead to divertor asymmetries** in both ASDEX Upgrade and JET

- Effects depend on the operational regime (SOL gradients)
- Results support the on-going efforts to model drifts in JET (EDGE2D) and ITER (SOLPS-ITER)

**Inclusion of drifts does not solve the existing problems in reproducing high-density and detached conditions**

- Points towards problems in plasma-neutral interaction and atomic processes
- Modelling other operational regimes (e.g. H-mode) is a separate issue

**SOL and divertor diagnostics play a crucial role in identifying missing physics**

- Measurements in the divertor volume have enabled verifying the modelled asymmetries at low density due to drifts and currents
- Still lacking $T_e$ measurements in the divertor volume
Back-up slides
Typical transport assumptions

Upstream profiles:

Poloidal variation: $B^{-a}$ dependence

L. Aho-Mantila et al, NF 2012
Drift effects in ASDEX Upgrade at low density

SOLPS runs with different physics included

- **none**: no currents or drifts activated
- **currents**: only currents activated, no drifts
- **dia**: diamagnetic drifts and currents activated
- **ExB**: ExB drifts and currents activated
- **all**: ExB + diamagnetic drifts and currents

L. Aho-Mantila et al, EPS 2014
Asymmetries in different conditions

- **Field reversal** reduces the heat flux asymmetry and can reverse the peak $T_e$ asymmetry.
- **N-seeding** reduces the asymmetries at the divertor entrance, but the radiation losses are still higher in the inner divertor.
- **Increased discharge density** cools down the SOL and both divertors, which reduces the asymmetries.

L. Aho-Mantila et al, EPS 2014
$E_r$ and flows

- Simulations underestimate flows in **forward field**
- Better match in **reversed field**

L. Aho-Mantila et al, NF 2012