Benchmarking DIV1D on SOLPS-ITER simulations of TCV plasmas

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Motivation and introduction

The exhaust

Heat flux q $\mathrm{MWm^{-2}}$
In ITER:
- Upstream [1]: $q_{||} \approx 100\ \mathrm{MWm^{-2}}$
- Target requirement [2]: $q_{\perp} \lesssim 15\ \mathrm{MWm^{-2}}$
- Solution [3]: detachment $q_{\perp} \approx 10\ \mathrm{MWm^{-2}}$

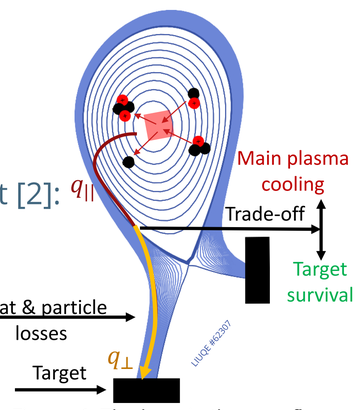


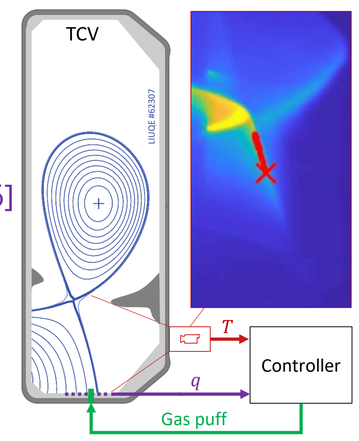
Figure 1. The heat in the core flows across the edge towards the target. There is a trade-off between target survival and core performance.

Control

Actuator
- Gas valve (puff) [4]

Sensors
- MANTIS camera (T) [5]
- Langmuir probes (q) [6]

Good controllers
- Designed with a dynamic model currently based on measurements [7,8]



Dynamic models

Envisioned role for DIV1D
- **Match** SOLPS-ITER equilibria
- **Transition** between equilibria
- Self-consistently with minimal complexity

Figure 2. Illustration of detachment control loop in the Tokamak á Configuration Variable (TCV) inspired by [5,7,8]. The MANTIS camera captures tangential C2+ emission which is an indication of plasma temperature. The Langmuire probes measure heat flux. Based on measurements, the controller decides on the amount of gas to be puffed.

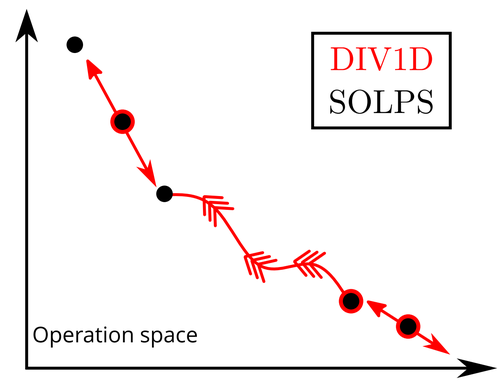


Figure 3. The operational space of the divertor plasma in which SOLPS-ITER describes static (black) operating points whereas DIV1D can dynamically (red) move around and transition between SOLPS-ITER solutions.

Models

SOLPS-ITER [9]

Combines:
- B2.5 multi-fluid plasma
- EIRENE Monte Carlo neutral

Simulated TCV plasma [10]:
- L-mode #62807
- $I_p = 250$ kA → 360 kW
- Gas puff scan

Important settings:
- $D_{\perp\alpha} = 0.2, \mathrm{X}_{\perp\alpha} = 1\ (m^2 s^{-1})$
- $\gamma \approx 5.7\ (-)$, R = 0.99

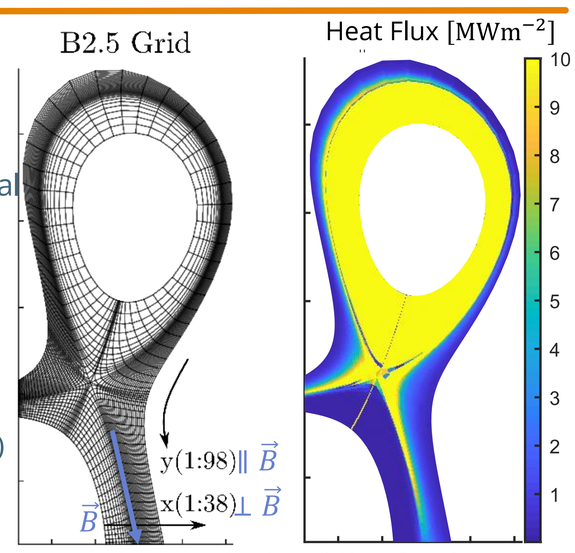


Figure 4. The B2.5 grid and parallel heat flux of SOLPS.

Models

DIV1D: a 1D dynamic divertor model [11]

Assumptions:
- $T_\mathrm{i} = T_\mathrm{e}$
- No radial losses

Balance equations, e.g. [12-15]:
- Particle, Momentum, Energy

Atomic processes:
- Ionization, Recombination, Charge exchange, Excitation [16], Carbon radiation [17]

Mimic cross-field transport (unique features)
- Effective heat flux expansion
- Neutral gas background

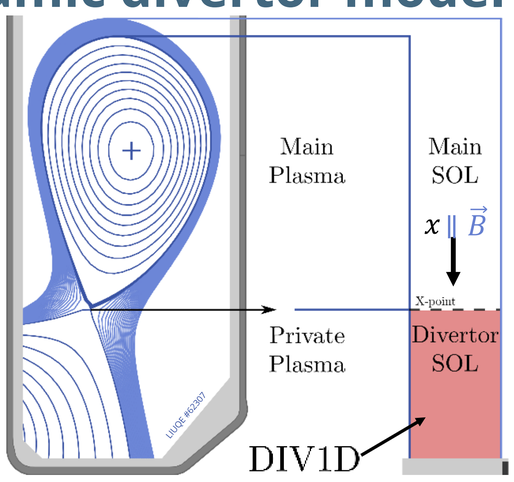


Figure 5. Dissemination of poloidal cross-section. DIV1D describes the divertor scrape-off layer (SOL) .

Method

Mapping SOLPS-ITER to 1D profiles

To compare, 2D solutions must be interpreted in 1D
→ Not trivial with drifts and X-points
A single flux-tube as in [13]
- Sources dominated by cross-field transport
- Does not represent macro divertor plasma

FWHM heat flux channel inspired on [18,19]
- Negligible cross-field sources on boundaries
- Average values represent profiles
- Variations indicate validity of 1D interpretation

→2D features of X-point difficult to interpret in 1D→ upstream →

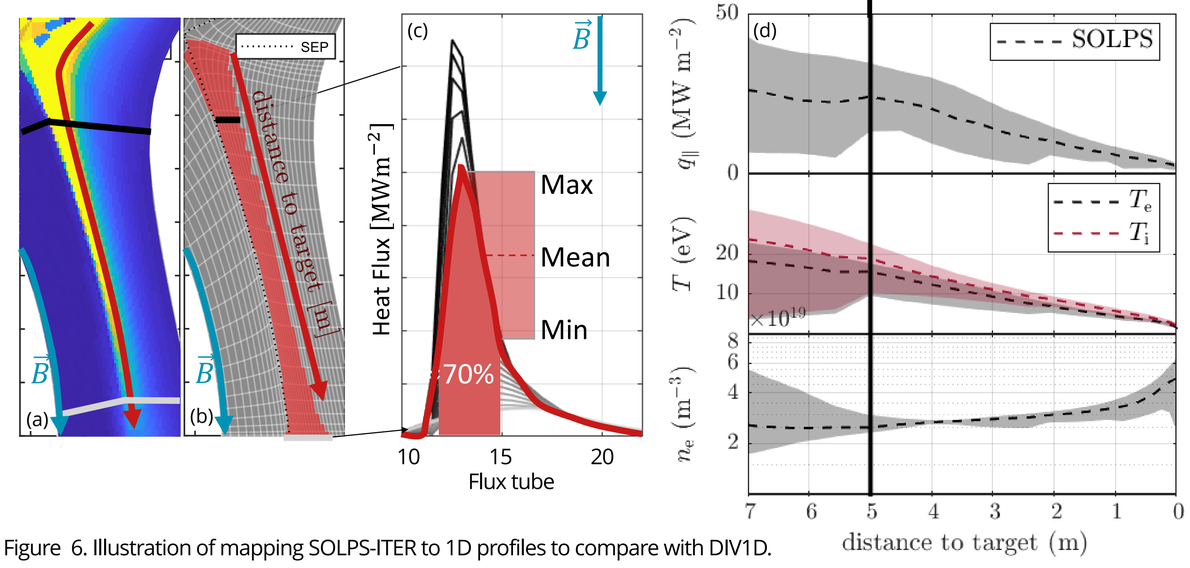


Figure 6. Illustration of mapping SOLPS-ITER to 1D profiles to compare with DIV1D.

Results

Matches and transitions between SOLPS-ITER?

Simulated DIV1D with varying upstream density $n_{e,u}$ and background gas density n_b. Other values were fixed. The static comparison in Figure 7 for the upstream density $n_{e,u} = 2.5 \cdot 10^{19}\ \mathrm{m^{-3}}$ shows good agreement in plasma profiles. The biggest error is visible in the parallel velocity. Figure 8 compares the scalars for a range of upstream densities $\mathrm{n_{e,u}}$, showing the background gas density, loss fractions $f_\mathrm{mom}, f_\mathrm{pwr}$ [3], target ion flux $\Gamma_{i,t}$, and target temperature T_t. There is good agreement in a density range of $\mathrm{n_{e,u}} = 1.8 - 2.7 \cdot 10^{19}\ \mathrm{m^{-3}}$.

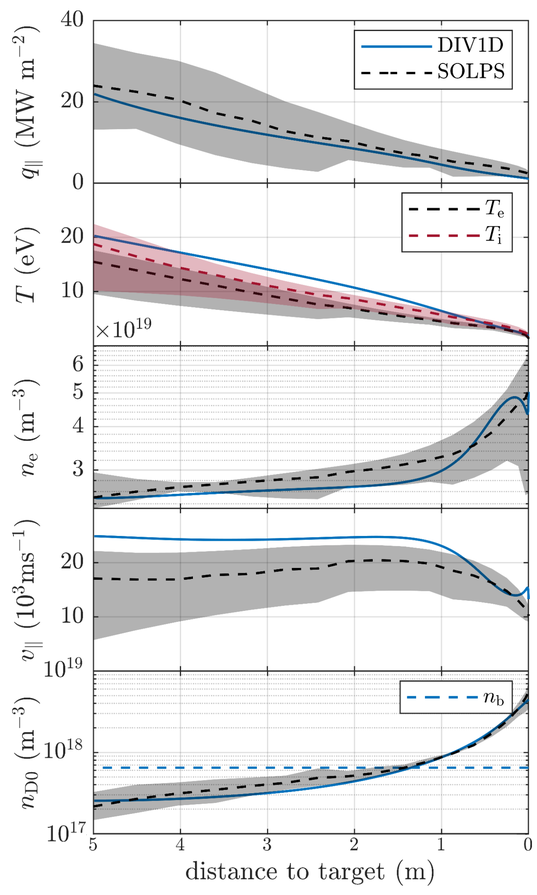


Figure 7. Comparison of 2D SOLPS-ITER solutions mapped to 1D profiles with DIV1D.

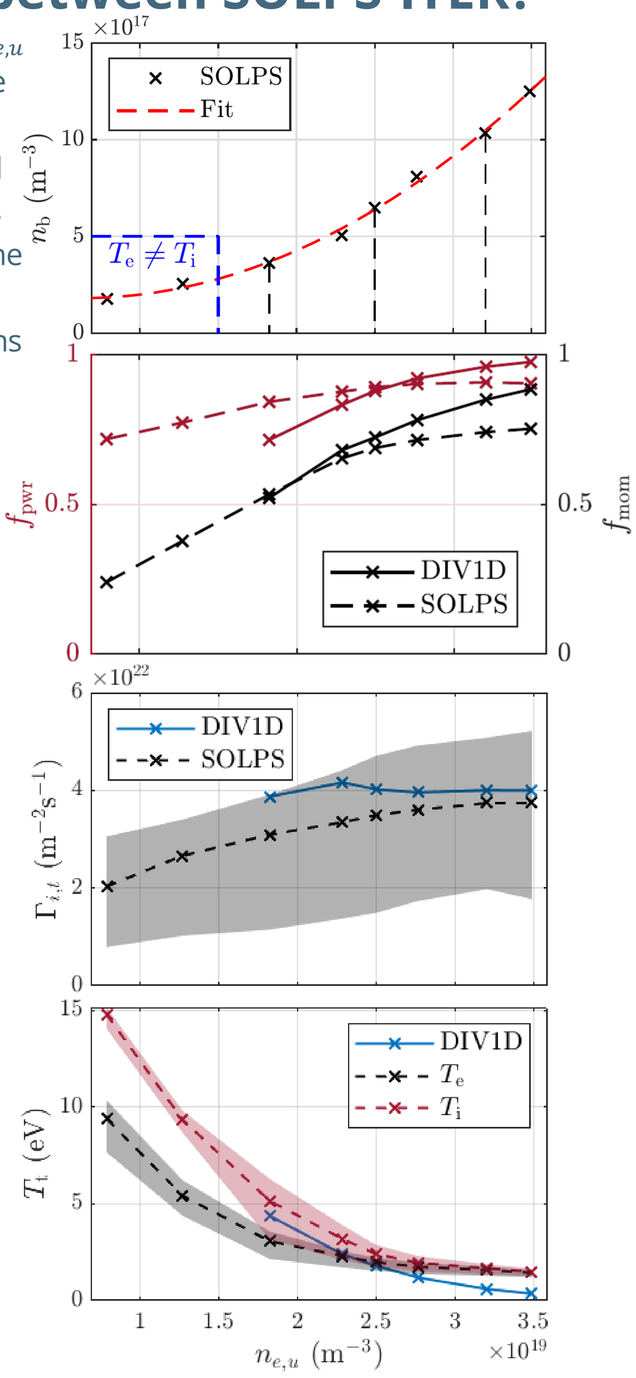


Figure 8. Comparison between mapped SOLPS solutions with DIV1D. In DIV1D we fixed $L = 5$ m, $q_{||,u} = 22\ \mathrm{MW/m^2}$, $f_\mathrm{C} = 3\%$, $\sin(\theta) = 0.6$, and the effective flux expansion $A_\mathrm{t}/A_\mathrm{u} = 2.3$. The upstream density and neutral background were varied.

Conclusion and Discussion

- Reasonable agreement between FWHM 1D SOLPS-ITER and DIV1D for upstream densities $n_{\mathrm{e,u}} = 1.8 - 2.7\ \mathrm{m^{-3}}$.
- Matching FWHM 1D SOLPS-ITER with DIV1D indicates both that DIV1D can describe the divertor plasma in 1D and that the FWHM 1D interpretation of 2D equilibria is physical.
- Discrepancies might be resolved by considering:
  - transport in radiation functions [17,20]
  - molecules [20], ExB drifts [21]
  - momentum and energy for neutrals [15]
- Future research will focus on:
  - Extending validity by resolving discrepancies
  - Reproducing on other (bigger) devices
  - Compare to measured dynamics of detachment [7,8]

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